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# ENVIRONMENTAL CONSIDERATIONS FOR SELECTING COST-EFFECTIVE DUST CONTROL TECHNOLOGIES

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**ENVIRONMENTAL CONSIDERATIONS FOR SELECTING COST-EFFECTIVE DUST CONTROL TECHNOLOGIES**

1. Purpose

a. This Public Works Technical Bulletin (PWTB) gives current information regarding the selection of technologies and chemical products for controlling dust on unpaved roads, landing strips, and helipads.

b. Proper dust control improves air quality and assists in preserving, protecting, conserving, and restoring the quality of the environment, as mandated by Department of Defense (DoD) policy. It also addresses other environmental concerns such as air quality.

c. All PWTBs are available electronically at the National Institute of Building Sciences' Whole Building Design Guide webpage, which is accessible through this link:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability

This PWTB applies to engineering activities at all US Army facilities.

3. References

a. Army Regulation (AR) 200-1, "Environmental Protection and Enhancement," revised 13 December 2007.

b. Title 40 of the Code of Federal Regulations (CFR), Parts 50, 51, 52, 53, and 58, “National Ambient Air Quality Standards for Particulate Matter,” *Federal Register*, Volume 70, Number 200, October 2006.

c. Title 40 CFR, Part 51, “Regional Haze Regulations,” *Federal Register*, Volume 64, Number 126, July 1999.

4. Discussion

a. It should be noted that there currently is no Army policy specifically directed to the subject matter of this PWTB. However, there is Army guidance on or closely related to the subject. This PWTB supports and is specifically in accordance with guidelines specified in TM 5-626 "Unsurfaced Road Maintenance Management," TM 5-822-12 "Design of Aggregate Surfaced Roads and Airfields," and TM 5-822-5 "Pavement Design for Roads, Streets, Walks, and Open Surfaces.”

b. AR 200-1 contains policy for implementing federal, state, and local environmental laws and DoD policies for preserving, protecting, conserving, and restoring the quality of the environment. The judicious use of dust suppressants improves air quality and addresses these policies.

c. 40 CFR, Parts 50 et al. contain policy for establishing ambient air quality standards and providing for control of fugitive dust emissions to meet set standards. The use of cost-effective dust palliatives reduces fugitive dust emissions from unpaved surfaces and addresses this law.

d. 40 CFR, Part 51 sets forth a national goal for visibility which is the “prevention of any future, and the remedying of any existing, impairment on visibility in Class I areas which impairment results from manmade air pollution.” Military activities may contribute to regional haze which impacts Class I areas, especially in the Southwest. Informed and strategic use of dust palliatives by military installations helps to address these national goals.

e. Appendix A contains background information pertaining to the research, development, and testing of dust control materials for the DoD and other federal and state agencies. It also discusses the types of data used to develop guidance for the selection of cost-effective dust control technologies that address environmental concerns. This appendix next outlines general issues associated with the generation of dust, the types of available dust control technologies, and guidelines for reducing environmentally harmful dust generation on unpaved surfaces.

f. Appendix B provides a question-directed worksheet to guide dust palliative selection as it relates to site-specific factors such as climate, soil type, traffic type, and traffic volume. This appendix also contains a listing of approximate dust palliative costs by category and guidance for developing a vendor list.

g. Appendix C contains references cited in text, a numbered list related to the sources used in Appendix B, and a list of abbreviations used in this document.

5. Points of Contact

a. Headquarters, US Army Corps of Engineers (HQUSACE) is the proponent for this document. The point of contact (POC) at HQUSACE is Mr. Malcolm E. McLeod, CEMP-CEP, 202-761-5696, or e-mail: Malcolm.E.Mcleod@usace.army.mil.

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FOR THE COMMANDER:

For JAMES C. DALTON, P.E., SES
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# APPENDIX A:
# OVERVIEW OF DUST CONTROL

## Background

*Chronology of Investigations*

Since 1946, the US Army Corps of Engineers (USACE) has been conducting a comprehensive research program on pavement maintenance, soil stabilization, and trafficability that has included companion studies to investigate the development and evaluation of dust control materials on roads, trails, landing strips, and helipads.

From 1966 to 1974, the US Army Engineer Research and Development Center (ERDC), formerly called the Waterways Experiment Station (WES) in Vicksburg, Mississippi, pursued a program to identify suitable dust control materials for use in the Southeast Asia theater of operation. Numerous promising materials were developed from these efforts. During the mid-1980s, results of several small-scale Facilities Technology Application Test (FTAT) demonstrations were published by WES concerning procedures and techniques for dustproofing unsurfaced roads and other areas on military installations using common, industry-standard suppressants.

During the early 1980s, the US Army Engineer Research and Development Center – Construction Engineering Research Laboratories (ERDC-CERL) in Champaign, Illinois, began investigating fugitive dust and dust control relating to compliance issues with National Ambient Air Quality Standards (NAAQS). The primary objective of this work involved developing designs and monitoring criteria for using high-volume air sampling systems to collect total suspended and respirable particulate air quality data associated with various dust control techniques and training activities at Fort Carson, Colorado.

During the early 1990s, WES conducted further investigations to develop and/or evaluate new dust control materials that had become available since the related efforts of the 1960s, 1970s, and 1980s. Results of these studies suggested that equipment, manpower, and logistical requirements associated with the proper use of dust control materials could be reduced by at least 30%.

During fiscal year (FY)96, in cooperation with the US Army Environmental Center (USAEC), ERDC-CERL demonstrated the performance, durability, and characteristics of several commercially available dust control products at Fort Hood, Texas, and Fort Sill, Oklahoma. Results from these two demonstrations, a similar study at Fort Campbell, Kentucky, and the previous research conducted by WES, provided the necessary data to begin summarizing and developing Army-wide documentation for dust control products.

During FY97, ERDC-CERL conducted additional research on dust control technologies as they relate to sandy soils at Fort McCoy, Wisconsin, and Fort Drum, New York. Results from these studies provided much-needed data on dustproofing and stabilization of sandy-textured soils in colder regions of the United States.

In the early 2000s, researchers at ERDC Geotechnical and Structures Laboratory (ERDC-GSL) continued the testing and evaluation of commercial and experimental dust control products for dust abatement in arid and semiarid environments as part of Joint Rapid Airfield Construction Program, thereby producing invaluable data for water-limited environments. Follow-on work conducted at Fort Leonard Wood, Missouri, by the US Environmental Protection Agency (USEPA), Midwest Research Institute, and ERDC-CERL provided Environmental Technology Verification reports for several next-generation dust suppressant chemicals. More recent work for dust control and soil stabilization in FY09-10 by ERDC-GSL involved experimental compounds derived from microbiological processes, and this work continues to provide important data relative to dust control products for the future.

This report compiles and summarizes this vast but obscure set of data resources, including those from academia and state and federal agencies, and then uses them to develop guidance for selecting dust control technologies for environmental concerns. The summarized data were also used to develop a question-based worksheet that allows Army and Civil Works personnel to select appropriate and cost-effective dust control technologies based on site-specific climate and soil characteristics.

*Literature Search*

To compile the objective data necessary to produce this dust control guidance and technology-selection worksheet (Appendix B), a review of existing dust control research and data resources was conducted. Sources for this review included: (1) published research in scientific and popular journals and trade magazines; (2) manufacturing and service company product evaluations and promotional literature; (3) unpublished theses and dissertations from universities and colleges; (4) published and unpublished reports associated with DoD entities such as major commands, research laboratories, and individual installations; (5) published and unpublished reports from other federal agencies such as the US Department of Agriculture (including Forest Service, Agricultural Research Service, and Natural Resources Conservation Service)and the US Department of Interior (Bureau of Land Management, Bureau of Reclamation, Bureau of Indian Affairs, Environmental Protection Agency, and Fish and Wildlife Service); (6) the US Department of Transportation; and (7) published and unpublished reports from state and local agencies involved with transportation, agriculture, environmental quality/conservation, air quality, and natural resources management.

*Data Requirements*

To assure that data obtained from the literature search were unbiased and reliable, careful attention was devoted to retrieving data that: (1) provided descriptions of site characteristics such as climate, soil type/texture, surface characteristics, and traffic patterns; (2) identified the chemical composition of dust control products used; (3) reported application rates and techniques; (4) detailed how performance, durability, cost, and upkeep requirements were evaluated; (5) compared two or more types of products; and (6) were quantitative in nature and clearly supported recommendations of one product over another. Literature meeting these requirements was then incorporated into a spreadsheet referencing the above criteria and subsequently used in the development of the dust control guidance and question-based worksheet (Appendix B).

**Dust Generation and Control**

Excessive dust generation on unsurfaced roads, helicopter landing zones, firing lines, and assembly areas on military installations contributes significantly to reduced air quality and associated Clean Air Act (CAA) compliance violations as CAA regulations have become more restrictive relative to particle size. Dust also increases safety hazards, health and respiratory problems, and vehicle maintenance requirements, and thus can reduce mission success. For example, dust can interfere with weapons targeting systems, landing clearance, and training delays. Dust generation is a preventable environmental problem that can often be controlled by proper road grading, surfacing, and maintenance practices. Preventing dust generation is a cost-effective way to avoid problems that can result in mission failure during training operations (Styron et al. 1985).

*Treating Dust Problems*

The main factors that lead to dust problems are loose surface materials, strong winds generated by atmospheric pressure changes, and vehicle movement (Figure A-1 and Figure A-2). Loose roadway materials are easily removed through wind action, resulting in surface degradation and enhanced dust generation because smaller particles (fines) necessary for proper bonding and surface strength have been eliminated. This situation will eventually lead to excessive road subsurface wear, thereby accelerating further surface destabilization and environmental concerns such as erosion (Figure A-3). In addition, climatic factors (e.g., low rainfall and high temperatures) contribute to dust problems, especially in arid and semiarid regions.

**Figure A-1. Military vehicles can generate dust by their operation on unpaved surfaces or in arid and semi-arid environments.**

**Figure A-2. Military vehicles can generate significant amounts of dust pollution due to their size and their intensity of use.**

**Figure A-3. Multiple vehicle convoys across unpaved roads and trails destabilize surfaces and result in heavy dust production.**

When its subgrade deteriorates, the road will require work such as regrading, the addition of fines to promote surface bonding and strength, geometric shaping, and compaction to recreate a hard surface layer and a properly crowned cross section. Frequently, only specific sections of roads, trails, and landing strips are problematic for excessive dust generation and can be treated individually as needed. Some examples of problem areas include (a) road/trail intersections, (b) road/trail segments close to high-speed paved roads or near housing and administrative areas, and (c) fuel and ammunition supply routes. This individual treatment approach specifically targets problem areas and assures that valuable personnel, equipment, and material resources are not wasted on areas with only marginal dust problems.

Chemical dust suppressants are considered a secondary solution, to be used only after maintenance practices have been implemented to the greatest extent possible (Figure A-4). The question-based worksheet in Appendix B provides guidelines for determining whether chemical dust suppressants are warranted, based on predominant and site-specific surface characteristics, soil types/textures, climate, and vehicle types.

**Figure A-4. Various products can be applied for dust control. Here, soybean oil is being applied to a properly graded and very heavily trafficked main supply route at Fort Campbell, Kentucky.**

Dust control methods can be categorized into the three major areas listed below. Applying these methods should follow the order given below, with the possibility that it may be necessary to employ all three methods to reduce dust emissions to a satisfactory level for environmental compliance. Note that, as stated below, the use of chemical dust suppressants is not recommended if intrinsic factors such as proper grading, drainage, and maintenance have not been utilized or are not adequate.

1. Good construction and maintenance practices are fundamental in providing durable and erosion-resistant traffic surfaces in dust-prone areas. Existing guidance shows that properly crowned roadway cross sections (referred to as geometry), well-graded materials composed of sufficient fines for strength and durability, and adequate drainage are vital to maintaining a hard surface that reduces dust emissions. Existing dust problem areas should first be assessed to ensure these basic factors are adequate. For more specific guidance regarding unpaved road construction and management, please refer to Technical Manual 5-822-12, “Design of Aggregate Surfaced Roads and Airfields,” (Department of Army 1990).

2. Mechanical stabilization involves mixing two or more gradations of substrate materials to ensure that the local soils have a wearing surface with correct grading and plasticity. The blending may take place at the construction site, a central plant, or a borrow area. After the soil is blended, it is spread and compacted to required densities by conventional means. A substrate that will considerably reduce dust generation is composed of well-graded gravel and sand mixtures, with sufficient amounts of clayey (cohesive) fines to promote surface bonding and wear resistance. Mechanical stabilization can be used under a variety of conditions and will subsequently reduce dust emissions.

3. Chemical dust suppressants should be considered as an add-on to the other two dust control methods, especially if mechanical stabilization is cost prohibitive and high dust generation persists. Chemical dust suppressants have a limited life span and require regular applications to achieve adequate dust control on a long-term basis. Note that tracked vehicle traffic is likely to reduce product performance standards by an estimated 50%–75% or more. Careful consideration should be given to the life-cycle management of chemical dust suppressants since other dust control options may prove more cost effective over time.

*Categories of Chemical Dust Suppressants*

Chemical dust suppressants (palliatives) are classified in the following general categories.

- Water-Attracting Chemicals (e.g., chlorides, salts, and brine solutions). This category of dust suppressants provides the most satisfactory combination of application ease, durability, cost, and dust control for semiarid, semihumid, and humid climates. Salts suppress dust because they attract moisture from the atmosphere, thereby keeping the trafficked surface somewhat moist and the soil particles agglomerated; thus, they tend to be most effective where relative humidity is higher. The most commonly used salts are calcium chloride (CaCl) and magnesium chloride (MgCl), but they are highly soluble and will leach away from the trafficked surface with precipitation. Because of this solubility, their effectiveness is limited and may not provide sufficient dust control for a second year. Subsequent applications may, however, be made at reduced rates due to residual effects. It should be noted that this product category is corrosive to metals and may not be an acceptable choice if vehicle exposure to corrosive materials is not advisable or if relatively frequent vehicle washing is not possible.

- Organic Non-Bituminous Chemicals (e.g., lignosulfonates, sulphite liquors, tall oil pitch, pine tar, vegetable oils, molasses, and synthetic oils). This category of dust suppressants performs best under arid and semiarid conditions, but is less effective on igneous crushed gravel and medium-to-low fine materials. Most of these products control dust through binding soil particles together, thereby preventing them from becoming entrained by wind or vehicle traffic. Lignosulfonates are waste products derived from the wood pulping industry. Oils, pine tar, and molasses are also derivatives of food and wood processing technologies and are often readily available locally, depending on location. A newer product in this category is referred to as synthetic oils and is often composed of isoalkanes and other proprietary compounds. As with water-attracting chemicals, the effectiveness of organic non-bituminous chemicals is limited and may not provide sufficient dust control for a second year, but subsequent applications may be made at reduced rates due to residual effects. Failures often occur if application is followed too closely by rainfall, because organic non-bituminous products have long curing times and may be rapidly leached out if not allowed to fully cure. Some of the commercial products in this product category may be visually unappealing, odorous, or very sticky upon application, all of which may preclude their use depending on location of the area to be treated.

- Petroleum-Based Binders and Waste Oils (e.g., bitumin emulsions, asphalt emulsions, and waste oils). This category of dust suppressants is the most effective dust suppressant for a variety of climatic conditions. These products control dust by binding particles together and are effective on many soil types and trafficked surface conditions. Generally, they are not water soluble or prone to evaporation and resist leaching even in relatively wet conditions. Unfortunately, waste oils can cause significant adverse environmental effects due to toxic materials and are not environmentally acceptable unless they have been processed to remove these materials. A number of asphalt emulsions, however, have been approved for use and, although relatively expensive compared to other product types, are considered effective under a broad range of soil types and climates. Similar to the organic non-bituminous product category, some of these commercial products may also be visually unappealing, odorous, or very sticky upon application. Such unappealing aspects may preclude these products' use depending on location of the area to be treated.

- Electro-Chemical Stabilizers (e.g., sulphonated petroleum, ionic stabilizers, and bentonite). These products work over a wide range of climatic conditions, are least likely to leach out, and are particularly effective on clayey or sandy surface materials. A disadvantage to this product category is that their efficacy is highly dependent on the clay mineralogy of the trafficked surface and may only be effective on very specific sites. A large variety of these materials are available and, when applied under highly specific trafficked surface and aggregate conditions, have been shown to produce dramatic reductions in dust generation. Unlike most traditional dust suppressants, these products have no standard laboratory tests for predicting their performance under field conditions, and their use often results in either unqualified success or failure. Until standard testing is developed for this product category, small-scale trials should be initiated and evaluated for efficacy prior to large-scale applications.

- Polymers (e.g., polyvinyl acrylics and acetates). These products bind surface soil particles together and form a semirigid film on the trafficked surface. They function by agglomerating fine particles, thereby forming a crust that is resistant to disintegration. The exact composition of these products may not be highlighted in Material Safety Data Sheets (MSDS) since they are often proprietary in nature. Most of the polymer products are supplied in concentrated form and require dilution with water before application. With slight variations in dilution and final application rates, polymers are generally suitable for use under a wide range of soil and climatic conditions. Unlike some of the other product types, most polyvinyl acrylics and acetates are considered non-toxic and environmentally friendly when used according to manufacturers' recommendations. They are most effective on lightly trafficked surfaces such as helicopter landing surfaces and in arid, semiarid, semihumid, and humid zones that receive 8–40 in. of precipitation per year.

- Microbiological Binders (e.g., cryptogams, blue-green algae inoculants, enzyme slurries, and microbial by-products). This category is especially important in arid climates, as cryptogams bind soil particles together, resulting in a reduction in the movement of dust particles. Inoculants that can be applied easily and evenly are currently under development. Many enzymes are adsorbed by clay particles, resulting in a compression of the pore space which aids in compaction and consequently reduces dust generation. Similar to the electro-chemical stabilizer product category, these products have shown great success under highly specific trafficked surface and aggregate conditions. Without standard testing procedures to predict their performance under field conditions, small-scale trials should be initiated and evaluated for efficacy prior to large-scale applications.

*Limitations of Dust Suppressants*

Depending on which state the military installation or civil works site is located in, there may be limitations as to which product category can be used. Prior to actually applying any chemical dust suppressants, it is imperative to determine if there are any regulatory limitations concerning its use. Most state departments of transportation, environmental quality, or environmental conservation can provide details concerning the application of specific dust suppressants. For example, the State of New York prohibits the use of salts (e.g., CaCl, MgCl) within 100 ft of regulated wetlands and limits yearly application rates for non-wetland areas. There are programs in the United States that have developed guidelines specific to the use of dust palliatives. These programs include the USEPA’s Environmental Technology Verification Program, state-level programs in California, Maryland, Michigan, Nevada, New York, and Pennsylvania, and a county-level program in Clark County, Nevada (where dust control in the rapidly developing desert region near Las Vegas is of prime importance). These programs have stringent requirements for testing product chemistry, toxicity, uniformity, application rates, curing times, and particulate matter (PM) control efficiency. These programs have been embraced by manufacturer and consumer alike, and are often used voluntarily by others outside of the program areas. At a minimum, it is always advisable to obtain a record of environmental consideration or other similar document prior to purchasing and applying any dust suppressant.

It is also important to note that similar products within a given product category are not necessarily equal in terms of performance, durability, cost, and ease of application. Vendors capable of providing dual services to supply and apply dust palliatives are not necessarily equal in terms of reliability, timeliness, and adherence to application specifications. This is why the above-mentioned technology verification programs are so important to both vendors and customers alike. Because the mention of specific trade names could be perceived as exclusionary by competing vendors, it is the responsibility of the end user of these products to ascertain whether a given vendor or product trade name can provide high-quality results or services. For this reason, details and contacts pertaining to each product category derived from the question-based worksheet (Appendix B) can be found in Appendix C. These references will often cite specific products within product categories by trade name, which should aid the user in identifying products with proven performance characteristics.

## Guidelines for Dust Control

### *Construction of New Roadway Surfaces*

The best way to provide long-term dust control is proper design and construction of new roads, trails, and landing zones.

Special consideration should be given to the factors listed below.

- Proper crown in the subgrade to assist in preserving a uniform thickness of surface material across the trafficked area.
- Proper crown of the wearing surface to ensure effective drainage of the surface to minimize loss of fines and potential leaching of chemical dust palliatives.
- Compaction of the subgrade and pavement material to minimize particle movement.

*Existing Roadway Surfaces*

Regular maintenance of existing roads and landing zones is the most cost-effective method to control dust emissions at a military installation or civil works site. According to Army guidance, special attention should be paid to:

- use of well-graded aggregates having adequate cohesive binder (fines);
- retention of the crown to provide adequate drainage;
- adequate drainage for rapid draining of the wearing surface, shoulder, and verge;
- proper compaction of wearing surface following the addition of aggregate and grading to increase the density and strength of the wearing surface and retention of larger aggregates; and
- avoid continuing grading during dry weather.

*Water Application*

Spraying water on a problem area usually gives immediate results and is inexpensive for short-term dust control. Water surrounds and adheres to dust particles making their movement more difficult. However, the effectiveness of water applications is short-lived, and it may cause the pumping of fines to the wearing surface if continual wetting conditions occur. In arid climates, conservation of water may be regulated so as to prohibit this method of dust control. In any case, application of water is only recommended as a short-term solution to dust emission problems.

# APPENDIX B: DUST SUPPRESSANT SELECTION WORKSHEET

## Background for Worksheet

The following question-based worksheet is designed to allow a military installation or civil works site that is experiencing dust control problems to evaluate various solutions. Chemical dust suppressant categories are recommended if warranted by traffic volumes, climatic factors, and soil types/textures. The recommended palliative categories are those that have shown best results from empirical studies and surveys of current literature done for this report. Product performance standards cited from these references should be reduced by an estimated 50%–75% if the predominant use is from tracked vehicles.

After working through the series of questions, the result will be a determination of the most effective chemical dust suppressant category for conditions at the installation. Once the proper palliative category has been established, application rates and concentrations are available from commercial manufacturers of the various products. Important information regarding cost-effective application of chemical dust suppressant on military installations or civil works sites can be found in Gebhart, Hale and Michaels-Busch (1996), Gebhart and Hale (1997), Styron, Hass and Kelley (1985), Hass (1986), Armstrong (1987), and Rushing et al. (2005, 2006), which are listed in Appendix C as references 17, 18, 38, 24, 4, and 34, respectively. Other references given after some of the questions in the worksheet below also correlate to the numbered list in Appendix C.

In order to make the most effective use of this worksheet, the following information should be readily available before answering the questions: (1) predominate type of traffic the area supports; (2) estimated traffic volume during the periods of most intense use; (3) characteristics of the trafficked surface including surface geometry, subgrade composition, materials used for its construction, drainage patterns, and maintenance schedules — all of which should be readily available from the Roads and Grounds Branch of the Directorate of Public Works (DPW); (4) average annual precipitation; and (5) predominant soil texture of the trafficked surface.

**Dust Suppressant Worksheet**

1. Has the area been identified as having a dust control problem?

   a. Yes   Go to Ques. 2

   b. No    Continue existing management practices

2. Does the area support military vehicle traffic?

   a. Yes   Go to Ques. 3

   b. No    See Appendix A

3. Does the area support aircraft traffic?

   a. Yes   Go to Ques. 4

   b. No    Go to Ques. 6

4. Is the type of aircraft fixed wing?

   a. Yes   Go to Ques. 10

   b. No    Go to Ques. 5

5. Are the aircraft helicopters?

   a. Yes   Go to Ques. 43

   b. No    Go to Ques. 3

6. Does the area support land vehicles?

   a. Yes   Go to Ques. 7

   b. No    Go to Ques. 14

7. Are the vehicles tracked or wheeled?

   a. Tracked  Go to Ques. 9

   b. Wheeled  Go to Ques. 8

8. Estimated number of wheeled vehicle passes per day during periods of heaviest use:

   a. >250     Go to Ques. 11

b. <250 Go to Ques. 13

9. Estimated number of tracked vehicle passes per day during periods of heaviest use:

a. >100 Go to Ques. 11

b. <100 Go to Ques. 13

10. Estimated number of aircraft landings per day during periods of heaviest use:

a. >50 Go to Ques. 14

b. <50 Go to Ques. 13

11. Are permanent surface treatments economically feasible (e.g., paving)? Paving costs are about $12–$20 per square yard, but can be significantly higher if predominately tracked vehicle traffic is expected, thereby increasing the pavement thickness required for satisfactory performance.

a. Yes Go to Ques. 12

b. No Go to Ques. 14

12. Apply permanent stabilization practices.

In this case, paving the surface will prove to be the most cost-effective overall solution when compared to costs of periodic unsurfaced road maintenance and regular application of dust suppressants.

Go to Ques. 13

13. Use of chemical dust suppressants may not be economically justified based on low traffic volumes. However, when safety or air quality concerns are a high priority, low traffic volumes should not preclude the use of chemical dust suppressants.

Go to Ques. 14

14. Has the surface been evaluated for geometry, materials, drainage, and maintenance practices?

a. Yes Go to Ques. 20

b. No Go to Ques. 15

15. Does the geometry of the surface appear to have a crown that facilitates drainage?

a. Yes Go to Ques. 16

b. No Go to Ques. 19

16. Do surface and subsurface materials appear to be stable without significant potholing, washboarding, or other forms of erosion?

a. Yes Go to Ques. 17

b. No Go to Ques. 19

17. Does the surface have adequate drainage for local conditions?

a. Yes Go to Ques. 18

b. No Go to Ques. 19

18. Are maintenance practices for the surface being performed on a regular basis?

a. Yes Go to Ques. 20

b. No Go to Ques. 19

19. Upgrades to drainage, surface and subsurface materials, grading, and/or maintenance practices may solve the dust control problem. Chemical dust suppressants should be considered if mechanical stabilization is not cost-effective and dust problems persist. Mechanical stabilization costs, which may include the addition, grading, mixing, and compaction of fresh aggregate materials, are about $4.00 to $5.00 per square yard. Most installation Directorates of Public Works and State Departments of Transportation can provide detailed information concerning mechanical stabilization practices and specifications.

Go to Ques. 20

20. Determine dominant climate influences, trafficked surface soil textures, and suitable dust control product categories.

Go to Ques. 21

21. The climate of the installation is classified as:

a. Arid (<12 in. of precipitation per year) Go to Ques. 22

b. Temperate (12–36 in. of precipitation per year) Go to Ques. 23

c. Humid ( >36 in. of precipitation per year) Go to Ques. 30

22. Soil texture of the trafficked surface is best classified as:

a. Sand/Gravel Go to Ques. 24

b. Loam Go to Ques. 25

c. Clay Go to Ques. 26

d. Limestone Go to Ques. 27

23. The temperate climate is classified as:

a. Semi-arid (12–24 in. of precipitation per year) Go to Ques. 28

b. Sub-humid (24–36 in. of precipitation per year) Go to Ques. 29

24. Recommended product category for the trafficked surface:

Primary: Organic Non-bituminous Go to Ques. 43

See references 1, 22, 33, 39, 50 (Appendix C)

Secondary: Salts, Polymers, or Petrol Go to Ques. 43

See references 1, 4, 22, 33, 38, 39, 50 (Appendix C)

25. Recommended product category for the trafficked surface:

All product categories are suitable at the installation Go to Ques. 43

See references 10, 21, 22, 36, 38, 39, 48 (Appendix C)

26. Recommended product category for the trafficked surface:

Primary: Organic Non-Bituminous Go to Ques. 43

See references 22, 50 (Appendix C)

Secondary: Salts or Electrochemical Stabilizers Go to Ques. 43

See references 38, 48 (Appendix C)

27. Recommended product category for the trafficked surface:

Primary: Salts Go to Ques. 43

See references 39, 50 (Appendix C)

Secondary: Organic Non-bituminous Go to Ques. 43

See references 22, 52 (Appendix C)

28. Soil texture of the trafficked surface is best classified as:

a. Sand/Gravel — Go to Ques. 31

b. Loam — Go to Ques. 32

c. Clay — Go to Ques. 33

d. Limestone — Go to Ques. 34

29. Soil texture of the trafficked surface is best classified as:

a. Sand/Gravel — Go to Ques. 35

b. Loam — Go to Ques. 36

c. Clay — Go to Ques. 37

d. Limestone — Go to Ques. 38

30. Soil texture of the trafficked surface is best classified as:

a. Sand/Gravel — Go to Ques. 39

b. Loam — Go to Ques. 40

c. Clay — Go to Ques. 41

d. Limestone — Go to Ques. 42

31. Recommended product category for the trafficked surface:

Primary: Petrol — Go to Ques. 44

See references 10, 21, 48 (Appendix C)

Secondary: Organic Non-Bituminous — Go to Ques. 44

See reference 22 (Appendix C)

32. Recommended product category for the trafficked surface:

Primary: Salts — Go to Ques. 44

See references 1, 2, 10, 30, 31, 40, 49 (Appendix C)

Secondary: Organic Non-Bituminous — Go to Ques. 44

See references 1, 2, 6, 10, 22, 40, 49 (Appendix C)

33. Recommended product category for the trafficked surface:

Primary: Organic Non-Bituminous Go to Ques. 44

See references 6, 22, 37 (Appendix C)

Secondary: Petrol Go to Ques. 44

See references 21, 22 (Appendix C)

34. Recommended product category for the trafficked surface:

Primary: Salts Go to Ques. 44

See references 19, 31 (Appendix C)

Secondary: Organic Non-Bituminous Go to Ques. 44

See references 19, 37 (Appendix C)

35. Recommended product category for the trafficked surface:

Primary: Organic Non-Bituminous; Petroleum Go to Ques. 44

See references 3, 11, 12, 13, 27, 41, 42, 43, 44, 46, 47 (Appendix C)

Secondary: Salts, Electrochemical Stabilizer Go to Ques. 44

See references 19, 23, 27, 28, 35, 45 (Appendix C)

36. Recommended product category for the trafficked surface:

Primary: Organic Non-Bituminous Go to Ques. 44

See references 3, 11, 12, 13, 17, 22, 25, 26, 41, 42, 43, 44, 46, 47, 49 (Appendix C)

Secondary: Salts Go to Ques. 44

See references 3, 11, 12, 13, 17, 23, 26, 32, 35, 41, 45, 49 (Appendix C)

37. Recommended product category for the trafficked surface:

Primary: Organic Non-Bituminous Go to Ques. 44

See references 11, 12, 13, 22, 25, 26 (Appendix C)

Secondary: Electrochemical Stabilizers Go to Ques. 44

See reference 7 (Appendix C)

38. Recommended product category for the trafficked surface:

Primary: Salts Go to Ques. 44

See references 8, 15, 19, 23, 27 (Appendix C)

Secondary: Organic Non-Bituminous Go to Ques. 44

See references 15, 25, 27 (Appendix C)

39. Recommended product category for the trafficked surface:

Primary: Petrol, Salts Go to Ques. 44

See references 16, 22, 32 (Appendix C)

Secondary: Organic Non-Bituminous Go to Ques. 44

See references 14, 19 (Appendix C)

40. Recommended product category for the trafficked surface:

Primary: Salts Go to Ques. 44

See references 16, 17, 38 (Appendix C)

Secondary: Electrochemical Stabilizers Go to Ques. 44

See reference 33 (Appendix C)

41. Recommended product category for the trafficked surface:

Primary: Salts Go to Ques. 44

See references 4, 14, 16, 22, 32 (Appendix C)

Secondary: Organic Non-Bituminous Go to Ques. 44

See references 14, 22 (Appendix C)

42. Recommended product category for the trafficked surface:

Primary: Salts Go to Ques. 44

See references 4, 16, 17, 18, 19 (Appendix C)

Secondary: Organic Non-Bituminous Go to Ques. 44

See references 17, 18, 19 (Appendix C)

43. Recommended product category for the trafficked surface:

Primary: Organic Non-Bituminous Go to Ques. 44

See reference 34 (Appendix C)

Secondary: Polymers, Petrol Go to Ques. 44

See references 18, 22 (Appendix C)

44. The economic evaluation for prolonged and repeated use of this product at 60 to 90 day intervals is:

a. Economical Go to Ques. 45

b. Not Economical Go to Ques. 46

45. A trial application of the product category has proven:

a. Effective Go to Ques. 47

b. Not Effective Go to Ques. 46

46. Consider paving or use of alternate dust palliative.

47. Implement large-scale use of product category and monitoring program.

**Dust Control by Product Category Cost and Vendor**

*Range of Material Costs*

A range of material costs for each dust control product category is presented below. The lowest value of the range is for materials only and does not include labor, equipment, or application costs. The highest value of the range would be typical for having a contractor/vendor perform the work and includes all materials, labor, and equipment for application.

Costs are presented on a volume or weight basis due to differences in soil types which influence dilution rates and final application rates. It should be noted that product costs can and will vary due to transportation distances and product volumes required. For example, the per-gallon cost associated with a 10,000 sq yd job will be higher than that associated with a 100,000 sq yd job. Some products, most notably those within the organic non-bituminous category, are waste products from other industrial activities; their cost and availability will fluctuate with the magnitude of those industrial activities and their proximity to the site in need of dust control.

| **Dust Control Product Category** | **Cost Range,* Materials Only** | **Cost Range,* Materials and Equipment for Custom Application** |
|---|---|---|
| Salts, Brine Solutions | $0.40 to $0.70 per gallon | $1.40 to $1.80 per gallon |
| Organic, Non-bituminous | $0.50 to $1.30 per gallon | $1.60 to $2.60 per gallon |
| Petroleum-based | $3.00 to $7.00 per gallon | $10.00 to $15.00 per gallon |
| Electrochemical | $5.00 to $13.00 per gallon<br>$60.00 to $90.00 per ton | $15.00 to $30.00 per gallon<br>$110.00 to $170.00 per ton |
| Polymers | $2.20 to $4.50 per gallon | $7.00 to $10.00 per gallon |

* Products within a category will have different costs due to the manufacturing process they are derived from and also because some products with a given category may have different application requirements and equipment types.

*Vendor Selection Information*

Many dust control product manufacturers have regional distributors that can provide current information regarding availability of multiple product types/categories, application recommendations and procedures, material and/or application costs, and expected performance under a given set of variables. Internet searches using combinations of keywords or phrases will provide a listing of vendors capable of supplying dust control products and services.[1]

Frequently, these vendors support detailed websites that include information regarding (1) experience with specific product categories; (2) case studies; (3) customer reviews, references, and points of contact; and (4) current regulatory data for each product category. This online information should help make comparisons between vendors and product categories very straightforward.

[1] Suggested keywords for Internet searches are: unpaved roads, dust control chemicals, dust palliatives, lignins, lignosulfonates, electro-chemical dust control, calcium/magnesium chloride, acrylic emulsions, polymer emulsions, synthetic oil, petroleum products, and asphalt emulsions.

## APPENDIX C:
## REFERENCES

**NOTE:** A few references in the numbered list that follows Table C-1 were cited in text, but most relate only to the numbers used for product information in the question-based worksheet in Appendix B, which is summarized in Table C-1.

The order of product information given in Table C-1 for each product category is: product type, concentration, application rate, and durability of performance (in days) for predominately wheeled vehicle traffic (reduce durability performance by 50%–75% if used in area receiving predominately tracked vehicle movement).

**Table C-1. Road products and information summarized by source.**

| Ref. No. | Author(s) | Salts | Organic Non-Bituminous | TS | Petroleum | Electrochemical | Polymers |
|---|---|---|---|---|---|---|---|
| 1 | Addo and Sanders | 32% MgCl; 0.25 gal/sq yd; 140 days | 25% solids calcium lignosulfonate; 0.50 gal/sq yd; 140 days | —— | —— | —— | —— |
| 2 | Apodaca and Huffman | 35% CaCl; 0.25 gal/sq yd; 70 days | 25% solids calcium lignosulfonate; 0.50 gal/sq yd; 70 days | —— | —— | —— | —— |
| 3 | Aquin et al. | 32% CaCl; 0.50 gal/sq yd; 90 days | 35% solids ammonium lignosulfonate; 0.50 gal/sq yd; 70 days | —— | —— | —— | —— |
| 4 | Armstrong | —— | —— | 38% CaCl; 0.35 gal/sq yd; 60 days | —— | —— | —— |
| 5 | Bassel | —— | —— | —— | Asphalt emulsion; 5:1 water:product ratio; 0.60 gal/sq yd; 75 days | —— | —— |

| Ref. No. | Author(s) | Salts | Organic Non-Bituminous | TS | Petroleum | Electrochemical | Polymers |
|---|---|---|---|---|---|---|---|
| 6 | Bennett and Gleeson | —— | Tall oil pitch emulsion; 1:3 water:product ratio; 2.08 gal/sq yd; 90 days | —— | —— | —— | —— |
| 7 | Bergeson and Brocka | —— | —— | —— | —— | Bentonite clay; 7-9% w:w ratio or 126-162 tons/mile; 365 days | —— |
| 8 | Bergeson et al. | 32% CaCl; 0.50 gal/sq yd; 180 days | —— | —— | —— | —— | —— |
| 9 | Bergeson and Wahbeh | —— | —— | —— | —— | Bentonite clay; 8% w:w ratio or 150 tons/mile; 365 days | —— |
| 10 | Bolander | 32% MgCl; 0.75 gal/sq yd; 60 days | 25% solids ammonium lignosulfonate; 0.75 gal/sq yd; 60 days | asphalt emulsion; 5:1 water:product ratio; 0.80 gal/sq yd; 60 days | —— | —— | —— |
| 11 | Boyd | 35% CaCl; 0.50 gal/sq yd; 90 days | 25% solids calcium lignosulfonate; 0.44 gal/sq yd; 90 days | —— | —— | —— | —— |
| 12 | Brown and Elton | 35% CaCl; 0.66 gal/sq yd; 90 days | 25% solids calcium lignosulfonate; 1.00 gal/sq yd; 90 days | —— | —— | —— | —— |
| 13 | Cleghorn | 35% CaCl; 0.35 gal/sq yd; 30 days | 25% solids calcium lignosulfonate; 0.50 gal/sq yd; 30 days | —— | —— | —— | —— |
| 14 | Edvardsson et al. | 32% MgCl; 0.02 gal/sq yd; 150 days | —— | —— | —— | —— | —— |

| Ref. No. | Author(s) | Salts | Organic Non-Bituminous | TS | Petroleum | Electrochemical | Polymers |
|---|---|---|---|---|---|---|---|
| 15 | Gebhart et al. | 38% CaCl; 0.50 gal/sq yd; 60 days | 25% solids calcium lignosulfonate; 0.50 gal/sq yd; 60 days | —— | —— | —— | Polyvinyl acrylic; 7:1 water to product ratio; 1.0 gal/sq yd; 90 days |
| 16 | Gebhart and Hale | 38% CaCl; 0.50 gal/sq yd; 90 days | 50% solids soybean oil; 0.40 gal/sq yd; 90 days | —— | —— | —— | (Same as for #17) |
| 17 | Gebhart | 38% CaCl; 0.50 gal/sq yd; 120 days | —— | —— | —— | —— | —— |
| 18 | Gebhart | (Same as for #19) | 25% solids calcium lignosulfonate; 0.50 gal/sq yd; 90 days | —— | —— | —— | —— |
| 19 | Giles et al. | —— | —— | —— | non-hazardous crude oil; 0.50 gal/sq yd; 240 days | —— | emulsified acrylic; 1:1 water to product ratio; 0.050 gal/sq yd; 240 days |
| 20 | Grau | —— | 25% solids calcium lignosulfonate; 2.00 gal/sq yd; 270 days | —— | petroleum resin emulsion; 0.25 gal/sq yd; 270 days | —— | polyvinyl acrylic; 5:1 water to product ratio; 1.0 gal/sq yd; 180 days |
| 21 | Hass | SALTS: 32% MgCl; 0.60 gal/sq yd; 120 days | —— | —— | —— | —— | —— |
| 22 | Hass | 32% MgCl; 0.80 gal/sq yd; 60 days | —— | —— | —— | —— | —— |

| Ref. No. | Author(s) | Salts | Organic Non-Bituminous | TS | Petroleum | Electrochemical | Polymers |
|---|---|---|---|---|---|---|---|
| 23 | Purdue University | —— | 30% solids beet molasses; 0.50 gal/sq yd; 180 days | —— | —— | —— | —— |
| 24 | Hoover | 38% CaCl; 0.25 gal/sq yd; 100 days | 25% solids ammonium lignosulfonate; 0.25 gal/sq yd; 100 days | —— | —— | —— | —— |
| 25 | Johnson and Olson | 32% MgCl; 0.30 gal/sq yd; 120 days OR 38% CaCl; 0.30 gal/sq yd; 200 days | —— | —— | —— | —— | acrylic polyvinyl; 0.65 gal/sq yd; 120 days |
| 26 | Lohnes and Coree | —— | —— | —— | —— | Bentonite; 2.0 lb/sq yd; >200 days | —— |
| 27 | Marks and Petermeier | —— | —— | —— | Ground roofing shingles; 1000 tons/mile, 365 days | —— | —— |
| 28 | Marshall | 42% CaCl; 0.50 gal/sq yd; 90 days | —— | —— | | —— | —— |
| 29 | Monlux | 29% MgCl; 0.50 gal/sq yd; 100 days | —— | —— | Asphalt emulsion; 0.39 gal/sq yd; 60 days | —— | —— |
| 30 | Muleski and Cowherd | 38% CaCl; 0.82 gal/sq yd; 60 days | —— | —— | Petroleum emulsion; 5:1 water:product ratio; 1.78 gal/sq yd; 60 days | —— | —— |

| Ref. No. | Author(s) | Salts | Organic Non-Bituminous | TS | Petroleum | Electrochemical | Polymers |
|---|---|---|---|---|---|---|---|
| 31 | Rushing et al. | 38% CaCl; 0.08 gal/sq yd; 90 days | Synthetic fluid/rosin; 0.80 gal/sq yd; 90 days | —— | —— | —— | Acrylic emulsion; 50% solids; 0.80 gal/sq yd; 90 days |
| 32 | Rushing et al. | Isoalkanes; 0.36 gal/sq yd; 7 days | —— | —— | —— | —— | —— |
| 33 | Rushing and Tingle | 38% CaCl; 0.40 gal/sq yd admixed; 220 days | —— | —— | —— | —— | Acrylic emulsion; 0.80 gal/sq yd; 80 days |
| 34 | Rushing and Newman | —— | —— | —— | —— | —— | Emulsified acrylic; 0.25 gal/sq yd; 30 days |
| 35 | Sontowski and Vliet | —— | 25% solids calcium lignosulfonate; 0.50 gal/sq yd; 60 days | —— | —— | —— | —— |
| 36 | Styron et al. | 32% MgCl; 0.50 gal/sq yd; 60 days | —— | —— | —— | —— | —— |
| 37 | Sudahl et al. | —— | 25% solids magnesium lignosulfonate; 2.0 gal/sq yd; 360 days <u>OR</u> corn oil + MgCl; 2.0 gal/sq yd; 360 days | —— | —— | —— | —— |
| 38 | Tetteh-Wayoe | 32% CaCl; 0.50 gal/sq yd; 120 days | 25% solids calcium lignosulfonate; 0.50 gal/sq yd; 120 days | —— | —— | —— | —— |

| Ref. No. | Author(s) | Salts | Organic Non-Bituminous | TS | Petroleum | Electrochemical | Polymers |
|---|---|---|---|---|---|---|---|
| 39 | Thompson and Visser | —— | —— | —— | Bitumen tar emulsion; 0.80 gal/sq yd; 90 days | —— | —— |
| 40 | Troedsson | —— | —— | —— | 50% solids soybean oil; 0.25 gal/sq yd; 180 days | —— | —— |
| 41 | USEPA | —— | Emulsified resin; 0.50 gal/sq yd; 105 days | —— | —— | —— | —— |
| 42 | USEPA | —— | —— | —— | Asphalt emulsion; 0.40 gal/sq yd; 105 days | —— | —— |
| 43 | USEPA | 20% MgCl; 0.50 gal/sq yd; 120 days | —— | —— | —— | —— | —— |
| 44 | USEPA | —— | Synthetic fluid isoalkane; 0.25 gal/sq yd; 120 days | —— | —— | —— | —— |
| 45 | USEPA | —— | Synthetic oil; 0.25 gal/sq yd; 119 days | —— | —— | —— | —— |
| 46 | Watson et al. | —— | —— | —— | Non-hazardous crude oil; 0.50 gal/sq yd; 365 days OR petroleum emulsion; 5:1 water:product ratio; 0.50 gal/sq yd; 120 days | —— | —— |
| 47 | Westway Trading Corp | 30% CaCl; 0.50 gal/sq yd; 180 days | 35% solids soybean oil; 0.25 gal/sq yd; 180 days | —— | —— | —— | —— |

| Ref. No. | Author(s) | Salts | Organic Non-Bituminous | TS | Petroleum | Electrochemical | Polymers |
|---|---|---|---|---|---|---|---|
| 48 | Zaniewski and Bennett | 35% MgCl; 0.50 gal/sq yd; 60 days OR 32% MgCl; 0.50 gal/sq yd; 60 days | 25% solids calcium lignosulfonate; 0.50 gal/sq yd; 60 days | —— | Petroleum emulsion; 5:1 water:product ratio; 0.75 gal/sq yd; 60 days | —— | —— |
| **NOTE:** Details of references used in this table are given in list below. | | | | | | | |

1. Addo, J.Q., and T.G. Sanders. 1995. *Effectiveness and Environmental Impact of Road Dust Suppressants*. Mountain-Plains Consortium Report Number 95-28A, Fargo, ND: North Dakota State University.

2. Apodaca, M., and D. Huffmon. 1990. *Dust Abatement Review and Recommendations*. USDA Forest Service-Gifford Pinchot National Forest, Washington.

3. Aquin, R., P. Korgemagi, and D.F. Lynch. 1986. *Evaluation of Tembind 35 Dust Palliative*, M1-83 Report. Ontario, Canada: Ministry of Transportation and Communications.

4. Armstrong, Jeffery P. 1987. *Dustproofing Unsurfaced Areas: Facilities Technology Application Test (FTAT) Demonstration, FY 86*. Miscellaneous Paper GL-87-19/ADA185185, Vicksburg, MS: US Army Waterways Experiment Station.

5. Bassel, J.R. 1992. *A Demonstration of a Dust Palliative*. USDA Forest Service, Technology and Development Program, Roads Tech Tips.

6. Bennett, D.M. and K. Gleeson. 1995. “Performance Evaluation of Tall Oil Pitch Emulsion for Stabilizing Unpaved Forest Road Surfaces.” In *Proceedings of Sixth International Conference on Low-Volume Roads*, Transportation Research Board, pp. 213-224.

7. Bergeson, K.L. and S.G. Brocka. 1995. “Bentonite Treatment for Fugitive Dust Control.” In *Sixth International Conference on Low Volume Roads, Vol. 2.*, Transportation Research Board, Washington, DC: National Academy Press.

8. Bergeson, K.L., J.W. Wadingham, S.G. Brocka, and R.K. Lapke. 1995. *Bentonite Treatment for Economical Dust Reduction on Limestone Surfaced Secondary Roads*. Project HR-351. Ames, IA: Highway Division, Iowa Department of Transportation and Iowa Highway Research Advisory Board.

9. Bergeson, K.L., and A.M. Wahbeh. 1990. *Development of an Economic Dust Palliative for Limestone Surfaced Secondary Roads*. Final Report. Ames, IA: Iowa Department of Transportation, Research, Project HR-297.

10. Bolander, P. 1989. “Chemical Additives for Dust Control.” *Transportation Research Record* 1589:42-49.

11. Boyd, K.R. 1983b. *Evaluation of Calcium Lignosulfonate as a Dust Palliative, Report 3*. Winnipeg, MB (Canada): Manitoba Department of Highways and Transportation.

12. Brown, D.A., and D.J. Elton. 1994. *Guidelines for Dust Control on Unsurfaced Roads in Alabama*, Final Report IR-94-02. Auburn, AL: Alabama Highway Research Center, Auburn University.

13. Cleghorn, H.P. 1992. *Dust Control and Compaction of Unpaved Roads-Field Trials*. MAT-92-02. Toronto, ON (Canada): Research and Development Branch, Ontario Ministry of Transportation.

14. Edvardsson, K., A. Gustafsson, and R. Magnusson. 2012. “Dust Suppressants Efficiency Study: In situ Measurements of Dust Generation on Gravel Roads.” *International Journal of Pavement Engineering* 13:11-31.

15. Gebhart, D.L., T. A. Hale, and K. Michaels-Busch. 1996. *Dust Control Material Performance on Unsurfaced Roads and Tank Trails*. Technical Report #SFIM-AEC-EQ-CR-99002. Aberdeen Proving Ground, MD: US Army Environmental Center, Aberdeen Proving Ground, MD.

16. Gebhart, D.L., and T.A. Hale. 1997. *Effectiveness of Dust Control Agents Applied to Tank Trails and Helicopter Landing Zones*. Technical Report 97/69. Champaign, IL: US Army Construction Engineering Research Laboratory.

17. Gebhart, D.L. 1997. *Effectiveness and Durability of Several Dust Control Agents on Unsurfaced Roads and Trails at Fort McCoy, Wisconsin*. Letter Report to ITAM Coordinator, Fort McCoy.Champaign, IL: US Army Construction Engineering Research Laboratory.

18. Gebhart, D.L. 1997. *Effectiveness, Durability, and Costs Associated with Several Dust Control Agents on Unsurfaced Roads at Fort Drum, New York*. Letter Report to ITAM Coordinator, Fort Drum.Champaign, IL: US Army Construction Engineering Research Laboratory.

19. Gilles, J.A., J.G. Watson, C.F. Rogers, D. Dubois, J.C. Chow, R. Langston, and J. Sweet. 1999. "Long-Term Efficiencies of Dust Suppressants to Reduce PM10 Emissions from Unpaved Roads." *Journal of the Air and Waste Management Association* 49:3-16

20. Grau, R.H. 1993. *Evaluation of Methods for Controlling Dust*. Technical Report L-93-25. Vicksburg, MS: US Army Waterways Experiment Station.

21. Hass, R.A. 1985. "Dustproofing Unsurfaced Tank Trails at Grafenwohr Training Area, Federal Republic of Germany, June 15-29, 1985." Miscellaneous Paper GL-86-40. Vicksburg, MS: US Army Waterways Experiment Station.

22. Hass, Robert A. 1986. *Dustproofing Unsurfaced Areas: Facilities Technology Application Test (FTAT) Demonstration, FY 85*. Technical Report GL-86-20/ADA176861, Vicksburg, MS: US Army Waterways Experiment Station.

23. Purdue University. 1992. *Highway Extension Research Project: Indiana Counties and Cities*. West Lafayette, IN: Purdue University, 10:10-11.

24. Hoover, J.M., D.E. Fox, M.T. Lustig, and J.M. Pitts. 1981. *Mission Oriented Dust Control and Surface Improvement Processes for Unpaved Roads*. Final Report, Iowa Highway Research Board Project, H-194.

25. Johnson, E.N. and R.C. Olson. 2009. Minnesota Local Road Research Board Investigation 842: *Best Practices for Dust Control on Aggregate Roads*. Technical Report MN/RC 2009-04. Maplewood, MN: Minnesota Department of Transportation.

26. Lohnes, R.A. and B.J. Coree. 2002. *Determination and Evaluation of Attenuation Methods for Managing And Controlling Highway Related Dust*. Technical Report 449, Final Report. Ames, IA: Iowa Highway Research Board, Iowa Department of Transportation.

27. Marks, V.J., and G. Petermeier. 1997. "Let Me Shingle Your Roadway." Paper No. 970256 in *Transportation Research Record 1589*. Paper sponsored by Committee on Chemical and Mechanical Stabilization. Iowa Department of Transportation, Research Project HR-2079. http://trb.metapress.com/content/m446w85467543j13/fulltext.pdf

28. Marshall, S.C. 1997. *Effectiveness of Calcium Chloride on Road Dust Suppression and Effects on Roadside Water and Soil, Denali National Park, Alaska*. M.A. Thesis, University of Wyoming.

29. Monlux, S. 1993. *Dust Abatement Product Comparisons in U.S. Forest Service Region One*. Internal report. Missoula, MT: USFS, Region 1.

30. Muleski, G.E., and C. Cowherd. 1987. *Evaluation of the Effectiveness of Chemical Dust Suppressants on Unpaved Roads*. EPA Report Number 600/2-87/102. Kansas City, MO: Midwest Research Institute (now MRIGlobal).

31. Rushing, J.F., A. Harrison, J.S. Tingle, Q. Mason, and T. McCaffrey. 2006. "Evaluation of Dust Palliatives for Unpaved Roads in Arid Climates." *Journal of Performance of Constructed Facilities* 20:281-286.

32. Rushing, J.F., V.M. Moore, and J.S. Tingle. 2006. *Evaluation of Chemical Dust Palliatives for Helipads*. Technical Report TR-06-02. Vicksburg, MS: U. S. Army Engineer Research and Development Center – Geotechnical and Structures Laboratory.

33. Rushing, J.F. and J.S. Tingle. 2007. "Evaluation of Products and Application Procedures for Mitigating Dust in Temperate Climates." *Journal of the Transportation Research Board* 189:305-311.

34. Rushing, J.F. and J.K. Newman. 2009. "Full Scale Testing of Chemical Dust Palliatives in a Semi-Controlled Environment." *Journal of Materials in Civil Engineering* 21:454-459.

35. Sontowski, D., and L. Vliet. 1977. *Lignosulfonate Dust Palliative Evaluation*. Geotechnical and Materials Branch, Ministry of Highways and Public Works, Victoria, British Columbia.

36. Styron, C.R., R.A. Hass, and K. Kelley. 1985. *Dustproofing Unsurfaced Areas; Facilities Technology Application Test Demonstrations, FY84*. Technical Report GL-85-11, US Army Waterways Experiment Station.

37. Surdahl, R.W., J.W. Woll, and H.R. Marquez. 2007. “Stabilization and Dust Control at the Buenos Aires National Wildlife Refuge, Arizona.” *Journal of the Transportation Research Board* 1999:312-321.

38. Tetteh-Wayoe, H. 1982. *Evaluation of M+F Road Stabilizer on Gravel Roads*. Edmonton, AB (Canada): Research and Development Branch, Alberta Ministry of Transportation.

39. Thompson, R.J. and A.T. Visser. 2007. Selection, Performance, and Economic Evaluation of Dust Palliatives on Surface Mine Haul Roads. *Journal of South African Institute of Mining and Metalurgy* 107:435-450.

40. Troedsson, K. 1998. “Questions and Answers: Road Dust Control with Soapstock-A Soybean Oil By-Product.” *U.S. Roads, Road Management and Engineering Journal*. http://usroads.com/journals/rmej/9806/rm980604.htm

41. US Environmental Protection Agency. 2006. “Dust Suppressant Products: SynTech Products Corporation’s TechSuppress.” EPA/600/R-05/129. Washington, DC: Environmental Technology Verification Program.

42. ______. 2006. “Dust Suppressant Products:SynTech Products Corporation’s PetroTac. EPA/600/R-05/135. Washington, DC: Environmental Technology Verification Program.

43. ______. 2006. “Dust Suppression Products: North American Salt Company’s DustGard.” EPA/600/R-05/127. Washington, DC: Environmental Technology Verification Program.

44. ______. 2006. “Dust Suppressant Products: Midwest Industrial Supply Inc.’s EnviroKleen.” EPA/600/R-05/134. Washington, DC: Environmental Technology Verification Program.

45. ______. 2006. “Dust Suppressant Products: Midwest Industrial Supply Inc.’s EK35.” EPA/600/R-05/128. Washington, DC: Environmental Technology Verification Program.

46. Watson, J.G., J.C. Chow, J.A. Gillies, H. Moosmuller, C.F. Rogers, D. DuBois, and J. Derby. 1996. *Effectiveness Demonstration of Fugitive Dust Control Methods for Public Unpaved Roads and Unpaved Shoulders on Paved Roads*. Final Report 685-5200.1F1. Nevada System of Higher Education: Desert Research Institute, Energy and Environmental Engineering Center.

47. Westway Trading Corporation. 1997. *Road Dust Control with Soapstock-A Soybean Oil By-product*.

48. Zaniewski, J.P., and A.K. Bennett. 1989. *Consumers Guide to Dust Control Technologies: State of the Art Report*. Center for Advanced Research in Transportation, Arizona State University. Phoenix, AZ: Arizona Office of Air Quality.

## ACRONYMS and ABBREVIATIONS

| Term | Spellout |
|---|---|
| AR | Army Regulation |
| CAA | Clean Air Act |
| CaCl | calcium chloride |
| CECW | Directorate of Civil Works, United States Army Corps of Engineers |
| CEMP-CE | Directorate of Military Programs, United States Army Corps of Engineers |
| CERL | Construction Engineering Research Laboratory |
| CFR | Code of the Federal Regulations |
| DPW | Directorate of Public Works |
| DoD | Department of Defense |
| EPA | Environmental Protection Agency; also USEPA |
| ERDC | Engineer Research and Development Center |
| FTAT | Facilities Technology Application Test |
| FY | fiscal year |
| GSL | Geotechnical and Structures Laboratory |
| HQUSACE | Headquarters, United States Army Corps of Engineers |
| MgCl | magnesium chloride |
| MSDS | Material Safety Data Sheet |
| NAAQS | National Ambient Air Quality Standards |
| POC | point of contact |
| PM | particulate matter |
| PWTB | Public Works Technical Bulletin |
| USACE | United States Army Corps of Engineers |
| USAEC | United States Army Environmental Center |
| WES | Waterways Experiment Station |