sierra research

Report No. SR2006-03-03

Alaska Rural Dust Control Alternatives

prepared for:

Alaska Department of Environmental Conservation

March 2006

prepared by:

Sierra Research, Inc.
1801 J Street
Sacramento, California 95814
(916) 444-6666

Report No. SR2006-03-03

ALASKA RURAL DUST CONTROL ALTERNATIVES

prepared for:

Alaska Department of Environmental Conservation

March 2006

Principal authors:

Earl Withycombe
Robert Dulla

Sierra Research, Inc.
1801 J Street
Sacramento, CA 95814
(916) 444-6666

ALASKA RURAL DUST CONTROL ALTERNATIVES

Table of Contents

Page

1. Introduction 1

2. Local Conditions 2

3. Dust Control Measures 9

4. Costs and Benefits 15

5. Recommendations 16

6. Literature Cited 18

APPENDIX A – Summary Information on Dust Palliatives

APPENDIX B – Dust Palliative Selection Guides

APPENDIX C – Bibliography

APPENDIX D – Detailed Cost Calculations of Dust Control Methods

1. INTRODUCTION

Air quality monitoring data collected in several rural Alaska communities over the past few years reveal elevated levels of fine particulate matter smaller than 10 microns in diameter (PM_{10}). The high readings are coupled with complaints of heavy dust conditions reported to the Alaska Department of Environmental Conservation (ADEC) from residents of these communities together with anecdotal information from local hospitals of increases in health problems and visits during these periods. (Trost, 2003)

Review of information collected from emission inventories and interviews of rural community residents has led ADEC to conclude that unpaved road use is a significant contributor to elevated PM_{10} levels in these communities. ADEC is interested in evaluating alternative methods for control of dust emissions from unpaved road use to assist the communities in air quality improvement. ADEC also believes that control measures that reduce emissions from unpaved road use will also reduce emissions from unpaved airfield use and from windblown dust emissions from these surfaces.

ADEC has requested that a study be conducted of these control measures that would:

1. Develop a matrix of feasible dust control strategies for reducing road and airport dust emissions;
2. Identify costs and benefits of various dust control materials and strategies; and
3. Identify and prioritize needs for identifying, selecting, and implementing effective, economic, and environmentally sound dust control measures.

For this study, Sierra performed a literature search on dust control from unpaved roads and collected specific data relative to dust problems in two rural Alaska communities and promising dust control measures.

###

2. LOCAL CONDITIONS

This limited study does not evaluate the feasibility of implementing dust control measures throughout rural Alaskan communities. Instead, we collected data from two communities that were deemed to be somewhat representative of those with elevated PM_{10} impacts. The communities selected by ADEC for focused study were Kotzebue and Noatak.

Climate

The region in which Kotzebue and Noatak are located experiences long, cold winters and short, cool summers. (ADCA, 2006) In Kotzebue, the average low temperature during January is -12ºF; the average high during July is 58ºF. For Noatak, temperatures average -21ºF to 15ºF during the winter, and 40ºF to 60ºF during the summer. Snowfall averages 40 to 48 inches, with total precipitation of 9 and 12 inches per year in Kotzebue and Noatak, respectively. Kotzebue Sound is ice-free from early July until early October. Relative humidity in the region averages over 60% for each month of the year. (Teck Cominco, 2005) The relatively cold temperatures in the region, however, mean that absolute humidity, or the total quantity of water in the air, is low except on the warmest of days. At Kotzebue, mean wind speeds range from 9 miles per hour in May to 13 miles per hour in January. (Trost, 2004) Extreme gusts exceed 34 miles per hour every month of the year. At these levels, Kotzebue is considerably windier than the average of all other monitored American communities. (City-Data, 2006) The combination of frequent wind and low absolute humidity means that exposed soil surfaces dry quickly after precipitation occurs and remain dry until the next precipitation event.

Demographics

Kotzebue and Noatak are rural communities located north of the Arctic Circle on or near the Kotzebue Sound in northwestern Alaska. Kotzebue lies on the Baldwin Peninsula bordering the Sound, while Noatak is approximately 55 miles north of Kotzebue on the Noatak River, which feeds into the Kotzebue Sound. Kotzebue, with a population of 3,130 people, is a coastal community and regional service and transportation center for smaller communities in the region. Noatak, with a population of 448, is an inland community representative of the fishing and subsistence economies of the region in general.

Roadways

Both communities depend on unpaved roads for intracommunity travel. Unpaved roads are used by a combination of light-duty passenger vehicles, all-terrain vehicles, and snow machines. Views of these unpaved roads in Kotzebue and Noatak are shown in Figures 1, 2, and 3. Both communities have access to limited gravel supplies, which are found in sporadic deposits and are used to construct and periodically resurface unpaved roads. Kotzebue, for example, imports gravel by barge from a commercial pit approximately 30 miles away.

Soils

The general geology of the region in which Kotzebue and Noatak lie consists of glacial alluvium deposited on the southern flank of the Brooks Range and redeposited by forces of water and wind. (Schoephorster, 1965; Furbush, 1971) The alluvium contains high levels of finely ground dust that contributes to dust emissions during disturbances of soil surfaces, either from mechanical abrasion or wind entrainment. Permafrost underlies most soils in this region, and limits the depths to which excavations can be undertaken for the recovery of fill material or gravel.

Kotzebue – The natural surface soils on most of the Kotzebue spit are poorly drained with high organic contents. The organic content derives from partially decomposed peat and the many roots of grasses, shrubs, and sedges. Because of the organic content and the lack of clay, these soils are nonplastic, or not cohesive, and not suitable for roadway structural sections or surfaces. (Furbush, 1971) The structural sections of roadways are best constructed from materials excavated from the limited deposits of gravelly sand located in the old beach ridges on the spit. Although these soils lack cohesion, their surfaces can be consolidated with appropriate treatment to reduce the release of fines and the generation of fugitive dust under vehicle travel.

Noatak – No soil survey has been conducted in Noatak, but surveys are available for other rural communities in the area of Noatak that lie along rivers. Two such surveys were conducted in the Kobuk and Deering communities, which are 128 miles east of Kotzebue on the Kobuk River and 57 miles south of Kotzebue at the mouth of the Inmachuk River, respectively. (Schoephorster, 1965; Hinton, 1967) The soils in these communities are primarily sandy loams that are nonplastic.

Figure 1
Typical Unpaved Street in Kotzebue

Figure 2
Unpaved Street Traffic in Kotzebue

Figure 3
Unpaved Street in Noatak

PM_{10} Levels

PM_{10} measurements have been collected in Kotzebue and Noatak on a seasonal basis in the past several years. These measurements have shown exceedances of the federal 24-hour PM_{10} ambient air quality standard of 150 ug/m^3 during the dry period of the year between breakup in early May and the arrival of increased rainfall in late July.[1]

Kotzebue – In 2002, PM_{10} concentrations were monitoring by five filter-based samplers and one continuous sampler at five locations in Kotzebue. Four of the locations were located adjacent (two upwind, two downwind) of a major unpaved road in the community, and the fifth was located within the community but not adjacent to a roadway. The monitoring period spanned from June 29 to September 25, 2002, and no exceedances of the federal 24-hour standard were recorded. These concentrations were lower than expected, perhaps because of the late project start, missing the dry months of May and June, and the location of the continuous sampler at an upwind roadway site. (Trost, 2004)

[1] On January 17, 2006, U.S. EPA proposed eliminating the PM_{10} standards and adopting PM-coarse (PM larger than 2.5 microns but smaller than 10 microns in diameter) standards. The proposed 24-hour standard is 70µg/m^3, and areas in which PM-coarse is dominated by rural windblown dust, agricultural, or mining emissions would be exempt from having to comply with this standard. A final decision will not be made on this proposal until September 2006.

In 2003, PM_{10} monitoring was conducted at the same five locations between May 31 and July 24. During this monitoring effort, a continuous PM_{10} monitor was located at one of the downwind roadway sites. During this period, several exceedances of the federal 24-hour standard were measured. PM_{10} measurements correlated with precipitation, meaning that 24-hour averages declined on days when precipitation fell, but an analysis of the data with respect to wind speed and direction did not yield any conclusive results. (Trost, 2004) A correlation of average daily PM_{10} with diurnal traffic counts also did not reveal a simple relationship.

In 2004, PM_{10} monitoring was conducted only at the pair of roadway sites recording the higher traffic counts and PM_{10} measurements in 2003. Filter-based samplers were used at each of the two sites and one continuous sampler was co-located at the downwind roadway site. The monitoring period spanned between May 26 to July 20, and several exceedances of the federal 24-hour standard were recorded. As in 2003, no distinct correlations could be found between PM_{10} measurements, wind speeds, and wind directions. During one of the exceedance days, however, all of the monitors recorded elevated measurements while the community was impacted by smoke from wildfires as verified by decreasing visibility as reported by the National Weather Service. (Trost, 2004)

Average and maximum 24-hour average PM_{10} values recorded in Kotzebue during these three monitoring periods are presented in Table 1. Values are reported separately for filter-based samplers and the continuous sampler, as the continuous sampler usually reported higher measurements than the co-located filter samplers.

Table 1
Kotzebue PM_{10} Monitoring Data

	2002	2003	2004
Filter-Based Measurements			
No. of Sampling Days	14	28	28
No. of Exceedance Days	0	5	10
Max. 24-Hour PM_{10}, $\mu g/m^3$	121	220	351
Highest Annual PM_{10}, $\mu g/m^{3*}$	50	55	131
Continuous Monitoring			
No. of Sampling Days	89	48	50
No. of Exceedance Days	1	10	10
Max. 24-Hour PM_{10}, $\mu g/m^3$	172	560	371
Annual PM_{10}, $\mu g/m^3$	28	94	93
Current Ambient Air Quality Standards			
24-Hour PM_{10}, $\mu g/m^3$	150		
Annual PM_{10}, $\mu g/m^3$	50		

*These values represent the highest annual average PM_{10} measurements recorded at any one of the 3 to 5 monitors operated in Kotzebue in each year.

These data indicate that 24-hour average concentrations of PM_{10} exceed the current national ambient air quality standard. Because less than a full year of PM_{10} data was collected in each of these years, no comparison to the annual standard can be made. If EPA determines in September 2006 that PM_{10} standards are to be abolished in favor of PM-coarse standards, and that communities in which fugitive dust sources dominate emissions of PM-coarse are exempt for having to comply with the new standards, then the proposed standards will not apply to communities like Kotzebue.

Noatak – PM_{10} monitoring was conducted in Noatak at a single monitoring site in 2003 and 2005. The monitoring site was located adjacent to a major unpaved road in the community and the community school. No monitoring of traffic or meteorological conditions was conducted in this community during these years.

In 2003, one filter-based sampler was operated intermittently between February 27 and September 12 in Noatak. One exceedance of the national 24-hour PM_{10} was recorded during ten acceptable monitoring days. Data collected during 7 of 17 monitoring days could not be used due to failure to satisfy federal monitoring criteria with respect to run times. Monitoring was not conducted between May 13 and July 2, when precipitation levels are the lowest of the year and when Kotzebue measured some of its highest PM_{10} measurements of 2003.

During the summer of 2005, two co-located filter-based samplers were operated in Noatak. Monitoring commenced on May 28, 2005, and data have been reported through November 6, 2005. During this period, several exceedances of the national 24-hour standard were recorded. Summaries of the Noatak monitoring data from 2003 and 2005 are presented in Table 2.

Table 2
Noatak PM_{10} Monitoring Data

	2003	2005
Filter-Based Measurements		
No. of Sampling Days	10	25
No. of Exceedance Days	1	9
Max. 24-Hour PM_{10}, $\mu g/m^3$	152	601
Annual PM_{10}, $\mu g/m^3$	38	177
Current Ambient Air Quality Standards		
24-Hour PM_{10}, $\mu g/m^3$	150	
Annual PM_{10}, $\mu g/m^{3*}$	50	

*Since less than a full year of PM_{10} measurements were made in each of these years, the annual average cannot be compared to the annual standard.

These data indicate that 24-hour average concentrations of PM_{10} periodically exceed the current national standard. If EPA determines in September 2006 that PM_{10} standards are to be abolished in favor of PM-coarse standards, and that communities in which fugitive dust sources dominate emissions of PM-coarse are exempt from having to comply with the new standards, then the proposed standards will not apply to communities like Noatak.

###

3. DUST CONTROL MEASURES

Controls for dust emissions from unpaved roads take several forms, which include the following:

- Reducing the numbers of vehicles using unpaved roads;
- Reducing vehicle speeds on unpaved roads;
- Correcting road structural deficiencies;
- Increasing the moisture content of unpaved road surface soils;
- Binding smaller particles to larger particles in unpaved road surface soils;
- Covering unpaved road surface soils with gravel; and
- Sealing unpaved road surface soils with pavement or other durable materials.

In the following sections, general information on each of these categories of control is presented. More detailed information is provided in Appendix A on controls that involve the application of dust palliatives applied to road surfaces.

Reducing Numbers of Vehicles

PM_{10} emissions from unpaved road travel are directly proportional to the number of vehicles traversing an unpaved road section. Emissions can be reduced by reducing the numbers of vehicles using an unpaved road, and this can be achieved by imposing weight or vehicle use restrictions, or by removing an unpaved road from service, among other methods. An example of this type of control was enacted recently by the City of Kotzebue, which now prohibits anyone under 14 years of age from operating an offroad vehicle (snowmachine and all-terrain vehicle) on city streets unless accompanied by an adult on the same machine. (Kotzebue, 2006) Closing an unpaved road to traffic may not be practical in rural Alaskan communities as restrictions imposed or induced on one unpaved road will simply divert traffic to other unpaved roads in affected communities.

Reducing Vehicle Speed

Studies show that PM_{10} emissions are proportional to vehicle speed. Based on an initial speed of 40 miles per hour, a reduction in the speed limit to 20 miles per hour results in a 65% reduction in dust emissions. (Succarieh, 1992) Vehicle speeds can be reduced through road postings and enforcement, or by altering the road surface to install waterbars (drainage channels) or speed bumps. Depending on the availability of law enforcement resources and community social cohesion, the enforcement of speed limits on unpaved roads may be a practical method of reducing PM_{10} emissions on heavily traveled unpaved roads. Roughing a roadway surface by installing speed bumps or waterbars to reduce speeds is of limited practicability as ATVs can negotiate these impediments without significant discomfort to operators and the speeds of larger vehicles creating dust emissions will be reduced only within a relatively short distance of the vertical disturbance. The greater width (relative to highway vehicles) of ATV tires will also entrain more dust even at lower speeds.

Proper Road Structural Maintenance

The long-term performance of any dust suppressant applied to a road surface depends upon many factors, including the type and gradation of the road materials, type and intensity of traffic loading, climate, type of dust suppressant, drainage and thermal stability, and available maintenance resources. These factors must be considered together in the proper maintenance of a road that will safely and cost-effectively resist dust generation. For example, if the road surface is not well drained, water will puddle either on the road surface or in adjacent low spots. Standing water will float soil fines to the surface and distribute them across the roadway surface with passing traffic. Standing water adjacent to a roadway has the potential to saturate the road sub-base, resulting in structural failure as evidenced by potholes. Aggregate in a roadway surface reduces tire forces on fine materials that increases the release of dust from a roadway. The loss of fines in the roadway surface leaves the aggregate unanchored and vulnerable to being pushed to the side of the road by tire forces. The success of palliatives to reduce dust depends on the repair and maintenance of good drainage on and adjacent to the road. (CPWA, 2005)

Increasing Moisture Content

Moisture in the surface soils of unpaved roads causes particles to adhere to each other through the surface tension of connecting water droplets and the adhesion of droplets to dust particles. The moisture content of surface soils can be increased either through direct application of water to roadway surfaces, or through the attraction of water to deliquescent salts added to surface soils.

Water is available in significant quantities in almost all rural Alaskan communities. Methods of conveying this water economically to unpaved roads for application as a dust control agent are problematical in smaller communities. Some larger communities, like Kotzebue, have water trucks in the fleets of roadway maintenance vehicles, and can take advantage of local water supplies for use in dust control efforts. Smaller communities do not have access to such equipment and have only limited capacity to apply water in sufficient quantities to effectively control dust emissions. Watering provides short-term reductions in dust generation depending on surface evaporation rates. Regular, light watering is more effective than less frequent, heavy watering. (Bolander, 1999)

Unpaved road dust control can also be implemented by the application of deliquescent salts to roadway surfaces. Calcium chloride and magnesium chloride absorb moisture from the air to keep surface soils in which these chemicals have been mixed at higher moisture contents than untreated soils. At 77ºF and 90% humidity, for example, calcium chloride will absorb more than 17 times its own weight in water. (CPWA, 2005) The performance of chlorides depends on the percent of surface soil passing a 200-mesh screen, with recommendations between 10 and 20 percent. (Morgan, 2005) Potential disadvantages to the use of these salts are that roads may become slippery when wet and vehicle corrosion may occur and roads may become more susceptible to freeze and thaw damage. Additionally, prolonged rainfall will leach the salts from the roadway, potentially impact groundwater and surface water quality, and attract wildlife potentially causing safety concerns. The practical utility of an application of one of these salts is no more than one year. (Morgan, 2005) Sodium chloride, or common rock salt, is also deliquescent, and has been tested in a limited number of studies, but it is not as effective as calcium or magnesium chloride.

Calcium chloride has been tested and used as a dust control palliative in several locations in Alaska over the past several years. These locations include Kotzebue, Teck Cominco's Red Dog Mine, and Haines, among other locations. Environmental impacts of chlorides include metal corrosion, and degradation to nearby vegetation, surface, groundwater, and aquatic species. (CPWA, 2005) In addition, because calcium chloride can substantially lower the freezing temperature of water, concentrations of the palliative in road soils can change the thermal stability of these soils.

Binding Particles Together

The largest group of dust palliatives used on unpaved roads and airfields consists of chemicals that are designed to bind fine soil particles together or to larger particles. These chemicals fall into several subgroups, such as the following:

- Petroleum-based binders,
- Organic nonpetroleum dust suppressants (lignins),
- Electrochemical stabilizers,
- Synthetic polymer products, and
- Pozzuolannic minerals (i.e. lime, cement, etc.).

Petroleum-based Binders – Petroleum-based binders used for dust suppression include emulsified asphalts, cutback asphalt, and Bunker C. These agents are used to coat surface soil particles with a thin layer of asphalt that binds the soil particles together and decreases their likelihood of becoming airborne. Some of these binders exhibit no adhesive properties, but instead increase the mass of fine particles, reducing their ability to become airborne. (Nevada DOT, 2003) Emulsified asphalt, because it is a mixture of asphalt and water in very small droplets, has the capability to penetrate unpaved road surfaces to coat more than just the surface particles, especially if the product is mechanically mixed into the top inch or two of road surface with a grader. Petroleum-based binders that contain fractions of lighter solvents, and especially those containing polycyclic aromatic hydrocarbons (many of which are carcinogens), can contaminate waterways if any migration of these lighter fractions occurs due to runoff.

Organic Nonpetroleum Dust Suppressants – Organic nonpetroleum dust suppressants include lignosulfonates, resins, and vegetable oils. Lignosulfonates derive from the manufacture of paper during which lignin is extracted from wood fibers. Lignin binds wood cells together and is a natural polymer. As a byproduct of paper manufacture, it occurs in solution with sodium, calcium, ammonium, or magnesium bisulphate. Lignosulfonates bind soil particles together due to a combination of chemical and physical interactions. Resins are usually synthesized as combinations of lignosulfonates and additives designed to neutralize adverse effects. Lignosulfonates are water soluble and will leach out of, or deeper into, roadway surface with rainfall. These products are also corrosive to aluminum and its alloys unless calcium carbonate is added. Lignosulfonates have a useful duration of a few months and work best with surface materials that have high fine contents and high plasticity indices in a dry environment. (CPWA, 2005) Because glacial tills contain low levels of clay and have low plasticity indices, lignosulfonates may be of limited value in controlling dust emissions from these soils. Additionally, because lignosulfonates are derivatives of sulfuric acid, the leaching of these palliatives by runoff can adversely impact watershed areas by affecting the acidity of water sources. Lignosulfonates are reported to not bind well on roads that had been treated previously with chloride compounds. (Lunsford, 2001)

Electrochemical Stabilizers – Electrochemical stabilizers include sulphonated petroleum, ionic stabilizers, and enzymes. These products are intended to neutralize the ionic charges of clay-sized particles, thereby allowing electrostatic forces to bind the particles. To be effective, electrochemical stabilizers need to be worked into the road surface, requiring equipment that may not be available in remote rural communities.

Synthetic Polymer Products – Synthetic polymer products include polyvinyl acrylics and acetates that are designed to bind soil particles together and form a semi-rigid film on the road surface. These products are formulated as either water soluble liquids or dry powders intended to be mixed with water. Because the products are applied in liquid form and are required to dry in binding soil particles together, care needs to be taken after application to assure that temperatures during the curing period will not approach freezing and that traffic will be diverted from application areas until curing is completed. Products that are available in liquid form only, such as Soil Sement, should not be stored at temperatures below freezing. Curing periods typically extend from 12 to 24 hours. Synthetic polymer products have been used for dust control and improved soil strength on a number of airfields in Northern Canada and Alaska.

Pozzuolannic Minerals – Pozzuolannic minerals, such as lime and cement, are typically added to non-plastic road surface material to produce a thin crust. These stabilizers must be field mixed into the road material and compacted. These surfaces, once hardened however, cannot reharden once disturbed by abrasive forces, such as those created by roads being crossed by snow machines or by roads being rebladed.

Covering of Unpaved Road Surface Soils With Gravel

The abrasion of unpaved road surface soils and release of fugitive dust by unpaved road traffic can be reduced by the application of gravel to the road surface. Gravel provides a hard-wearing surface that protects soils from the abrasive forces of vehicle wheels. Traffic causes abrasion between the aggregates, however, which over time creates fine dust. The degradation is somewhat dependent upon the hardness of the aggregate. (This is one reason why urban areas don't like to sand their roads in winter.) Gravel will not reduce the strength of vortex airflows behind passing vehicles from entraining loose soil particles into the air, however. In the absence of a well-constructed roadbase using crushed aggregate, surface gravel will be pushed down into the road surface by traffic, especially during wet conditions. If the road surface does not contain a sufficient quantity of fine material of high plasticity (cohesion) to hold surface gravel in place, traffic can also cause surface gravel to be expelled laterally from the road's driving lanes. To be effective over more than a short period of time, new gravel applied to a road must be anchored to the road surface by incorporation into a cohesive surface layer, whether by use of well-graded aggregate mixes or by use of soil adhesives (i.e., chip seals). Even washed, well-graded wear courses (like D-1) produce dust over time due to traffic wear causing aggregate degradation.

In the event that gravel is lost to the roadway surface through vertical migration into noncohesive soils in the subbase, the use of geotextile fabrics may be of benefit. These fabrics are constructed of polymer threads that are very high in tensile strength, and are available in designs that either form water barriers or allow water, but not fine soil, to migrate through. (Hopkins, 1989)

Sealing of Unpaved Road Surface Soils With Pavement or Other Durable Materials

The most effective, and expensive, method of controlling fugitive dust emissions from unpaved road surfaces is the application of pavement or other durable materials to the road surfaces. Asphalt concrete and Portland concrete wear courses, when applied to road surfaces, provide durable and effective traffic surfaces that prevent the abrasion of soil surfaces. Except for roadways carrying more than 250 to 500 vehicles per day, the use of paving to control dust emissions may not be cost-effective. (Bolander, 1999) In the past few years, several roads in Kotzebue that carry more than 500 vehicles per day have been paved. (Hadley, 2006) Thin pavements, such as chip seals, have been applied to roads in southern Alaska, but these surfaces have fallen apart completely during the first breakup. (Reckard, 1988) Rigid pavements are often not cost-effective in areas underlain by permafrost. The road itself causes thermal instability, which can lead to road foundation instability.

Fiberglass plates are used in cold climate oilfields to provide temporary road surfaces over native soil. These interlocking plates are typically manufactured in sections that are 14 feet long by 8 feet wide by 2 inches thick. The plates are designed to carry very heavy loads over short distances without the need to construct structural roadbeds in areas like northwestern Alaska, where construction aggregate is in very limited supply. The plates are expensive, costing about $2,000 per plate, but appear to have a significant lifespan. (Compositech, 2005) Some question exists, however, as to whether such plates are skid resistant at the vehicle speeds typical in rural communities.

Selection Guides

Several publications found in the literature search for this study contain selection guides for choosing chemical dust palliatives on the basis of road traffic levels, soil type, and other parameters. These guides are presented in Appendix B.

Bibliography

An extensive bibliography of unpaved road dust control literature has been compiled by Temple Stevenson for a report on dust control methods for unpaved mining roads in Wyoming's Powder River Basin. (Stevenson, 2004) This bibliography is reproduced in Appendix C.

###

4. COSTS AND BENEFITS

The costs of dust control on unpaved roads in rural Alaskan communities can be calculated on the basis of available market data, but the benefits of each control method will vary depending on the soil type, traffic level, and road design, among other factors. As a result, approximate costs for various control methods are presented here on the basis of delivery to and application in Kotzebue. The control methods included in the cost analysis are limited to those that are technologically feasible in northwestern Alaska. The range of control effectiveness for each of the control methods derives from the literature, not from studies conducted in cold climates.

The costs of dust control methods, per mile of treated roadway in northwestern Alaska, are summarized in Table 3. Labor and equipment costs are based on data provided by the Alaska Department of Transportation and Public Facilities (ADOT&PF). (Adler, 2006) Detailed cost calculations are presented in spreadsheet format in Appendix C.

Table 3
Dust Control Method Costs and Effectiveness
($ per mile of road treated)

Dust Control Category	Specific Product	Control Cost ($ per mile of road treated)	Control Effectiveness Range	Control Duration
Moisture Increase	Watering	$32	0% - 50%*	1-2 hours
	Calcium Chloride	$26,000	0% - 70%**	6 months
Particle Agglomeration	EK-35	$20,000	0% - 99%***	1 year
	Lignosulfonate	$22,000	0% - 90%*	2 months
	Soil Sement	$26,000	0% - 84%****	1 year
Soil Coverage	Gravel	$84,000	0% - 30%*	3 months
	Geotextile	$27,000	N/A	10 years
	Asphalt Paving	$2,700,000	90% - 99%	15 years
	Fiberglass Plates	$2,800,000	90% - 99%	10 years

* Orlemann, 1983
** Morgan, 2005
*** MRI, 2002
**** California ARB, 2002

###

5. RECOMMENDATIONS

Dust Control Measures

In the context of rural Alaskan communities, unpaved road dust control is expensive. This is due to the transportation costs of dust palliatives, the scarcity of aggregate, and the limited equipment available for road improvement and maintenance. Because of these conditions, dust control in these communities should start with the least expensive options first. These options include speed controls and restrictions on vehicle use in sensitive areas (i.e., near schools, hospitals, and residential areas).

The next least expensive control method is the reconstruction of unpaved roads to provide good drainage and a solid base. The use of geotextiles to support a road surface over poor quality soils may be a reasonably cost-effective method of improving road structure in areas where underlying soils impose requirements for frequent maintenance. Sound engineering judgment is required to make this determination. Without good drainage and road base, the benefits of additional dust control measures will be limited. Where useful, rural community representatives should enlist assistance of an Alaskan registered professional engineer or consult the Alaska Tribal Technical Assistance Program (TTAP-AK), administered by Eastern Washington University, to help identify the causes of unpaved road structural failures and evaluate the options for resolving deficiencies. The ADOT&PF Local Technical Assistance Program (LTAP) may assist TTAP-AK. For more information on TTAP-AK see *http://www.ewu.edu/TTAP*.

Depending on the availability of equipment and manpower, the watering of roads during high dust periods is an available if not wholly effective method of dust control. Because monitoring data suggest that high dust generation rates occur sporadically during the two-month period following breakup, short term control measures like watering can provide limited benefits provided that impacted communities have access to water trucks.

The optimization of benefits from the application of dust palliatives is dependent on local soil and traffic conditions that require site-specific investigations. These investigations should begin with analyses of the soils from which unpaved roads are constructed. Upon request, TTAP-AK with potential assistance from ADOT&PF's LTAP, may assist rural communities with technical assistance and/or training on proper techniques for soil analyses useful in the palliative selection process.

Depending on local soil and traffic conditions, some deliquescent salts and synthetic polymer products may provide adequate levels of dust control on rural community unpaved roads. These products, which include calcium chloride and EK-35, have been tested in several locations in Alaska and have been demonstrated to control dust emissions. Because the successful use of these products is dependent upon a number of factors that vary from community to community, pilot tests of selected products for a summer season should be undertaken in affected communities before community-wide application is pursued.

Further Research

Better characterizations of unpaved road structural conditions and soil characteristics are needed in rural communities with elevated PM_{10} levels in order to identify the most cost effective methods of dust control. This work could be undertaken by TTAP-AK or consulting engineers on a single-visit basis to assist communities that have determined they need help in reducing dust emissions.

Pilot project testing of dust palliatives and other methods of reducing emissions from unpaved road use should be undertaken in communities desiring to invest in dust control. The selection of dust control methods for testing should be based on an analysis of local road conditions. The benefits of dust palliative use should be measured with simple monitoring technology like the University of Colorado Dustometer, which can be quickly mounted in the bed of a pickup and uses common 8 inch by 10 inch fiberglass filters to collect dust samples while the pickup traverses either treated or untreated road sections. (Sanders, 1993) The results of pilot testing should be documented and published on a website for review by rural community representatives.

Finally, additional research on innovative control measures should be undertaken. The budget and duration of this study allowed for a limited review of the literature available on unpaved road dust control research. Given the challenges of climate and resource limitations in rural Alaskan communities, especially those in the northern portion of the state that are remote and accessible only by air, the standard solutions to unpaved road dust are not available. More work needs to be done in investigating and developing solutions that rely primarily on limited local resources.

###

6. LITERATURE CITED

http://www.bah-abingdon-staging-site.com/CAARC/info_rep/pdf/dustchecklist.pdf

ADCA, Community Database Online, Alaska Division of Community Advocacy, http://www.commerce.state.ak.us/dca/commdb/CF_BLOCK.htm, accessed on January 6, 2006

Adler, C., 2006, labor rates from recent Northern Region construction contract and equipment rates (adjusted for northern Alaska) from the Rental Rate Blue Book, https://www.equipmentwatch.com/Marketing/RRBB_overview.jsp

Baxter, R., 2001, "Arrest That Fugitive Dust," *Erosion Control*, March/April 2002, http://www.forester.net/ecm_0203_arrest.html

Beckard, M., 1988, *Cost Effectiveness of Selected Roadway Dust Control Methods for the Mendenhall Valley, Juneau, Alaska*, prepared for Alaska Department of Environmental Conservation by Alaska Department of Transportation and Public Facilities, http://www.dot.state.ak.us/stwddes/research/assets/pdf/ak_rd_88_08.pdf, accessed on December 20, 2005

Bolander, P. and A. Yamada, 1999, *Dust Palliative Selection and Application Guide*, U.S. Department of Agriculture Forest Service, http://www.dot.state.ak.us/stwddes/research/assets/pdf/dust_sag.pdf, accessed on December 20, 2005

California ARB, 2002, *Evaluation of The Air Quality Performance Claims For Midwest Industrial Supply, Inc. Soil Sement Dust Suppressant*, California Air Resources Board, http://www.arb.ca.gov/eqpr/midwest.htm (accessed on January 20, 2006)

Compositech, 2005, http://www.composite-tech.com/products/durabase.html, accessed on December 14, 2005, and telephone communication with Dennis Swarthout, President, on December 15, 2005

CPWA, 2005, *Dust Control for Unpaved Roads, A Best Practice by the National Guide to Sustainable Municipal Infrastructure*, Canadian Public Works Association, http://www.infraguide.ca/lib/Db2File.asp?fileid=4555, accessed on January 5, 2006

City-Data.com, 2006, Kotzebue AK, http://www.city-data.com/city/Kotzebue-Alaska.html, accessed on January 7, 2006

Furbush, C.E., 1971, *Soils of the City of Kotzebue*, USDA Soil Conservation Service

Hadley, J., 2006, Telephone communication with Jeff Hadley, City of Kotzebue, January 10, 2006

Hinton, R.B., and M.R. Dixon, 1967, *Soils of the Deering Area*, Alaska, USDA Soil Conservation Service

Hopkins, J., 1989, *Geotextile Selection and Installation Manual for Rural Unpaved Roads*, prepared for U.S. Federal Highway Administration by Oklahoma State University

Kotzebue, 2006, City website, http://kotzpdweb.tripod.com/city/index.html, accessed on January 11, 2006

Lunsford, G.B., and J.P. Mahoney, 2001, *Dust Control on Low Volume Roads, A Review of Techniques and Chemicals Used*, prepared for Federal Highway Administration, http://www.dot.state.ak.us/stwddes/research/assets/pdf/fhwa_lt_01_002.pdf

Morgan, R.J., V.R. Schaefer, and R.S. Sharma, 2005, *Determination and Evaluation of Alternative Methods for Managing and Controlling Highway-Related Dust, Phase II – Demonstration Project*, Iowa State University, http://www.dot.state.ia.us/materials/research/reports/reports_pdf/hr_and_tr/reports/tr506.pdf, accessed on December 23, 2005

MRI, 2002, *Report of 3-Month Test of Dust Suppression Products – Preliminary Testing, Midwest Industrial Supply, Inc. EK35*, prepared by Midwest Research Institute for U.S. Environmental Protection Agency, http://www.epa.gov/etv/pdfs/vrvs/05_vr_ek35.pdf, accessed on January 10, 2006

Nevada DOT, 2004, *Construction Site Best Management Practices Manual*, http://www.nevadadot.com/reports_pubs/Water_Quality/pdfs/BMP_Section3.pdf, accessed on January 4, 2006

Orlemann, J.A., F.J. Kalman, J.A. Cummings, E.Y. Lim, 1983, *Fugitive Dust Control Technology*, Noyes Data Corporation

Sanders, T.G., and J.Q Addo, 1993, *Effectiveness and Environmental Impact of Road Dust Suppressants*, http://www.ndsu.nodak.edu/ndsu/ugpti/MPC_Pubs/html/MPC94-28.htm, accessed on January 4, 2006

Schoephorster, D.B., and C.D. Bowen, 1965, *Soils of the Kobuk Area, Alaska*, USDA Soil Conservation Service

Stevenson, T., 2004, *Dust Suppression on Wyoming's Coal Mine Haul Roads*, prepared for Industries of the Future Converse Area New Development, http://www-personal.ksu.edu/~sstevens/Dust%20Manual%20102704.pdf, accessed on January 4, 2006

Succarieh, M., 1992, *Control of Dust Emissions From Unpaved Roads*, prepared for Alaska Cooperative Transportation and Public Facilities Research Program by the University of Alaska Fairbanks, http://www.dot.state.ak.us/stwddes/research/assets/pdf/fhwa_ak_rd_92_05.pdf, accessed on December 20, 2005

Teck Cominco, 2005, *Summary of Mine Related Fugitive Dust Studies, Red Dog Mine Site*, Teck Cominco Alaska Incorporated, http://www.dec.state.ak.us/air/doc/RD_Mine_Fugitive_Dust_Studies_3-05.pdf, accessed on December 22, 2005

Trost, B, 2003, *Quality Assurance Project Plan for the State of Alaska Kotzebue Road Dust Study*, prepared for Alaska Department of Transportation & Public Facilities by Alaska Department of Environmental Conservation

Trost, B., 2004, *Effectiveness of Paving on Airborne Particulate Matter: A Preliminary Assessment of Fugitive Dust From Roads in Kotzebue, Alaska, Interim Report – 2002-2004*, prepared for Alaska Department of Transportation & Public Facilities by Alaska Department of Environmental Conservation

U.S. Army, 2006, Dust Palliative Dichotomous Key, U.S. Army Clean Air Research Center, http://www.bah-abingdon-staging-site.com/CAARC/info_rep/pdf/dustchecklist.pdf, accessed on January 4, 2006

###

APPENDIX A

Summary Information on Dust Palliatives

(from Dust Palliative Selection and Application Guide,
U.S. Department of Agriculture Forest Service,
November 1999)

Table 1—Road dust suppressants.

Dust Suppressant Category	Attributes	Limitations	Application	Origin	Environmental Impact
Water	• agglomerates the surface particles • normally, readily available	• evaporates readily • controls dust generally for less than a day • generally the most expensive and labor intensive of the inorganic suppressants	• frequency depends on temperature and humidity; typically only effective from 1/2 to 12 hours	• any potable water source	• none
Water Absorbing: Calcium Chloride (deliquescent)	• ability to absorb water from the air is a function of temperature and relative humidity; for example, at 25°C (77°F) it starts to absorb water at 29% relative humidity, and at 38°C (100°F) it starts to absorb water at 20% relative humidity • significantly increases surface tension of water film between particles, helping to slow evaporation and further tighten compacted soil as drying progresses • treated road can be regraded and recompacted with less concern for losing moisture and density	• requires minimum humidity level to absorb moisture from the air • doesn't perform as well as MgCl in long dry spells • performs better than MgCl when high humidity is present • slightly corrosive to metal, highly to aluminum and its alloys, attracts moisture, thereby prolonging active period for corrosion • rainwater tends to leach out highly soluble chlorides • if high fines content in treated material, the surface may become slippery when wet • effectiveness when less than 20% solution has performance similar to water	• generally 1 to 2 treatments per season • initial application: flake: @ 0.5 to 1.1 kg/m^2 (1.0 to 2.0 lb/y^2), typical application 0.9 kg/m^2 (1.7 lb/y^2) @ 77% purity liquid: 35 to 38% residual @ 0.9 to 1.6 L/m^2 (0.2 to 0.35 g/y^2), typical application is 38% residual concentrate applied undiluted @ 1.6 L/m^2 (0.35 g/y^2) • follow-up: apply @ 1/2 to 1/3 initial dosage	• by-product in the form of brine from manufacture of sodium carbonate by ammonia-soda process and of bromine from natural brines • three forms: flake, or Type I, @ 77 to 80% purity pellet, or Type II, @ 94 to 97% purity clear liquid @ 35 to 38% solids	• water quality impact: generally negligible if the proper buffer zone exists between treated area and water • fresh water aquatic impact: may develop at chloride concentrations as low as 400 ppm for trout, up to 10,000 ppm for other fish species • plant impact: some species susceptible, such as pine, hemlock, poplar, ash, spruce, and maple • potential concerns with spills of liquid concentrate

Table 1—Road dust suppressants (continued).

Dust Suppressant Category	Attributes	Limitations	Application	Origin	Environmental Impact
Water Absorbing: Magnesium Chloride (deliquescent)	• starts to absorb water from the air at 32% relative humidity independent of temperature • more effective than calcium chloride solutions for increasing surface tension, resulting in a very hard road surface when dry • treated road can be regraded and recompacted with less concern for losing moisture and density	• requires minimum humidity level to absorb moisture from the air • more suitable in drier climates • in concentrated solutions, very corrosive to steel (note: some products may contain a corrosive-inhibiting additive); attracts moisture, thereby prolonging active period for corrosion • rainwater tends to leach out highly soluble chlorides • if high fines content in treated material, the surface may become slippery when wet • effectiveness when less than 20% solution has performance similar to water	• generally 1 - 2 treatments per season • initial application: 28 to 35% residual @ 1.4 to 2.3 L/m^2 (0.30 to 0.5 g/y^2), typical application is 30% residual concentrate applied undiluted @ 2.3 L/m^2 (0.50 g/y^2) • follow-up: apply @ 1/2 initial dosage	• occurs naturally as brine (evaporated)	• water quality impact: generally negligible if the proper buffer zone exists between treated area and water • fresh water aquatic impact: may develop at chloride concentrations as low as 400 ppm for trout, up to 10,000 ppm for other fish species • plant impact: some species susceptible such as pine, hemlock, poplar, ash, spruce, and maple • potential concerns with spills
Water Absorbing: Sodium Chloride (hygroscopic)	• starts to absorb water from the air at 79% relative humidity independent of temperature • increases surface tension slightly less than calcium chloride	• requires minimum humidity level to absorb moisture from the air • moderately corrosive to steel in dilute solutions • tends not to hold up well as a surface application	• generally 1 - 2 treatments per season • higher dosages than calcium treatment	• occurs naturally as rock salt and brines	• same as calcium chloride

Table 1—Road dust suppressants (continued).

Dust Suppressant Category	Attributes	Limitations	Application	Origin	Environmental Impact
Organic Petroleum Products	• binds and/or agglomerates surface particles because of asphalt adhesive properties • serves to waterproof the road	• under dry conditions some products may not maintain resilience • if too many fines in surface and high in asphaltenes, it can form a crust and fragment under traffic and in wet weather • some products are difficult to maintain	• generally 1 to 2 treatments per season • 0.5 to 4.5 L/m^2 (0.1 to 1 g/y^2) depending on road surface condition, dilution, and product • the higher viscosity emulsions are used for the more open-graded surface materials • follow-up: apply at reduced initial dosages	• cutback asphalt: SC-70 • Asphalt emulsion: SS-1, SS-1h, CSS-1, or CSS-1h mixed with 5+ parts water by volume • modified asphalt emulsions • emulsified oils • mineral oils	• wide variety of ingredients in these products • “used” products are toxic • oil in products might be toxic • need product specific analysis • potential concerns with spills and leaching prior to the product “curing”
Organic Nonpetroleum: Lignin Derivatives	• binds surface particles together • greatly increases dry strength of material under dry conditions • retains effectiveness during long dry periods with low humidity • with high amounts of clay, it tends to remain slightly plastic permitting reshaping and additional traffic compaction	• may cause corrosion of aluminum and its alloys • surface binding action may be reduced or completely destroyed by heavy rain, due to solubility of solids in water • becomes slippery when wet, brittle when dry • difficult to maintain as a hard surface, but can be done under adequate moisture conditions	• generally 1 to 2 treatments per season • 10 to 25% residual @ 2.3 to 4.5 L/m^2 (0.5 to 1.0 g/y^2), typical application is 50% residual concentrate applied undiluted @ 2.3 L/m^2 (0.50 g/y^2) or 50% residual concentrate applied diluted 1:1 w/water @ 4.5 L/m^2 (1.0 g/y^2) • may be advantageous to apply in two applications • also comes in powdered form that is mixed 1 kg to 840 liters (1 lb to 100 gallons) of water and then sprayed	• water liquor product of sulfite paper making process, contains lignin in solution • composition depends on raw materials (mainly wood pulp) and chemicals used to extract cellulose; active constituent is neutralized lignin sulfuric acid containing sugar	• water quality impacts: none • fresh water aquatic impacts: BOD may be high upon leaching into a small stream • plant impacts: none • potential concern with spills

Table 1—Road dust suppressants (continued).

Dust Suppressant Category	Attributes	Limitations	Application	Origin	Environmental Impact
Organic Nonpetroleum: Molasses/Sugar Beet Extract	• provides temporary binding of the surface particles	• limited availability	• not researched	• by-product of the sugar beet processing industry	• water quality impact: unknown • fresh water aquatic impact: unknown • plant impact: unknown, none expected
Organic Nonpetroleum: Tall-Oil Derivatives	• adheres surface particles together • greatly increases dry strength of material under dry conditions	• surface binding action may be reduced or completely destroyed by long-term exposure to heavy rain, due to solubility of solids in water • difficult to maintain as a hard surface	• generally 1 treatment every few years • 10 to 20% residual solution @ 1.4 to 4.5 L/m^2 (0.3 to 1.0 g/y^2); typical application is 40 to 50% residual concentrate applied diluted 1:4 w/water @ 2.3 L/m^2 (0.5 gal/y^2)	• distilled product of the kraft (sulfate) paper making process	• water quality impact: unknown • fresh water aquatic impact: unknown • plant impact: unknown
Organic Nonpetroleum: Vegetable oils	• agglomerates the surface particles	• limited availability • oxidizes rapidly, then becomes brittle	• generally 1 treatment per season • application rate varies by product, typically 1.1 to 2.3 L/m^2 (0.25 to 0.50 g/y^2) • the warmer the product, the faster the penetration • follow-up: apply at reduced initial dosages	• some products: canola oil, soybean oil, cotton seed oil, and linseed oil	• water quality impact: unknown • fresh water aquatic impact: some products have been tested and have a low impact • plant impact: unknown, none expected

Table 1—Road dust suppressants (continued).

Dust Suppressant Category	Attributes	Limitations	Application	Origin	Environmental Impact
Electrochemical Derivatives	• changes characteristics of clay-sized particles • generally effective regardless of climatic conditions	• performance dependent on fine-clay mineralogy • needs time to “set-up,” i.e. react with the clay fraction • difficult to maintain if full strengthening reaction occurs • limited life span	• generally diluted 1 part product to anywhere from 100 to 600 parts water • diluted product also used to compact the scarified surface	• typical products: sulfonated oils, ammonium chloride enzymes, ionic products	• need product specific analysis • some products are highly acidic in their undiluted form
Synthetic Polymer Derivatives	• binds surface particles because of polymer’s adhesive properties	• difficult to maintain as a hard surface	• generally 1 treatment every few years • 5 to 15% residual solution @ 1.4 to 4.5 L/m^2 (0.3 to 1.0 g/y^2); typical application is 40 to 50% residual concentrate applied, diluted 1:9 w/water @ 2.3 L/m^2 (0.50 gal/y^2)	• by-product of the adhesive manufacturing process • typically 40 to 60% solids	• water quality impact: none • fresh water aquatic impact: generally low • plant impact: none • need product specific analysis
Clay Additives	• agglomerates with fine dust particles • generally increases dry strength of material under dry conditions	• if high fines content in treated material, the surface may become slippery when wet	• generally 1 treatment every 5 years • typical application rate is at 1 to 3% by dry weight	• mined natural clay deposits	• water quality impact: unknown • fresh water aquatic impact: none • plant impact: none

Table 2—Suppressant manufacturers.

Suppressant Category		Product Name	Manufacturer or Primary Distributor	Phone Number	Web Site
Water Absorbing	Calcium Chloride	Calcium Chloride Liquid	General Chemical	800-668-0433	www.genchem.com
		Calcium Chloride Flakes	General Chemical	800-668-0433	www.genchem.com
		Dowflake	Dow Chemical	800-447-4369	www.dowcalciumchloride.com
		Liquidow	Dow Chemical	800-447-4369	www.dowcalciumchloride.com
	Magnesium Chloride	DustGard	IMC Salt	913-344-9334	
		Dust-Off	Cargill Salt Division	800-553-7879	
		Chlor-tex	Soil-Tech	702-873-2023	www.soil-tech.com
	Blend of Calcium and Magnesium Chloride	Dust Fyghter	Midwestern Industrial Supply, Inc.	800-321-0699	www.midwestind.com
	Sodium Chloride	Morton Salt	Morton International	312-807-2000	
		IMC Salt	IMC Salt	800-323-1641	
Organic Petroleum	Asphalt Emulsion	CSS-1	Any major asphalt supplier		
	Cutback	MC-70	Any major asphalt supplier		
	Dust Oil/Dust Fluids	Fuel Oil	Pacific Northern Industrial Fuels	206-282-4421	
		Duo Prime Oil	Lyondell Petrochemical Co.	800-423-8434	(white mineral oil)
		EnviroKleen	Midwestern Industrial Supply, Inc.	800-321-0699	www.midwestind.com (synthetic iso-alkane)
	Modified Asphalt Emulsion	Asphotac	Actin	219-397-5020	
		Coherex	Witco Corp.	800-494-8287	www.witco.com
		DOPE-30	Morgan Emultech, Inc.	530-241-1364	
		PennzSuppress-D	Pennzoil-Quaker State Co.	713-546-4000	www.pennzsuppress.com
		Penetrating Emulsion Primer (PEP)	Koch Asphalt Co.	909-829-0505	www.kochmaterials.com
		Petro Tac	Syntech Products, Inc.	800-537-0288	www.syntechproducts.com
		Road Pro	Midwestern Industrial Supply, Inc.	800-321-0699	www.midwestind.com
		Sandstill	Energy Systems Associates, Inc.	703-503-7873	
Organic Nonpetroleum	Lignosulfonate	DC-22	Dallas Roadway Products, Inc.	800-317-1968	www.dallasroadway.com
		Dustac	Georgia Pacific West, Inc.	360-733-4410	(was Lignosite)
		Dustac-100	Georgia Pacific West, Inc.	360-733-4410	www.gp.com/chemical/ lignosulfonate
		CalBinder	California-Fresno Oil Co.	209-486-0220	www.calfresno.com
		Polybinder	Jim Good Marketing	805-746-3783	
		RB Ultra Plus	Roadbind America Inc.	888-488-4273	www.roadbind.com

Table 2—Suppressant manufacturers (continued).

Suppressant Category		Product Name	Manufacturer or Primary Distributor	Phone Number	Web Site
	Molassas/Sugar Beet	Dust Down	Amalgamated Sugar Co.	208-733-4104	
	Tall Oil Emulsion	Dust Control E	Pacific Chemicals, Inc./ Lyman Dust Control	604-828-0218 or 800-952-6457	
		Dustrol EX	Pacific Chemicals, Inc / Lyman Dust Control	604-828-0218 or 800-952-6457	
		Road Oyl	Soil Stabilization Products Co., Inc.	800-523-9992	www.sspco.org
	Vegetable Oils	Soapstock	Kansas Soybean Association Indiana Soybean Association	800-328-7390 800-735-0195	
		Dust Control Agent SS	Greenland Corp.	888-682-6040	
Electro-chemical	Enzymes	Bio Cat 300-1	Soil Stabilization Products Co., Inc.	800-523-9992	www.sspco.org
		EMCSQUARED	Soil Stabilization Products Co., Inc.	800-523-9992	www.sspco.org
		Perma-Zyme 11X	The Charbon Group, Inc.	714-593-1034	www.natural-industrial.com
		UBIX No. 0010	Enzymes Plus, Div of Anderson Affiliates	800-444-7741	
	Ionic	Road Bond EN-1	C.S.S. Technology, Inc.	800-541-3348	www.csstech.com
		Terrastone	Moorhead Group	831-685-1148	www.terrastone.com
	Sulfonated Oils	CBR Plus	CBR Plus, Inc. (Canada)	604-684-8072	www.cbrplus.com
		Condor SS	Earth Sciences Products Corp.	503-678-1216	www.earthscienceproducts.com
		SA-44 System	Dallas Roadway Products, Inc.	800-317-1968	www.dallasroadway.com
		Settler	Mantex	800-527-9919	
		TerraBond Clay Stabilizer	Fluid Sciences, LLC	888-356-7847 or 318-264-9448	www.fluidsciences.com
Synthetic Polymer Emulsions	Polyvinyl Acetate	Aerospray 70A	Cytec Industries	800-835-9844	www.cytec.com
		Soil Master WR	Enviromental Soil Systems, Inc.	800-368-4115	
	Vinyl Acrylic	Earthbound L	Earth Chem Inc.	970-223-4998	www.earthchem.com
		ECO-110	Chem-crete	972-234-8565	www.chem-crete.com/ soilstabilizer.htm
		PolyPavement	PolyPavement Company	323-954-2240	www.polypavement.com
		Liquid Dust Control	Enviroseal Corp.	561-969-0400	www.enviroseal.com
		Marloc	Reclamare Co.	206-824-2385	
		Soiloc-D	Hercules Soiloc	800-815-7668	
		Soil Seal	Soil Stabilization Products Co., Inc.	800-523-9992	www.sspco.org
		Soil Sement	Midwestern Industrial Supply, Inc.	800-321-0699	www.midwestind.com
		TerraBond PolySeal	Fluid Sciences, LLC	888-356-7847	www.fluidsciences.com
	Combination of Polymers	Top Shield	Base Seal International, Inc.	800-729-6985	www.baseseal.com

Table 2—Suppressant manufacturers (continued).

Suppressant Category		Product Name	Manufacturer or Primary Distributor	Phone Number	Web Site
Clay Additives	Bentonite	Central Oregon Bentonite	Central Oregon Bentonite	541-477-3351	
		Pelbon	American Colloid Co.	800-426-5564 or 847-392-4600	www.colloid.com
		Volclay	American Colloid Co.	708-392-4600	www.colloid.com
	Montmorillonite	Stabilite	Soil Stabilization Products Co., Inc.	800-523-9992	www.sspco.org

APPENDIX B

Dust Palliative Selection Guides

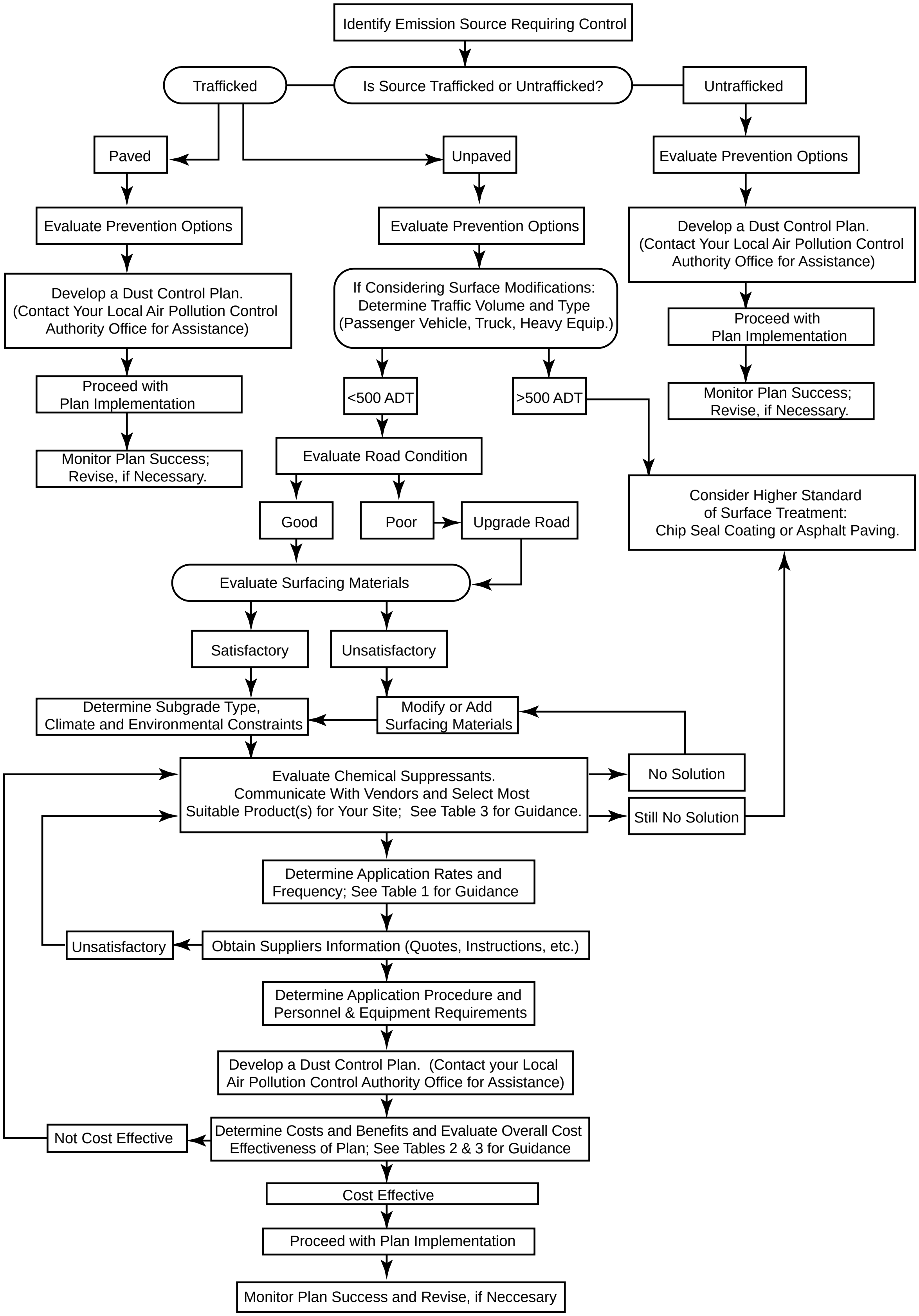


Figure 1—Guidelines for cost-effective selection and use of dust palliatives.

Table 3—Product selection chart.

Dust Palliative	Traffic Volumes, Average Daily Traffic			Surface Material								Climate During Traffic		
				Plasticity Index			Fines (Passing 75μm, No. 200, Sieve)							
	Light <100	Medium 100 to 250	Heavy >250 (1)	<3	3–8	>8	<5	5–10	10–20	20–30	>30	Wet &/or Rainy	Damp to Dry	Dry (2)
Calcium Chloride	✓✓	✓✓	✓	✗	✓	✓✓	✗	✓	✓✓	✓	✗ (3)	✗ (3,4)	✓✓	✗
Magnesium Chloride	✓✓	✓✓	✓	✗	✓	✓✓	✗	✓	✓✓	✓	✗ (3)	✗ (3,4)	✓✓	✓
Petroleum	✓	✓	✓	✓✓	✓	✗	✓ (5)	✓	✓ (6)	✗	✗	✓ (3)	✓✓	✓
Lignin	✓✓	✓✓	✓	✗	✓	✓✓ (6)	✗	✓	✓✓	✓✓	✓ (3,6)	✗ (4)	✓✓	✓✓
Tall Oil	✓✓	✓	✗	✓✓	✓	✗	✗	✓	✓✓ (6)	✓ (6)	✗	✓	✓✓	✓✓
Vegetable Oils	✓	✗	✗	✓	✓	✓	✗	✓	✓	✗	✗	✗	✓	✓
Electro-chemical	✓✓	✓	✓	✗	✓	✓✓	✗	✓	✓✓	✓✓	✓✓	✓ (3,4)	✓	✓
Synthetic Polymers	✓✓	✓	✗	✓✓	✓	✗	✗	✓✓	✓✓ (6)	✗	✗	✓	✓✓	✓✓
Clay Additives (6)	✓✓	✓	✗	✓✓	✓✓	✓	✓✓	✓	✓	✗	✗	✗ (3)	✓	✓✓

Legend

✓✓ = Good ✓ = Fair ✗ = Poor

Notes:

(1) May require higher or more frequent application rates, especially with high truck volumes
(2) Greater than 20 days with less than 40% relative humidity
(3) May become slippery in wet weather
(4) SS-1 or CSS-1 with only clean, open-graded aggregate
(6) Road mix for best results

highly variable depending on road, traffic, and other conditions, and should be tried before any wide-scale application.

Figure 3–1: Dust suppressant selection process

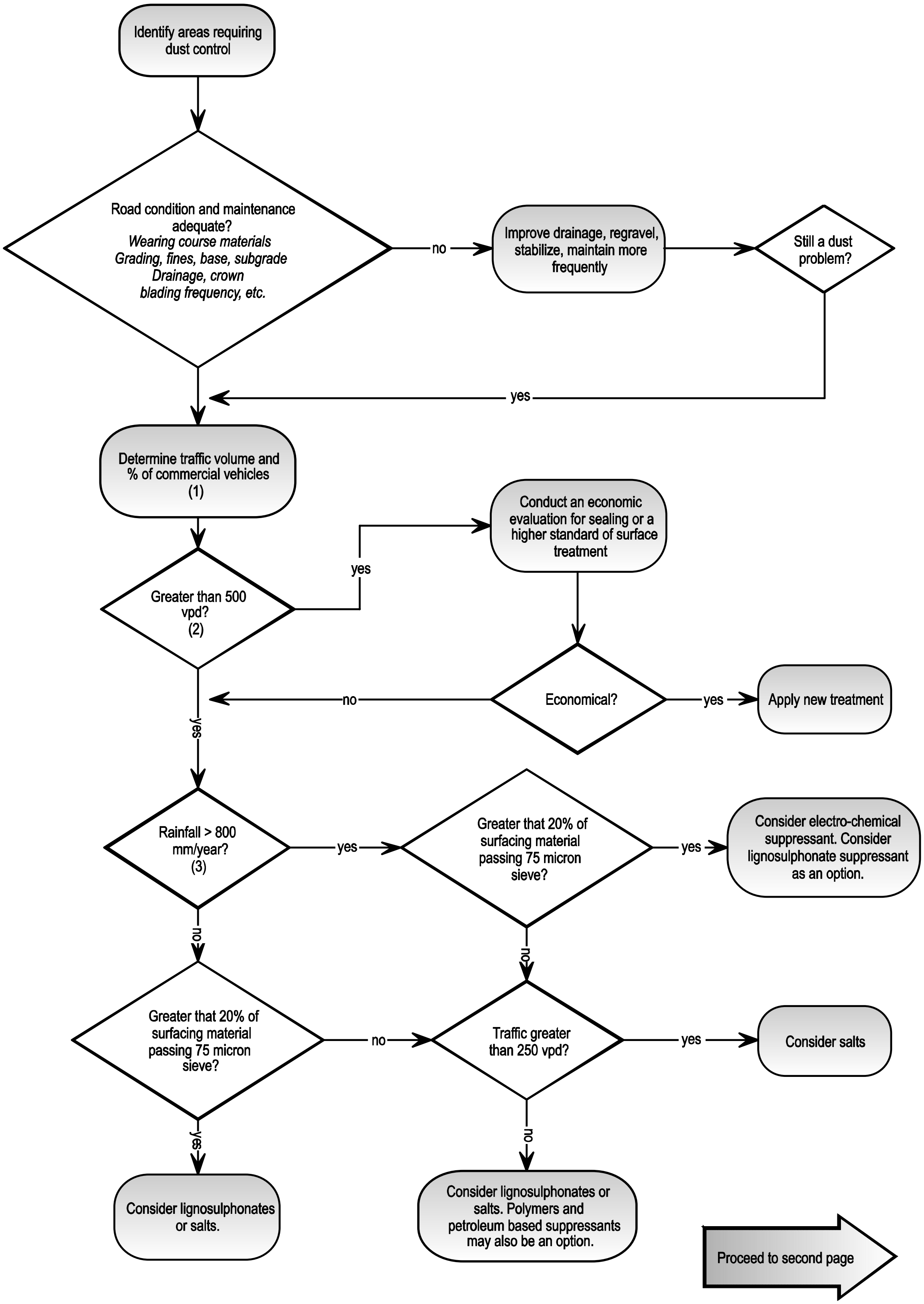
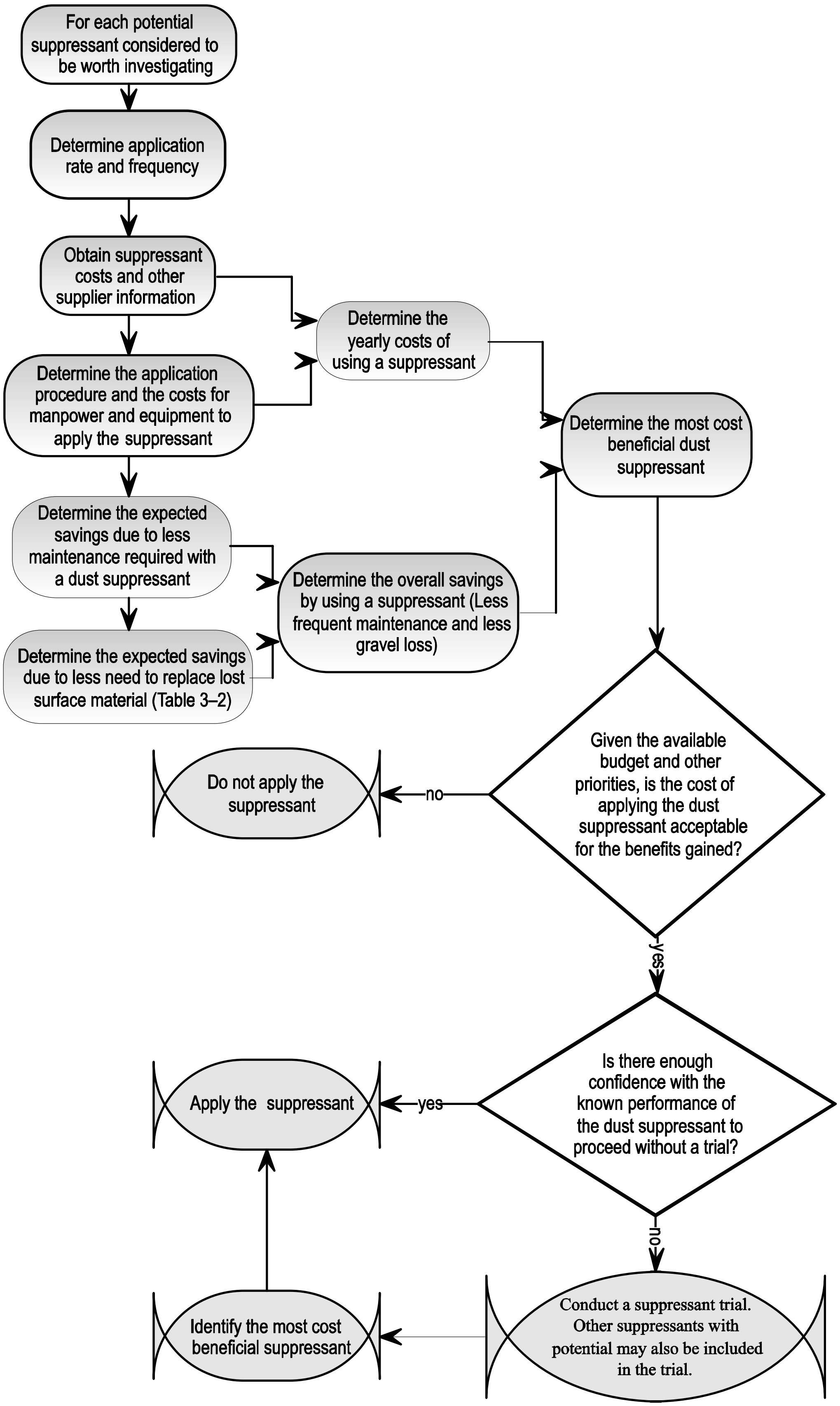


Figure 3–1: Dust suppressant selection process (cont'd)



Dust Palliative Dichotomous Key

1. Has the area been identified as having a dust control problem?
   a. Yes — Go to 2
   b. No

2. Does the area support military vehicle traffic?
   a. Yes — Go to 3
   b. No

3. Does the area support aircraft traffic?
   a. Yes — Go to 4
   b. No — Go to 6

4. Is the type of aircraft fixed-wing?
   a. Yes — Go to 10
   b. No — Go to 5

5. Are the aircraft helicopters?
   a. Yes — Go to 43
   b. No — Go to 3

6. Does the area support land vehicles?
   a. Yes — Go to 7
   b. No — Go to 14

7. Are the vehicles tracked or wheeled?
   a. Tracked — Go to 9
   b. Wheeled — Go to 8

8. Estimated number of wheeled vehicle passes per day during periods of heaviest use:
   a. More than 250 — Go to 11
   b. Less than 250 — Go to 13

9. Estimated number of tracked vehicle passes per day during periods of heaviest use:
   a. More than 100 — Go to 11
   b. Less than 100 — Go to 13

10. Estimated number of aircraft landings per day during periods of heaviest use:
    a. More than 50 — Go to 14
    b. Less than 50 — Go to 13

11. Are permanent surface treatments, such as paving, economically feasible? Paving costs are about $6 to $10 per square yard, but can be significantly higher if predominantly tracked-vehicle traffic is expected because thicker pavement is required for satisfactory performance.
    a. Yes — Go to 12
    b. No — Go to 14

12. Apply permanent stabilization practices. Paving the surface will be more cost-effective than periodic unsurfaced road maintenance and regular application of dust suppressants.

13. The use of chemical dust suppressants may not be economically justified based on low traffic volumes; good construction and maintenance practices are recommended instead. 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 14

14. Has the surface been evaluated for geometry, materials, drainage, and maintenance practices?
    a. Yes — Go to 20
    b. No — Go to 15

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

    a. Yes Go to 16

    b. No Go to 19

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

    a. Yes Go to 17

    b. No Go to 19

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

    a. Yes Go to 18

    b. No Go to 19

18. Is surface maintenance performed on a regular basis?

    a. Yes Go to 20

    b. No Go to 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/or dust problems persist. Mechanical stabilization, which may include the addition, grading, mixing, and compaction of fresh aggregate materials, costs about $2 to $3 per square yard. Most installation Directorate of Public Works and State Department of Transportation departments can provide detailed information about mechanical stabilization practices and specifications.

    Go to 20

20. Determine dominant climate influences, trafficked-surface soil textures, and suitable dust control product categories. Go to 21

21. The climate of the installation is classified as:

    a. Arid *(less than 12" of precipitation per year)* Go to 22

    b. Temperate *(12"-36" of precipitation per year)* Go to 23

    c. Humid *(more than 36" of precipitation per year)* Go to 30

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

    a. Sand/gravel Go to 24

    b. Loam Go to 25

    c. Clay Go to 26

    d. Limestone Go to 27

23. The temperate climate is classified as:

    a. Semi-arid *(12"-24" of precipitation per year)* Go to 28

    b. Sub-humid *(24"-36" of precipitation per year)* Go to 29

24. Recommended product category for the trafficked surface:

    Primary: *Organic, Non-bituminous* Go to 43

    see references 1, 20, 37

    Secondary: *Salts or Petrol* Go to 43

    see references 1, 4, 20, 31, 37

25. Recommended product category for the trafficked surface:

    All product categories are suitable.

    Go to 43

    see references 10, 20, 31, 35

26. Recommended product category for the trafficked surface:

    Primary: *Organic, Non-bituminous* Go to 43

    see references 20, 37

    Secondary: *Salts or Electro-chemical Stabilizers* Go to 43

    see references 31, 35

27. Recommended product category for the trafficked surface:

Primary: *Salts* Go to 43

see references 31, 37

Secondary: *Organic, Non-bituminous* Go to 43

see references 20, 37

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

a. Sand/gravel Go to 31

b. Loam Go to 32

c. Clay Go to 33

d. Limestone Go to 34

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

a. Sand/gravel Go to 35

b. Loam Go to 36

c. Clay Go to 37

d. Limestone Go to 38

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

a. Sand/gravel Go to 39

b. Loam Go to 40

c. Clay Go to 41

d. Limestone Go to 42

31. Recommended product category for the trafficked surface:

Primary: *Petrol* Go to 44

see references 10, 35

Secondary: *Organic, Non-bituminous* Go to 44

see reference 20

32. Recommended product category for the trafficked surface:

Primary: *Salts* Go to 44

see references 1, 2, 10, 25, 27, 28, 32, 36

Secondary: *Organic, Non-bituminous* Go to 44

see references 1, 2, 6, 10, 20, 25, 32, 36

33. Recommended product category for the trafficked surface:

Primary: *Organic, Non-bituminous* Go to 44

see references 6, 20, 30

Secondary: *Petrol* Go to 44

see reference 20

34. Recommended product category for the trafficked surface:

Primary: *Salts* Go to 44

see references 18, 28

Secondary: *Organic, Non-bituminous* Go to 44

see references 18, 30

35. Recommended product category for the trafficked surface:

Primary: *Organic, Non-bituminous* Go to 44

see references 3, 11, 12, 13, 33

Secondary: *Salts* Go to 44

see references 18, 21

36. Recommended product category for the trafficked surface:

Primary: *Organic, Non-bituminous* Go to 44

see references 3, 11, 12, 13, 16, 20, 23, 24, 33, 36

Secondary: *Salts* Go to 44

see references 3, 11, 12, 13, 16, 21, 24, 29, 36

37. Recommended product category for the trafficked surface:

Primary: *Organic, Non-bituminous* Go to 44

see references 11, 12, 13, 20, 23, 24

Secondary: *Electro-chemical Stabilizers* Go to 44

see reference 7

38. Recommended product category for the trafficked surface:

Primary: *Salts* Go to 44

see references 8, 15, 18, 21

Secondary: *Organic, Non-bituminous* Go to 44

see references 15, 23

39. Recommended product category for the trafficked surface:

Primary: *Petrol* Go to 44

see references 20, 29

Secondary: *Organic, Non-bituminous* Go to 44

see references 14, 18

40. Recommended product category for the trafficked surface:

Primary: *Salts* Go to 44

see references 16, 31

Secondary: *Electro-chemical Stabilizers* Go to 44

see reference 29

41. Recommended product category for the trafficked surface:

Primary: *Salts* Go to 44

see references 4, 14, 20, 29

Secondary: *Organic, Non-bituminous* Go to 44

see references 14, 20

42. Recommended product category for the trafficked surface:

Primary: *Salts* Go to 44

see references 4, 16, 17, 18

Secondary: *Organic, Non-bituminous* Go to 44

see references 16, 17, 18

43. Recommended product category for the trafficked surface:

Primary: *Polymers* Go to 44

see references 17, 20

Secondary: *Petrol* Go to 44

see reference 20

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

a. Economical Go to 45

b. Not economical Go to 46

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

a. Effective Go to 47

b. Not effective Go to 46

46. Consider paving or use of an alternate dust palliative.

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

REFERENCES

NOTE: *Order of product details are:* PRODUCT CATEGORY: product type; concentration; application rate; durability of performance in days for predominately wheeled vehicle traffic; reduce performance by 50 ro 75 percent for predominatly tracked-vehicle traffic

1. Addo, J.Q., and T.G. Sanders. 1995. Effectiveness and environmental impact of road dust suppressants. Mountain-Plains Consortium Report Number 95-28A, North Dakota State University.
   SALTS: 32 percent MgCl; 0.25 gal/sq yd; 140 days.
   ORGANIC NON-BITUMINOUS:
   25 percent solids calcium lignosulfonate;
   0.50 gal/sq yd; 140 days.

2. Apodaca, M., and D. Huffmon. 1990. Dust abatement review and recommendations. USDA Forest Service-Gifford Pinchot National Forest.
   SALTS: 35 percent CaCl; 0.25 gal/sq yd; 70 days.
   ORGANIC NON-BITUMINOUS:
   25 percent solids calcium lignosulfonate;
   0.50 gal/sq yd; 70 days.

3. Aquin, R., P. Korgemagi, and D.F. Lynch. 1986. Evaluation of Tembind 35 dust palliative, Ontario Ministry of Transportation and Communications. M1-83 Report.
   SALTS: 32 percent CaCl; 0.50 gal/sq yd; 90 days.
   ORGANIC NON-BITUMINOUS:
   35 percent solids ammonium lignosulfonate;
   0.50 gal/sq yd; 70 days.

4. Armstrong, Jeffery P. 1987. “Dustproofing Unsurfaced Areas: Facilities Technology Application Test (FTAT) Demonstration, FY 86.” Miscellaneous Paper GL-87-19/ADA185185, U.S. Army Waterways Experiment Station.
   SALTS: 32 percent MgCl; 0.50 gal/sq yd; 60 days.
   SALTS: 38 percent CaCl; 0.35 gal/sq yd; 60 days.

5. Bassel, J.R. 1992. A demonstration of a dust palliative. USDA, Forest Service, Technology and Development Program, Roads Tech Tips, May 1992.
   PETROLEUM: Asphalt emulsion;
   5:1 water:product ratio;
   0.60 gal/sq yd; 75 days.

6. Bennett, D.M. and K. Gleeson. 1995. Performance evaluation of tall oil pitch emulsion for stabilizing unpaved forest road surfaces. sixth international Conference on Low-Volume Roads, Transportation Research Board, pp. 213-224.
   ORGANIC NON-BITUMINOUS:
   Tall oil pitch emulsion; 1:3 water:product ratio;
   2.08 gal/sq yd; 90 days.

7. Bergeson, K.L. and S.G. Brocka. 1995. Bentonite treatment for fugitive dust control. Sixth International Conference on Low Volume Roads, Vol. 2., Transportation Research Board, Washington, DC, National Academy Press.
   ELECTROCHEMICAL: Bentonite clay;
   7-9 percent w:w ratio or 126-162 tons/mile;
   365 days.

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. Highway Division, Iowa Department of Transportation and Iowa Highway Research Advisory Board, Project HR-351.
   SALTS: 32 percent CaCl; 0.50 gal/sq yd;
   180 days.

9. Bergeson, K.L., and A.M. Wahbeh. 1990. Development of an economic dust palliative for limestone-surfaced secondary roads. Final report. Iowa Department of Transportation, Research project HR-297.
   ELECTROCHEMICAL: Bentonite clay;
   8 percent w:w ratio or 150 tons/mile; 365 days.

10. Bolander, P. 1989. Chemical additives for dust control. Transportation Research Record 1589:42-49.
SALTS: 32 percent MgCl; 0.75 gal/sq yd; 60 days.
ORGANIC NON-BITUMINOUS:
25 percent solids ammonium lignosulfonate; 0.75 gal/sq yd; 60 days.
PETROLEUM: Asphalt emulsion;
5:1 water:product ratio; 0.80 gal/sq yd; 60 days.
Order of product details are: PRODUCT. CATEGORY: Product type; concentration; application rate; durability of performance in days for predominantly wheeled vehicle traffic; reduce performance by 50 to 75 percent for predominantaly tracked-vehicle traffic.

11. Boyd, K.R. 1983a. Evaluation of calcium lignosulfonate as a dust palliative, Report 2, Manitoba Department of Highways and Transportation.
SALTS: 35 percent CaCl; 0.50 gal/sq yd; 90 days.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 0.44 gal/sq yd; 90 days.
ORGANIC NON-BITUMINOUS:
25 percent solids sodium lignosulfonate; 0.44 gal/sq yd; 90 days.

12. Boyd, K.R. 1983b. Evaluation of calcium lignosulfonate as a dust palliative, Report 3, Manitoba Department of Highways and Transportation.
SALTS: 35 percent CaCl; 0.50 gal/sq yd; 90 days.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 0.44 gal/sq yd; 90 days.
ORGANIC NON-BITUMINOUS:
25 percent solids sodium lignosulfonate; 0.44 gal/sq yd; 90 days.

13. Boyd, K.R. 1986. Summary of the 1985 lignosulfonate evaluations, Manitoba Department of Highways and Transportation, Materials and Research.
SALTS: 35 percent CaCl; 0.50 gal/sq yd; 90 days.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 0.44 gal/sq yd; 90 days.
ORGANIC NON-BITUMINOUS:
25 percent solids sodium lignosulfonate; 0.44 gal/sq yd; 90 days.

14. Brown, D.A., and D.J. Elton. 1994. Guidelines for dust control on unsurfaced roads in Alabama, Final report IR-94-02, Alabama Highway Research Center, Auburn University.
SALTS: 35 percent CaCl; 0.66 gal/sq yd; 90 days.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 1.00 gal/sq yd; 90 days.

15. Cleghorn, H.P. 1992. Dust control and compaction of unpaved roads-field trials. MAT-92-02. Research and Development Branch, Ontario Ministry of Transportation.
SALTS: 35 percent CaCl; 0.35 gal/sq yd; 30 days.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 0.50 gal/sq yd; 30 days.

16. 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-ET-CR-96196, United States Army Environmental Center, Aberdeen Proving Ground, MD.
SALTS: 38 percent CaCl; 0.50 gal/sq yd; 60 days.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 0.50 gal/sq yd; 60 days.

17. 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, United States Army Construction Engineering Research Laboratories, Champaign, IL.
SALTS: 38 percent CaCl; 0.50 gal/sq yd; 90 days.
ORGANIC NON-BITUMINOUS: 50 percent solids soybean oil; 0.40 gal/sq yd; 90 days.
POLYMERS: Polyvinyl acrylic; 7:1 water to product ratio; 1.0 gal/sq yd; 90 days.

18. 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.
SALTS: 38 percent CaCl; 0.50 gal/sq yd; 120 days.

19. 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.
SALTS: 38 percent CaCl; 0.50 gal/sq yd; 120 days.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 0.50 gal/sq yd; 90 days.
Order of product details are: PRODUCT. CATEGORY: Product type; concentration; application rate; durability of performance in days for predominantly wheeled-vehicle traffic; reduce performance by 50 to 75 percent for predominantly tracked-vehicle traffic.

20. Grau, R.H. 1993. "Evaluation of Methods for Controlling Dust." Technical report L-93-25, U.S. Army Waterways Experiment Station.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 2.00 gal/sq yd; 270 days.
PETROLEUM: Petroleum resin emulsion; 0.25 gal/sq yd; 270 days.
PETROLEUM: Petroleum resin emulsion; 0.25 gal/sq yd; 270 days.
POLYMERS: Polyvinyl acrylic; 5:1 water to product ratio; 1.0 gal/sq yd; 180 days.

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, U.S. Army Waterways Experiment Station.
SALTS: 32 percent MgCl; 0.60 gal/sq yd; 120 days.

22. Hass, Robert A. 1986. "Dustproofing Unsurfaced Areas: Facilities Technology Application Test (FTAT) Demonstration, FY 85." Technical report GL-86-20/ADA176861, U.S. Army Waterways Experiment Station.
SALTS: 32 percent MgCl; 0.80 gal/sq yd; 60 days.

23. Highway Extension Research Project: Indiana Counties and Cities. 1992. Purdue University, 10(4):10-11.
ORGANIC NON-BITUMINOUS:
30 percent solids beet molasses; 0.50 gal/sq yd; 180 days.

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.
SALTS: 38 percent CaCl; 0.25 gal/sq yd; 100 days.
ORGANIC NON-BITUMINOUS:
25 percent solids ammonium lignosulfonate; 0.25 gal/sq yd; 100 days.

25. Kolot, J.B. 1984. Report on dust treatment test sections. Saskatchewan Highways and Transportation internal report.
SALTS: 30 percent CaCl; 0.50 gal/sq yd; 120 days.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 0.50 gal/sq yd; 120 days.

26. Marks, V.J., and G. Petermeier. 1997. Let me shingle your roadway. Interim report, Iowa Department of Transportation, Research Project HR-2079.
PETROLEUM: Ground roofing shingles; 1000 tons/mile, 365 days.

27. Marshall, S.C. 1997. Effectiveness of calcium chloride on road dust suppression and effects on roadside water and soil. M.A. thesis, University of Wyoming.
SALTS: 42 percent CaCl; 0.50 gal/sq yd; 90 days.

28. Monlux, S. 1993. Dust Abatement Product Comparisons in U.S. Forest Service Region One. Internal report, USFS, Region 1, Missoula, MT.
SALTS: 29 percent MgCl; 0.50 gal/sq yd; 100 days.
PETROLEUM: Asphalt emulsion; 0.39 gal/sq yd; 60 days.

29. Muleski, G.E., and C. Cowherd. 1987. Evaluation of the effectiveness of chemical dust suppressants on unpaved roads. Midwest Research Institute. EPA report number 600/2-87/102.
SALTS: 38 percent CaCl; 0.82 gal/sq yd; 60 days.

PETROLEUM: Petroleum emulsion;
5:1 water:product ratio; 1.78 gal/sq yd; 60 days.
Order of product details are: PRODUCT.
CATEGORY: Product type; concentration; application rate; durability of performance in days for predominantly wheeled-vehicle traffic; reduce performance by 50 to 75 percent for predominantly tracked-vehicle traffic.

30. Sontowski, D., and L. Vliet. 1977. Lignosulfonate dust palliative evaluation. Geotechnical and Materials Branch, Ministry of Highways and Public Works, Victoria, British Columbia.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 0.50 gal/sq yd; 60 days.

31. Styron, C.R., R.A. Hass, and K. Kelley. 1985. “Dustproofing unsurfaced areas; facilities technology application test demonstrations, FY84,” Technical report GL-85-11, U.S. Army Waterways Experiment Station.
SALTS: 32 percent MgCl; 0.50 gal/sq yd; 60 days.

32. Tetteh-Wayoe, H. 1982. Evaluation of M+F road stabilizer on gravel roads. Research and Development Branch, Alberta Ministry of Transportation.
SALTS: 32 percent CaCl; 0.50 gal/sq yd; 120 days.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 0.50 gal/sq yd; 120 days.

33. Troedsson, K. 1994. Hot on the trail of a new dust control product:soybean soapstock. Minnesota Technology Exchange, University of Minnesota, 2(2):3-4.
PETROLEUM: 50 percent solids soybean oil;
0.25 gal/sq yd; 180 days.

34. Unger, M. 1990. Investigation of relationship of visible emissions to TSP/PM10 control eficiency. Indiana Department of Environmental Management/Indiana University Northwest.
PETROLEUM: Petroleum emulsion;
5:1 water:product ratio; 0.70 gal/sq yd; 75 days.

35. 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, Desert Research Institute.
PETROLEUM: Non-hazardous crude oil;
0.50 gal/sq yd; 365 days.
PETROLEUM: Petroleum emulsion;
5:1 water:product ratio; 0.50 gal/sq yd; 120 days.

36. Westway Trading Corporation. 1997. Road dust control with soapstock-A soybean oil by-product.
SALTS: 30 percent CaCl; 0.50 gal/sq yd; 180 days.
ORGANIC NON-BITUMINOUS:
35 percent solids soybean oil; 0.25 gal/sq yd; 180 days.

37. Zaniewski, J.P., and A.K. Bennett. 1989. Consumer’s guide to dust control technologies. Center for Advanced Research in Transportation, College of Engineering and Applied Sciences, Arizona State University.
SALTS: 35 percent MgCl; 0.50 gal/sq yd; 60 days.
SALTS: 32 percent MgCl; 0.50 gal/sq yd; 60 days.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 0.50 gal/sq yd; 60 days.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 0.50 gal/sq yd; 60 days.
ORGANIC NON-BITUMINOUS:
25 percent solids sodium lignosulfonate; 0.50 gal/sq yd; 60 days.
ORGANIC NON-BITUMINOUS:
25 percent solids calcium lignosulfonate; 0.50 gal/sq yd; 60 days.
PETROLEUM: Petroleum emulsion;
5:1 water:product ratio; 0.75 gal/sq yd; 60 days.

APPENDIX C

Bibliography
(from Dust Suppression on Wyoming's Coal Mine Haul Roads,
October 2004)

Primary Author	Authors	Title	Year	Name of Journal or Publication	Name of Publisher	URL
Arizona Dept of Environmental Quality		Arizona Department of Environmental Quality Air quality exceptional and natural events policy PM_{10} best available control measures	2001			
Associated Press International		EPA Watching Dust From Mines, Roads	2003	Associated Press State and Local Wire	Associated Press	
Australia Dept of the Environment and Heritage		Dust Control, Best Practices Environmental Management in Mining, Australia	98	Sustainable Industry; Sustainable Minerals	Australia Government; Department of the Environment and Heritage	www.deh.gov.au/industry/industry-performance/minerals/booklets/dust/dust1.html
Axetell, Ken, Jr.		Survey of Fugitive Dust from Coal Mines	78	EPA 68014489	EPA	
Banard, W.R.	Stensland, G.J; Gatz, D.F.	Development of Emission Factors for Unpaved Roads: Implications of the New PM_{10} regulations. Transactions, PM_{10} Implementation of Standards	88	Air Pollution Control Association		
Barnard, W.		Improved fugitive dust PM_{10} emissions estimates for trends	92	Transactions, Standards and Non-Traditional Particulate Source Controls	Air and Waste Management Association	
Barnard, W.R.		Development of emission factors for unpaved roads	88	Transactions, PM_{10} Implementation Standards	Air Pollution Control Association	
Baxter, Roberta		Arrest that Fugitive Dust!	2003	Erosion Control	Forester.net	http://www.forester.net/ecm_0203_arrest.html
Becker, D.C.		Quantifying the Environmental Impact of Particulate Deposition from Dry Unpaved Roadways		unpublished Master's thesis Iowa State University		
Beggs, T. W.		User's Guide: Fugitive Dust Control Demonstration Studies	85	EPA	EPA	
Berthelot, C.	Carpentier, A.	Gravel Loss characterization and Innovative Preservation Treatments of Gravel Roads: Saskatchewan, Canada	2003	Transportation Research Record	National Research Council	
Blackwood, T. R.		Assessment of Road Carpet for Control of Fugitive Emissions from Unpaved Roads	79	EPA	EPA	
Blanc, T.R.		Lingosulfonate Stabilization		Proceedings - ARTBA-NACE Conference Local Transportation		

Primary Author	Authors	Title	Year	Name of Journal or Publication	Name of Publisher	URL
Bolander, P.	Chitwood, L.; Steele, H.M.;	Lessons learned from the failure of a bituminous surface treatment in central Oregon		Transportation Research Record	National Research Council	
Bolander, P., Yamada, A.		Dust Palliative Selection and Application Guide	99	Forest Service Technology and Development Program	San Dimas Technology and Development Center	
Bolander, Peter		A Guideline to Liquid Spray Applications for Erosion Contol, Dust Abatement, and Tackifiers	96	U.S. Forest Service		
Bolander, Peter		Chemical Additives for Dust Control - What We've Used and What We've Learned	96	USDA Forest Service, Portland Oregan		
Carnes, D. H.		The control of fugitive emissions using windscreens	82	Third Symposium on the Transfer and Utilization of Particulate Control Technology, Vol IV.	USEPA	
Carter, R.		Cut costs by controlling dust; heavy haul-road dust can stir up haulage and maintenance problems	96	Coal Age, vol 104, n 12		
Champlin, Robert L.		Control of Fugitive Dust from mining haul roads	78	EPA	University of Wyoming, Institute of Energy and Environment	
Colbert, W.	Center for dirt and gravel road studies	Natural Systems Approach to preventing environmental harm from unpaved roads	2003	Transportation Research Record, v 1, n 1819	National Research Council	
Council of Fresno County Government		Overview of Regional Transportation Planning Agency Process to Identify and Implement Best Available Control Measures in Support of the PM_{10} Plan for the San Joaquin Valley	2002			http://www.fresnocog.org/aq-modeling/bacm/bacm.htm
Countess, Richard		Methodology for Estimating Fugitive Windblown and Mechanically Resuspended Road Dust Emissions Applicable for Regional Scale Air Quality Monitoring	2001	Western Governor's Association Contract 30203-9	Western Governor's Association	
Cowherd, C		Cost Effectiveness of road dust controls	82	EPA Report	EPA	

Primary Author	Authors	Title	Year	Name of Journal or Publication	Name of Publisher	URL
Cowherd, C	Kinsey, J.S.	Identification, Assessment and Control of fugitive dust particulate emissions	86	EPA Report	EPA	
Cowherd, C.	et al.	Development of Emissions Factors for Fugitive Dust Sources	74	EPA		
Cowherd, C.	Guenther, C.M.	Development of Methodology and emission inventory for fugitive dust for the regional air pollution study.	76	EPA Office of Air Quality Planning and Standards		
Cowherd, C.	Kuyhendal, W.B.	Fine Particle Components of PM_{10} From Fugitive Dust Sources	97	Air & Waste Management Assoc. 1997 Proceeding		
Cowherd, C.		Fugitive Dust Emissions	96	MRI		
Cowherd, C.		Profiling Data for open fugitive dust sources Prepared for US EPA, Emission Factors and Inventory Group, Office of Air Quality Planning and Standards	99	EPA, MRI		
CTIC		Road Dust Suppressants	89	Colorado Transportation Information Center, Bulletin #3	Dept. of Civil Engineering, Colorado State Universtiy	
Cuscino, Thomas		Fugitive Dust from Vehicles Traveling on unpaved roads	76	EPA	EPA	
Dubyk, S.		Fugitive Dust Control Techniques and Businesses	2004	website	New Mexico Dept of Environmental Air Quality Bureau	www.nmenv.state.nm.us/aqb/dust_control.html
Dulla, R.G.	Withycombe, E	Particulate control measure feasibility STUDY	97	Maricopa Association of Governments Report	Sierra Research	
Dunkins, R.		Fugitive Dust Background Document and Technical Information Document for Best Available Control Measures	92	EPA		
Dyck, R.I	Strukel, J.J.	Fugitive Dust Emissions From Trucks on Unpaved Roads	76	Environ. Sci. Technol. 10, 1046-1048		
Eaton, R.A;	Gerard, S; Gate, D.W.	Rating Unsurfaced Roads	88	Army Corps of Engr.		
Engle, David		Road Maintenance Techniques and Products Have Made Great Strides	2004	Forester Communications January/Feburary	Forester.net	
Englehart, P.J.	Muleski, G.E.	Open fugitive dust PM_{10} control strategies study	80	Study	Midwest Research Institute	
EPA	EC/R Inc. NC	Control Techniques for Particulate Emissions from Stationary Sources, Vol 1		EPA 450381005a	EPA	

Primary Author	Authors	Title	Year	Name of Journal or Publication	Name of Publisher	URL
EPA	EC/R Inc. NC	Control Techniques for Particulate Emissions from Stationary Sources, Vol 2		EPA 450381005b	EPA	
EPA		40 CFR Part 52: SIPs for Lead Nonattainment - IIB: Reasonable Available Control Measures (draft)	92	EPA	EPA	
EPA	Western Regional Air Partnership	40 CFR Part 5: Regional Haze Regulations Vol. 64, No. 126, July	1999	Federal Register	EPA	www.wrapair.org/309/index.html
EPA	Midwest Research Institute	Compilation of Air Pollution Emissions Factors Volume 1, AP-42, Chapter 13 Unpaved Roads		EPA	Emission Factor and Inventory Group	http://www.epa.gov/ttn/chief/ap42/ch13
EPA	Midwest Research Institute	Emission Factor Domumentation for AP-42 Section 13.2.2 Unpaved Roads	1998	EPA final report		
EPA	Wyo Dept of EQ	USEPA Region 8 - State Implementation Plan - Wyoming - Section 14 - Control of Particulate Emissions	98		Wyoming Dept of Environmental Quality	https://yosemite.epa.gov/R8/R8Sips.nsf/Wyoming?OpenView
EPA		Emission Control Technologies and emission factors for unpaved road fugitive emissions	87	EPA	EPA (The Center)	
EPA	Midwest Research Institute	Emission Factor Documentation for AP-42 Section 13.2.2 Unpaved Roads	1998	EPA final report	EPA	
EPA		EPA's Interpretation of the HSWA prohibition on the use of hazardous waste as a dust suppressant	85	EPA	EPA	
EPA		National Air pollutant emission trends, procedures	2000	EPA	EPA	
EPA		Review of Surface Coal Mining Emission Factors		EPA		http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s09.pdf
Epps, A.	Eshan, M.	Laboratory Study of Dust Palliative Effectiveness	2002	Journal of Materials in Civil Engineering		
Ferguson, John H.		Fugitive Dust:Nonpoint Sources		MU Ag Guide	Univeristy of Missouri Extension	
Fitz, D. R.	Moon, K. C, and Zeldin, M.	Evaluation of fugitive dust control methods in the Coachella Valley	93	Proceedings Air and Waste Management Association	Air and Waste Management Association	

Primary Author	Authors	Title	Year	Name of Journal or Publication	Name of Publisher	URL
Fitz, D. R.		Evaluation of Watering to control dust in high winds	2000	JAWMA		
Fitz, D. R.		Field Study to Determine limits of best available control methods for fugitive dust under high wind conditions.	96	CE-CERT Document	University of California	
Fitz, D.R	Bumiller, K	Evaluation of Watering to Control Dust in High Winds	2000	JAWMA 50, 570-577		
Frazer, Lance		Down with Road Dust (innovations) Dust Stop	2003	Environmental Health Perspectives	National Institute on Environmental Health Sciences	
Freeston, Frank J.		Runoff of oils from rural roads treated to suppress dust	72	EPA	EPA	
Fu, L.	Leung, D.Y.C.	Analysis on Emission Factor of Fugitive Dust from Road Traffic	97	J. Environmental Science 9, 501		
Gambatese, J.	James, D	Dust Suppression using a truck-mounted water spray system	2001	Journal of Construction Engineering and Management, V 137, n1	American Society of Civil Engineers	
GCVTC		Recommendations for Improving Western Vistas: Report of the Grand Canyon Visibility Transport Commission to the US EPA	96	Reports to the EPA	Western Governor's Association	Grand Canyon Visibility Transport Commission
Gebhart, Dick L.	Denight, M., Grau, R.H.	Dust Control Guidance and Technology Selection Key	99		US Army Construction Engineering Research Labratories, Land Management Laboratory	
Gebhart, Dick L.	Thomas Hale and Kim Michaels-Busch	Dust Control Material Performance on Unsurfaced Roadways and Tank Trails	96	USAEC Technical Report	US Army Construction Engineering Research Labratories, Land Management Laboratory	http://aec.army.mil/usaec/technology/dustcontrol.pdf

Primary Author	Authors	Title	Year	Name of Journal or Publication	Name of Publisher	URL
Gillies, J.A.	Watson, J.G.; Rogers, C.F.; DuBois D.W.; Chow, J.C.; Langston, R.; Sweet, J.	Long-Term Efficiencies of Dust Suppression to Reduce PM_{10} Emissions From Unpaved Roads	99	Journal of the Air and Waste Management Association 49, 3-16	Air and Waste Management Association	JAWMA Paper: Long-Term Efficiencies of Dust Suppressants to Reduce PM10 Emissions from unpaved roads
Grantz, D.A		Wind Barriers Offer Short-Term Solution to Fugitive Dust	98	California Agric., 53, 14		
Hagen, L.J.	Mostafa, N.; Hawkins, A.	PM_{10} Generation by Wind Erosion.	96	Proceedings, International Confrence on Air Pollution from Agricultural Operations		
Harding Lawson Associates		Evaluation of PM_{10} Emissions Factors for Paved Roads Prepared for Regional Air Quality Council, Denver, CO	91	Regional Air Quality Council, Denver Colorado	Harding Lawson Associates	
Hewitt-Daly, Mary		Overview of Fugitive Dust Emissions	2000		Malcolm Pirnie	http://www.pirnie.com/docs/resources_pubs_air_may00_6.html
Holmberg, M.		Soy Oil Ready to Eat Your Dust	89	Successful Farming, v 87, n 11		
Hoover, J.M.	Bergerson, K.L; Fox, D.E; Denny, C.K.; Handy, R.L.	Mission Oriented Dust Control and Surface Improvement Processes for Unpaved Roads. Final Report	81	Iowa Hwy. Res. Board Proj. HR-151		
Hubbard, S. J.		Assessment of the current status of the environmental aspects of fugitive dust sources associated with mining	76	EPA	PEDCO-Environmental Specialists	
Jackson, D.	Jackson, N.;Mahoney, J.;	Washington State Chip and Seal Study	90	Transportation Research Record	National Research Council	
James Informational Media		Taming the Haul Road Dust Demon	2003	AGGMAN	Mercur Media, Inc	www.aggman.com/0703_pages/0703marketing.html
Johnson, T.	Gillette, D.A.; Schwiesow, R.	Fate of Dust Particles from Unpaved Roads Under Various Atmoshperic Conditions.	92	Precipitation Scavenging and Atmosphere-Surface Exchange. Edited by S. Schwartz and W.G. N. Slinn	Hemisphere Publishing Co., Washington, 933-948	

Primary Author	Authors	Title	Year	Name of Journal or Publication	Name of Publisher	URL
Jutze, G. A.	Axetell, K.	Investigation of Fugitive dust, Volume I - Sources, emissions and control.	74	EPA	EPA	
Jutze, G. A.	Axetell, K.	Investigation of Fugitive dust, Volume II - Control Strategy and regulatory approach.	74	EPA	EPA	
Jutze, G.A.	et al.	Investigation of Fugitive Dust Sources Emission and Control	74	EPA		
KCAPCD		Rule 402: Fugitive Dust, Kearn County Air Pollution Control District	93	website		www.arb.ca.gov/DRDB/KER/CURHTML/R402.HTM
Kern County Air Pollution Control District		Chemical Dust Suppressants: a list of products and suppliers, Kern County Air Pollution Control District	2003	website	Kern County Air Pollution Control District	http://www.kernair.org/compliance_assistance.htm
Kinsey, J.S.		Control Technology for sources of Pm_{10}	85	EPA	EPA	
Kirchner, Henry W, P.E.		Road Dust Suppressants Compared	88	Public Works, Vol. 119, No. 13		
Lane, D.D.	Baxter, T.E.; Cuscino, T.; Cowand, C, Jr.;	Use of Laboratory Methods to Quantify Dust Suppressants Effectiveness	84	Trans., Soc. Of Min. Engr. Of AIME, 274-2001		
Larkin Laboratory		Calcium Chloride and Magnesium Chloride for Dust Control	86	Larkin Laboratory 1691 N. Swede Rd. Midland Michigan 48640		
McCoy, J.F.		Evaluation of Dust Controls used on upaved haul roads	83	Report	U.S. Bureau of Mines	
Midwest Research Institute		Unpaved Road Emission Impact	91	Report	Arizona Dept of Environmental Quality	
Midwest Research Institute		Fugitive Dust Source Characterization	99			http://www.mriresearch.org/ResearchServices/Environment/Measurement/FugitiveDust.asp
Minnesota Pollution Control		Fugitive Dust Control Surface Treatments at Industrial Facilities: Water treatment considerations	2002	Air Quality General N 1, March	Minnesota Pollution Control Age	
MND Associates		Estimation of PM_{10} dust fluxes from emissions factors for different fugitive dust sources.	99	EPA, Emissions Factors and Inventor Group, Office of Air Quality Planning and Standards	Research Triangle Park, NC; MND Associates, Toronto	

Primary Author	Authors	Title	Year	Name of Journal or Publication	Name of Publisher	URL
Mollinger, A.M	Nieutwstadt, F.T.M.; Scarlett, B.	Model Experiments of the Resuspension Caused By Road Traffic	93	Aerosol Sci. Technol 19, 330-338		
Monlux, S.	USDA Forest Service	Stabilizing unpaved roads with calcium chloride	2003	Transportation Research Record	National Research Council	
Morey, Jennifer E.	Niemeirer, Debbie, Limanond, Thirayoot	A Stochastic Framework for Estimating Unpaved Road VMT for PM_{10} Mobile Emissions Inventories	2001		University of California Davis Dept. of Civil and Env. Engineering	
Muleski, G.E	Stevens, K.M.	PM_{10} Emissions From Public Unpaved Roads in Rural Arizona. Transactions, PM_{10} Standards and Nontraditional Particulate Source Controls	92	Air and Waste Management Association		
Muleski, G.E.		Definition of the Long-Term Control Efficiency of Chemical Dust Suppressants applied to unpaved roads	85	EPA	EPA	
Muleski, G.E.		Evaluation of the Effectiveness of Chemical Dust Suppressants on Unpaved Roads	87	EPA	EPA	
Muleski, G.E.		Extended Evaluation of Unpaved Road Dust Suppressants in the Iron and Steel Industry	84	EPA	EPA	
New Mexico Environment Department - Air Quality Bureau		Implementation and Determination of Best Available Control Measures for Reducing Windblown Dust from Manmade Sources in Dona Ana County, California	2000		New Mexico Environment Department - Air Quality Bureau	www.nmenv.state.nm.us/aqb/dust_control.html
Nicholoson, K.W.	Branson, J.R.; Giess, P.; Cannell, M.	The Effects of Vechicle Activity on Particle Resuspension	89	J. Aerosol Sci. 20, 1425-1428		
North Carolina Division of Air Quality		Cost Analysis Chart Agenda Item 18 Economic Analysis of Particulates From Fugitive Dust Emission Sources	2003		North Carolina Division of Air Quality Department of Environmental and Natural Resources	http://daq.state.nc.us/search.shtml
Ohio EPA		Reasonable Available Control Measures for Fugitive Dust Sources	80	Report	EPA	

Primary Author	Authors	Title	Year	Name of Journal or Publication	Name of Publisher	URL
Organiscak, J.A.	Page, S.J.; Cecala, A.B.; Kissell, F.N.	Surface Mine Dust Control Chapter 5 (includes Haul road dust control)		Surface Mine Dust Control		
Orlemann, J. A.		Fugitive Dust Control Technology	83	EPA	EPA	
Palmer, James T	Thomas, V.; Boresi, Arthur P.	Strength and Density Modification of Unpaved Road Soils Due to Chemical Additives, MPC Report No. 95-39	95	University of Wyoming, Department of Civil and Architectural Engineering		
Piechota, T. (ed)	Van Ed, J; J. Batista, K. Stave, D. James	Potential Environmental Impacts of Dust Suppressants: "Avoiding Another Times Beach" Expert Panel Summary, EPA	2002`	UNLV, EPA (600/R-04/031)	UNLV, EPA	http://www.epa.gov/nerlesd1/cmb/pdf/dust.pdf
Prevatt, C.V.	Hart, D. E.	No More Brownouts:Dust Abatement in Support of Tactical Helicopter Operations	2003	Marine Corps Gazette	Marine Corps Association	
Richard, George	Safriet, D. W.	Guidelies for Development of Control Strategies in Areas with Fugitive Dust Problems	77	EPA	EPA	
Roberts, J.W.	Mangold, H. A; Rossano, A. T.	Cost and benefits of road dust control in Seattle's Industrial valley	75	JAPCA		
Roberts, J.W.		Cost and Benefits of Road Dust Control in Seattle's Industrial Industrial Valley		Journal of the Air Pollution Association, Vol 25 #9		
Rosbury, K. D	Zimmer, R. A.	Cost-effectiveness of dust controls used on unpaved haul roads. Vol I.	83	Report	U.S. Bureau of Mines	
Rosbury, K. D		Cost-effectiveness of dust controls used on unpaved haul roads. Vol II (data).	83	Report (contract J0218021)	U.S. Bureau of Mines	
Sanders, T. G.		Effectiveness and Environmental Impact of Road Dust Suppressants. MPC-94-28. Fargo, ND. Mountain Plains Consortium, USDOT.	93	Mountain Plains Consortium Proceedings		http://ehp.niehs.nih.gov/members/2003/111-16/innovations.html
Sanders, T. G.	Ado, J.Q.; Ariniello, A.; Heiden, W.F.	Relative Effectiveness of Road Dust Suppressants	97	Journal of Transportation Engineering, Sept/Oct		
Schultz, Brad		NEAP Controls (BACM determination for Industrial Fugitive Dust Sources-Unpaved Road Control)	2004		South Dakota Dept of Environment and Natural Resources Air Quality	http://www.state.sd.us/denr/DES/AirQuality/NEAP/neapcontrols.htm
Seton, Johnson and Odell, Inc		Portland Road Dust Demonstration Project. Appendix.	83	Report - Dept of Public Works	City of Portland	

Primary Author	Authors	Title	Year	Name of Journal or Publication	Name of Publisher	URL
Singer, Rexford D.		Control of Open Fugitive Dust Sources	88	EPA		
Singer, Rexford D.		Environmental Evaluation of Dust Suppressants	82	EPA	Bureau of Mines, USDInterior	
Singh, Vivek		Hydrologic Impacts of Disturbed Lands Treated with Dusts Suppressants		Journal of Hydrologic Engineering		
Skorseth, K.	Selim, A.	Gravel Roads- Maintenance and Design Manual Section IV. Dust Control and Stabilization	2000	South Dakota Local Transportation Assistance Program (SD LTAP)		http://www.epa.gov/owow/nps/gravelroads/sec4.pdf
States, J.	Steward, M., Brown, T.	Solving the Next Impediment to Coal Bed Methane Development in the Powder River Basin (Abstract)	2004			
Thomas, S., Addo, J.		Experimental Road Dust Measurement Device	2000	Journal of Transportation Engineering, November/December		
Thompson, R.J.	Visser, A.T.	Benchmarking and Management of Fugitive Dust Emissions from Surface-Mine Haul Roads	2002	Transactions of the Institution of Mining and Metallurgy, Section A: Mininng Industry, 111 28-34		
Thompson, R.J.	Visser, A.T.	Evaluation and Modeling of Haul Road Dust Palliatives	2000	Coal-the future, 12th International Confrence on Coal Research (Sandt on: S.A.I.M.M., 2000) 53-60. Symp. Series S26		
Thompson, R.J.	Visser, A.T.	Mangement of Unpaved Road Networks on Opencast mines	99	Transportation Research Record (TRR) 1652, 1999, 217-24		
Thompson, R.J.	Visser, A.T.	Mine Haul Road Fugitive Dust Emission and Exposure Characterisation	2001	J. Mine Vent.Soc.S.Afr., 54(1), 18-30		
Thompson, R.J.	Visser, A.T.	The Reduction of the Safety and Health Risks Associated with the Generation of Dust on Strip Coal Mine Haul Roads	2000	Pretoria: Safety in Mines Research Advisory Committee, 2000	Collieries Sub-Committee Final Report for Project COL 467	
Torrez, Lucien		Inspector's Guide for fugitive dust emission sources: causes and control techniques, recommendations and examples	84	EPA	EPA	

Primary Author	Authors	Title	Year	Name of Journal or Publication	Name of Publisher	URL
U. S. Dept of Engergy		Dust Suppression with Less Water: Pollution Prevention Case Study (using Soil-Sement) Los Alamos Ntl. Laboratory		US Dept Energy Fact Sheet	US Dept of Energy Office of Environmental Mgmt	
U.S. Bureau of Mines		Cost-Effectiveness of Dust Controls Used on Unpaved Mine Haul Roads	83	Report for U.S.B.M. by Pedco Environmental Inc.		
UMA Engineers, Planners and Surveyors		Guidelines for Cost Effective Use and Application of Dust Palliatives	87	Roads and Transportation Association of Canada (RTAC)		
Undlin, David		Case Study: Coal Mine Road Dust is Controlled in 12-mile Trial with DusTreat Program	2003	GE Betz		
Undlin, David		GE Betz Western Energy Company Study, Haul Road Dust Control Status	2003	GE Betz		
Undlin, David		Jacobs Ranch, GE Betz Study on Dust, Graphs	2003	GE Betz		
US Dept of Transportation		Chapter 8 Transportation Conformity Reference Guide - PM_{10} Nonattainment and Maintenance Areas	2003	Federal Highway Adm	US Dept of Transportation	http://www.fhwa.dot.gov/environment/conformity/ref_guid/partii.htm
Veranth, J.M	Pardyjak, E.R.; Seshadri, G.	Vehichle-Generated Fugitive Dust Transport: Analytic Models and Field Study	2003	Atmos.Environ., 37(16), 2295-2303		
Warhurst, Michael		An environmental assessment of alkylphenol ethoxylates and alkylphenols	1995	Report	Friends of the Earth (England, Wales and Northern Ireland)	www.foe.co.uk/resource/reports/ethoxylates_alkylphenols.pdf
Watson, J.G.	Chow, J.C.; Gillies, J.; Rodgers, C.F.; Langston, R.	Effectiveness Demonstration of Fugitive Dust Control Methods for Public Unpaved Roads and Shoulders	96	Air and Waste Management Assoc. 1996 Proceeding		
Watson, J.G.		Fugitive Dust Emissions	2000	Air Pollution Engineering Manual	Van Nostrand Reinhold, NY	
Watson, J.G.	Chow, Judith	Reconciling Urban Fugitive Dust Emissions Inventory and Ambient Source Contributions Estimates: Summary of Current Knowledge and Needed Research	2000	Desert Research Institute Document 6110.4F	Desert Research Institute	

Primary Author	Authors	Title	Year	Name of Journal or Publication	Name of Publisher	URL
Wellman, E.A.	Barraclough, S.	Establishment of Acceptable Dusting Criteria for Aggregate Surface Roads	72	USDA Forest Service Administration Study 7110	Winema National Forest	
Wittorff, D.N.		The Contribution of Road Sanding and Salting Material on Amibient PM_{10} Concentrations	94	A&WMA and US EPA		
Wrage, R	Shouse, S.	Dust Control on Rural Roads		Report	Iowa State Extension	
Zielinska, B	McDonald, J; Hayes, T; Chow, J.C.; Fujita, E.M. and Watson, J. G.	Northern Front Range Air Quality Study: Volume B Source Measurement	98	DRI Report	Desert Research Institute	
		A look at dust control and road stabilizers (buyer's guide - several summarizing articles)	2000	Better Roads		A look at dust control and road stabilizers
		Controlling Dust on Unpaved Roads	89	Rural Transp. Fact Sheet No. 84-02. T2 Program	University of Kansas Transp. Ctr. Lawrence Kansas	
		Controlling Dust: Which Materials should you use?	98	Better Roads, v68, n 6		
		Dust Contol, Road Maintenance Costs Cut With Calcium Chloride	90	Public Works, Vol. 121. No.6		
		Dust control fights erosion	92	Better Roads, v 62, n 10		
		Guidelines for use and application of dust palliatives	90	Public Works, Vol 21, n 1		
		How to control dust on an unpaved, unstable road		Better Roads, v68, n 6		
		Review of recent developments in surface dressing	92	Highways and transportation, vol 39, n 9		

APPENDIX D

Detailed Cost Calculations of Dust Control Methods

Unpaved Road Dust Control Costs

Project: Rural Alaska Dust Control Alternatives
Client: Alaska Department of Environmental Conservation

Constants:

Labor

Laborer Charge Rate =	$37.60	/hr (C. Adler, 1/5/06)
Equipment Operator Charge Rate =	$44.30	/hr (C. Adler, 1/5/06)
Crew Foreman Charge Rate =	$45.80	/hr (C. Adler, 1/5/06)

Equipment

Grader Charge Rate =	$121.01	/hr (C. Adler, 1/5/06)
Dump Truck Charge Rate =	$59.51	/hr (C. Adler, 1/5/06)
Frontend Loader Charge Rate =	$78.53	/hr (C. Adler, 1/5/06)
Water Truck Charge Rate =	$26.53	/hr (C. Adler, 1/5/06)

Control Measure:

Watering

Water Truck Capacity =	2500	gal. (C. Adler, 1/5/06)
Water Application Rate =	0.125	gal/yd2 (Marin Co. Stormwater Dust Control BMP, 2006)
Water Application Coverage =	20000	yd2
=	180000	ft2
=	1.42	mi (@ 24' width)
Vehicle Speed =	5	mph (estimated)
Water Application Time =	17	min.
Truck Refill Time =	22	min. (estimated)
Total Watering Cycle Time =	39	min
Labor Allocation =	1	equipment operator
Labor Cost =	$28.83	/watering cycle
Equipment Allocation =	1	water truck
Equipment Cost =	$17.26	/watering cycle
Total Watering Cycle Cost =	$46.09	/watering cycle
=	$32.45	/mile-watering pass

Calcium Chloride Application

1st Calcium Cloride Application Rate =	1.5	lb/yd2 (Bolander, 1999)
2nd Calcium Cloride Application Rate =	0.75	lb/yd2 (Bolander, 1999)
Total Calcium Chloride Application Rate =	2.25	lb/yd2
=	31,680	lb flake/mi
Calcium Chloride Cost =	$1,400	for 2800 lb tote (FOB Anchorage, Univar/Dow Chemical, 1/5/06)
Calcium Chloride Haul Cost =	$625	/2800 lb tote (Seattle to Kotzebue, Northland Services, 1/11/06)
Total Calcium Chloride Cost =	$2,025	/2800 tote @ Kotzebue
=	$22,913	/road-mile
Application Labor =	1	crew foreman
+	2	equipment operator
Application Time =	12	hr/mile (estimated)
Labor Cost =	$1,613	/road-mile
Application Equipment =	1	frontend loader
+	1	water truck
+	1	grader
Equipment Use Time =	4	hr - frontend loader (estimated)
=	8	hr - water truck (estimated)
=	8	hr - grader (estimated)
Equipment Cost =	$1,494	/road-mile
Total Applied Cost =	$26,020	/road-mile

Synthetic Polymer Products

EK-35 Application Rate =	50	ft2/gal (ADOT, Kiana Airfield Report)
=	2534	gal/mi (@ 24 foot width)
EK-35 Cost =	$5.95	/gal (FOB Seattle, Midwest Industrial Supply, 1/6/06)
EK-35 Density =	7.66	lb/gal (Midwest Industrial Supply, 9/17/04)
EL-35 Transport Cost =	$447	/2000 lb tote (Seattle to Kotzebue, Northland Services, 1/11/06)
=	1.71	/gal
Total EK-35 Cost =	$7.66	/gal
=	$19,416	/mile
Application Labor =	1	equipment operator
+	1	laborer
Application Time =	8	hr/mile (estimated)
Labor Cost =	$655	/mile
Application Equipment =	1	water truck
Equipment Use Time =	8	hr - water truck (estimated)
Equipment Cost =	$212	/mile
Total Applied Cost =	$20,283	/mile

Lignosulfonate Products

Lignosulfonate Application Rate =	5000	gal/mi (@ 24 foot width, Midwest Industrial Supply, 1/17/06)
Lignosulfonate Cost =	$11,700	/5000 gal FOB Seattle Midwest Industrial Supply, 1/17/06)
Lignosulfonate Density =	8.40	lb/gal (estimated)
Lignosulfonate Transport Cost =	$9,377	/5000 gallons in totes (Seattle to Kotzebue, Northland Services, 1/11/06)
Total Lignosulfonate Cost =	$21,077	/road-mile
Application Labor =	1	equipment operator
+	1	laborer
Application Time =	8	hr/mile (estimated)
Labor Cost =	$655	/mile
Application Equipment =	1	water truck
Equipment Use Time =	8	hr - water truck (estimated)
Equipment Cost =	$212	/mile
Total Applied Cost =	$21,945	/mile

Soil Sement

Soil Sement Application Rate =	0.28	gal/yd2 (California ARB, 2002)
=	3942	gal/mi (@ 24 foot width)
Soil Sement Cost =	$4.42	/gal (FOB Seattle, Midwest Industrial Supply, 1/20/06)
Soil Sement Density =	9.01	lb/gal (Midwest Industrial Supply, 1/20/06)
EL-35 Transport Cost =	$447	/2000 lb tote (Seattle to Kotzebue, Northland Services, 1/11/06)
=	$2.01	/gal
Total Soil Sement Cost =	$6.43	/gal
=	$25,355	/mile
Application Labor =	1	equipment operator
+	1	laborer
Application Time =	8	hr/mile (estimated)
Labor Cost =	$655	/mile
Application Equipment =	1	water truck
Equipment Use Time =	8	hr - water truck (estimated)
Equipment Cost =	$212	/mile
Total Applied Cost =	$26,223	/mile

Gravel

Gravel Application Rate =	4	in. depth (estimated)
=	1,564	yd3/mile (@ 24 foot width)
Gravel Cost =	$52	/yd3 (in place @ Kotzebue, J. Hadley, 1/12/06)
=	$81,351	/road-mile
Pre-Grading Labor =	1	equipment operator
Pre-Grading Time =	16	hr (estimated)
Labor Cost =	$709	/road-mile
Pre-Grading Equipment =	1	grader
Equipment Use Time =	16	hr (estimated)
Equipment Cost =	$1,936	/road-mile
Total Application Cost =	$83,996	/road-mile

Geotextile Fabric

Geotextile Cost =	$1.63	/yd2 (http://www.dot.state.ak.us /stwddes/bidtabs/18363/ /18363.xls)
=	$22,950	/mile (@ 24 foot width)
Geotextile Weight =	4.0	oz/yd2 (http://www.maine.gov mdot/mlrc/geotextiles.php)
=	3,520	lb/road-mile
Shipping Cost =	$1,357	/road-mile (Northland Services, 1/11/06)
Installation Labor =	2	laborers
Installation Time =	42	hr (estimated)
Labor Cost =	$3,176	/road-mile
Total Installation Cost =	$27,484	

Asphalt Paving

Bid for Kotzebue Paving Project =	$2,064,685	(not including curbs, sidewalks, approaches, 24 foot width, J. Hill/ADOT, 1/12/06)
Length of Kotzebue Paving Project =	4,028	ft (@ 24' width, J. Hill/ADOT, 1/13/06)
Cost of Asphalt Paving =	$2,706,204	/road-mile (@ 24 foot width)

Fiberglass Plates

Plate Cost =	$2,000	/8'x14'x2" plate (D. Swarthout, 12/22/05)
Plate Shipping Cost =	$431	/plate (Northland Services, 1/11/06)
Total Plate Cost =	$2,431	/plate
=	$2,750,728	/road-mile (@ 24 foot width)
Pre-Grading Labor =	1	equipment operator
Pre-Grading Time =	16	hr (estimated)
Pre-Grading Labor Cost =	$709	/road-mile
Installation Labor =	2	laborers
+	1	equipment operator
Installation Time =	42	hr (estimated)
Installation Labor Cost =	$5,048	/road-mile
Pre-Grading Equipment =	1	grader
Installation Equipment =	1	dump truck
+	1	frontend loader
Total Equipment Cost =	$7,767	/road-mile
Total Installed Cost =	$2,764,252	/road-mile