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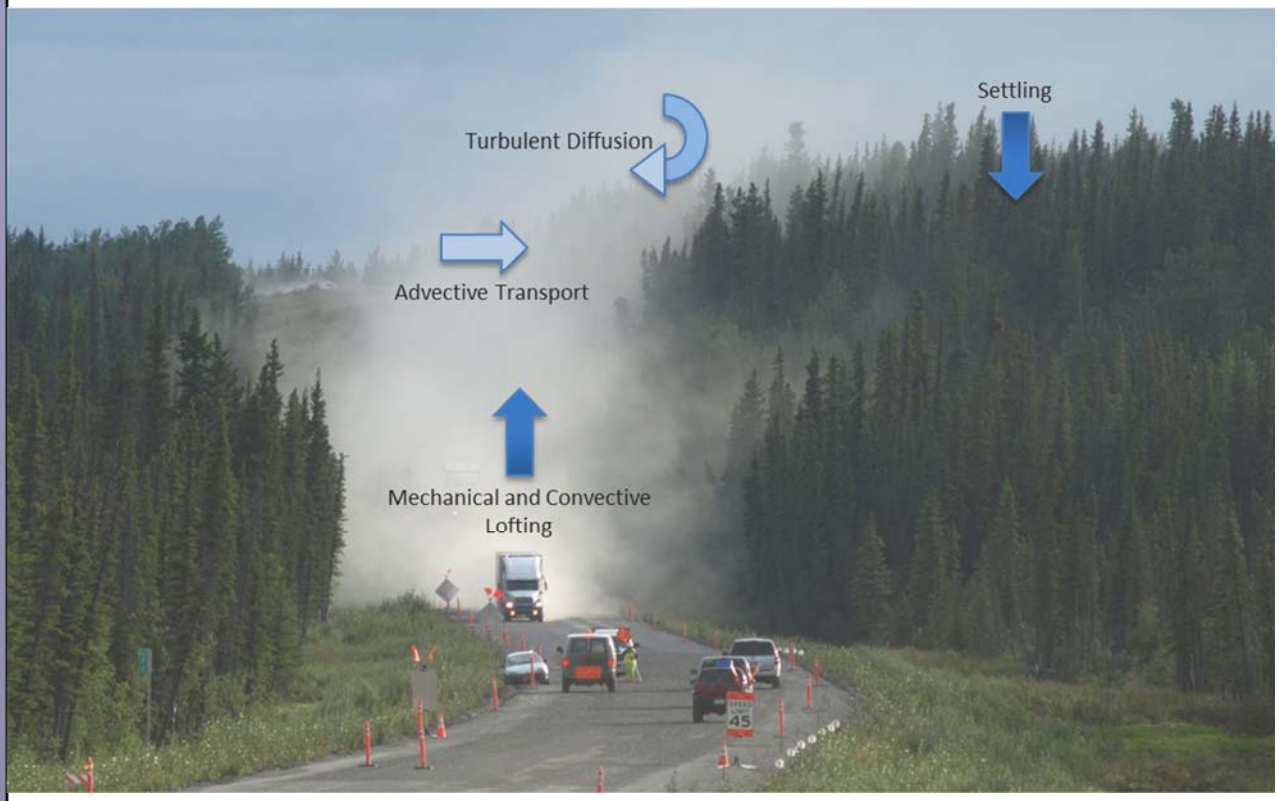
Alaska University Transportation Center

Managing Dust on Unpaved Roads and Airports



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October 2014

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Fugitive dust emanating from vehicle traffic on unpaved roads and runways can have significant impacts on safety, health, quality of life, and the cost of maintenance. Managing dust provides a means of reducing these impacts. Shearing forces created at the interface between the surface and vehicle tires produce dust on unpaved surfaces. The dust produced becomes airborne as a result of turbulence created by moving vehicles. Once airborne, different monitoring techniques can be used to assess the amount of fugitive dust produced and to measure the effectiveness of dust management strategies. Communities can manage dust by properly constructing and maintaining the unpaved surface, reducing vehicle speed on roads, and with the proper use of dust palliatives. The proper gradation of aggregate, the right profile, and good drainage are all necessary for reducing fugitive dust from unpaved roads and runways. Moreover, reducing vehicle speed on unpaved roads can dramatically reduce the amount of fugitive dust and result in longer periods between maintenance events. Several different types of palliatives are available for both managing dust on unpaved roads and runways. The choice of palliative is dependent on aggregate gradation, traffic amounts, climate, and location (remote or accessible).

14- KEYWORDS : Dust Control (Fmbbe), Dust (Rbmduf), Unpaved roads (pmrccu), Gravel roads (Pmrccug), Lignosulfonate (RBmdmv), Calcium Chloride (Rbcgned), Vegetable oils (Rbmdyk), synthetic fluids,

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic	m^3
		meters NOTE: volumes greater than 1000 L shall be		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inc h	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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Abstract

Fugitive dust emanating from vehicle traffic on unpaved roads and runways can have significant impacts on safety, health, quality of life, and the cost of maintenance. Managing dust provides a means of reducing these impacts. Shearing forces created at the interface between the surface and vehicle tires produce dust on unpaved surfaces. The dust produced becomes airborne as a result of turbulence created by moving vehicles. Once airborne, different monitoring techniques can be used to assess the amount of fugitive dust produced and to measure the effectiveness of dust management strategies. Communities can manage dust by properly constructing and maintaining the unpaved surface, reducing vehicle speed on roads, and with the proper use of dust palliatives. The proper gradation of aggregate, the right profile, and good drainage are all necessary for reducing fugitive dust from unpaved roads and runways. Moreover, reducing vehicle speed on unpaved roads can dramatically reduce the amount of fugitive dust and result in longer periods between maintenance events. Several different types of palliatives are available for both managing dust on unpaved roads and runways. The choice of palliative is dependent on aggregate gradation, traffic amounts, climate, and location (remote or accessible).

Chapter 1 Introduction

1.1 Importance of Dust Management

The road network in the United States currently contains approximately 1.6 million miles (2.5 million km) of unpaved roads in the United States, which is two-fifths of the entire U.S. highway network (FHWA 1998). In 2005 the US EPA estimated unsealed roads contributed 10,506,374 tons of fine soil particulates, commonly referred to as PM10 (soil particles ranging in size from 10µm to 2.5µm) or simply "dust" (Federal Register 2006). A simple ratio of these two values results in a staggering emission rate of 7.9 tons of dust per mile of unpaved road per year. Considering the in place cost of base course material to be $25 per ton, we can estimate that the loss of dust is costing federal, state, and local agencies around $260M per year. This cost does not represent the additional impacts of losing these fine soil particles off of the road surface and the resulting high levels of dust in our environment.

Loss of this material off of unsealed surfaces results in three issues. The first issue is degradation of the road surface. Fine soil particles act as a binder. Corrugations, potholes, and rutting are all evidence of loss of the fine particles and associated degradation leading to unsafe driving surfaces. Loss of these fines results in frequent maintenance of the unpaved surface at great expense. The second issue is safety. Large nearly opaque clouds of dust lofting from behind vehicles obviously obscure drivers' vision.

The third issue is health and quality of life. According to an extensive review detailed in the Federal Register (2006) ambient particles smaller than or equal to 10 µm in aerodynamic diameter are capable of penetrating to the deeper thoracic regions of the respiratory tract resulting in respiratory health issues. Further, high particulate matter levels in the air degrade the quality of life as fine soil particles coats surfaces inside homes and businesses.

Because Alaska is a predominately rural state, unpaved roads represent a major portion of our roadways and streets. The quality of life for those living along gravel surfaced roads is lowered because respiratory ailments, impact substance food preparation and storage and reduced visibility that results in a safety hazard.

The expectation for many communities is that paving their roads will solve their problems. While this may be possible in some cases, lack of suitable material or cost, prohibitive sources, unsuitable foundations, or inability to maintain paved roads preclude this option. Suitable options for reducing fugitive dust from roadways may be institutional controls, dust control palliatives or stabilizing chemicals. However, there is little consensus on how to measure the effectiveness, economics and environmental impacts of dust control approaches that are compatible with the subsistence lifestyle common to rural Alaska.

Historically, road managers have controlled dust by applying calcium chloride or magnesium chloride to the road surface. These products are relatively inexpensive and easily applied. However, both these salts easily leach out of the soil during precipitation events. Our experience has shown us that salts lose their effectiveness in about one-year depending upon location. In some locations use of these salts is not an option. For example, in rural Alaska where hunting, fishing, and berry picking comprise a good portion of the residences food supply, residences do not like salt palliatives due to the impact on their food supply.

Unsealed runways contribute dust to the environment as well. However, runway managers cannot apply salt palliatives on these surfaces due to their corrosive nature. Additionally, salts may not be an option in environmentally sensitive areas. In locations where salt is not an option other means of chemical stabilization of the fine particles are required.

These alternative means of dust control include non-petroleum based organics, such as lignosulfonate and tall oils, synthetic polymers, and electrochemical products. Applications of these products are somewhat site specific and they all work with varying success. Yet, up to now our measure of how well these products are working to control dust on an unsealed surface has been largely qualitative. Typically the qualitative measure involves asking the question "is there dust in the air after a vehicle passes?" In the past, there has been no tested instrument and methodology to evaluate how well different products will control dust and how long we can expect them to be effective. Understanding the effectiveness of palliatives as well as the longevity of these products is important as state and municipality budgets become smaller. The research program reported leading up to this manual developed the instrumentation and the methodology for evaluating the effectiveness of dust control methods. With this instrumentation, transportation officials are able to compare and contrast the performance of different dust management techniques.

1.2 Health Issues Caused by Dust

The elderly, children, people with chronic lung disease, influenza or asthma may feel discomfort when subjected to dust. The health effects of dust are related to the size of the particles that enter the body. Figure 1.1 shows the relationship of particle sizes EPA has defined as trigger points of concern, namely PM2.5 and PM10, and the human hair. Major health concerns from exposure to PM10 include effects on breathing, damage to lung tissue, cancer and premature death. According to the report "Health Effects of PM10 in New Zealand," the mortality rate increases between 4.3% in Switzerland, France and Austria to 10% suggested by WHO per 10 μgm^{-3} increase in PM10. (Environet 2003) The report suggests that the variance is due to, in part, to the overall health of the region being studied and the source of the PM10.

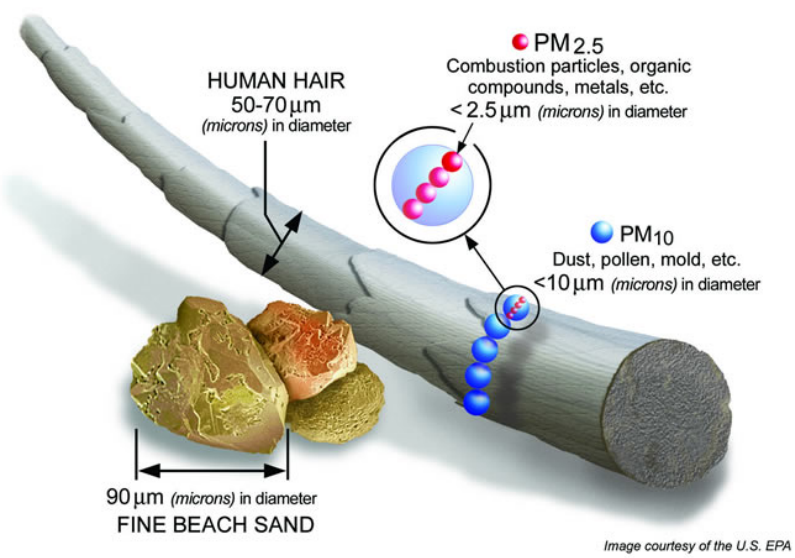

Figure 1.1. Relationship of particulate matter to the size of a human hair.

The finer fraction PM2.5 may penetrate into the alveoli reducing the transfer of oxygen to the bloodstream. Particles less than 1 micron can actually enter the bloodstream directly.

Since nearly 34 % of particles in the air are from unpaved roads, unpaved road represent a real health hazard for those who live along those roads (Sanders et. al.). Figure 1.2 shows the particle size count for 5 g sample passing the #40 sieve material dropped through a 5 foot column. Note that there are a significant number of particles in the 1 to 0.3 micron particle size range which is the limit of the instrument. As stated before, these particles are capable of entering the bloodstream.

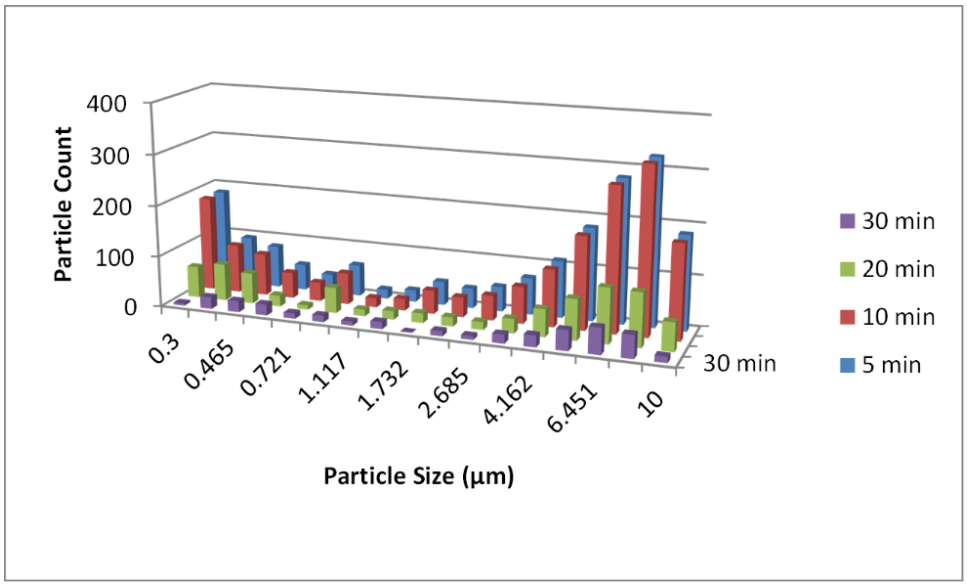

Figure 1.2 Particle size distribution measured in a dust settlement column

The smallest of particles found in road dust can be held in the atmosphere for hours or days. As a result each passage of a vehicle will add additional fine particles to the atmosphere making the total particle concentration cumulative. These smaller particles can be transported miles away from the source or enter the home causing an increased health concern since those with respiratory health issues cannot escape the dust.

The primary intent here is to provide an increased awareness of the health issues surrounding dust. There are a number of publications that provide a more in-depth discussion of dust related health impacts. The reader should refer to those documents or a health professional if additional information is required.

1.3 References

Environet. 2003. *Health Effects of PM10 in New Zealand, Air Quality Technical Report 39.* print, Wellington, New Zealand: New Zealand Ministry for the Environment.

FHWA. 1998. *Problems Associated with Gravel Roads.* print, Washington DC: Federal Highway Administration, Local Technical Assistance Program, FHWA-SA-98-045.

Chapter 2 How Dust Forms

2.1 Creation of Road Dust

A technical definition of mechanically generated dust is solid particulate matter capable of temporary (seconds to hours) suspension in air. To attach a size range to these small particles, these particles are smaller than medium sized sand but larger than the majority of particulates found in smoke. This categorization places these particles between approximately 0.5 to more than 100 µm in particle diameter (Hinds, Aerosol Technology 1999). As a size reference, the typical diameter of a human hair is 50 to 70 µm.

The generation of dust from unpaved roads can be from multiple sources. Mechanical breakdown of the surfacing aggregate on unpaved roads results in the generation of dust. As vehicles pass over the surfacing aggregate, the shearing force created at the interface between the vehicle tires and the aggregate generates dust. The weight of the vehicle also results in particle-to-particle grinding as the tires rolls over the aggregate. This repetitive grinding breaks down the particles generating dust. Fine soil particles in the size range of dust are also present in surface aggregate at the time the aggregate is placed on the unpaved road surface. These small particles are necessary for proper construction and performance of the road surface. Airborne dust from other sources (agricultural fields, unpaved lots, etc.) can settle out onto the road resulting in re-suspension as vehicles pass. Finally, deposition of dust attached to vehicles and vehicle tires by vehicles entering the road is another likely source of dust. Figure 2.1 illustrates each of these processes. The dust present on the road from these different sources is available to become airborne, becoming fugitive dust.

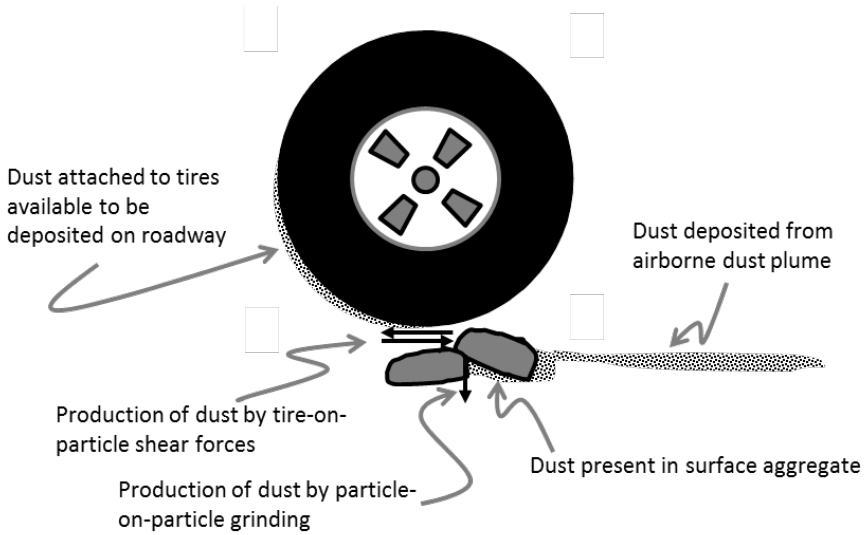

Figure 2.1. Sources of dust on unpaved roads

2.2 Fugitive Dust

Once dust generated from a road surface is airborne it is considered fugitive dust. The technical definition of fugitive dust is dust discharged into the atmosphere from an open source as opposed to from a confined flow stream such as an industrial stack (U.S. EPA 1995)). There are three mechanisms associated with vehicle movement that dislodge particles from the surface resulting in fugitive dust: mechanical sheer, shear stresses created by turbulence, and saltation bombardment. Mechanical sheer

is simply the dislodging and thrusting of dust into the air by the action of the tires in contact with the different dust sources discussed previously. It is interesting to note that the number of tires on the vehicle has a very little influence on the quantity of dust produced from a vehicle (Gillies et al., 2005). Instead Gillies found that vehicle speed and weight have a greater influence on dust production. These results indicate that the other two mechanisms (turbulence and bombardment saltation) may have a greater influence on the amount of dust produced by a moving vehicle.

Turbulence created by the displacement of air around and above a moving vehicle creates shearing forces that can dislodge particles from the ground surface. Once dislodged, turbulent eddies and vortices lift particles off the ground surface (Figure 2.2). As air passes over a moving vehicle air is forced upward over the vehicle accelerating as it gets "squeezed" between the top of the vehicle and the air above. Behind the vehicle there is room for air expansion, however the air cannot immediately fill this space. The flow therefore separates from the top surface of the vehicle creating a zone of low pressure in the space directly behind the vehicle and an associated vortex (roll-up flow). The vortex lifts dust from near the road surface created by mechanical shear and turbulence created under the vehicle. Wake eddies will continue to dislodge and lift particles from the surface and keep particles suspended for a distance behind the vehicle. Larger and less aerodynamic vehicles will create the relatively greatest amount of turbulence resulting in relatively large plumes of fugitive dust (Figure 2.3). Moreover, vehicle speed also has a strong influence on the quantity of dust produced owing to the increased magnitude of turbulence produced with speed (Gillies et al., 2005, Williams et al., 2008) The final mechanism that creates fugitive dust is a result of displaced particles bombarding other particles lifting these particles off the ground surface – a process called saltation bombardment (Figure 2.2). These particles are then available for further lifting by turbulent eddies and roll-up flow as previously described.

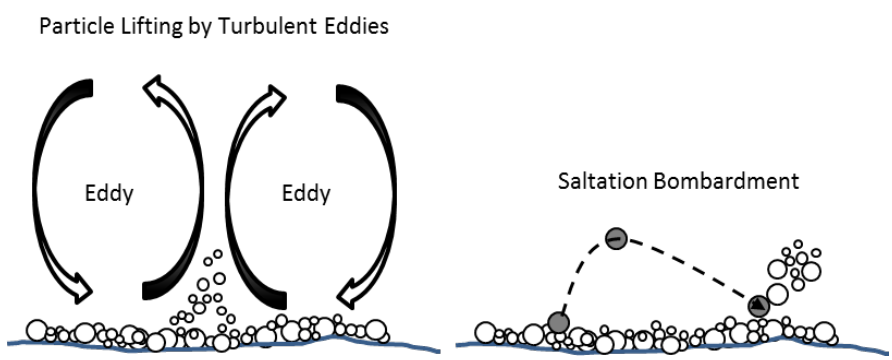

Figure 2.2. Mechanisms for lifting particles off the ground surface (after Klose and Shao, 2013).

Figure 2.3. Creation of fugitive dust

The height that fugitive dust is lifted is not only a function of the turbulence created by a vehicle but also dependent upon the stability of the atmosphere. Under stable conditions air does not have a tendency to rise from the ground surface. A good example of when the air is stable is cold winter nights when both the atmosphere and ground surface are cold. As the air is heated at the ground surface by the sun (warm summer afternoons), the air has a tendency to rise from the ground surface, the greater the temperature difference between the ground surface and the above atmosphere the greater the rate of rise and the more unstable the atmosphere. Under these conditions, fugitive dust is lifted to greater elevations than is possible by the vortices created by vehicles alone (Gillies et al., 2005). This process is shown in Figure 2.3.

Once in the atmosphere, fugitive dust will be displaced away from the source area (the road) by wind (advective transport). The settling of particles back to the ground surface is a complicated combination of buoyancy due to rising heated air, turbulence created by traffic on the road or wind moving around obstructions near the road, and gravitational settling. Figure 2.4 illustrates this process. Dust shown in this figure is a result of sweeping at a construction site. Under these conditions fugitive dust is still created by the fundamental methods described previously; mechanical shear (the action of the sweeping brush), shear created by turbulence (the turbulent air movement created by the motion of the brush), and bombardment saltation and lifted by turbulent eddies and buoyancy. However, the contribution from each mechanism will be different than would be created by a vehicle traveling on a gravel road.

Figure 2.4. Process involved in particle movement and settling

During the settling process, relatively larger particles will settle back to the ground surface shortly after being lofted. The smallest of the particles can stay aloft for several hours up to days depending on

atmospheric conditions. The time required for dust to settle from different heights can be theoretically determined (Hinds, 1999). For example assume that a passing vehicle lifts a plume of dust to maximum height of 2 m from the road surface. The settling time from this height for the range of particle diameters that define dust ranges from 20.7 hours to a few seconds (

Figure 2.5).

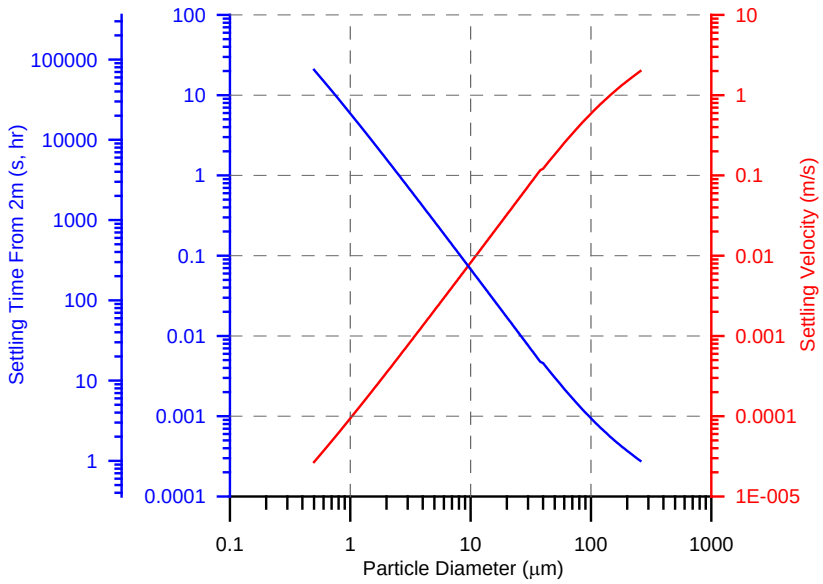

Figure 2.5. Particle settling time and terminal settling velocity

Once aloft, the amount of time the particles stay aloft allows them to be blown a range of distances from the road. Depending on the speed of the wind the largest particle will settle back onto the road surface or the shoulder. The particles shown on the road shoulder and side slope in Figure 2.6 are a good example of the deposition of these relatively larger particles. The amount of time the smallest particles can stay aloft (up to days depending on size and height that they are lifted) cause optical haze commonly seen in rural areas during dry weather conditions (Figure 2.7).

Figure 2.6. Relatively large dust particles that have settled out at the edge of a gravel road

Figure 2.7. Optical haze caused by small dust particles

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Chapter 3 Measuring Dust

3.1 Monitoring

Monitoring dust from unpaved roads has three main goals to: 1) to assess if an area is in compliance with regulatory standards, 2) to quantify dust emissions from unpaved roads, and 3) to determine if dust management strategies are effective. To accomplish these monitoring goals, particulate sampling methods include simplistic visual assessments, deposition monitors, stationary non- and semi-continuous monitors, and mobile monitors. Each of these methods will be discussed.

PM10 is particulate matter having an aerodynamic diameter less than or equal to 10 micrometers (µm) and typically consists of common crustal materials (note: volcanic ash particles may also fall into this size fraction). It is this size fraction of particulate matter that is used as a measure of fugitive dust. The regulatory standard in the United States for PM10 established by the Environmental Protection Agency (US EPA) is 150 $\mu g/m^3$ averaged over a 24-hour period. An area meets this standard if the 24-hour PM10 concentration does not exceed 150 $\mu g/m^3$ more than once per year, on average, over a three-year period (Federal Register, 2013). The US EPA has adopted methodologies to assess whether or not an area meets this standard (US EPA, 1999).

Quantification of the sources of particulate matter is a necessary step in meeting the air quality regulations. Emission factors have been developed for this quantification step. An emission factor is a representative value that relates the quantity of pollutant released (mass of particulate matter in this case) to the atmosphere to an activity associated with the release of that pollutant, such as vehicle-distance driven on an unpaved road (US EPA, 1995). Quantification of dust emissions is a necessary step in the development of these emission factors for unpaved roads (Cowherd et al., 1974; Cowherd and Englehart, 1985). Moreover, measurements of fugitive dust from unpaved roads is a necessary step in developing strategies to reduce overall particulate matter concentrations in impacted areas.

Application of dust palliatives is one method of reducing the impact that unpaved roads have on overall fugitive dust in an area as well as loss of the material integral to a well performing road. Monitoring methods for assessing the effectiveness of dust palliatives have been developed over the last number of years (Sanders et al., 1997; Edvardsson et al., 2012; Eckhoff, 2012). The focus of monitoring for evaluating dust control does not necessarily have to be on measuring PM10. Measuring dust generated over the size range referred to in Chapter 2 (0.5 to 100 µm) may be adequate. Not restricting the monitoring to PM10 allows for a greater range of monitoring techniques.

3.2 Visual Monitoring

Qualitative assessments of the amount of dust generated by unpaved roads are conducted repetitively by anyone living next to an unpaved road or traveling on an unpaved road. Visual assessments of dust levels are based on the capability of the human eye to detect contrast between an object (such as buildings or trees along the roadway) and its surroundings. The scattering and absorption of light by particulates in the air reduces the contrast, making these objects less visible. Since the clarity of an object seen through a cloud of dust will be perceived differently from person to person, visual monitoring is a subjective measurement (Watson, 2002). However, over a range of particulate concentrations, such as the range of no perceivable particulate matter up to a minimal amount of particulate matter in the atmosphere, the difference in perception by different observers is small enough that a subjective scale may be a useful tool for monitoring dust. (Thompson and Visser 2007) have developed such a scale. These researchers propose dividing the dust levels behind a moving vehicle

into five categories of progressively greater concentrations of dust. A series of photographs with verbal description aids the observer in making a decision on dust conditions. With such a scale it is perceivable that one could make visual assessments of dust levels at locations where frequent dust control measures are necessary such as construction sites to determine the action needed.

3.3 Dustfall monitoring

Dustfall monitoring is a passive monitoring technique that involves catching dust in non-directional or directional stationary gauges. Dust can be captured by either open, upward facing containers similar to rain gauges or by directional gauges. Open, upward facing container type gauges are used to monitor dust deposition to the ground surface (Hall and Upton, 1988; Hall et al., 1993; Hall et al., 1994; ASTM, 2010). Containers used in these gauges are shaped like a disk or bowl and are placed horizontally. A hole in the middle of the container allows captured precipitation (along with particulates) to drain into a bottle. Hall and Upton (1988) used inverted Frisbees® (a flying disk toy) as containers attached to collection bottles (Figure 3.1). These researchers found that these toys provide superior collection efficiency. To prevent dust particles from blowing out of the container once captured, a coating of a sticky additive can be applied to the container walls (Hall and Upton, 1988). At the conclusion of the measurement period the collected mass of dust is measured in the laboratory.

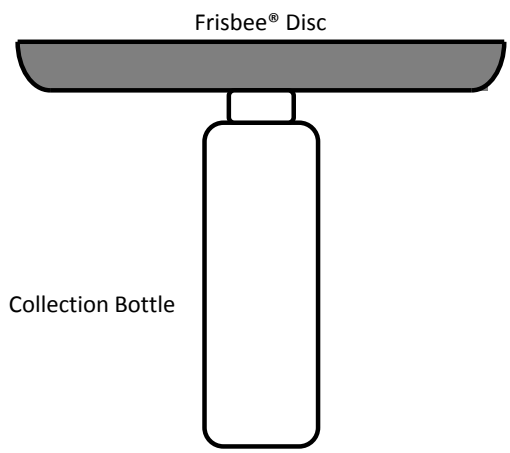

Figure 3.1. Non-directional dustfall gauge (Hall and Upton, 1988)

Directional stationary gauges capture particles travelling horizontal. A typical design consists of four vertical sampling tubes mounted on a vertical support stand with each tube set at right angles to each other (Hall et al., 1993). Each tube contains a sampling slot along the long axis. The gauge is positioned such that the open sampling slots of each tube line up with the four cardinal points of the compass. This orientation allows for the determination of the source direction of the dust. A collection bottle is mounted below each sampling tube. As with the non-directional samplers, the mass of particulates captured by the gauge is measured in the laboratory at the conclusion of the monitoring period.

While simple in design and operation, dustfall monitors have limitations. Only the largest of particles fall at an angle approaching vertical (Harrison, 1986). Most particles fall at angles shallow to the horizontal. Hence, results from an upward facing open non-directional dustfall gauges may not be representative of the actual amount of dust deposited in an area. Moreover, the very presence of a gauge will alter the airflow and particulate deposition in the immediate area of the gauge. Thus, the results from the gauge may differ from what is actually occurring. Further, dust may blow out of the container on windy days. However, this type of monitoring may be effective if the goal is to determine relative dustiness of unpaved roads such as before and after the implementation of a dust management program or to determine the distance particulates may be traveling from the unpaved road.

3.4 Filter Sampling

A standard method of determining dust concentration in ambient air is to use a pump to draw a specific volume of ambient air through a size selective inlet and then through a filter. After a suitable period, the filter is removed and the mass of dust filtered from the air over the measurement period is measured gravimetrically, chemically, or by measurement of a physical property such as reflectance in a

laboratory. Filter monitoring is effective for the entire size range of dust or for a selection of particles less than a certain size range, such as PM10.

Size selective inlets for PM10 select only those particles that are less than 10 µm in aerodynamic diameter. Three types of inlets techniques are used for particle discrimination: impaction, cyclonic, and selective filtration (Pio, 1986, Chow, 1995). Impaction inlets separate particle sizes by inertia. With this type of inlet, air pulled into the sampler accelerates as the dimensions of the flow path are restricted. Barriers (impactors) create an abrupt change in the airflow direction. At this point in the inlet momentum causes particles greater than 10 µm to continue along the original path colliding with the impactors and being excluded from the air stream. An alternative design of this inlet is known as a virtual impactor. In this design, openings replace the impactors directing larger particles out of the airstream. Cyclonic inlets remove particles greater than 10 µm by forcing the airstream into a spiral pathway. The resulting centrifugal force on the particles causes them to move outward to a collecting surface. Selective filtration inlets excludes particles of differing diameter through a uniform pore sized filters.

Instruments designed to sample the concentration of particulate less than 30 µm in aerodynamic diameter (total suspended particles) exclude particles greater than this range by the configuration of the air entry points in the sampler. In these samplers the air inlets are sized such that particles with diameters larger than 30 µm have a sedimentation speed that causes them to drop out of the airflow prior to entering the instrument. Figure 3.2 shows a typical sampler for this type of measurement. A sampler configured for PM10 sampling will be similar to the one shown in Figure 3.2, however a different size selective inlet than the one shown in the figure (discussed previously) will be positioned upstream of the filter (Figure 3.3).

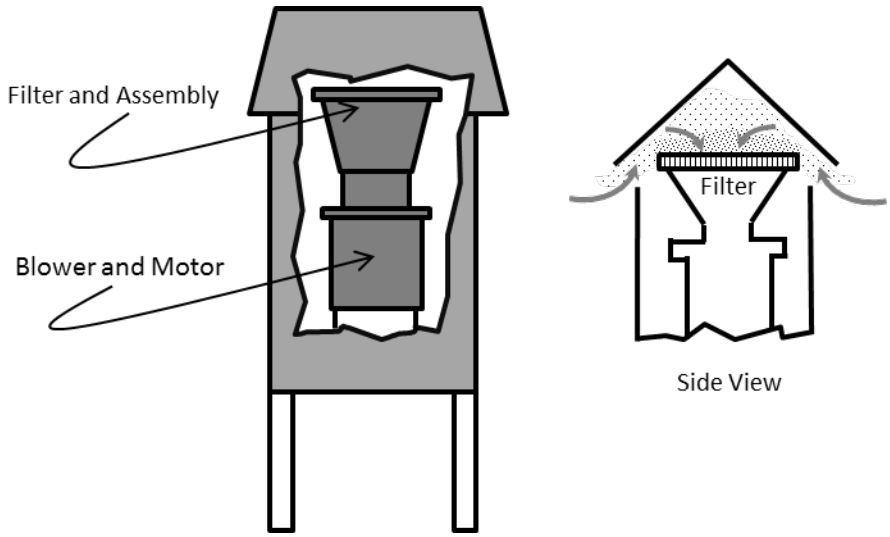

Figure 3.2. Typical filter monitoring instrument with size selective inlet that excludes particles less than 30 µm

Filter media consist of tightly woven fibrous mats or plastic membrane containing microscopic pores (Chow, 1995). The choice of filter should take into account the collection efficiency of the filter, flow resistance and loading capacity, material strength, chemical stability, and temperature stability of the filter material. Filters should capture 99% of the particles passing through them regardless of the particle size or flow rate through the filter (Federal Register, 1987a). The strength of the filter material

Figure 3.3 HiVol Sampler

should keep the filter from being damaged during use and should minimize leakage. Chemical reactions between the filter material and the captured particulates should not occur and fluctuating temperature should not alter the filter's porosity (US EPA, 1999). US EPA (1999) and Chow (1995) provide guidance on filter selection.

US EPA has established a federal reference method for monitoring PM10 compliance monitoring (Federal Register, 1987a). The filter method fits the requirements for the Federal Reference Method (FRM). More specifically, the FRM incorporates inertial separation of the particles larger than 10 µm followed by filtration and gravimetric determination of PM_{10} mass retained on the filter. A common FRM method used in the United States is the High Volume Sampling (HiVol) method. Details of this monitoring method can be found in US EPA (1999) and Chow (1995). US EPA can also approve PM10 monitoring methods that are equivalent to the FRM. These methods are classified as federal equivalent methods, or FEMs (Federal Register, 1987b). Approved FEMs include several semi-continuous type monitoring systems to be described subsequently.

3.5 Semi-continuous Sampling

Several types of PM10 monitors provide semi-continuous concentration values. The three most commonly used systems are the beta attenuation monitor (BAM), the tapered element oscillating microbalance (TEOM), and the light scattering nephelometers.

Beta-attenuation analyzers use a stream of electrons (beta rays) generated from a radioactive source (typically low-level carbon-14) to quantify the amount of particulates accumulated on a quartz-fiber filter tape. As with non-continuous samplers, these instruments employ a pump to draw a specific volume of ambient air through a size selective inlet and the tape that filters the PM10 particles out of the airstream. The tape advances to a new position upon completion of the measurement. Particulate concentrations as a function of time are determined by knowing the time the first measurement started and how often the tape is advanced. This method is an FEM.

A change in the natural frequency of a vibrating glass tube (sensor) resulting from the accumulation of particulates on a filter is the fundamental operating principle of the TEOM. The TEOM operates by warming the air pulled into the instrument to a preset temperature, usually 30°C to 50°C to minimize thermal expansion and contraction of the glass tube as well as to evaporate liquid water and volatile PM2.5 components. The warmed sample air containing the particulates then passes through a filter cartridge attached to a glass tube. The deposition of the particles on the filter results in changes of the vibration frequency of the tube. Based on a relationship between the vibration frequency and accumulated mass, the instrument computes the total mass accumulation on the filter over a set time. This method is also an FEM.

Instruments that take advantage of reflectance of light by particles in the air are called nephelometers. The instrument draws air into a measurement cell where a light beam is focused onto the sample. Quantification of the light reflected of the particles relates directly to the concentration of particles in the air stream. Filters or size selective inlets upstream of the measurement cell can be used to exclude particles larger than the size range of concern. Nephelometer measurement methods are not

considered by the US EPA to be FEMs, however they have been used in several gravel road dust studies that will be discussed subsequently.

3.6 Measuring Road Dust

Use of the measurement techniques described above to assess fugitive dust from unpaved roads begin to appear in the literature around 1970. Anderson (1971) may have been the first to measure fugitive dust from an unpaved road. To assess vehicle dust production in New Mexico the author positioned a filtration monitor at the edge of a road. The author also attached the instrument to the backend of a vehicle as it was traveling at a set speed. With these measurements the author estimated the mass per mile of dust produced. Using a different technique to quantify the amount of fugitive dust produced from an unpaved road, Wellman and Barraclough (1972) measured dust using visible light illuminated through the dust plume. A study conducted by Roberts (1973, also published in Roberts et al., 1975) closely followed the study by Wellman and Barraclough (1972). In this study the author evaluated the cost effectiveness of converting unpaved roads to paved roads. As part of the study methodology the authors mounted a cascade impactor, originally developed to measure the size distribution of particles in air ducts (Pilat et al., 1970), to a trailer towed behind a car. Hoover et al. (1973) and Handy et al. (1975) measured dust emanating from unpaved roads using the dustfall method. In a study to determine fugitive dust sources that have a major impact on particulate levels, Jutze and Axetell (1974) sampled emissions from unpaved roads using HiVol samplers and BAMs (however it is a little unclear the relationship between the beta gauge used in this study and the BAM gauge described previously). Sultan (1976) also conducted road dust studies using the dustfall method as well as HiVol sampling. As part of an effort by the US EPA to develop emission factors for fugitive dust sources, Cowherd et al. (1974) used dustfall and HiVol sampling to develop emission factors (mass of particulates per vehicle-mile) for unpaved roads.

There have been many other studies using the methods described in this chapter since these relatively early studies on measuring fugitive dust from unpaved roads. Many studies are advancing the early work on use of mobile monitors to assess the ability of unpaved roads to produce fugitive dust. Mobile monitors have several advantages over stationary monitors. These advantages will be discussed later in the chapter. Following the early work by Anderson (1971) and Roberts et al., (1975), Irwin et al. (1986) positioned ducting behind the rear wheel of a truck. The authors used photometry to measure the opacity of the air stream entering the duct as the vehicle was moving. The authors named their measurement device RDM (Road Dust Monitor). Sanders and Addo (2000) developed the Colorado State University (CSU) Dustometer. The authors secured a metal box containing a glass fiber filter to a truck rear bumper. A suction pump pulled the air stream behind the vehicle through the filter. A system similar to the RDM and CSU Dustometer was developed by Thenoux et al. (2007). As with the CSU Dustometer, this system (named Dust Mat) mounts on a truck's rear bumper. A laser photometer quantifies the number and size of particles pulled through a sampling chamber by a micropump. Differing from the RDM, the Dust Mat quantifies the number of particles by diffraction of a light beam as opposed to reflectance.

Several mobile monitors use a nephelometer to quantify dust concentrations produced by vehicle. Common to all these systems is an intake that pulls continuous air samples through a vendor supplied nephelometer. The position of the intake differs between mobile monitors. Kuhns et al. (2001) developed the TRAKER, which was later improved (Etyemezian et al., 2003). Inlets in this system are located behind both rear tires of a cargo van. The system also has an intake positioned underneath the front bumper of the vehicle to measure background particulate concentrations. Edvardsson (2009) developed a mobile dust monitoring methodology that includes mounting an intake on the driver side

rear view mirror of a car to record a background concentration and to the rear of the vehicle to measure the fugitive dust created by the car.

The University of Alaska Fairbanks (UAF) DUSTM was developed for the measurement of fugitive road and runway dust in remote rural communities (Eckhoff, 2012). Instead of mounting an intake on a standard vehicle, the researchers mount the intake on a small all-terrain vehicle (ATV). The intake is located behind one of the rear tires on the ATV. Background samples are not necessary since the vehicle traffic in small rural villages is minimal allowing the operator to take measurements when the ATV is the only vehicle on the road. Appendix A contains the testing methodology for the UAF-DustM to determine if a road or runway treated with a dust palliative is performing within a certain specification. Appendix B contains an example construction specification.

There are several advantages of using mobile monitors over stationary monitors to quantify the fugitive dust produced from unpaved roads. Most likely the greatest advantage in the use of mobile monitors is the ability to assess an entire unpaved roadway's surface to produce fugitive dust. With a mobile monitor that uses a nephelometer to quantify the concentration of dust a typical methodology for measuring the dust produced from an unpaved surface involves driving the monitor along the surface to be measured taking frequent measurements. Measurements of fugitive dust from an unpaved road using stationary monitors are taken from the plume of fugitive dust produced from the road. Hence this measurement represents some sort of an average particulate concentration from a section of the road whose length is dependent on the position of the monitor in relationship to the road. Another advantage of mobile monitors is the minimal time required to obtain a measurement. With a mobile monitor, measurements of an unpaved road's ability to produce fugitive dust takes hours as opposed to weeks required by some stationary monitor methodologies. The minimal measurement time allows the use of mobile monitors in construction specifications (an example specification is included in Appendix B). The main disadvantage of mobile monitors is there is currently no standard methodology. Hence a measurement obtained using the TRAKER (Etyemezian et al., 2003) will most likely be different from a measurement taken using Evardsson's methodology (Evardsson and Magnusson, 2009) and may or may not correlate well with results from a Federal Reference Method sampler.

3.7 Summary

This chapter presents several particulate monitoring methods for use in assessing fugitive dust from unpaved roads. Visual assessments are the simplest methodologies. While this method might be useful where quick decisions are necessary, such as would be the case with dust control in construction areas, they are subjective and difficult to use for decisions where costs and risks are significant. The concept of dustfall sampling is easily understood and the methodology is relatively simple and inexpensive. The best use of this methodology may be to make semi-quantitative assessments of the effectiveness of dust management strategies over time. The relatively more complex monitoring techniques used by regulatory agencies to assess compliance with air quality regulations are the methods that the US EPA designates as FRMs and FEMs. Practitioners have often used these methods to obtain a rigorous assessment of fugitive dust from unpaved roads such as would be required in the development of emission factors. Finally this chapter discusses mobile monitors. This type of monitoring methodology appears to be most useful for assessing the effectiveness of dust control strategies.

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Chapter 4 Preparing the Road for Palliatives and Stabilizers

Good dust management starts with a good road. Dust control measures have proven to work best on well prepared roadways with the right surface course. The effectiveness of palliatives and stabilizers decreases as we deviate from the ideal. This chapter is provided to help users understand how roadway preparation impacts performance and understand what needs to be done before applying palliatives.

Good gravel roads begin with three basic principles:

- The right materials
- The right profile
- Good drainage

Managing these three principles will reduce dust even without the use of palliatives. The first is use of proper materials. The embanked material must be able to carry traffic loadings in through all seasons. The detailed design of the embankment will not be discussed in detail here. There are numerous publication and design procedures available. Suffice it to say that, if not properly designed, damage to the roadway will occur before dust control chemicals fulfil their potential.

4.1 The Right Materials

We will focus on the surface course material here. The intent is not to replicate that body of literature. Rather, the intent is to summarize the most important elements of selecting a good surface course. Ideally the surface course should be hard and durable. If the material is soft, it will tend to break down, increasing the fines and potentially increase dust. In some cases, the surface has broken down to the point where it can no longer carry traffic or becomes mud during rainfall.

Next, the gradation of the surface should be proper. The gradation determines many of the properties of the surface course including the ability to

- Carry traffic.
- Resist tire abrasion.
- Resist damage due to rain and snow.
- Resist washboarding.
- Minimize dust.

Figure 4.1 provides a good representation of the effects of gradation on the performance as a function of gradation and shrinkage product which is related to shrinkage product.

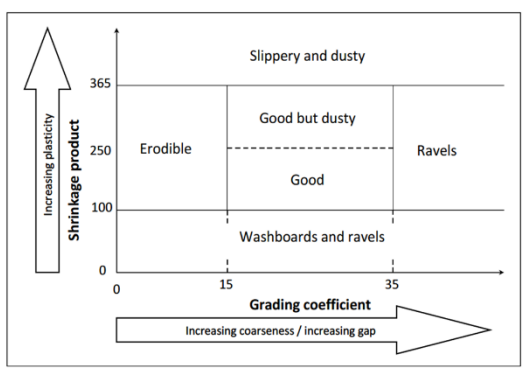

Figure 4.1 Relationship of soil properties and surface cource performance (Paige-Green 1989)

The grading coefficient (G_c) is defined as

$$G_c = ((P1.0\ inch - P\#8)\ x\ P\#4)/100$$

Where P is the percent passing.

The shrinkage product (S_p) is defined as

$$S_p = P\#40\ (PI\ x\ 0.5)$$

Where PI is the plastic index.

Figure 4.1 is intended to be a guideline and must be adjusted to local conditions. In Alaska, most of the soils used for gravel surfacing is non-plastic which indicates the material is likely ravel and washboard. However, experience has shown that if the gradation is properly selected, this can be minimized. While it would be desirable to increase the plasticity by adding clay, the cost is prohibitive. As will be discussed in Chapter x, the lack of plasticity affects which palliatives or stabilizers may be most effective in Alaska.

Figure 4.2 illustrates how gradation affects the stability of the surface course. It also shows, there is a balance between course and fines that provide good performance with low dust production. It is that balance which should be sought.

Numerous agencies have developed gradations which have proven to work well. Examples of those gradations are provided in Table 4.1. Note that they vary somewhat, but they all have similar attributes including high fines content. As will be discussed later, research is proving that palliatives have a specific range of fines that optimize their performance which generally fall within the specifications indicated

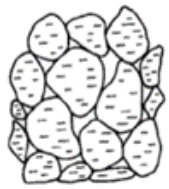	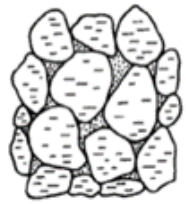	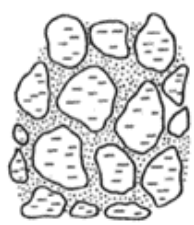
Aggregate with Low Fines	Aggregate with Proper Fines	Agregate with Excess Fines
Grain-to-grain contact	Good strength and resistant to abrasion	Lower strength due to loss of loss of grain to grain contact of the larger aggregate
Low stability unless confined	Good stability	Low stability
Premeable	Resistant to moisture infiltration	Loss of strength in the presence of moisture
Difficult to obtain uniform compaction	Requires some compactive effort.	Easily compacted under the right moisture content
Generates excess float	Overall good performance	Generates considerable dust

Figure 4.2 Relationship between gradation and surface course performance

Table 4.1 Sample surface gradations

Sieve	DOT&PF E-1 (a)	DOT&PF F-1 (a)	US Forest Service No 3. (b)	FHWA Grading F (b)	South Dakota (c)
1"	100	100	100	100	
3/4"	70-100	85-100		97-100	100
3/8"	50-85	60-100	60-100		
1/2"					
No. 4	35-65	50-85	50-85	41-71	50-78
No. 8	20-50	40-70			37-67
No. 10			40-70		
No. 40			24-45	-40	13-35
No.50	15-30	25-45			
No. 200	8-15	8-20	8-15	5-16	4-15
Plastic Index	10 max	10 max	4-9		4-12

(a) Alaska Standard Specifications for Highways 2004

(b) Federal Highway Standard Specifications For Construction of Roads and Bridges on Federal Highway Projects 2003

(c) South Dakota Standard Specifications for Highways and Bridges 2004

One additional concept must be introduced to completely understand how gradation impacts performance, the maximum density. The maximum density occurs when the gradation minimizes voids in the soil after compaction. The voids ratio, the volume of voids divided by the total voids, provides a good indicator of performance. Too many voids and we get loss of stability, increased raveling and washboarding as shown in Figure 4.3 and increased dust. Too few voids and there is no room for liquids in the soil matrix to hold the soil together. For example, sand has a high voids content and thus poor performance as a surface course.

Borrowing from the asphalt industry, we can use the Maximum Density Line to estimate the gradation that gives the maximum density. We do this by plotting the percent passing each sieve against the sieve size to the 0.45 power. This is commonly called the 0.45 power plot. Figure 4.4 shows the Alaska E-1 surface course plotted on the 0.45 power plot. The space between the maximum density line and the gradation represents the void space in the soil matrix. The further away from the line, the greater the void space. This is the space in which the liquid whether water or chemical will reside. If the gradation falls too close to the line, little or no liquid will penetrate into the soil. If the gradation is too far from the maximum density line, the liquid will readily drain out. Unfortunately, there is little research that defines the appropriate void ratio for palliatives. However, research does suggest that being on the maximum density line does create a tight surface that does not allow the product to penetrate. Consequently, practitioners should ensure that the gradation does not follow the maximum density line if the use of palliatives or stabilizers are anticipated.

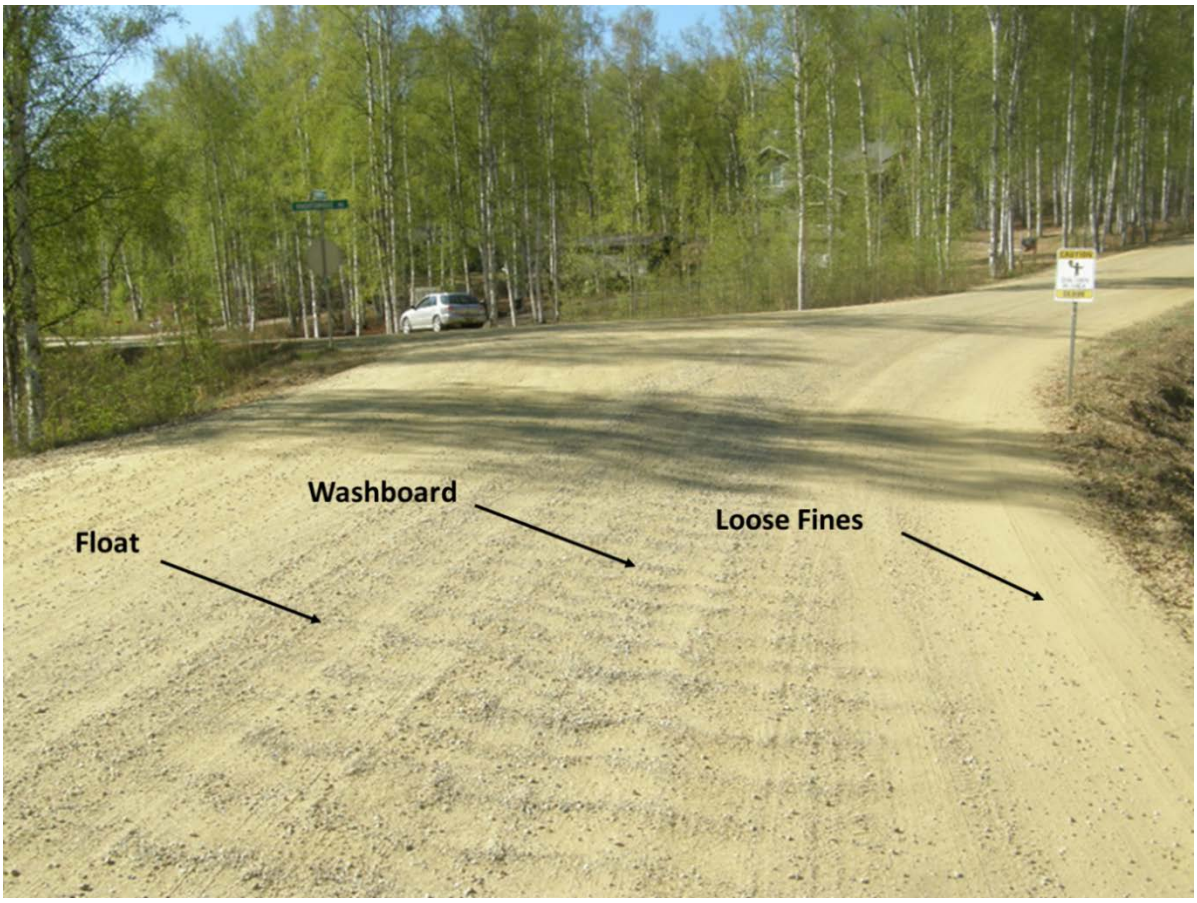

Figure 4.3 Attributes of gravel road distress

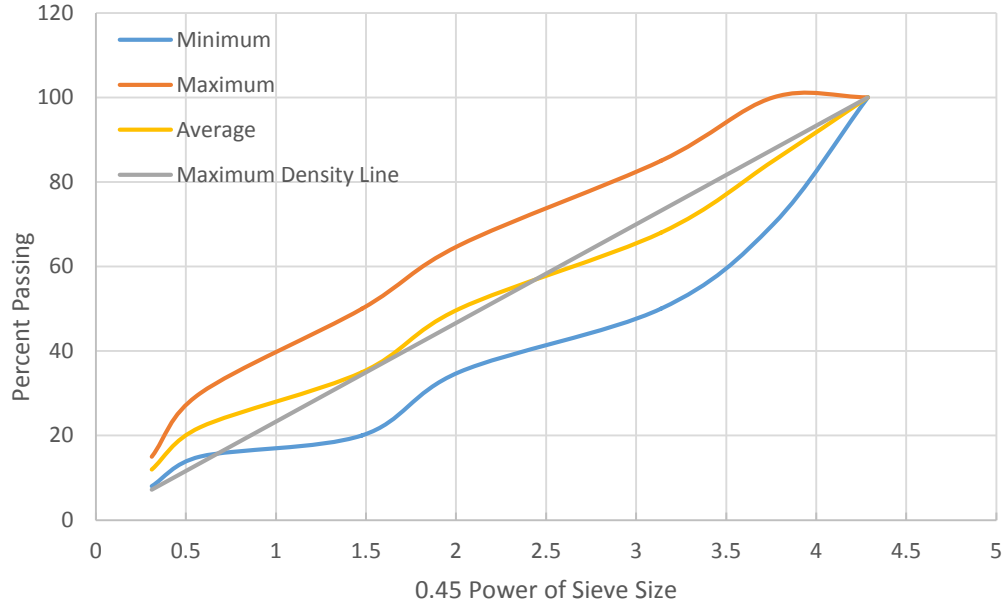

Figure 4.4 "0.45" power plot of Alaska E-1 surface course

4.2 Measuring Stability

Stability or soil strength can be measured using a variety of tests. The most common is the California Bearing Ratio (CBR). CBR simply measures the resistance of the soil to the penetration of a piston into the soil. Soaked CBR values greater than 20 are considered usable for surface courses.

The dynamic cone penetrometer (DCP) is growing in popularity. By measuring the number of blows required to drive a point one inch into the soil provides a measure of soil stiffness. Correlations have been developed between the dynamic cone penetrometer and other tests. The advantage of the DCP is that it is easily performed in the field. However, care must be taken when using the DCP to measure stiffness in the first few inches. Since the soil has a tendency to loosen as the point is driven into the surface, the values may be suspect.

The plate bearing test is another relatively simple test which has seen little use recently. This test simply measures the depth that a plate penetrates into a soil as it is loaded.

Other tests include unconfined compression tests, resilient modulus testing and undrained confined compression tests. Since these tests are costly to perform, they are rarely used for gravel surfacing.

4.3 Use of In-Situ Surfacing Material

While it is better to use high quality surfacing materials, availability and cost may prohibit its use. In these cases an understanding of the material and the chemicals to be used become critical. If the surface course material is close to the desirable gradation, adjustments in grading, application rates and frequency of maintenance will provide acceptable results. In cases where the surface course varies significantly from the desired gradation require increased care in selection of chemical treatments.

4.4 The Right Profile

The cross section of the roadway is also critical to the performance of the roadway including the amount of dust produced. The crown of the roadway should be between 3 and 5%. Below 3% the water tends to pond on the roadway resulting in potholes as shown in Figure 4.5. When palliatives are used, ponded water can result in decreased performance. If the crown exceeds 5%, the surface of the roadway will likely erode removing surface course and any palliative with it. The results of a proper crown can be seen in Figure 4.6.

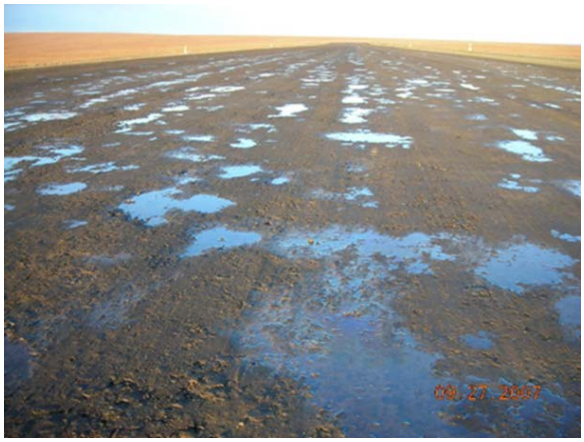

Figure 4.5 Ponding due to lack of crown

Getting the proper crown requires a trained motor-grader operator. However, there are aids that will help to operator achieve the proper crown. Figure 4.7 shows a slope indicator that can be attached to the blade which will help the operator set the blade at the right angle. A simple slope indicator can be created using a torpedo level, a straight edge such as a 2x6 and a wedge. Both options are inexpensive with high benefits.

Figure 4.6 Proper crown after rain

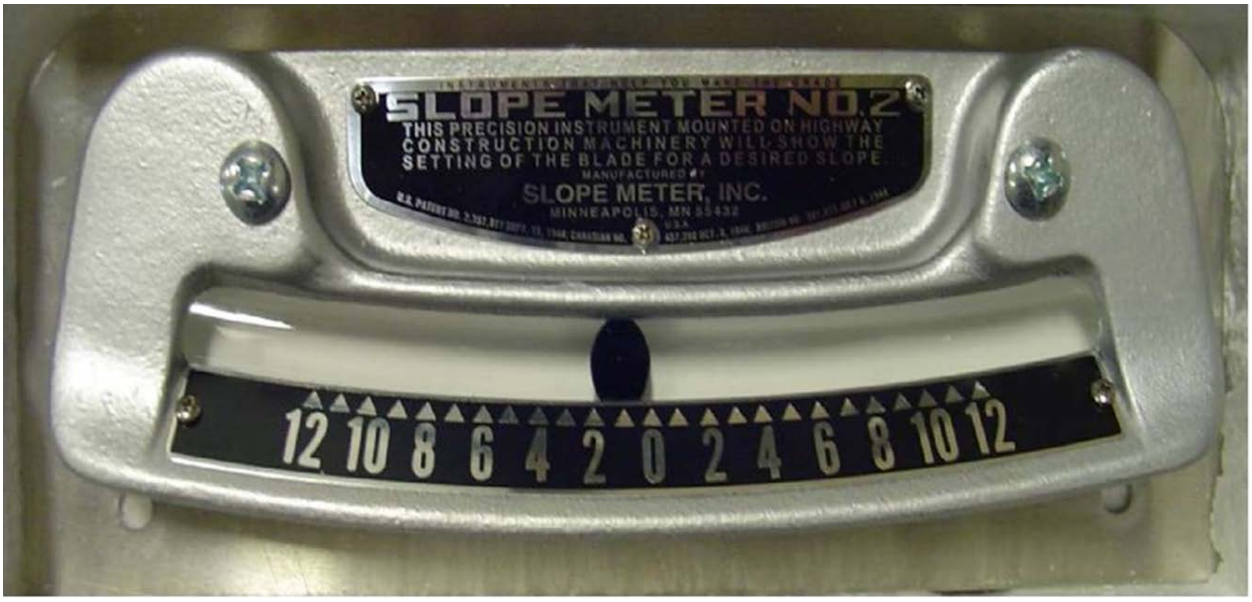

Figure 4.7 Commercial slope meter, courtesy of Slope Meter Inc.

4.5 Good Drainage

Good drainage is a critical feature of any good roadway. If water is allowed to stand in the roadway, the strength of the embankment is weakened and hydraulic action of water will create potholes. This is true whether the roadway is paved or gravel. However, those who maintain gravel roadways often create drainage problems by filling in ditches or building berms along the edge of the roadway. Figure 4.8 is an example of the creation of a berm. Figure 4.9 is an excellent example of the lack of a ditch. Note that the water is being directed onto the roadway in this photo.

Figure 4.8 Ponded water due to improper ditching

Figure 4.9 Water routed to roadway due to improper ditching

Figure 4.10 shows an example of proper grading. Note that a there is a gap under the blade to the left of centerline indicating a slope. The material at the edges of the roadway are feathered, eliminating any berm. Note also the forward tilting of the blade to provide proper placement of the material.

Figure 4.10 Proper grading improves roadway performance

4.6 Summary

We cannot expect palliatives and stabilizers to correct design, construction and maintenance problems on gravel roads. Further, as the number of deficiencies increase we can expect the cost of managing dust to increase. If the deficiencies are great enough, dust management becomes essentially impossible. While this chapter is not intended to cover the engineering and maintenance of gravel roads in detail, it does point out the critical areas of concern. The reference section provides sources of additional information for the practitioner. These sources will help fill in the detail not provided in this chapter.

Maintenance crews need adequate training to ensure they are maintaining the roadway correctly. Improper maintenance will rapidly erode even the best engineering and construction, reducing the probability of a successful dust reduction program.

4.7 References

Alaska Department of Transportation and Public Facilities, *Standard Specifications for Highway Construction, 2004*

Federal Highway Administration, Standard Specifications for Construction of Highway and Bridge, 2003

Paige-Green. (1989). *The Influence of Geotechnical properties on the Performance of Gravel Wearing Course Materials.* South Africa: Ph.D. Thesis University of Pretoria.

South Dakota Department of Transportation, Standard Specifications for Highway and Bridge Construction

Chapter 5 Dust Management

5.1 Introduction

Researchers have conducted many studies on the performance of dust control palliatives over the last century and have reported their studies in the literature. Many studies have been conducted on the common palliatives: water, hydroscopic salts, and lignonsulphonates. On the contrary, only a handful of studies have been conducted on more recent additions to the selection of palliative types: polymers and synthetic fluids. In addition, multiple studies have shown the influence speed has on the amount of fugitive dust created. The purpose of this chapter is to provide some guidance on the performance of these different palliatives types. The majority of the performance guidance provided in this chapter comes from literature. Guidance on the performance of synthetic fluids and polymers comes from literature and the authors' research.

5.2 Managing Speed

Referring to the discussion on the creation of fugitive dust in Chapter 2, one can see how increased vehicle speeds result in increased quantities of fugitive dust. Both mechanical shear and shear produced by turbulence increase with increasing vehicle speed resulting in greater amounts of fugitive dust as shown in Figure 5.1. The source of the results shown in Figure 5.1 is the US EPA emission factor empirical equation for vehicles traveling on unpaved publicly accessible roads, dominated by light duty vehicles (US EPA, 1995).

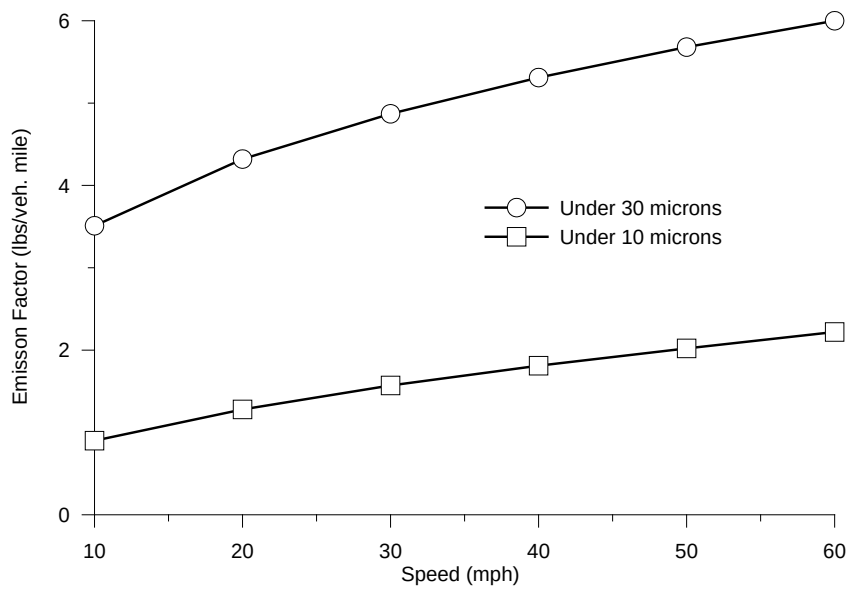

Figure 5.1 Dust generation per vehicle mile traveled as a function of speed (EPA, 1995)

Roberts et al. (1975) also found that the total particulates lofted were a function of speed. These researchers measured the amount of dust generated by a vehicle traveling at progressively higher speeds with a mobile monitor. Figure 5.2 shows their results.

A comparison of the US EPA (1995) emission factors versus those measured by Roberts et al. (1975) shows a greater emission factor with speed measured by Roberts et al. (1975). Most likely the difference between the two results is due to the method of measurement. While US EPA uses static monitors placed at strategic locations off set from the road (EPA, 1998), Roberts et al (1975) used a mobile monitor towed behind the moving vehicle.

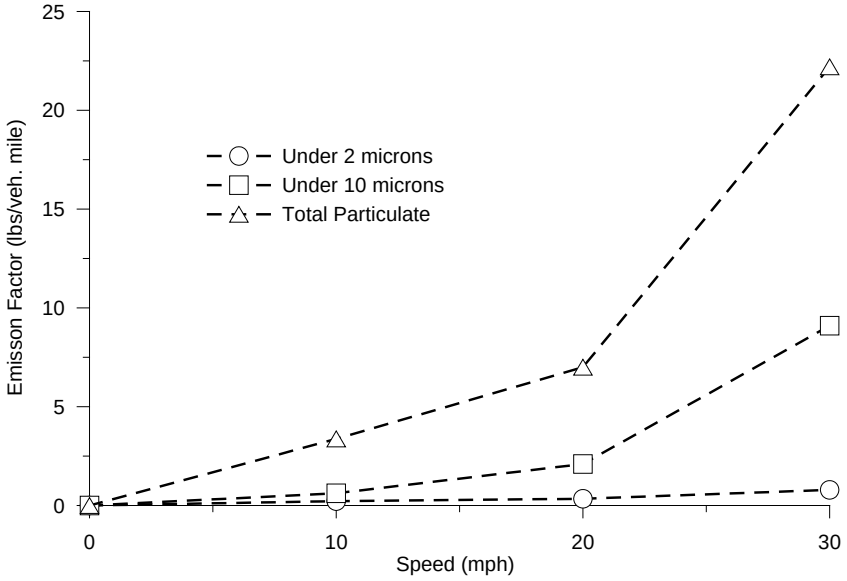

Figure 5.2 Relationship between speed and fugitive dust from a grave road (Roberts et al., 1975)

According to the US EPA's emission factors a light vehicle travelling at 15 miles per hour will loft about 1.1 lbs of PM10 per vehicle mile traveled (VMT). The PM10 lofted by a vehicle traveling at 30 miles per hour would be about 1.6 lb/VMT. Roberts et al.'s results indicate that at 15 miles per hour a vehicle will loft 1.5 lbs of PM10 per VMT and 9.1 lbs/VMT at 30 mph. To provide an example of the magnitude of PM10 lofted on a typical unpaved road consider a two-mile stretch of road. If an average of 20 vehicles passes over the road at an average speed of 30 miles per hour a total of 64 lbs of PM10 will be generated per day or over 1900 lbs per month according to the emission factors developed by the US EPA (1995). However, according to the emission factors developed by Roberts et al. (1975), this same scenario produces 10,920 lbs of PM10. Reducing the speed to 15 mph results in an approximately 30% reduction in lofted PM10 according to the US EPA emission factors and a 83% reduction in dust according to the emission factors developed by Roberts et al. (1975).

Photographs of fugitive dust behind a vehicle moving at different speeds is an effective way of illustrating the impact vehicle speed has on the amount of dust produced by a vehicle. Shown in the following series of photographs (Figure 5.3) is a vehicle traveling at 15, 35, and 45 mph. The increase in dust with increased vehicle speed is evident.

It is interesting to note that a reduction in vehicle speed will also result in a greater longevity of the dust control palliatives to be discussed subsequently. The effectiveness of dust control palliatives diminish when the road is distressed. Indication of a distressed road includes corrugations (washboards), loose gravel on the road surface (often called float), and potholes. While potholes are a result of a poorly graded road, the forces imparted by vehicle (and trailer) tires on the road create corrugations. Shearing force imparted on the road surface by the vehicle's drive tires creates float. Lowering vehicle speed reduces these forces, which increases the longevity of both the road and the dust control palliative.

Figure 5.3 Fugitive dust created by a vehicle at different speeds (photo courtesy of Tom Moses)

5.3 Palliatives

There are a large number of palliatives available, each having its usage. A brief discussion of the types of palliatives will be provided here. However, four are, at present, most attractive for use in Alaska:

- Water,
- Calcium Chloride,
- Synthetic Fluids, and
- Polymers.

Dust palliatives can be categorized into groups according to chemical formulation. The Alaska Department of Public Transportation and Public Facilities (ADOT&PF) has had experience with several of the different palliatives as shown in Table 5.1.

5.3.1 Water

Probably the most used dust palliative is water, especially to control dust on construction sites. Yet, use of water on unpaved roads to control dust is an expensive option as was acknowledged in the literature as early as 1907 (Byrne, 1907). Capillary forces created when water exists in soil pore space agglomerates the surface particles resulting in retention of the fine particles and decreased loft times on

particles that become fugitive dust. As anyone who has used water to control dust knows, water's ability to control dust is short lived; less than an hour in hot dry climates to multiple hours and up to possibly a day in other climates (Foley et al, 1996; Rushing et al, 2000).

Table 5.1. Categories of dust palliatives (after Bollander, 1999 look at to do list) and ADOT&PF experience with different palliatives

Palliative	*Products*	*Applied in Alaska in the Past*
Water	Fresh and saline	Yes
Salts and brines	Calcium chloride and magnesium chloride	Calcium Chloride
Petroleum-based organics	Asphalt emulsion, cutback solvent, dust oils, modified asphalt emulsion	Yes
Non-petroleum based organics	Vegetable oils, molasses, animal fats, ligninsulfonate, tall oil emulsions	Ligninsulfonate
Synthetic polymers	Polyvinyl acetate, vinyl acrylic	Several proprietary products
Electrochemical products	Enzymes, ionic products (e.g. aluminum chloride), sulfonated oils,	EMC^2, Permazyme
Clay additives	Bentonite, montmorillonite	Montmorillonite
Mulch and fiber mixtures	Paper mulch with gypsum binder, wood fiber mulch mixed with brome seed	Polyolyfin fiber reinforcement

Aggregate gradation, atmospheric temperature and humidity, wind speed, and traffic all directly relate to the performance of water in controlling dust. For gravel roads, the surface course needs to contain a certain amount of fines to retain water near the surface reducing the amount that drains down into the soils below. The amount of water retention is directly related to the fines content, however as the fine content increases the structural integrity of the road surface decreases resulting in rutting. Typical percent fines content specified for surface aggregates are between 6 and 15%. Some specifications will allow fines (silt and clay) content as high as 20%. Intuitively, water applied to roads on hot days with low humidity and high winds will rapidly evaporate necessitating frequent applications. Passing vehicles enhance the evaporation of water from the road surface; hence greater frequency of traffic reduces longevity. Owing to the short-lived effectiveness of water, this dust suppressant may only be appropriate for construction sites and possibly small communities that only experience periodic conditions conducive to creating fugitive dust.

Application of Water

Foley et al (1996) recommend frequent light applications of water to the road surface as opposed to heavy watering. As the authors discuss, heavy watering results in degradation of the road surface by loss of fines through pumping and subsequent washing of the material from the road surface. Addition of surfactants to the water is also an option. Surfactants aid in the infiltration of the water and the wetting of the soil particles resulting in improved formation of agglomerates.

Struss and Mikucki (1977) discuss the appropriate timing for reapplication of water on roads cut directly into native soils with high plastic limits. Starting with a recently watered surface, a wet plastic soil road surface will deform under tire pressure. At this stage of water content tire marks as vehicles pass over the surface will be evident, however fugitive dust is absent due to the high water content. As the soil dries tire marks are no longer evident but the soil surface still has a glossy appearance. Fugitive dust emissions are low at this stage, but as the authors state, the road surface appears as if dust will soon become a problem. However, watering the road at this stage of drying would be premature, since the soil immediately below this surface layer is still wet. Moisture from these underlying soils works its way to the surface soils by the continuous pumping action created by vehicle loading. The re-wetting of the

surface layer results in a temporary glossy appearance. As the soils continue to dry, moisture levels directly below the surface layer will be insufficient to retain dust particles resulting in a dusty surface layer. As the authors explain, the progression rate of the drying front below the road surface is directly dependent on the vehicle traffic, vehicle speed, and relative humidity. The generation of fugitive dust from the roadway starts once the drying front is sufficiently deep such that the surface layer is not receiving sufficient moisture. Water is required to control fugitive dust at this point.

5.3.2 Salts and Brines

Salts (most commonly calcium chloride and magnesium chloride) control dust by adsorbing and retaining moisture in the surface material. Calcium and magnesium chlorides are deliquescent chemicals, meaning they attract enough water from the atmosphere to form liquid water. In the process these salts will dissolve in the produced water. When added to soil, these chemicals add enough water to the soil to control fugitive dust by the same mechanism discussed in the previous section. These chemicals are most effective at suppressing dust when the relative humidity is greater than around 30 to 40 percent. During morning hours when relative humidity is typically high and temperatures are low the salt treated road surface retains moisture. As the temperatures rise and relative humidity drops in the afternoon, evaporation removes less moisture from a salt treated road surface in comparison to untreated road surfaces. Morgan et al (2005) discuss impact of soil gradation on the dust suppression performance of salt compounds. These authors state that to be effective, the road surface soil should be comprised of between 10 to 20 percent fines (silts and clays). Due to the high solubility of these compounds in water wet weather conditions may wash the compounds out of the road surface, thus frequent application of these compounds may be necessary. In addition these compounds are corrosive eliminating their use on unpaved runways.

Salts are known to be an irritant to eyes, nose and respiratory passages. While they may cause discomfort, salts do not have long-term health effects. Perhaps the greatest disadvantage to the use of calcium chloride in Alaska is the bitter taste it imparts to fish drying in the village. The advantage of salts is that they are the lowest cost dust palliative available. The cost of applying $CaCl_2$ in Alaska was between $6,000 and $7,000 dollars/mile.

Application of Salts and Brines

Salts have long been the most widely used palliative in roadway dust management because of the relatively low cost and ease of application. Most jurisdictions use calcium chloride ($CaCl_2$) or magnesium chloride ($MgCl_2$) as dust palliatives. The recommended application rate of salt is generally between 1.0 and 1.5 percent by weight. This equates to between 9 and 18 tons per mile assuming an aggregate unit weight of 130 lb/ft^3, a 24-foot top and the treated depth is two inches.

The Alaska DOT&PF uses about 8-9 tons per mile on the Dalton Highway for the first application. In year 2, 6 tons per mile are used. In year three 4 tons are used. In year 5, the rotation restarts with 8 tons per mile. The amount of $CaCl_2$ applied may vary due to local aggregate and climate conditions.

Applicators apply salts in either a liquid or a solid form. Solid $CaCl_2$ is most commonly used in Alaska. To apply salt in solid form, a grader blade mixes the product into the top two inches of the surface course while adding water. The amount of water added to the material depends on the existing moisture content and the fines content. Care must be taken to assure enough water is added to allow complete and uniform mixing of the salt into the soil, but not so great that the aggregate becomes unworkable or that excess water leach salt out of the soil.

Salt is usually delivered in one-ton super sacks, which allows crews to easily estimate how far each bag should spread. As an example, a super sack of salt would cover a distance of between 256 and 385 ft assuming a 24-foot top, 2 inches of thickness and an aggregate unit weight of 130 lb/ft^3. Conditions and results will change by location; hence local experience should guide the choice of effective application rates.

Some jurisdictions prefer to apply the salt in the form of brine. In this case, the concentration of salt in the brine must be determined so that the application rate of the residual salt is consistent with the 1 to 1.5 percent by weight. Otherwise the process is essentially the same as application in solid form.

Owing to the chemicals high solubility and its deliquescent nature, once applied the chemical is continuously being lost from the road surface where it is needed. Hence, relatively frequent re-applications of this dust palliative to the road surface are necessary. The life expectancy of the salt is about one year. Many jurisdictions reduce the quantity of salt after one or two years to account for the remaining salt in the soil. While most do not test for remaining salt, there are simple tests which will quantify the remaining salt.

5.3.3 Non-Petroleum Palliatives

This category of suppressant includes a variety of industrial waste products, animal fats, resins, and vegetable oils of which lignosulphonates are the most widely used. During the paper making process (pulping) lignin, which is considered a waste product of the process, is released and can be recovered as lignosulphonates. As a dust suppressant, the lignin polymer binds soil particles together. To maximize binding Brown and Elton (1994) suggest that the best use of this product is on cohesive or clayey soils. lignosulphonates is water soluble and easily washed out of the road surface. To help retain the mixture in the road surface (Han 1992) recommends a fines content of between 4 and 8%. Depending upon climatic conditions and surface condition frequent applications may be necessary. This product is also corrosive unless combined with calcium carbonate.

Han and Marti (1996) discuss the successful use of acidulated soybean oil soap stock (soap stock) in controlling fugitive dust on aggregate surfaced roads. Soaps stock is the biodegradable byproduct of the caustic refining process of soybean oil. Experience with this product in Minnesota indicates that the best conditions for this product are on light duty unpaved roads with less than 100 ADT. The palliative works best on surfaces with fines content between 5 and 20%. However, soap stock does not appear to hold up on road sections that experience large shear forces such as curves. Marti (2013) documents the use of used canola oil to control dust on Canadian Roads.

Unaltered vegetable oils are not recognized as an effective dust palliative since the product only coats the soil and provide no binding action. As they age, unaltered vegetable oils oxidize and become brittle losing their ability to adhere to the particle. Furthermore animals may be attracted to roadways treated with vegetable oils causing a traffic hazard.

Application of Non-Petroleum Palliatives

Lignosulphonates are applied to the road surface as a liquid mixture. Brown and Elton (1994) found 25% solids content in the mixture to be optimum. Ripping the surface to a depth of 1 to 2 inches prior to application of the mixture results in a better performance compared to applying to an unprepared surface (Jones and Mitchley, 2001; Han 1992). For a ripped surface, lignosulphonate mixed with water is applied to the spread material, mixed, and re-compacted. Jones and Mitchley (2001) recommend an application rate of between 1 and 3 kg/m^2 (0.2 lb/ft^2 to 0.6 lb/ft^2) of solid material per year. Considering a mixture with 25% solids content the solids application rate suggested by Jones and Mitchley (2001)

results in a mixture application rate of 0.1 to 0.3 gallons per square foot. The exact application rate is dependent on traffic and climate.

5.3.4 Synthetic Fluids

Synthetic Fluids comprise several different compounds that promote soil particle binding. The definition of synthetic materials are produced by reaction of purified feedstocks, usually from refined crude oil. This is different from fluids such as diesel or mineral oil derived from the physical separation process of crude oil. (Adapted from CFR 9 Part 435)

Consequently, synthetic fluids are a family of products, each of which are formulated for specific properties. In the case of dust palliatives, the synthetic fluid is specifically reacted to produce a product that reduces dust. Several synthetic products are provided by vendors under the product names EK-35, Enviroclean, and Durasoil. Manufactures of synthetic dust palliatives guard their formulation carefully. Consequently, the exact formulations of the different products are not available to the public. This makes it difficult to fully understand the properties of the material. However, test results indicate they are nontoxic.

Synthetic fluids hold fines in the soil with capillary forces, much in the same manner as water. The benefit of synthetic fluids over water is they are non-volatile at atmospheric temperatures so they will not evaporate from the road surface. In addition the viscosities of the different available synthetic fluids are greater than water, hence they will not drain as rapidly through the soil. Manufactures have added "binders" to their synthetic fluids to increase the bond between soil particles and to slow the drainage of the palliative through the soil. As with the synthetic fluid products, the binders are proprietary, hence little is known about the binding action and if it truly does improve the palliative performance.

As with water, $CaCl_2$ and lignosulphonates, the retention of synthetic fluids in the road surface is necessary in order for the product to control dust. Hence, retention is dependent on the amount of fines in the aggregate. Using a mobile monitor (described in Chapter 2), the authors tested the effectiveness of synthetic fluids in controlling dust on multiple aggregate surfaced runways in rural Alaska. Eckhoff (2012) provides a description of the general testing methodology. Using this test methodology, the dust control effectiveness is quantified as the average amount of PM10 measured behind the vehicle. The percentages of fines in the aggregates making up the surfaces of each runway were also determined. Figure 5.4 shows the results.

As indicated in these results a fines content of between approximately 9 and 13% appears to be optimum. The figure also shows that the result from the runway at Summit does not follow the overall trend. While there is still more to learn about the fundamentals of dust control using synthetic fluids, one possible explanation as to why this point is off the trend is the overall gradation of the aggregates. Figure 5.6 compares the 0.45 power plots (refer to Chapter 4) for the aggregate used to surface the St Michael runway to the aggregate used to surface the Summit runway. This comparison shows three main differences between the aggregate gradations: (1) the gradation of the Summit aggregate is closer to the gradation that would provide the maximum density, (2) there are less large and midsize particles (greater than 1.18mm or the No.16 sieve), and (3) the fines content in the Summit aggregate is slightly greater than in the St Michael aggregate. To expand on the difference in the fines content it is interesting to note that the ratio of the percentage of clay to the percent fines in the Summit aggregate is approximately twice that found in the St Michael aggregate. Hence the Summit aggregate has a greater amount of clay for the same fraction of fines in comparison to the St Michael aggregate. Furthermore the ratio is the highest ratio of all the seven sites tested. To date it is unclear if this difference in fines content is the reason behind the disparate results shown in Figure 5.5. Additional

study is required. These results suggest that the aggregate gradation plays a role in the performance of a synthetic fluid. It is well known that the aggregate gradation and the maximum density is a factor in asphalt performance. However, there are most likely additional soil properties influencing the performance of synthetic fluid palliatives.

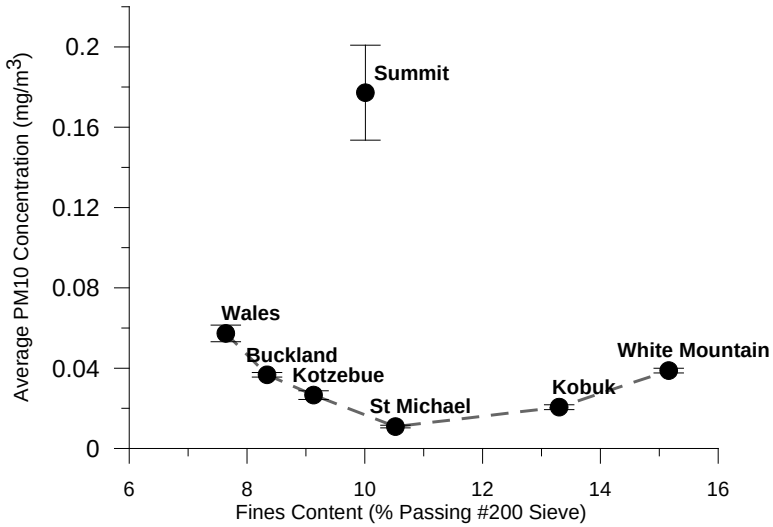

Figure 5.4 Determination of the range of fines content that will result in the best performance of a synthetic fluid applied to aggregate surfaced runways

As with any road dust palliative, the performance of synthetic fluid palliatives will diminish over time. The reduction in the dust control performance of a synthetic fluid palliative is due to the following:

- loss of the palliative from the wearing surface,
- breakdown of the forces holding the small particles in the wearing surface,
- tracking of dust onto the treated surface from untreated roads and driveways by vehicles, and
- reduction in the integrity of the road (corrugations and potholes).

Loss of palliative will occur by several different methods. Given that the palliative stays a liquid after application, the liquid will continually migrate downward away from the wearing surface leaving only a residual amount in the surface aggregates. Several factors will control the downward migration rate including the quantity of fines in the aggregate and the amount of water contained in the aggregate. As with any liquid draining through soil, the rate of drainage and the fines content are inversely related. Hence, palliatives applied to aggregates with greater fines content will retain the palliative for a longer period. Additionally, palliatives will be removed from the subsurface by attachment to vehicle tires and through the processes that remove fine particles from the road surface as fugitive dust or entrained in runoff water from the road surface.

As discussed in Chapter 2, shear forces created between the road surface and vehicle drive tires create road dust. These shear forces also breakdown the forces created by palliatives that hold the fine particles in the road surface. Continued breakdown of these attractive forces results in diminished effectiveness of any applied dust control palliative. Hence, greater wear will occur in areas that sustain these greater forces such as curves, inclines, and areas on the road that require changes in speed such as road intersections with traffic controls and intersections with driveways.

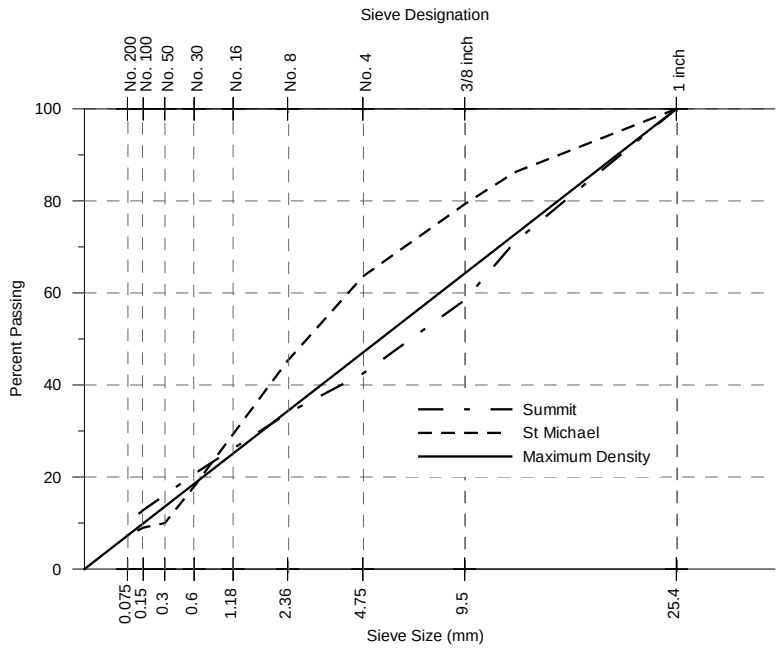

Figure 5.5 "0.45" plot of aggregates used to surface runways in Summit and St. Michael, Alaska

Dust from unpaved and untreated road surfaces or driveways connecting to treated road surfaces will result in the treated surface becoming dusty, a process known as track on. Most likely the applied synthetic fluid palliative will control some amount of this tracked on dust if a sufficient amount of palliative is present in the wearing surface. However large amounts of dust tracked onto the treated surface will result in dusty areas where these untreated surfaces connect with the treated road.

Corrugations and potholes in the road surface as well as the presence of float are all symptoms of a distressed road. Loss of fines from the aggregate contributes to these unpaved road distresses. However, once formed the effectiveness of any synthetic fluid palliative remaining in the road surface is greatly diminished owing to the breakdown in the wearing surface structure.

A study performed by the authors in Eagle, Alaska (Eckhoff, 2012) illustrates how increased shear forces and track-on contribute to the reduction in palliative performance. For this study a synthetic fluid palliative was applied to 1.2-mile stretch of unpaved road (Amundsen Avenue). The mobile monitor developed by the authors (UAF-DUSTM) was used to measure the effectiveness of the palliative along the length of treated road. Figure 5.6 illustrates an example of the results. As this figure shows, higher PM10 concentrations were measured at the intersections with untreated roads and driveways illustrating the impact of track-on at the uncontrolled intersections and increased shear along with track-on at the controlled intersections. This figure also illustrates the impact of increased shear along the curves in the road.

These results indicate that a more frequent application of palliative in the areas that experience increased shear will improve the longevity of the overall palliative application. In addition, treating a 50-foot section of connecting roads with palliative on each side of the treated road will decrease track-on and increase the longevity of the dust control measure.

Several factors influence the longevity of an applied synthetic fluid including the type of vehicle the road supports (light vehicles versus heavy), the average daily traffic, the average vehicle speed, the number

of intersection with traffic controls, the number of intersections and driveways joining the treated road, climatic conditions, aggregate characteristic, quality of the construction, quality of the surface preparation prior to application, and quality of the palliative application. To better understand the performance of synthetic fluid palliatives applied to unpaved runways, the authors tested several different runways treated with synthetic fluids shortly after application, approximately one year after application (the following summer season after application), and approximately two years after application (the second summer season following application). For each runway, measurements were taken on the treated runway section and on an untreated section that was constructed in the same manner as the treated section. These measurements were made using the UAF-DUSTM. Runways tested one and two years after application were not necessarily the same runways tested the previous year. Figure 5.8 shows the mean value with the standard error in the mean for each runway tested and the mean of the combined control measurements for all the runways tested during each time period.

Figure 5.7 shows the overall decrease in the palliative performance as shown by the overall increase in the mean values for the runways tested following application. Since the treated gravel surfaces in this study were runways and not roads, this decrease in the effectiveness of the dust control palliatives represents loss of the liquid palliative by drainage through the aggregates and by breakdown of the forces holding the small particles through the shear forces created by aircraft utilizing the runway. The only types of aircraft utilizing these runways are propeller driving owing to the gravel surfaces and size. Hence, the shear force created at the runway surface by these aircraft is prop wash. If the aircraft parking area is not treated, track-on from this area may also contribute to the fugitive dust originating on the runway.

Choosing a mean PM10 concentration of 0.1 mg/m^3 to compare the performance of each runway allows for a closer examination of the palliative performance on each runway. This mean PM10 concentration represents a 97% reduction in the mean PM10 concentration from the mean of all the control measurements. The mean PM10 concentration of the control sections is equal to 2.88 mg/m^3. Shortly after application all but one of the runways achieved this mean PM10 concentration (this includes Eagle). One year after application, 6 of the 10 runways tested (this includes Noatak) achieved a mean PM10 value of 0.1 mg/m^3. Two years after application 2 of the 5 runways measured were still able to achieve this mean PM10 concentration.

One site that does not appear to completely follow the trend in mean PM10 concentration towards the mean control value is the runway at White Mountain. One year after application of the palliative on this runway the mean value increased from 0.039 to 0.574 mg/m^3. Two years after application the mean value decreased to 0.095 mg/m^3. Though it appears from the results as if the palliative performance rebounded two years after application, in actuality the decrease in the mean value was due to a high moisture content due to a rain event that occurred just prior to conducting the field test. By two years after application sufficient palliative was not present in the aggregate and the high moisture content controlled the dust.

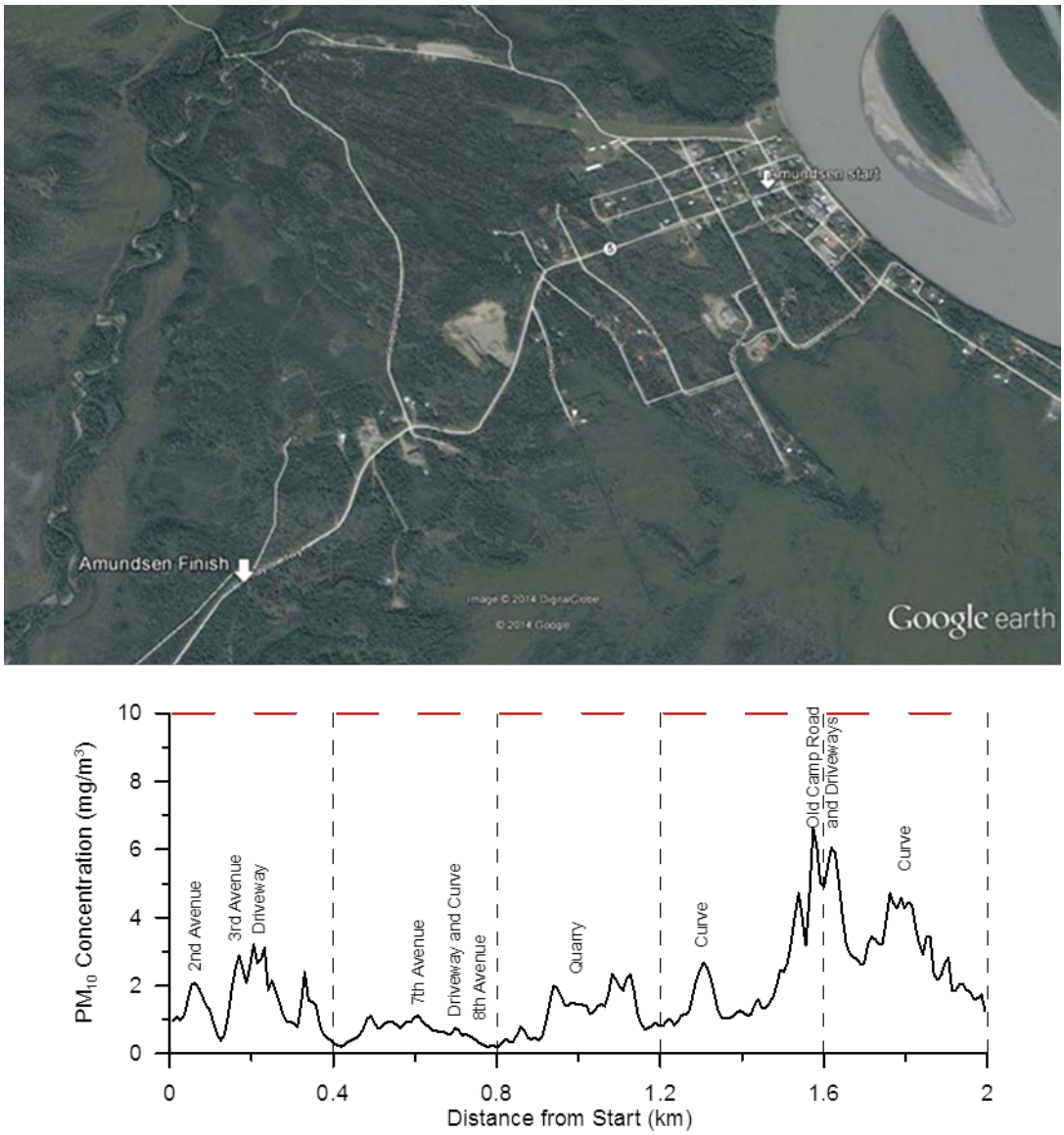

Figure 5.6 PM10 measured along a section of Amundsen Avenue in Eagle, Alaska treated with synthetic fluid

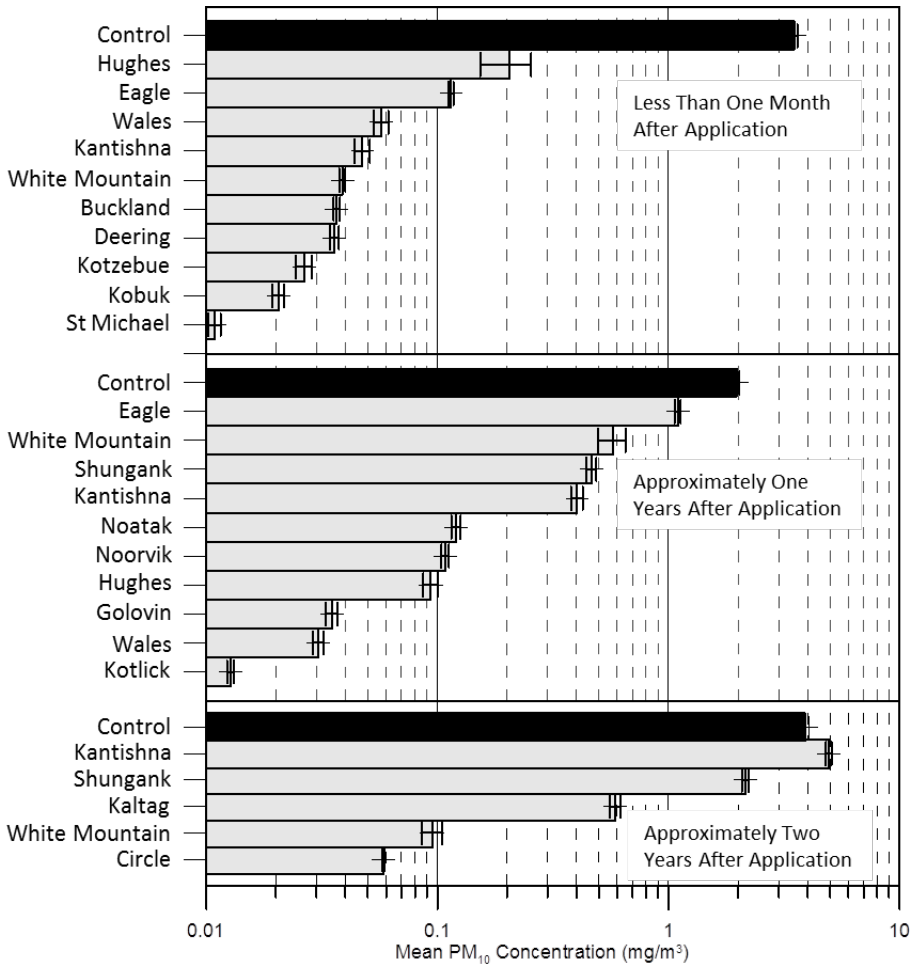

Figure 5.7 Mean PM10 concentration for Alaskan gravel runways treated with synthetic fluid and the combined mean value of the control sections at each runway

Application of Synthetic Fluids

The application of Liquid Chemical Treatments have many parallels to applying liquid asphalt for surface seals. There are three key ingredients to a good application

1. Proper preparation of the surface
2. Appropriate application rate
3. Uniform application.
4. Applying Synthetic Fluids

Proper application rate is critical to the performance of any chemical treatment. Figure 5.8 shows an extreme case on improper application of the chemical. It is clear that the equipment being used was incapable of uniform application of the palliative. The photo on the left of Figure 5.8 shows the same site one year later. Note the wear between the areas where the chemical was placed. It is surprising that the surface has performed as well as it has.

Figure 5.8 improper application (left) and performance (right)

As shown, the equipment must be able to apply the chemical uniformly. A number pieces have been tried, some successful, some not. Examples of each are provided to help the reader avoid prior failures and emulate successes.

The asphalt distributer truck with the correct nozzles or snivies would be the ideal application equipment. However, there is a reluctance to use distributer trucks because of the potential for contaminating the tank making it unusable for asphalt emulsions. There have been some complaints about the difficulty in cleaning the pumps and spray bars after use.

Many communities have water trucks. As a result, it is tempting to use them for applying chemical treatments. As shown in Figure 5.9, most water trucks are not capable of applying liquids uniformly. Note that the chemical is concentrated in the center of the bar while the outer reaches of the bar have little chemical. In addition, the flow is in discrete paths.

Figure 5.9 Uneven application with a water truck

DOT&PF developed a portable sprayer which can be flown to rural Alaska on a small aircraft. The system consists of a pump, a manifold and a series of sprayers. The system is then connected directly to the totes in which the liquid chemical is delivered. The spray system can then be mounted on a flatbed truck, pickup or mounted on a trailer pulled by an All-Terrain Vehicle (ATV). Figure 5.101 shows the system mounted on a trailer. In this case both the sprayer and the trailer were flown in on a small aircraft. Some communities are considering the use of this system to spray water as a dust management

Figure 5.10 Portable applicator developed by the Alaska DOT&PF

program at critical locations such as around the schools or other high traffic areas. The portability and low cost of the system are very attractive. Further the system is capable of applying liquids far more uniformly than water trucks.

That said, there are problems which need to be resolved. Careful inspection of Figure 5.12 shows that the spray is not entirely uniform. Ideally the spray should have triple overlap at the point it reaches the ground. Alternately, the fans should provide a double overlap. In order to ensure the fans don't interfere with each other, the nozzles should be uniformly angled between 15 and 30 degrees from the axis of the bar. A relatively simple redesign of the spray bar would correct the problems noted in this system. Despite this flaw, the system has been able produce a uniform surface. This is in part due to the need to make multiple passes to get the necessary application rate and to ensure penetration of the liquid into the surface. Note also the quality of the surface in the photo. As stated earlier, the quality of the surface also improves the uniformity of application.

The typical application rate for synthetic fluids is typically between 30 and 40 square feet/ gallon of product. This can vary with the soil and product. In many cases, 2 or more applications at a lower application rate will be required to get full penetration. Resist the temptation to reduce the total application rate because of pooling. The volume of fluid applied will determine the effectiveness and longevity of the palliative. The selection of the volume of fluid applied to the surface should be carefully selected through testing or experience. If properly selected, the dust should be reduced by 90% or more and last about 2 years.

Figure 5.11 Uneven fan distribution

5.3.5 Polymers

Polymers are large molecules which have repeated subunits. These molecules can be engineered to produce many of the products we see every day including neoprene, polyvinyl chloride (PVC), silicone and synthetic rubber.

Polymers used is soil stabilization are typically a blend of polymers which may include vinyl acrylics and polyvinyl acrylics, PVA's. PVA's are stronger, but brittle while acrylics are more flexible. Consequently, producers balance the polymers used in order to obtain the properties required for use in soil stabilization. The exact formulation of the soil stabilization polymers are proprietary and a closely guarded secret of each producer. Consequently, it becomes the responsibility of the user to assure the product meet the need.

Unfortunately, engineering data for polymer soil stabilization products is quite limited. As shown in Figure 5.12, polymer treated surfaces can produce pavement like surfaces. This roadway, located on horseshoe lake road was constructed in Aeolian sand with the addition of 4% polymer and .5% plastic fiber. The photo on the right was taken after three years. During that time no grading had taken place.

Collins (2011) found that adding 2% polymer to the Fairbanks Silt increased the CBR from 7 to 21. He further found that the addition of synthetic fluids had essentially no impact on CBR values. Similarly, he found that adding 1.1% polymer to Horseshoe Lake Sand increased the CBR from 14 to 33. Interestingly, increasing the polymer content to 4% reduced the performance. This is likely due to the high moisture content, since part of the curing process requires the evaporation of water. This points out the need for laboratory testing to ensure the correct dosage rate for polymers to work correctly.

Polymer products come in two forms; emulsion and powdered. Collins found that the gain in strength is equivalent for both forms. The emulsion form is convenient since it can be easily applied by spray. However, if the product may freeze before application, the powdered form is preferred since the emulsified product cannot be frozen. Further, shipping costs will be reduced if shipped as a powder.

Figure 5.12 Horseshoe Lake Road before and after three years of applying polymer

The polymer powder can be applied in two ways. First, it can be mixed with water and applied in the same manner as the emulsified product. Or, it can be applied as a powder to the roadway, mixed with the soil and water added. Discussions with product users shows there is no clear consensus as to which method is preferred. However, applying the product as a powder is a bit more labor intensive.

Research and experience is showing that the addition of cement significantly increases the strength of the soil as shown in Figure 5.13 and Figure 5.14. Using cement and polymer together has several advantages over traditional soil-cement which include

- Reduced cement required
- Reduced potential for shrinkage cracking
- Increased flexibility of the soil.

Figure 5.15 and Figure 5.16 show the impact of adding cement to the modulus of the material. Note that there is a maximum modulus for Horseshoe Lake sand.
It is important to understand that the data provided here are not universal. It is therefore suggested that a mix design be performed using the soil, cement and polymer combination required. Further, the designer should select the target strength and modulus for the design in order to obtain a cost effective mix.

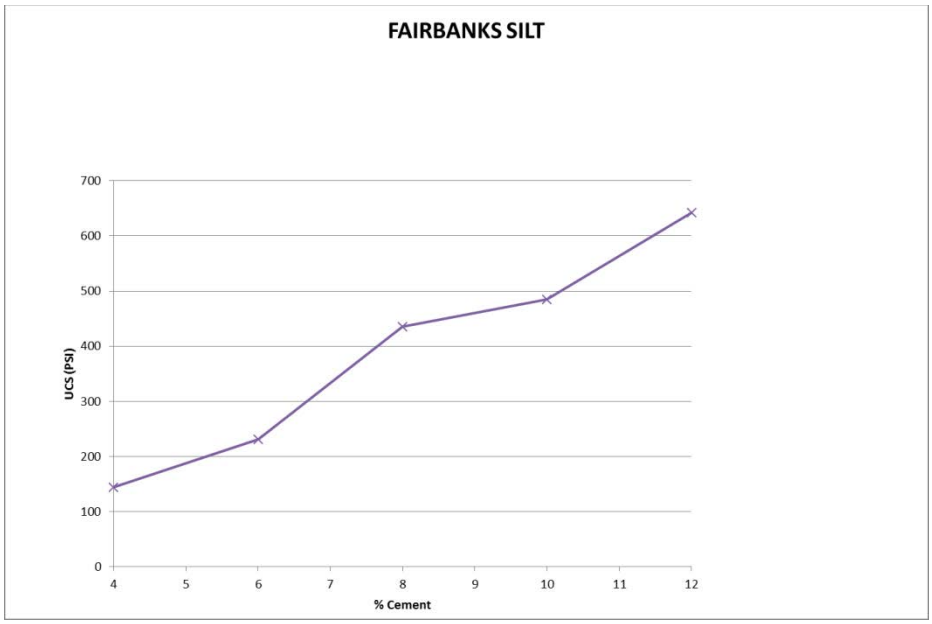

Figure 5.13 Addition of cement to 2% polymer in Fairbanks Silt

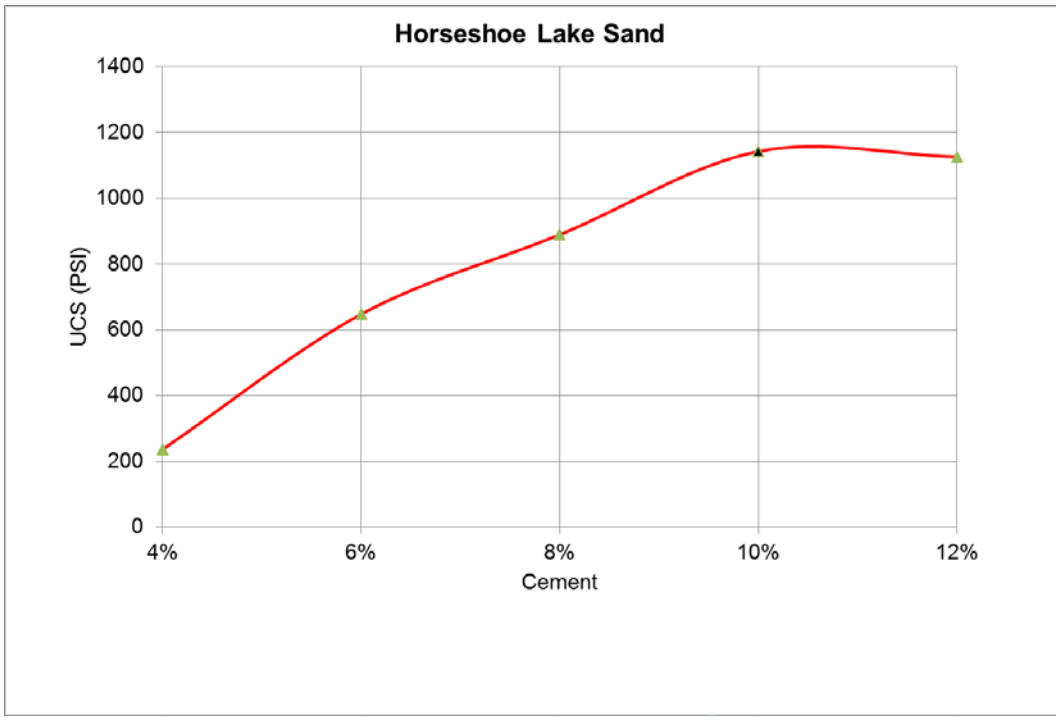

Figure 5.14 Inclusion of cement with 2% polymer in Horseshoe Lake Sand

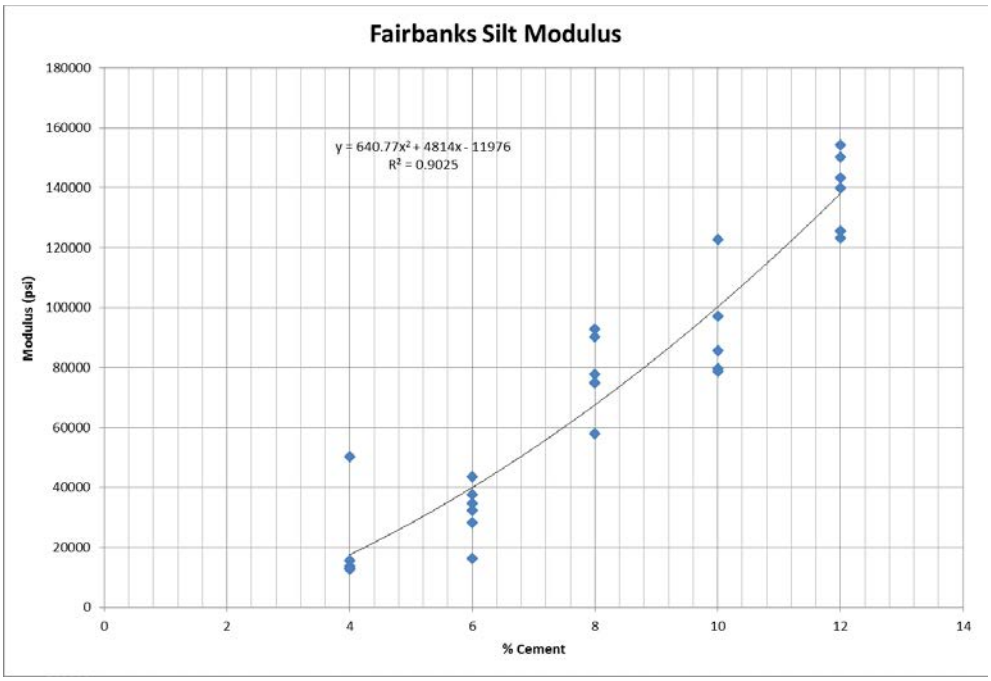

Figure 5.15 Impact of the addition of cement on the soil modulus with 2% polymer

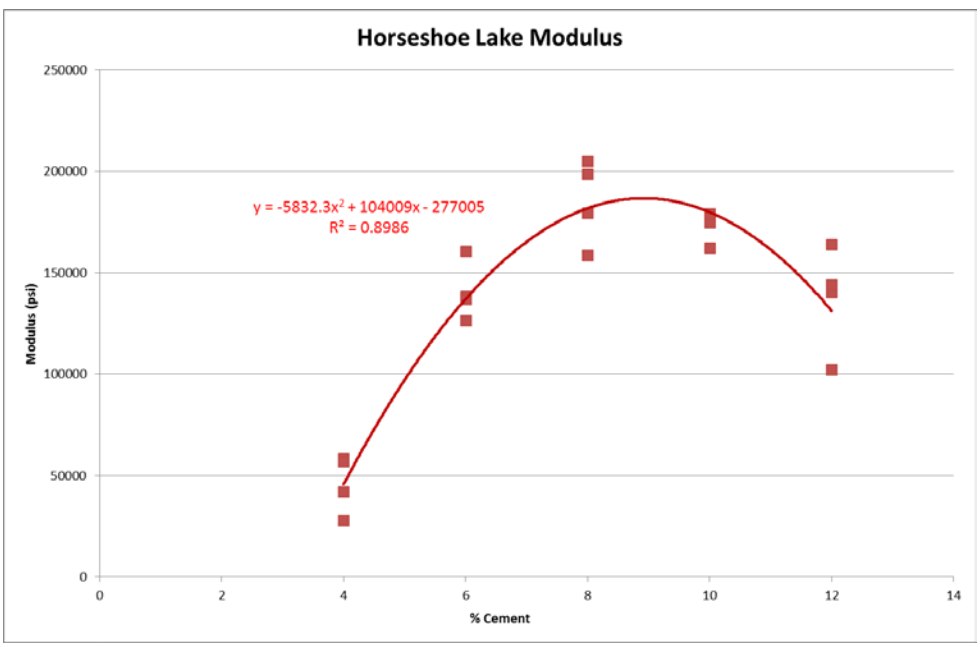

Figure 5.16 Impact of the addition of cement into Horseshoe Lake sand treated with 2% polymer

5.3.6 Applying Polymer Stabilizers

Controlling dust from any unpaved road surface is a matter of stabilizing the soil used for the road's wearing surface. Stabilization requires that the wearing surface should be able to withstand the abrasive effects of the vehicles for which the road was designed to accommodate. Soil stabilization is brought about by good design and construction as well as with proper materials. In many cases the available material for road construction is not desirable as explained in Chapter 4. This is especially true in many areas of Alaska where the soil is often too sandy or too fine. Thus, many of these soils simply do not meet the criteria for good palliative performance. In these cases the use of polymer stabilizers may be considered. Because these materials bind the soil, the application rates should be determined through careful analysis of the soil strength and the traffic.

Polymer stabilizers can be applied in either liquid or solid form. The choice is generally a matter of preference, however, in Alaska, the solid form has a number of advantages. First, shipping is less expensive since the water has been removed. Secondly, the solid form can be over-wintered since freezing will not hurt the product.

If the solid form is used, it can be applied to roadway as a solid and water added to the roadway surface and mixed. Mixing should be in accordance with the manufacturers recommendations. If desired, small amounts of cement can be added to further enhance the strength of the polymer.

If the polymer is mixed with water either on site or from the manufacturer, the liquid may be topically applied or mixed into the soil. If multiple applications are necessary to obtain penetration of the polymer, the complete process must be completed before the polymer sets. Once the polymer sets, the surface will be sealed and will not allow further penetration of the liquid.

Again uniform application is critical. Consequently, the selection of equipment and the use of a well-trained crew is important.

5.4 Selecting the Right Palliative

Selecting the right palliative is critical. Jones and Surdahl (2014) proposed a method which ranks each palliative base on the use. Table 5.2 is an adaptation of that methodology based on the experience gained in Alaska. It should be noted that the plastic index included by Jones and Surdahl is missing from the table because all of the surface materials to date have no plasticity. Consequently, no attempt was made to include the impact of plasticity.

The process is straight forward. Simply select the value under each parameter (average daily traffic, climate, fines content and geometry) and sum them. For example, for water if the average daily traffic is less than 100, the climate is damp, the fines content is 15-25%, with flat terrain and straight roads, the sum would be 21. Note since there are no steep grades or sharp curves, these values for these parameters would be 0. Repeat this process for each palliative and order the values from smallest to largest. The most appropriate palliative would be the one with the least value and the least appropriate palliative would be the one with the largest value. This ranking must be tempered by life cycle costs as discussed in Chapter 6 and constraints. For example, if corrosion is an issue, calcium chloride and lignosulphonate would not be appropriate.

Table 5.2 is intended to be a guide and may require adjustment based on local conditions and additional data. That said, it does provide and excellent starting point.

Table 5.2 Palliative Selection Table for Palliatives Used in Alaska (adapted from Jones and Surdahl, 2004)

Palliative	Average Daily Traffic			Climate			Fines Content				Geometry		Sum
	<100	100 - 250	>250	Wet	Damp	Dry	<8%	8-15%	15 -25%	>25%	Steep Grades	Sharp Curves	
Water	7	50	50	1	7	1	50	1	7	10	7	1	
Water + Surfactant	7	50	50	50	7	1	50	1	7	50	1	1	
Salts (CaCl)	1	1	7	50	1	50	50	1	1	50	1	7	
Organic Non-Petroleum (Lignosulfonate)	1	1	7	50	1	1	50	1	1	10	1	7	
Organic Petroleum (Synthetic Fluids)	1	1	7	7	1	1	7	1	7	50	7	7	
Polymer	1	7	50	7	7	1	7	1	7	10	7	7	

Notes:

a. Salts may not perform well when the relative humidity is less that about 35%.
b. If the palliative is to be stored over the winter unheated, ensure the product can withstand freezing.
c. The table addresses the most common palliatives used in Alaska. If other products are being considered, refer to Jones and Surdahl.

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Chapter 6 Economic Analysis of the Use of Dust Management Introduction

Dust control measures are implemented for two reasons: economic and intrinsic values. The intrinsic values include quality of life. Because of their nature, intrinsic values are difficult to place a value on and will not be considered as part of the economic analysis.

The economic value of dust control measures can be divided into three parts: Agency Costs, Public Costs and Environmental Costs. The agency costs refer to the cost to the road agency for surfacing, grading, chemical or other treatments, and overhead. Public costs include health costs, safety costs such a crashes caused by decreased visibility, delay costs due to the reduced speed. Finally, Environmental Costs include water quality, damage to plants near the roadway and reduced air quality. Environmental costs are difficult to assess. In addition, environmental impacts are often regulated. As a result, the cost of complying with these regulations is generally passed along to the agency.

The most comprehensive performance and cost model for gravel roads is The Highway Design and Maintenance Standards Model (HDM-III and HDM-IV) produced by the World Bank. This model considers gravel loss, rutting, roughness, and vehicle maintenance and fuel costs. However, the model is likely too costly to implement on a local agency level (Watanatada 1987). None the less the model does provide guidance in understanding economic analysis of gravel roads.

Most of this chapter will deal with Agency Costs recognizing that public, political and environmental pressures may have as much or more impact on the decision process than economics. That said, an economic analysis is a valuable tool for decision makers to base their decision. The tools provided here are a guideline rather than a rigid approach because each agency and each project has its unique requirements. Nonetheless, the approach presented here can be modified to meet those needs.

The first step is to evaluate the cost of current practice. These costs may include

- The cost and frequency of replacing surface course material.
- The cost and frequency of grading
- The cost of watering if used
- Management costs
- If costs to the public are included;
    - Delay costs due to slower speeds
    - Cost of crashes
    - Health costs
    - Vehicle damage
    - Cost of crop or meat damage in farming and subsistence areas

6.1 Computing First Costs

The cost of replacing surface course is straight forward. It is simply the sum of the cost of purchasing the material at its source, haul costs, placement costs and the costs associated with planning and management of the surface course replacement activity. In either case, agency records will provide a good source of information.

However, estimating the life of the gravel surfacing is somewhat difficult since there are only a few studies that have developed deterioration equations for aggregate surface courses. In the United States, the focus has been on loss of loftable fines which represent only a portion of the aggregate loss over time. Loss of fines is related to the loss of aggregate since the fines bind the aggregate together. Consequently, when fines are lost, the remaining loose aggregate is either thrown off the surface by traffic or becomes float on the surface.

Surface course replacement frequency will vary with traffic, material characteristics, grading frequency, climate and available funding. Agency records will help establish the life expectancy of the surface course. Be aware that many agencies may delay the replacement of surfacing due to lack of funding which will skew the analysis effort. However, there are aggregate loss equations that may be useful provided they are adjusted for local conditions.

The following equation for gravel loss has been developed for Brazil (Visser 1981).

$$GL = D\left[1.58 + 0.366(G) + 0.083(SV) - 0.210(PI) + 0.0132(NC) + 0.0081(NT) + \frac{420.45}{R}\right]$$

Where GL annual gravel loss in mm
- D number of days between blading in hundreds (days/100)
- NC number daily light vehicles in both directions
- NT average heavy traffic in both directions
- G absolute value of grade in percentage
- SV percent surface material passing the 0.074 mm sieve
- PI plasticity index of surfacing material (%)
- R radius of horizontal curve in meters (note R is infinite for a straight road)

A similar equation was developed for gravel roads in South Africa (Paige-Green 1989).

$$GL = D[ADT\ x\ (0.059 + 0.0027(N) - .006(P26)) - 0.367 - 0.0014(PF) + 0.474(P26)]$$

Where: GL Annual Gravel Loss in mm
- N Weinert N-value (climate region)
- ADT Average Daily Traffic
- PF Plastic Factor
- P26 percentage passing the 26.5 mm sieve (approximately 1 inch)
- D the number of days between blading

The Weinert N-value can be estimate using the following equation:

$$N = \frac{12E_J}{P_a}$$

Where: E_j evaporation during the warmest month
P_a annual precipitation

Finally, the World Bank develop the HDM-III model for gravel loss (Paterson, 1987)

$$MLA = 365\left\{3.46 + 0.246(MMP)(RF) + MAX\left[0\ or\ 0.022 + \frac{0.969(C)}{57300}\right] + 0.00342(P075) - 0.0092(MMP)(PI) - 0.101MMP\right\}$$

Where: MLA annual material loss (mm)
PI Plastic Index
MMP mean monthly precipitation
C average horizontal curvature of the road (deg./km)
P075 percent passing a 0.075mm sieve
RF 10 x average absolute grade

If one of the equations listed above is used, it should be calibrated to local conditions. For example, In Cantwell, Alaska the expected dust season is about 5 months. Consequently, one could expect the aggregate loss predicted would be multiplied by 5/12 to account for the period when the surface is thawed. Other factors such as aggregate source may also require calibration.

The service life can be estimated by looking at agency records. However, recognize that the frequency of surface course replenishment is often a function of funding rather than need.

Once the annual aggregate loss is determined, the service life of the surface course is simply the thickness of the surface course divided by the aggregate loss. The equivalent annual cost of the surface can be computed by the equation

$$EAC = (Cost\ of\ inplace\ surfacing)(\tfrac{A}{P}, rate\ of\ return, surface\ life\ (years))$$

A/P, (capital recovery factor) refers to the column in the tables labeled with the same designation. This equation converts first cost into an equivalent annual cost.

For example if 4 inches of surface course on a 24 ft. wide surface costs $100,000 lasts 4 years we can compute the equivalent annual cost of the placement of the surface using a 4% rate of return to be

$$EAC = \$100{,}000(0.27549) = \$27547$$

The value 0.27549 was found in Appendix A. Note that one cannot simply divide the first cost by the life because of the time value of money.

6.2 Computing Annual Maintenance Costs

Estimating the cost of grading depends on a number of parameters. Perhaps the greatest is that the frequency of grading is often a function of budget rather than need. For example, a roadway segment may need to be graded four times per year to maintain a reasonably smooth surface. Because of budget constraints, it gets graded only once a year. Even if a chemical treatment were to reduce, the needed grading by 50%, the agency would still see no benefit to its budget. There are several ways to handle this. One is to simply consider only the cost to the agency and accept status quo. Another way is to consider the cost of not grading and managing dust to the public and seek additional funding. A third method is to consider assume that grading will be done when needed for the analysis. For purposes of this analysis, we will assume that grading will be done when needed.

A grader can typically cut and layout one mile of roadway in about 2.5 hours. The cost of grading would then be Type equation here.

$$Grading\ cost = hours(wet\ rental\ of\ equipment + loaded\ operator\ costs)$$

These costs are agency dependent. For this example we will assume an equipment rental rate of $80/hour, a operator cost of $45/hour or $125/hour. This results in a cost of $312 per mile for each grading.

Summing the EAC of the placement cost and grading costs the agency cost would be $27,850.

6.3 Estimating the cost of dust control

In many cases the cost of applying a palliative is straight forward since it represents the sum of the cost of the product, the cost of placement and the costs associated with the planning and management of the placement. However, when the application of a palliative is combined with the placement or replacement of the surface course, care must be taken to separate the incremental costs of applying the palliative. For example, mobilization of equipment, material placement, grading and compaction costs are a function of surfacing and would occur whether or not a palliative is used. However, the cost of applying a palliative would include the cost of the product, the time equipment is active applying product and the labor required to apply the palliative. Obviously the cost of applying palliative is lower at the time of resurfacing.

DOT&PF estimates the cost of applying $CaCl_2$ to the roadway to be $7,000/mile. $CaCl_2$ must be placed annually, consequently, the EAC of applying $CaCl_2$ is $7,000/mile. However, if the department used a synthetic fluid at a placement cost of $50,000 which has a life of 2 years, The EAC of that placement at a 4% rate of return would be $22,260. This is considerably more than $CaCl_2$ so $CaCl_2$ would be chosen all other things being equal. However, as discussed in Chapter 5, $CaCl_2$ is not always acceptable and would be rejected on that basis.

6.4 Estimating the benefits of dust control

Estimating the benefits to the agency of dust control is somewhat difficult because the benefits have rarely been quantified. Unfortunately, the performance of most palliatives has been anecdotal. Consequently, assigning a dollar value to the benefits becomes subjective. That said, this does not preclude estimating the benefits based on experience of agency staff or others. For example, DOT&PF feels that roadway grading costs are reduced by 50 % and the life expectancy of the surface course is doubled through the use of $CaCl_2$. While there have been no studies to verify, these estimates, this does

provide a reasonable starting point for analysis. Like most agencies, the data before the use of $CaCl_2$ does not exist making it difficult to develop those relationships without a study that would impact the traveling public.

Using the performance information provided, we can make a reasonable estimate of the benefits of using $CaCl_2$ by DOT&PF.

If we assume the life of the surface course is double the example used in section 7.1 we can determine the equivalent annual cost of the surface with a life of 8 years would be

$$EAC = \$100{,}000(.14853) = \$14{,}853$$

The benefit of using $CaCl_2$ would be the difference between $27,547 and $14,852 or $12,695.

The benefits due to less frequent grading is simply the annual savings due to the reduced grading frequency. If we assume twice monthly grading without $CaCl_2$, the frequency would drop to monthly using $CaCl_2$. Since the roadway is gradable only 5 months of the year, we can reduce the grading by 5. This results in an annual savings of $1,560/mile (5 x 132).

The total savings by using $CaCl_2$ would then be the sum of the savings or $16,413. Since this is greater than the $7,000 required to treat the roadway, it is worthwhile. If we assume the application of synthetic fluids would provide the same benefits, we would not likely use the synthetic fluid since the benefits are less than the $22,260 cost of application.

This does not mean that synthetic fluids will not be used. For example, DOT&PF uses synthetic fluids on runways where corrosion precludes the use of $CaCl_2$. Further, the average cost of surface course on rural Alaskan runways exceeds $150/ton, the cost of synthetic fluids becomes attractive. In many cases, regrading of the runway is reduced to once every two years which also provides significant savings. The proof is left to the reader.

6.5 User costs

Many agencies do not consider user costs for three reasons

1. User costs do not impact the budget of the agency
2. User costs generally overwhelm the economic analysis
3. User costs are difficult to quantify

Evaluation of user costs are instructive whether or not they are used in the decision process. Dust management impacts not only air quality, but also roadway roughness, structural strength of the roadway, and safety. All of these impact the road user. Road user costs include

- Vehicle maintenance costs
- Fuel costs
- Delay costs due to reduced speed
- Costs due resulting from crashes

Most of the definitive research on user costs related to gravel roads is done outside the U.S. The most comprehensive user cost model can be found in the World Bank HDM models (Watanatada 1987). A brief summary of the literature is provided here.

- If more required, the reader should obtain the documents provided in the chapter reference section.
- It is estimated that fuel costs for light trucks increases by 15% due to roughness (Chatti 2010).
- Fuel consumption for heavy trucks rises between 3% and 27% (F. Tan 2012).
- The World Bank estimates that 10% of crashes on gravel roads are due to reduced visibility caused by dust (Greening 2011).
- Mercier concluded that roughness on gravel roads had little impact on gravel roads until they became very rough (S. Mercier 2004).

There isn't a single set of equations that can be used to estimate any of these parameters. The available equations may not be directly applicable to local conditions. Consequently, the information provided here should be used as approximations until better relationships can be developed.

6.6 Environmental costs

Like user costs, environmental costs are often difficult to quantify. The U.S. has focused primarily on health issues as discussed in Chapter 1. Consequently, most of the knowledge of environmental impacts beyond health has been developed by the World Bank, South Africa, Brazil and other countries in Africa.

Traffic generated dust has been shown to have a significant impact on agriculture. Most of the information available appears to be anecdotal. The following bullets provide a brief summary of the available literature.

- Researchers have found that the courser fraction of dust has greater impact than PM10 and PM2.5 (Greening 2011). Interestingly, the subsistence farmer may be impacted the most.
- Studies in South Africa indicate dust was coating fruit 300 meters from the roadway. Similarly, studies in New Zealand show crops were subjected to traffic-generated dust at a distance of up to 250 meters (McCrae 1984).
- In the US reports indicate that dust increases the mite population on watermelon plants indicating that dust inhibits the effectiveness of insecticides (Greening 2011).
- Greening also lists impacts of dust on plants to include
    - reduced photosynthesis
    - Hindered pollination
    - Reduce effectiveness of sprays (herbicides and pesticides)
    - Reduced yield of plant production.

Impacts on animal health is speculative. Consequently, it is, at present, impossible to quantify the impact of dust on animals.

Dust may degrade water quality near gravel roads. However, there appears to be very few studies relating to water quality and dust from gravel roads. Studies in the US have reported development of algae in some lakes due to at least in part to dust (Greening 2011). Greening also reports that fugitive dust from roadways contaminates water supplies near the roadway. However, at this point there is insufficient information to evaluate the cost of dust on water quality.

As can be seen, assessment of environmental cost is quite difficult. However, in many cases health and environmental concerns may outweigh decisions based on agency costs.

Summary

Standard engineering economics can be used to evaluate whether the application of dust control measures is attractive. Agency costs are attainable, but may require some investigative work to obtain the data.

Agencies, often do not consider user costs since they do not directly impact the agency budget. However, it is clear that user costs could easily outweigh agency costs. Unfortunately, there are no universally accepted methods to calculate user costs nor is there clear guidance on assigning costs to delay. There have been models developed by the World Bank which are attractive, but may well be beyond the capability of most local agencies. Consequently, any agency wishing to evaluate user costs would be wise to employ persons with demonstrated skills in engineering economic analysis.

Environmental costs of fugitive dust are extremely difficult to obtain since there are few studies which quantify the environmental impacts. Most of the research in the US focus on health impacts of dust. While there are a few studies which address the impact of roadway dust in Africa, they tend to be anecdotal. That said, health and environmental concerns will often drive decisions.

6.7 References

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Chapter 7 Quick Reference

7.1 Chapter 1 Introduction

- Fugitive dust from roadways pose three threats: safety, health and loss of roadway surface aggregate.
- Dust management provides a strategy to reduce dust and improve the quality of life.

7.2 Chapter 2 How Dust Forms

- Dust from unpaved roads and runways form from
  - Shear forces between the surface and the tire
  - From the vortices caused by air movement around the vehicle
  - Saltation bombardment of the surface by loosened particles
- Dust is moved and mixed in the air by
  - Convective and mechanical lift
  - Advective transport
  - Turbulent diffusion
- Particle settling time dependent on the particle, uplift, and wind.

7.3 Chapter 3 Measuring Dust

- The primary reasons for measuring dust are
  - Conformance to air quality laws and regulations
  - Determining the effectiveness of dust management strategies
  - Estimating the life of a wearing course
- Monitoring techniques include
  - Visual monitoring which is a subjective method using a visual scale
  - Dustfall monitoring which collects dust on a surface or container over a specified period of time
  - Filter sampling which collects dust on a filter over a specified period of time
  - Semi-continuous samplers which use sensors to measure the density of dust in real time
- Road dust measurement
  - Typically use either a continuous sampler or filter measurement, although visual measurement are sometimes used.
  - Dust usually measured directly behind the vehicle or tire

7.4 Chapter 4 Preparing the Road for Palliative and Stabilizers

- Good gravel roads begin with
  - The right materials
  - The right profile
  - Good drainage
- A good surface course
  - Has between 8 and 15% fines
  - Has a gradation that provides stability under loading and resistance to tire abrasion

- The crown should be between 3 and 5%; typically 3 to 4% in northern climates
- Drainage is critical including ditches, berms, approaches, etc.

7.5 Dust Management

- Dust management includes
  - Managing speed
  - Use of palliatives
  - Good maintenance techniques
- Managing speed
  - As speed increases so does dust produced.
  - Occurrence of Potholes and washboarding increase with speed
- Palliatives
  - Water is a good palliative but the effective life of water can be measured in minutes to hours.
  - Salts and brines are the most commonly used and lowest cost palliative other than water.
    - Apply at 1 to 1.5 % by weight. Subsequent applications may be less to account for in-situ salt.
    - May be applied in either solid or liquid form
    - Don't use were corrosion cannot be tolerated
    - If $CaCl_2$ or $MgCl_2$ comes in contact with food, the food will taste bitter.
- Non-Petroleum palliatives
  - Most common is Lignosulphonates
    - Typically applied as liquid.
    - Apply at 0.1 to 0.3 gallons per square foot at a treatment depth of 2 inches
  - Soybean oil soap stock
    - Used in Midwest U.S. with success
    - Works best with fines between 5 and 20%
    - Minnesota suggests using in roads with an ADT of less than 100 vehicles per day
    - Does not hold up well under large shear forces such as those that might be produced on curves, areas where vehicles accelerate or decelerate, and by vehicles with aggressive tires such as All-Terrain Vehicles (ATV's)
  - Vegetable oil
    - Life expectancy low; around a month
    - Rapidly oxidizes
    - Does not withstand high shear forces
  - Synthetic fluids
    - Promote soil particle binding
    - Generally proprietary
    - Optimum fines content between 9 and 12%
    - Life expectancy between 1 and 3 years
    - Can be allowed to freeze without damage
    - Remain liquid throughout their life

        - Typical application rates: 30 to 40 square feet per gallon
    - Polymers
        - Used when surface course does not have stability to carry traffic
        - Life: 3 to 5 years. May require light surface application to extend life.
        - Can be applied in either solid or liquid form
        - Provides a watertight seal
        - Since it resides in the soil as a solid, grading destroys the soil bonds.
    - Application of palliatives
        - Carefully prepare the surface prior to application
        - Pick the right product
        - Use good application equipment that applies the product uniformly
        - Apply only in good weather
    - Table 5.2 provides a palliative selection table which can be used to identify palliatives which are most likely to work for many applications in Alaska

7.6 Chapter 6 Economic Analysis of the Use of Dust Management

- Economic analysis is the comparison of the cost of dust management to the benefits derives
- Costs may include
    - First cost of application including materials, labor, equipment, traffic control and management
    - Costs of maintenance over time
    - Costs to the public due to delays or vehicle damage
    - Costs due to environmental impacts
- Benefits include
    - Increased life of surface course
    - Reduced maintenance costs
    - Reduced user costs
    - Reduced environmental impacts
- User and environmental costs are often difficult to estimate and are ignored

Appendix A: Testing the Performance of a Dust Palliative on a Treated Unpaved Road with the UAF-DustM

This procedure is applicable for testing using the University of Alaska Fairbanks (UAF) DustM mobile monitor or a similar type of mobile monitor. The UAF-DustM is installed on the back of an all-terrain vehicle (ATV) and uses a nephelometer style instrument (DustTrak™ aerosol monitor) to measure the amount of dust (PM10) produced by the moving ATV. As the ATV passes over the treated surface a vacuum pump in the aerosol monitor pulls a continuous air sample through an intake installed near one of the rear tires of the vehicle (opposite side from the engine exhaust pipe). At one-second intervals the aerosol monitor quantifies the amount of particulates equal to or small than 10µm in the air space near the rear of the vehicle and reports the values in concentration units (mass/volume). This procedure is applicable to similar mobile monitor designs with alteration of several of the steps detailed below.

1. Preparing for the measurement
   a) The length of treated road to be tested should be at least 1500 feet long (Refer to Figure A-1). Included in this length are two acceleration and deceleration zones as shown in Figure A-1. The minimum length of these acceleration and deceleration zones is 100 ft. It is best if the acceleration and deceleration zones are located on the treated road surface.

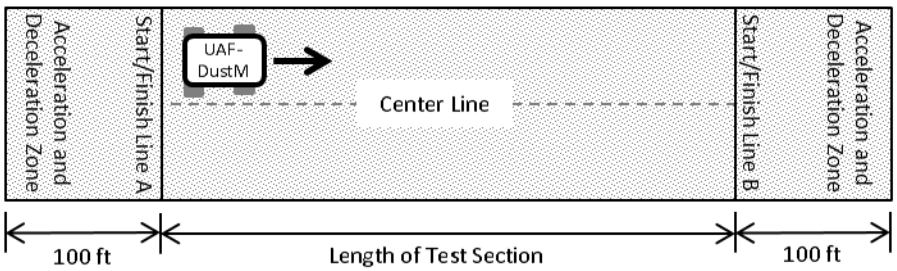

Figure A-1 Dust Palliative Performance testing on an unpaved road

   b) Mount the UAF-DustM on the back of an ATV. The ATV must have a functional speedometer. Position the intake near the rear tire opposite of the engine exhaust pipe. The intake must be 14 inches back from the rear tire and 14 inches up from the ground surface.
   c) Record in the field book the location of the test, the date and time, the general condition of the surface to be tested, the general weather condition at the time of the test, and if there are any signs of recent rain (e.g. damp ground, water puddles in the area). Draw a rough schematic of the test section showing of the start/finish lines. It is also helpful to obtain the latitudes and longitudes of the start/finish lines, the start and end points of curves in the road, and intersections of connecting roads and driveways.

2. Testing – Run 1

a) Position the ATV in the Acceleration and Deceleration Zone behind *Start/Finish Line A* in a location so the operator can accelerate to 20 mph before crossing the start/finish line. Test runs in this direction are called "*A-Runs*".
b) Make sure that the DustTrak™ is recording the correct time and date.
c) Program the DustTrak™ to record a reading on one-second intervals.
d) Turn on the DustTrak™ in a non-recording mode and allow the instrument to run until the instrument is detecting a steady background concentration.
e) Start the DustTrak™ and quickly start a stopwatch.
f) Gradually accelerate the ATV to 20 mph prior to crossing *Start/Finish Line A*.
g) At the point the ATV crosses *Start/Finish Line A* press the lap function on the stopwatch to record the time between the start of the DustTrak™ and crossing *Start/Finish Line A*. This elapsed time is t_1
h) Proceed to *Start/Finish Line B* in straight line at a steady 20 mph. During this phase of the test it is important to drive as steady as possible avoiding any rapid steering adjustments or changes in speed.
i) When the ATV reaches *Start/Finish Line B* press the lap timer function on the stopwatch to record the time between the two start/finish lines. This elapsed time is t_2.
j) Decelerate in the Acceleration/Deceleration Zone.
k) Stop the DustTrak™ and the stopwatch and the. This is elapsed time t_3.
l) Record the lap times t_1, t_2, and t_3 in the field book.

3. Testing – Run 2
   a) Position the ATV in the lane of the road opposite from the previous run behind *Start/Finish Line B* such that it is facing *Start/Finish Line A* and there is enough room to accelerate to 20 mph before crossing *Start/Finish Line B*. Runs in this direction are called "*B Runs*".
   b) Clean the intake with a soft brush.
   c) Turn on the DustTrak™ in a non-recording mode (if available) and allow the instrument to run until the instrument is detecting a steady background concentration.
   d) Start the DustTrak™ and quickly start a stopwatch.
   e) Gradually accelerate the ATV to 20 mph prior to crossing *Start/Finish Line B*.
   f) At the point the ATV crosses *Start/Finish Line B* press the lap function on the stopwatch to record the time between the start of the DustTrak™ and crossing *Start/Finish Line B*. This elapsed time is t_1
   g) Proceed to *Start/Finish Line A* in straight line at a steady 20 mph. During this phase of the test it is important to drive as steady as possible avoiding any rapid steering adjustments or changes in speed.
   h) When the ATV reaches *Start/Finish Line A* press the lap timer function on the stopwatch to record the time between the two start/finish lines. This elapsed time is t_2.
   i) Decelerate in the Acceleration/Deceleration Zone.
   j) Stop the stopwatch and the DustTrak™. This is elapsed time t_3.
   k) Record the lap times t_1, t_2, and t_3 in the field book.

4. Testing – Run 3
   a) Position the ATV behind *Start/Finish Line A* such that it is facing *Start/Finish Line B* and there is enough room to accelerate to 20 mph before crossing *Start/Finish Line B*.
   b) Clean the intake with a soft brush.
   c) Turn on the DustTrak™ in a non-recording mode (if available) and allow the instrument to run until a steady background concentration is reached.
   d) Repeat steps 2-d through 2-k.

5. Testing – Run 4, 5, and 6
   a) For Run 4 repeat steps 3-a through 3-k.
   b) For Run 5 repeat steps 4-a through 4-d.
   c) For Run 6 repeat steps 3-a through 3-k.

6. Data Analysis
   a) Import the data for the six runs into a spreadsheet program.
   b) Exclude the acceleration and deceleration portions of each run by removing the datum points for the time period zero to t_1 and from t_2 to t_3.
   c) If the length of the treated road tested is greater than 2600 ft (excluding the acceleration and deceleration zones), divide the tested road into sections according to the following table.

Table A-1 – Number of Sections

Road Length	Sections (N)	Road Length	Sections
Between 1300 and 2599	1	Between 13000 and 14299	10
Between 2600 and 3899	2	Between 14300 and 15599	11
Between 3900 and 5199	3	Between 15600 and 16899	12
Between 5200 and 6499	4	Between 16900 and 18199	13
Between 6500 and 7799	5	Between 18200 and 19499	14
Between 7800 and 9099	6	Between 19500 and 20799	15
Between 9100 and 10399	7	Between 20800 and 22099	16
Between 10400 and 11699	8	Between 22100 and 23399	17
Between 11700 and 12999	9	Between 23400 and 24699	18
Number of section (N) determined from: *N = int(L/1300)*, where L equals the treated road length, and *int* is the integer of the ratio.			

   d) Divide the treated road length (L) by the number of sections to obtain the length of each section (l).

$$l = L/N$$

   e) Determine the number of datum points per section (n) using the equation below. Since a fraction of a datum point is not possible, round the resulting value to the nearest whole number. Due to rounding the last section will either have a few more or a few less data points than the N-1 other sections. This is acceptable and will not result in any appreciable influence on the results.

$$n = l/29.3$$

f) Determine the mean ($\bar{x}_N$) and standard deviation (s_N) for each multiple of *n* data points. For example if the treated section is 6395 ft long (L = 6395 ft), there are 4 sections (N = 4) and each section is approximately 1599 ft long (l = 1599 ft). The first three sections will contain 55 datum points each (the actual value of n equals 54.57, hence the value for n is rounded up to the nearest whole number, 55). Section four will have 53 datum points. The mean ($\bar{x}_N$) and standard deviation (s_N) is then calculated for each section. These calculations are required for both lanes of the road.

7. Statistical Analysis for Determining if the Tested Sections Pass or Fail a Compliance Specification
   a) Refer to a dust palliative specification for the target compliance concentration (C in units of mg/m^3).
   b) Sections with $\bar{x}_N$ less than or equal to the value for C passes the specification.
   c) For sections with $\bar{x}_N$ greater than the value for C calculate the value of Z using the equation below. If Z is less than or equal to 1.64, the section passes. If Z is greater than 1.64 the section fails.

$$Z = \frac{\bar{x}_N - C}{s/\sqrt{n}}$$

Testing the Performance of a Dust Palliative on a Treated Gravel Runway

This procedure is applicable for testing using the University of Alaska Fairbanks (UAF) DustM mobile monitor or a similar type of mobile monitor. The UAF DustM is installed on the back of an all-terrain vehicle (ATV) and uses a nephelometer style measurement instrument (DustTrak™ aerosol monitor) to measure the amount of dust (PM10) produced by the moving ATV. As the ATV passes over the treated surface a vacuum pump in the aerosol monitor pulls a continuous air sample through an intake installed near one of the rear tires of the vehicle (opposite side from the engine exhaust pipe). At one-second intervals the aerosol monitor quantifies the amount of particulates equal to or small than 10µm in the air space near the rear of the vehicle and reports the values in concentration units (mass/volume). This procedure is applicable to similar mobile monitor designs with alteration of several of the steps detailed below.

1. Preparing for the measurement
   a) Position the ATV on one end of the runway in the runway overrun zone at the edge of the treated surface. Each runway-overrun zone will serve as the acceleration and deceleration zone for the test. Starting at one side of the runway each run will be positioned progressively towards the other side of the treated zone (refer to Figure A-2).

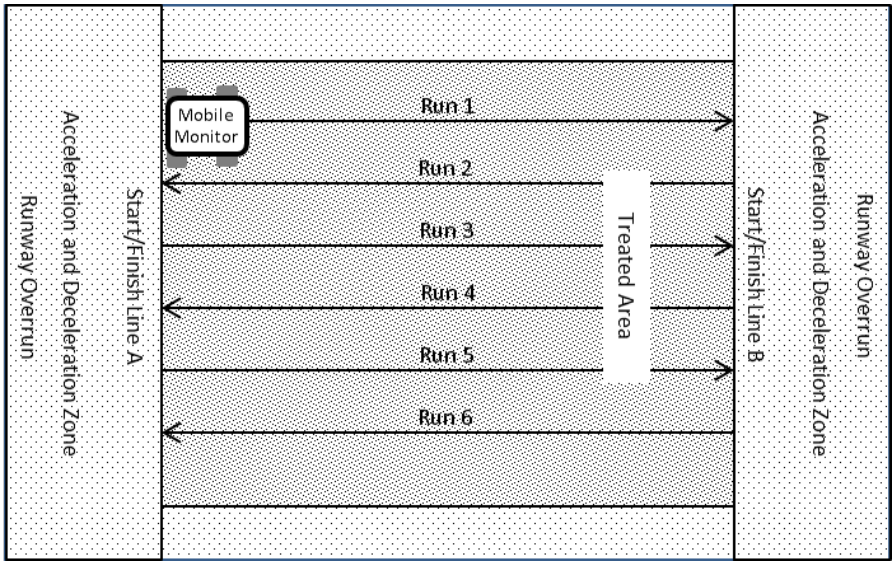

Figure A-2 Dust palliative performance testing on a gravel runway.

   b) Mount the UAF-DustM on the back of an ATV. The ATV must have a functional speedometer. Position the intake near the rear tire opposite of the engine exhaust pipe. The intake must be 14 inches back from the rear tire and 14 inches up from the ground surface.
   c) Record in the field book the location of the test, the date and time, the general condition of the surface to be tested, the general weather condition at the time of the test, and if there are any signs of recent rain (e.g. damp ground, water puddles in the area). Draw a rough schematic of the runway and the start/finish lines.

2. Testing – Run 1
   a) The position of the ATV in the Acceleration and Deceleration Zone behind *Start/Finish Line A* should be in a location so the operator can accelerate to 20 mph before crossing the start/finish line. Test runs in this direction are called *"A-Runs"*.
   b) Determine the perpendicular distance from one of the edges of the treated section to the position of the ATV or use a GPS to mark the location of the starting point for the run.
   c) Make sure that the DustTrak™ is recording the correct time and date.
   d) Program the DustTrak™ to record a reading on one-second intervals.
   e) Turn on the DustTrak™ in a non-recording mode and allow the instrument to run until the instrument is detecting a steady background concentration.
   f) Start the DustTrak™ and quickly start a stopwatch.
   g) Gradually accelerate the ATV to 20 mph prior to crossing *Start/Finish Line A*.
   h) At the point the ATV crosses *Start/Finish Line A* press the lap function on the stopwatch to record the time between the start of the DustTrak™ and crossing *Start/Finish Line A*. This elapsed time is t_1
   i) Proceed to *Start/Finish Line B* in straight line at a steady 20 mph. During this phase of the test it is important to drive as steady as possible avoiding any rapid steering adjustments or changes in speed.
   j) When the ATV reaches *Start/Finish Line B* press the lap timer function on the stopwatch to record the time between the two start/finish lines. This elapsed time is t_2.
   k) Decelerate in the Acceleration/Deceleration Zone.
   l) Stop the stopwatch and the DustTrak™. This is elapsed time t_3.
   m) Record the lap times t_1, t_2, and t_3 in the field book.
   n) Determine the perpendicular distance from one of the edges of the treated section to the stopping position of the ATV or use a GPS to mark the location of the ending point for the run.

3. Testing – Run 2
   a) Position the ATV in the next position over from the location of the previous run (refer to Figure 1) behind *Start/Finish Line B* such that it is facing *Start/Finish Line A*. The position of the ATV should be such that there is enough room to accelerate to 20 mph before crossing *Start/Finish Line B*. Runs in this direction are called "*B Runs*".
   b) Determine the perpendicular distance from one of the edges of the treated section to the position of the ATV or use a GPS to mark the location of the starting point for the run.
   c) Clean the intake with a soft brush.
   d) Turn on the DustTrak™ in a non-recording mode (if available) and allow the instrument to run until the instrument is detecting a steady background concentration.
   e) Start the DustTrak™ and quickly start a stopwatch.
   f) Gradually accelerate the ATV to 20 mph prior to crossing *Start/Finish Line B*.
   g) At the point the ATV crosses *Start/Finish Line B* press the lap function on the stopwatch to record the time between the start of the DustTrak™ and crossing *Start/Finish Line B*. This elapsed time is t_1

h) Proceed to *Start/Finish Line A* in straight line at a steady 20 mph. During this phase of the test it is important to drive as steady as possible avoiding any rapid steering adjustments or changes in speed.
i) When the ATV reaches *Start/Finish Line A* press the lap timer function on the stopwatch to record the time between the two start/finish lines. This elapsed time is t_2.
j) Decelerate in the Acceleration/Deceleration Zone.
k) Stop the stopwatch and the DustTrak™. This is elapsed time t_3.
l) Record the lap times t_1, t_2, and t_3 in the field book.
m) Determine the perpendicular distance from one of the edges of the treated section to the stopping position of the ATV or use a GPS to mark the location of the ending point for the run.

4. Testing – Run 3
   a) Position the ATV in the next position over from the location of the previous run behind *Start/Finish Line A* such that it is facing *Start/Finish Line B* and there is enough room to accelerate to 20 mph before crossing *Start/Finish Line B*.
   b) Determine the perpendicular distance from one of the edges of the treated section to the position of the ATV or use a GPS to mark the location of the starting point for the run.
   c) Clean the intake with a soft brush.
   d) Clean the intake with a soft brush.
   e) Turn on the DustTrak™ in a non-recording mode (if available) and allow the instrument to run until a steady background concentration is reached.
   f) Repeat steps 2-d through 2-n.

5. Testing – Run 4, 5, and 6
   a) For Run 4 repeat steps 3-a through 3-m.
   b) For Run 5 repeat steps 4-a through 4-f.
   c) For Run 6 repeat steps 3-a through 3-m.

6. Data Analysis
   a) Import the data for the six runs into a spreadsheet program.
   b) Exclude the acceleration and deceleration portions of each run by removing the datum points for the time periods zero to t_1 and from t_2 to t_3.
   c) If the length of the runway tested is greater than 2600 ft (excluding the acceleration and deceleration zones), divide each run into sections according to the following table.

Table 1 – Number of Sections For Each Test Run on a Gravel Runway

Runway Length	Sections (N)
Less than 2599	1
Between 2600 and 3899	2
Between 3900 and 5199	3
Between 5200 and 6499	4
Number of section (N) determined from: $N = int(L/1300)$, where L equals the treated road length, and *int* is the integer of the ratio.	

   d) Divide the treated runway length (L) by the number of sections to obtain the length of each section (l).

$$l = L/N$$

e) Determine the number of datum points per section (n) using the equation below. Since a fraction of a datum point is not possible, round the resulting value to the nearest whole number. Due to rounding the last section will either have a few more or a few less data points than the N-1 other sections. This is acceptable and will not result in any appreciable influence on the results.

$$n = l/29.3$$

f) Determine the mean ($\bar{x}_N$) and standard deviation (s_N) for each multiple of *n* data points. For example if the runway length is 4500 ft long (L = 4500 ft), there are 3 sections (N = 3) and each section is 1500 ft long (l = 1500 ft). Each section will contain 51 datum points each (the actual value of n equals 51.19, hence the value for n is rounded up to the nearest whole number, 51). Section three will have 52 datum points. The mean ($\bar{x}_N$) and standard deviation (s_N) is then calculated for each section for each run.

7. Statistical Analysis for Determining if the Tested Sections Pass or Fail a Compliance Specification
   a) Refer to a dust palliative specification for the target compliance concentration (C in units of mg/m^3).
   b) Runs with $\bar{x}_S$ less than or equal to the value for C passes the specification..
   c) For sections with $\bar{x}_S$ greater than the value for C calculate the value of Z using the equation below. If Z is less than or equal to 1.64, the section passes. If Z is greater than 1.64 the section fails.

$$Z = \frac{\bar{x}_S - C}{s/\sqrt{n}}$$

ITEM P-167 DUST PALLIATIVE

DESCRIPTION

167-1.1 Furnish all materials, equipment, and labor necessary to apply the specified dust control agent in accordance with the manufacturer's recommendations at the locations shown on the plans.

PRODUCTS

167-2.1 Dust palliative shall be approved by the Engineer. The product furnished under this specification shall meet all requirements cited herein. Documentation substantiating conformance with all of the requirements in this specification must be provided 5 days prior to the pre-construction conference. Failure to meet any requirement herein or failure to provide the substantiating documentation may result in the rejection or disqualification of the use of the proposed product. A minimum of 2 contacts with organizations that have successfully used the product on gravel runways in arctic conditions must be supplied with a bid.

MATERIAL

167-2.2 The product must be confirmed by an independent certified laboratory to have passed all the requirements of Boeing's D6-17487, Rev. R "Testing of Airplane Maintenance Materials" within the last 1 year. Specifically:

a. Sandwich Corrosion Test, ASTM F1110-90
b. Acrylic Crazing Test, ASTM F484-83 using Type C acrylic
c. Paint Softening Test, ASTM F502
d. Hydrogen Embrittlement Test, ASTM F519-93 using cadmium plated type 1a, 1c or 2a.

167-2.3 The product must be capable of being topically applied over a prepared gravel surface without the use of water for diluting.

167-2.4 The manufacturer/supplier must certify that the following properties/characteristics are present:

a) Synthetic Fluid
b) Immiscible in water
c) Performance not affected by freeze thaw cycles: at temperatures down to -70 degrees F
d) Non-Flammable & Non-Volatile
e) Final product shall not stick to and be tracked by tire traffic after 1 week of dwell time. (Non-Tacky)
f) Product is environmentally safe for aquatic species and requires no specialized response or cleanup if a spill occurs.

g) ASTM Viscosity Index of ≥ 90
h) Pour Point ≤ -15^{0}C ASTN D1298
i) Brookfield Dynamic Viscosity ≤ 500cP @ 0^{0}C

167-2.5 Contractor shall submit proof to the Engineer in the form of test reports and certificates to verify that the dust palliative product is in environmental compliance. The Contractor is responsible for any costs associated with the testing of soil and dust control product prior to its application. Products shall not contain or emit chlorinated fluorocarbons (CFC's or Freon's) and shall not contain or emit volatile organic compounds (VOC's) that exceed Federal or State air quality limitations. Products and their degradation products shall not be composed of elements, compounds, mixtures or produce runoffs with the characteristics identified under Code of Federal Regulations Title [40 § 261.3], emit or off gas during placement, use or degradation of hazardous air pollutant listed under Section 112 of the Federal Clean Air Act [42 U.S.C. § 7412], be a hazardous chemical substance or mixture pursuant to Section 7 of the Federal Toxic Substances Control Act [15 U.S.C.§ 2606], be prohibited for use by the Alaska Department of Environmental Conservation, the Environmental Protection Agency, or any applicable law, rule or regulation.

Product runoff and their degradation product runoffs shall not contain concentrations that exceed the parameters designated in Section 2.18 'Table 5' of the National Pollution Discharge Elimination System (NPDES) Multi-Sector General Permit for Industrial Activities. Adequate proof can be shown by providing one of the following:

(A) Documentation from a reputable laboratory to have an aquatic toxicity test results for lethal concentration at 50% (LC50) showing that the product has a rating of "slightly toxic" (LC50>10mg/L) or better as described in EPA guidelines. Acute and chronic toxicity testing must be performed per U.S. EPA guidelines for all of the following species: (Rainbow trout / *Oncorhynchus mykiss*, Fathead minnow / *Pimephales Promelas* & Mysid Shrimp / *Americamysis bahia*)

(B) Provide complete and accurate listing of all individual chemical constituents (including proprietary chemical information) and percentage of each in a given volume of pure chemical product.

Products or their components and degradation products shall be tested and certified by the manufacturer not to be substances or composed of substances known to be, or reasonably anticipated to be carcinogenic or toxic by the U.S. Department of Health and Human Services. Products must have hazardous Materials Identification System (HMIS) ratings equal to or less than the following for each category: H=1; F=1; R=1; PPE=X.

CONSTRUCTION METHODS

167-3.1 GENERAL. Surface dust control shall be applied to the areas as shown on the plans before September 1 of the contract completion year. An evenly applied spray application method shall be used. The product shall not be applied in the rain or when the in-situe moisture levels are within 3% or more of the optimum moisture content (OMC) of the surface being treated.

167-3.2 RATE OF APPLICATION. The minimum rate of application shall be 1 gallon per 30 square feet. Minimum application rates listed in this section are not assured by the Department to meet the performance testing requirements. The manufacturer should be consulted for an appropriate application rate to ensure performance requirements can be met.

167-3.3 WEATHER LIMITATIONS. Do not apply dust control agent when rain is imminent or in any condition where agent may wash away prior to its full penetration.

Do not apply dust control agent to a saturated surface, or when the air temperature is below 50°F unless approved by the Engineer.

Do not apply dust control agent during windy conditions which prevent a uniform distribution of the product.

167-3.4 EQUIPMENT. Provide equipment for applying the dust control agent that is approved by the product supplier and conforms to the following requirements:

Use a distributor that is designed, equipped, maintained and operated to apply the agent uniformily through a calibrated spray bar system in accordance with the application rates. Nozzle height for application shall not exceed 20 inches.

167-3.5 APPLICATION SET-UP. The product supplier shall supply detailed guidelines or procedure for applying their product to the runway surface. Their guidelines or procedure will be considered by the Engineer for use if there is a conflict with this section. Ensure that the application system provides a uniform delivery of the dust control product at the required application rates, with a 50% overlap of the spray pattern. Application setup shall be approved by the Engineer.

167-3.6 Quality Testing. After the product is applied and the product manufacturers recommended dwell period has passed, but not within two weeks of application the performance will be tested. The construction Engineer will coordinate the testing procedure which will be subsidiary to pay item P-167a. The testing procedure will include using the UAF DustM apparatus as developed by the University of Alaska Fairbanks using their dust reduction test methods. The test methods will be performed on surfaces

treated by the dust control product. The test results of the DustM testing procedure will result in a pay factor from the table below being assigned by the testing agent.

Concentration (mg/m^3)	Pay Factor
<0.060	1.10
0.060 – 0.070	1.00
0.071 – 0.080	0.90
0.081 – 0.09	0.80
0.09 or above	Re-Apply

If testing indicates the concentration levels are greater than 0.09 mg/m^3, the Contractor is required to Re-Apply additional product, at no additional cost to the Department.

METHOD OF MEASUREMENT

167-4.1 The quantity of the Surface Dust Control as applied to all areas of crushed aggregate surface course or as ordered by the Engineer will be measured as a single unit of work.

BASIS OF PAYMENT

167-5.1 The accepted quantity of Dust Palliative shall be paid for at the contract lump sum price, which shall include full compensation for furnishing all materials, labor, equipment, tools, and incidentals necessary to acceptably complete the work. The cost of the required quality testing procedure is subsidiary to pay item P-167a and will be paid for by the Contractor. If all work is accepted as complete in accordance with the specifications and dust control treatment areas are tested by the DustM testing procedures then a pay adjustment per item P-167b will be made using the formula below.

P-167b = ((pay factor) x (P-167a)) – (P-167a)

Payment will be made under:

Item P-167a Dust Palliative – Per Lump Sum
Item P-167b Dust Palliative Price Adjustment – Contingent Sum