Roads and Sidewalks

Dust Control for Unpaved Roads

This document is the tenth in a series of best practices for the design, maintenance and management of municipal roads and sidewalks. For titles of other best practices in this and other series, please refer to <*www.infraguide.ca*>.

National Guide to Sustainable Municipal Infrastructure®

NRC · CNRC FCM Federation of Canadian Municipalities Fédération canadienne des municipalités Canada

Dust Control for Unpaved Roads

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INTRODUCTION

InfraGuide® — Innovations and Best Practices

Why Canada Needs InfraGuide

Canadian municipalities spend $12 to $15 billion annually on infrastructure but it never seems to be enough. Existing infrastructure is ageing while demand grows for more and better roads, and improved water and sewer systems responding both to higher standards of safety, health and environmental protection as well as population growth. The solution is to change the way we plan, design and manage infrastructure. Only by doing so can municipalities meet new demands within a fiscally responsible and environmentally sustainable framework, while preserving our quality of life.

This is what the National Guide to Sustainable Municipal Infrastructure (InfraGuide) seeks to accomplish.

In 2001, the federal government, through its Infrastructure Canada Program (IC) and the National Research Council (NRC), joined forces with the Federation of Canadian Municipalities (FCM) to create the National Guide to Sustainable Municipal Infrastructure (InfraGuide). InfraGuide is both a new, national network of people and a growing collection of published best practice documents for use by decision makers and technical personnel in the public and private sectors. Based on Canadian experience and research, the reports set out the best practices to support sustainable municipal infrastructure decisions and actions in six key areas: decision making and investment planning, potable water, storm and wastewater, municipal roads and sidewalks, environmental protocols, and transit. The best practices are available online and in hard copy.

A Knowledge Network of Excellence

InfraGuide´s creation is made possible through $12.5 million from Infrastructure Canada, in-kind contributions from various facets of the industry, technical resources, the collaborative effort of municipal practitioners, researchers and other experts, and a host of volunteers throughout the country. By gathering and synthesizing the best Canadian experience and knowledge, InfraGuide helps municipalities get the maximum return on every dollar they spend on infrastructure—while being mindful of the social and environmental implications of their decisions.

Volunteer technical committees and working groups—with the assistance of consultants and other stakeholders—are responsible for the research and publication of the best practices. This is a system of shared knowledge, shared responsibility and shared benefits. We urge you to become a part of the InfraGuide Network of Excellence. Whether you are a municipal plant operator, a planner or a municipal councillor, your input is critical to the quality of our work.

Please join us.

Contact InfraGuide toll-free at **1-866-330-3350** or visit our Web site at ***www.infraguide.ca*** for more information. We look forward to working with you.

The InfraGuide Best Practices Focus

Municipal Roads and Sidewalks

Sound decision making and preventive maintenance are essential to managing municipal pavement infrastructure cost effectively. Just as $1 of timely rehabilitation will save $5 of reconstruction, $1 of timely prevention will delay $5 of rehabilitation. Municipal roads and sidewalks best practices address two priorities: front-end planning and decision making to identify and manage pavement infrastructures as a component of the infrastructure system; and a preventive approach to slow the deterioration of existing roadways. The best practices set out will ensure for instance that the right treatment is selected for the right road at the right time and will provide guidance in implementing individual treatments successfully, e.g. crack-sealing, rut mitigation. Example topics include timely preventative maintenance of municipal roads; construction and rehabilitation of utility boxes; and progressive improvement of asphalt and concrete pavement repair practices.

Decision Making and Investment Planning

Elected officials and senior municipal administrators need a framework for articulating the value of infrastructure planning and maintenance, while balancing social, environmental and economic factors. Decision making and investment planning best practices transform complex and technical material into non-technical principles and guidelines for decision making, and facilitate the realization of adequate funding over the life cycle of the infrastructure. Examples include protocols for determining costs and benefits associated with desired levels of service; and strategic benchmarks, indicators or reference points for investment policy and planning decisions.

Environmental Protocols

Environmental protocols focus on the interaction of natural systems and their effects on human quality of life in relation to municipal infrastructure delivery. Environmental elements and systems include land (including flora), water, air (including noise and light) and soil. Example practices include how to factor in environmental considerations in establishing the desired level of municipal infrastructure service; and definition of local environmental conditions, challenges and opportunities with respect to municipal infrastructure.

Potable Water

Potable water best practices address various approaches to enhance a municipality's or water utility's ability to manage drinking water delivery in a way that ensures public health and safety at best value and on a sustainable basis. Issues such as water accountability, water use and loss, deterioration and inspection of distribution systems, renewal planning and technologies for rehabilitation of potable water systems and water quality in the distribution systems are examined.

Transit

Urbanization places pressure on an eroding, ageing infrastructure, and raises concerns about declining air and water quality. Transit systems contribute to reducing traffic gridlock and improving road safety. Transit best practices address the need to improve supply, influence demand and make operational improvements with the least environmental impact, while meeting social and business needs.

Storm and Wastewater

Ageing buried infrastructure, diminishing financial resources, stricter legislation for effluents, increasing public awareness of environmental impacts due to wastewater and contaminated stormwater are challenges that municipalities have to deal with. Storm and wastewater best practices deal with buried linear infrastructure as well as end of pipe treatment and management issues. Examples include ways to control and reduce inflow and infiltration; how to secure relevant and consistent data sets; how to inspect and assess condition and performance of collections systems; treatment plant optimization; and management of biosolids.

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EXECUTIVE SUMMARY

This best practice provides a readily available source of information for minimizing or controlling dust from unpaved roads in rural and urban areas by using a dust suppressant. It is also intended to assist the reader to determine when additions or modifications to dust control programs may be effective and cost efficient.

Dust emissions from unpaved roads can impair the vision of drivers and therefore, be a safety hazard. From a road agency perspective, the loss of fine particles from unpaved roads can also reduce surface longevity and increase maintenance costs. Inhaling fine dust particles can be a health hazard to road users and residents. Dust can also be a nuisance and have environmental and economical implications like reduced crop yields and cleaning expenses to those residents who live along unpaved roads.

There are two primary methods of dust control for unpaved roads. One is engineered and the other chemical suppressant application. The engineered method ensures the road is well designed and constructed with suitable materials to withstand the expected vehicle loads. If appropriate engineering measures fail to provide adequate dust control, then chemical dust suppressants should be considered.

Although dust suppressants are used extensively across Canada, there is a need to quantify the impact their use has on a cost-effective maintenance program. Selecting a dust suppressant and calculating its cost effectiveness are relatively complicated procedures due to the many variables involved. This best practice distills the available information and provides a way of identifying the most suitable suppressants for certain situations, in terms of performance versus cost, in the simplest possible manner.

This publication describes the expected performance, limitations, and potential environmental impacts of various suppressants. It also examines the most commonly used types of dust suppressants and the conditions under which they are most effective or ineffective. Their effectiveness can depend on factors, such as daily traffic loads, regional climate, type of aggregate used, and fines content.

To aid in determining the most effective suppressant to use, methods for evaluating dust emission reduction and a possible future method to take quantifiable measurements of dust emissions are also described.

1. General

1.1 Introduction

Dust emissions from unpaved roads can impair the vision of drivers and therefore, be a safety hazard. From a road agency perspective, the loss of fine particles from unpaved roads can also reduce surface longevity and increase maintenance costs. Inhaling fine dust particles can be a health hazard to road users and residents. Dust can also be a nuisance and have environmental and economical implications like reduced crop yields and cleaning expenses to those residents who live along unpaved roads.

Although dust suppressants are used extensively across Canada, there is a need to quantify the impact their use has on a cost-effective maintenance program. The selection of a dust suppressant and calculating its cost effectiveness is a complicated procedure due to the many variables involved. This best practice distills the available information and provides a way of determining the most suitable suppressants, in terms of performance versus cost, in the simplest possible manner. The information was obtained from a review of relevant literature and a survey of municipalities considered representative of all Canadian geographic locations. Other stakeholders, authorities, and experts in the field of dust suppression were also interviewed or involved with the review of this document.

1.2 Purpose and Scope

This best practice provides a readily available source of information for controlling dust from unpaved roads in rural and urban areas by using a dust suppressant. It is also intended to assist the reader in determining when additions or modifications to dust control programs may be effective and cost efficient.

The cost-benefit analysis compares the costs of implementing a dust control program to the additional costs that would occur without a dust control program due to increased costs for replacement materials and maintenance. The financial benefits of dust control with respect to preventing hazards to safety, health, property, and the environment are difficult to measure and are not included in the analysis.

1.3 How to Use This Document

The contents of this document should be applied with a clear understanding and appreciation that the practices and methodologies described are intended to provide guidance; they should not be construed as definitive best practices.

Minimizing road dust emissions will improve driving safety, reduce nuisance and inhalation health hazards to nearby residents and workers, and reduce negative environmental impacts. These benefits are difficult to estimate financially and have not been quantified in the available literature. These benefits are, however, frequently the reasons used to justify the cost of a dust control program.

After a discussion of the rationale for a dust control program, the work description section provides a step-by-step process to decide what dust control method is most appropriate: alterations to road construction materials, vehicle speed restrictions or methods, or the use of suppressants or sealants.

Having determined that the use of a dust suppressant is appropriate, a dust suppressant selection process is provided to identify the types of suppressant most likely to be cost effective. Factors to be considered in determining the most cost beneficial suppressant are discussed.

The applications section describes how to implement the recommended methods or tools described in this best practice. The limitations section describes potential limitations. The final section summarizes methods used to evaluate dust emission reduction and describes a possible future method to take quantifiable measurements of dust emissions.

Minimizing road dust emissions will improve driving safety, reduce nuisance and inhalation health hazards to nearby residents and workers, and reduce negative environmental impacts.

1.4 Glossary

Brine — Solution of salt in water. The strength of a brine is measured as a percentage of solids by mass. For example, a 40 percent magnesium chloride brine has 40 percent solids by mass.

Deliquescent salts — Calcium chloride and magnesium chloride salts are deliquescent (readily drawing moisture from the atmosphere and melting). Calcium chloride is available as a flake or brine. Magnesium chloride is available as a brine. Brine solids contents are variable.

Dilution ratio — The ratio of the volume of concentrate to volume of water. Example: 1:4 means one volume of concentrate is mixed with four volumes of water.

Dust suppressant — Any treatment material for reducing fugitive dust emissions. Water, surfactants, and foams are effective only for very short periods.

Grading coefficient (Gc) — A measure of the potential for particle interlock defined by the product of the gravel component of the material (the percentage retained between the 26.5 mm and 2 mm sieves) and the percentage passing the 4.75 mm sieve.

Hygroscopic — Readily drawing moisture from the atmosphere, but not melting. Dry sodium chloride is hygroscopic.

Ravelling — A process where the surface material of a road is broken down by traffic to form loose material (e.g., gravel). The process is likely to occur where there is a deficiency of fine material, low cohesion between particles, poor particle size distribution, and inadequate compaction.

Shrinkage product (Sp) — A measure of the plasticity of the road surface materials defined by the product of the bar linear shrinkage test and the percentage of fines in the road surfacing material.

Topical — Applied directly to the road surface (e.g., by using a hose, or spray bar).

vpd — Vehicles per day. The average number of vehicles passing along a road in one day.

2. Rationale

2.1 Background

Fourteen road maintenance authorities responded to a survey conducted for this study. Of the kilometres of unpaved roads within their jurisdiction, half were either continuously or spot treated with dust suppressants (See Figure 2–1 below).

In the surface layer of an unpaved road, there should be a proportion of very fine particles that are less than 75 mm in diameter. These are usually referred to as fines. These fines fill the spaces between larger-sized aggregate and provide cohesion. Road conditions can deteriorate rapidly once these fines are lost in the form of dust. Coarse aggregate becomes easily dislodged and moved, by traffic, onto the shoulder or into the ditch. This dislodged aggregate, when airborne, can also cause damage to vehicles.

There are two primary methods of dust control for unpaved roads: *engineered* and *chemical suppressant* application.

- Engineered method ensures the road is well designed to withstand expected vehicle loads, that it is well drained, and the size distribution of materials in the surfacing layer (coarse aggregate and fine aggregate,) is selected to achieve maximum durability. Of course, many existing gravel roads have been built to less than ideal specifications. As a result, dust suppressants are used even on poorly designed and constructed roads due to cost considerations. However, ensuring that roads are well constructed is the primary choice for dust control, because dust suppressants will have little effect on poorly constructed roads.
- In situations where all reasonable engineered methods have failed to reduce dust emissions to acceptable levels, the fallback option is to use chemical dust suppressants. Chemical suppressants bind the particles in a road surface together to prevent their escape into the atmosphere due to wind or by air turbulence from passing vehicles. Routine maintenance activities should not contribute to the loss of fine material.

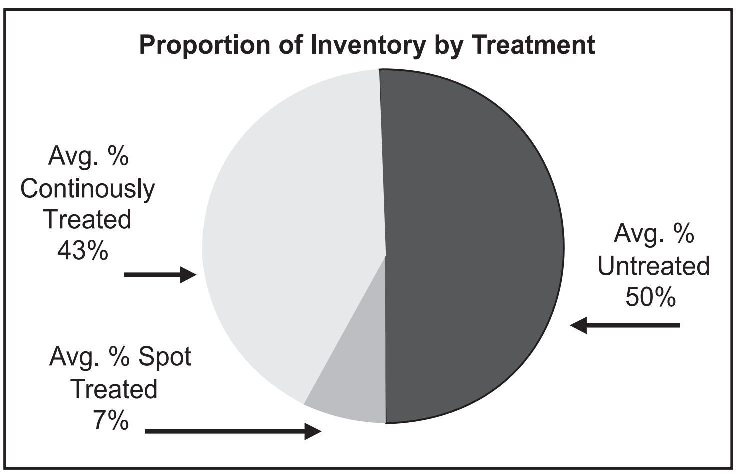
Material that is lost from a road surface will need to be replaced. This regravelling can take a significant proportion of the available road maintenance budget. Roads with adequate dust suppression do not deteriorate as fast as roads without dust suppression and have lower maintenance costs. Cost benefits result from the application of dust suppressants that reduce maintenance expenses.

Roads with adequate dust suppression do not deteriorate as fast as roads without dust suppression and have lower maintenance costs.

This guide examines the most commonly used types of dust suppressants and the conditions under which they are most effective or ineffective. Their effectiveness can depend on factors such as daily traffic loads, regional climate, type of aggregate used, and fines content. In short, there can be a wide range in the performance of each suppressant depending on many variables. There has been insufficient research to date to quantify the effects of each variable, but experience has provided sufficient qualitative information to make informed decisions when selecting a suppressant.

Figure 2–1 Unpaved Roads—Proportion of Kilometres Treated and Untreated

Figure 2–1: Unpaved Roads—Proportion of Kilometres Treated and Untreated



The fine particles (less than 75 μm diameter), retained by a suppressant within the road surface, increase the stability of the road surface and, therefore, reduce the rate of road deterioration.

If the generation of dust were only a nuisance, it might be economically feasible to plant vegetative filters adjacent to residential properties to catch the dust emissions. However, the progressive loss of fines from a road surface will accelerate deterioration, necessitating increased maintenance work, and frequent replacement of the road surface material. Material replacement and maintenance costs can be determined with reasonable accuracy, and the financial benefits of retaining fines in the road surface can be estimated.

Although the main reason for applying a dust suppressant is to minimize dust emissions, other spin-off benefits can occur that will offset the cost of purchase and application. The fine particles (less than 75 μm diameter), retained by a suppressant within the road surface, increase the stability of the road surface and, therefore, reduce the rate of road deterioration. This reduced deterioration, in turn, reduces the rate of loss of surface aggregate and the need for frequent shaping or grading.

2.2 Benefits

Dust from unpaved roads can cause many impacts that may be reduced with dust control.

- Health: Fine dust particles may become a health hazard when inhaled, aggravating existing respiratory health problems. The Canadian government ambient air quality objectives for particulate matter are in transition. National ambient air quality objectives still exist for total suspended particulate (TSP). They do not, however, reflect the current scientific understanding of the health effects of particulates or the priority Canadian governments are placing on this public health issue. Already, some provinces, such as British Columbia and Newfoundland and Labrador, have put provincial standards for PM 10 and PM 2.5 in place that reflect more realistic levels based on health effects.
- Safety: Untreated roads may contribute to increased frequency and severity of motor collisions. Accident potential is increased due to loss of visibility and less traction due to loose gravel. About 2.3 times more people are killed per vehicle mile of travel on unpaved than paved roads in the United States (Hoover, 1971).
- Vegetation: Large amounts of dust may stress vegetation due to increased heat absorption and decreased transpiration.
- Aquatic resources: High levels of dust falling into aquatic systems may adversely affect aquatic plants and fish that are not adapted to high levels of sedimentation.
- Aesthetics cleaning, property values: Dust produces an immediate visual impact that may affect residents who live near dust-prone roads. For people living along these roads, dust can mean grimy houses, gray laundry, and dust covering everything.
- Vehicle damage: Loss of fines will lead to loose aggregate on the road surface that can damage windshields. Dust will also clog filters and increase abrasion of moving parts.
- Road maintenance costs: Treated roads can lower road maintenance costs by reducing gravel loss and blading time. A private sector suppressant supplier estimated in 1993 that the average untreated road loses 300 tons of aggregate per mile per year.
- Legal requirements: In the Canadian National Ambient Air Quality Guideline, measured as total suspended particulate (TSP), the standards for dust over 24 hours are 120 micrograms per cubic metre ($\mu g/m^3$), and averaged over a year are 60 $\mu g/m^3$. Some provinces have more stringent criteria.

Twelve communities in Canada (four provinces, four cities, three municipalities and one contractor) responded to a survey, which asked: *"What is the greatest problem in your jurisdiction as a result of dust from unsealed roads (numbered in order of priority, i.e., 1 = greatest problem)?"*

The average values of all the responses are listed below. Evidently, the safety of road users is the greatest priority, followed by loss of surface gravel and nuisance concerns. The least priority was given to health and environmental concerns.

Safety of Roadway Users	1.6
Nuisance Concerns	2.6
Loss of Surfacing Gravel	2.6
Health Concerns	3.9
Environmental Concerns	3.9

The survey also asked what percentage of public complaints comes from road users compared to those residing adjacent to roads. The results indicated that 77 percent of complaints come from adjacent landowners/ farmers and adjacent developments; 15 percent are users' visibility and safety concerns and 8 percent are the result of vehicle damage.

2.3 Risks

- Although there are many advantages to using dust suppressants, there are also a few disadvantages, which are primarily environmental in nature.
- Chloride salts will dissolve in water and can be washed out of the road during rainfall. This brine can migrate and negatively affect nearby vegetation and aquatic species. It can also cause vehicle corrosion and their use near airports should be discouraged.
- Hygroscopic salts used in a gravel/hard-surface transition may track onto the hard surface and make the pavement very slippery under certain conditions.
- Toxic hydrocarbons from petroleum-based suppressants can leach out and negatively impact water bodies.
- Lignosulphonates applied to roads will dissolve in water. When this happens, the lignosulphonates, because they are organic, will gradually decompose, consuming the oxygen dissolved in the water. This may have negative impacts on aquatic life.
- Roads treated with dust suppressants can be slippery when wet, particularly during a heavy downpour. No evidence of research data supporting this statement could be found during a literature search. Some dust suppressants form a hard surface layer crust and can be difficult to rework during maintenance.

3. Work Description

Introduction

Figure 3–1 illustrates the decision-making process required to select the most cost-beneficial dust control method or suppressant. It should be referred to frequently when reading this section because it defines the key steps to be made in choosing a dust suppressant. Before progressing through the flow chart, awareness of the environment in which the suppressant will be applied should be known. In particular, if there are environmentally sensitive zones adjacent to the roadway, local authorities should be consulted to get the most up-to-date information that may circumvent the process described below. More information regarding regulations and guidelines, can be found in Section 3.4.1.

- Step 1: Determine if the dust problem is caused by poor design and construction of the road. If deficiencies in surfacing material gradation, plasticity, bearing capacity, drainage, or cross section are identified, they should be corrected before considering suppressant application. Dust suppressants will not work well on poorly designed and constructed roads. If dust levels are unacceptable along some short sections of a road, such as in residential areas, consider introducing vehicle speed restrictions.
- Step 2: Conduct a cost-benefit analysis to decide if the road should be sealed or paved. The average vehicles per day (vpd) traffic volume and how much of this traffic consists of commercial vehicles is often a good indicator to decide if this analysis should be done. If the vpd is less than 50, it is unlikely that further road improvements will be cost beneficial. If the vpd is greater than 500, conduct a cost-benefit analysis of sealing or paving the road.
- Step 3: Examine Table 3–1 to determine suppressants that may be suitable. Note the flow diagram in Figure 3–1, which gives a very broad indication of what major suppressants may be suitable. A more accurate evaluation may be obtained by consulting Table 3–1.
- Step 4: Check provincial restrictions on the use of certain suppressants to ensure the suppressants selected are permitted.
- Step 5: Ensure the appropriate suppressant has been selected. Figure 4–1 shows regions with a high annual rainfall (greater than 800 mm/year) where water-soluble suppressants, such as chloride salts and lignosulphonates, may not be as effective. If your region falls within this area and water-soluble suppressants have been selected, check with other road maintenance authorities nearby to evaluate their experience with such suppressants.
- Step 6: Calculate the yearly cost of using a dust suppressant. This depends on the cost of the suppressant, the application rate, and the number of applications required per year. This can be calculated relatively easily using information from the supplier on dust suppressant costs and from information in this best practice on application rates and frequency of application. There may also be an up-front capital cost if any additional application equipment or storage facilities are required.
- Step 7: Determine whether to conduct a trial application of the dust suppressant. If the suppressant is new on the market or there is little experience with its use in the subject region, a trial may be wise. Some suppressants, such as electro-chemical stabilizers, are notorious for being highly variable depending on road, traffic, and other conditions, and should be tried before any wide-scale application.

3. Work Description

Figure 3–1
Dust suppressant
selection process

Figure 3–1: Dust suppressant selection process

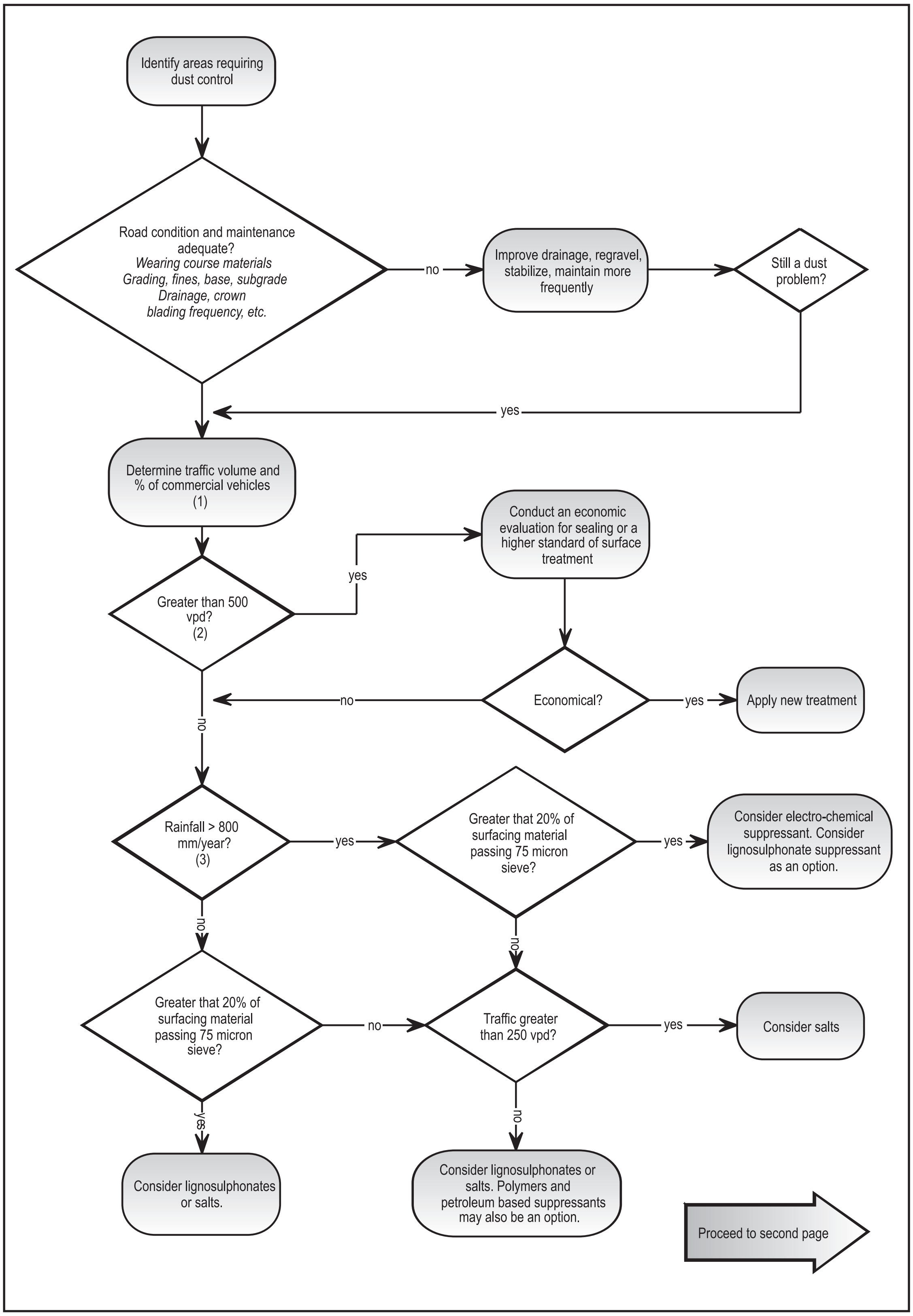
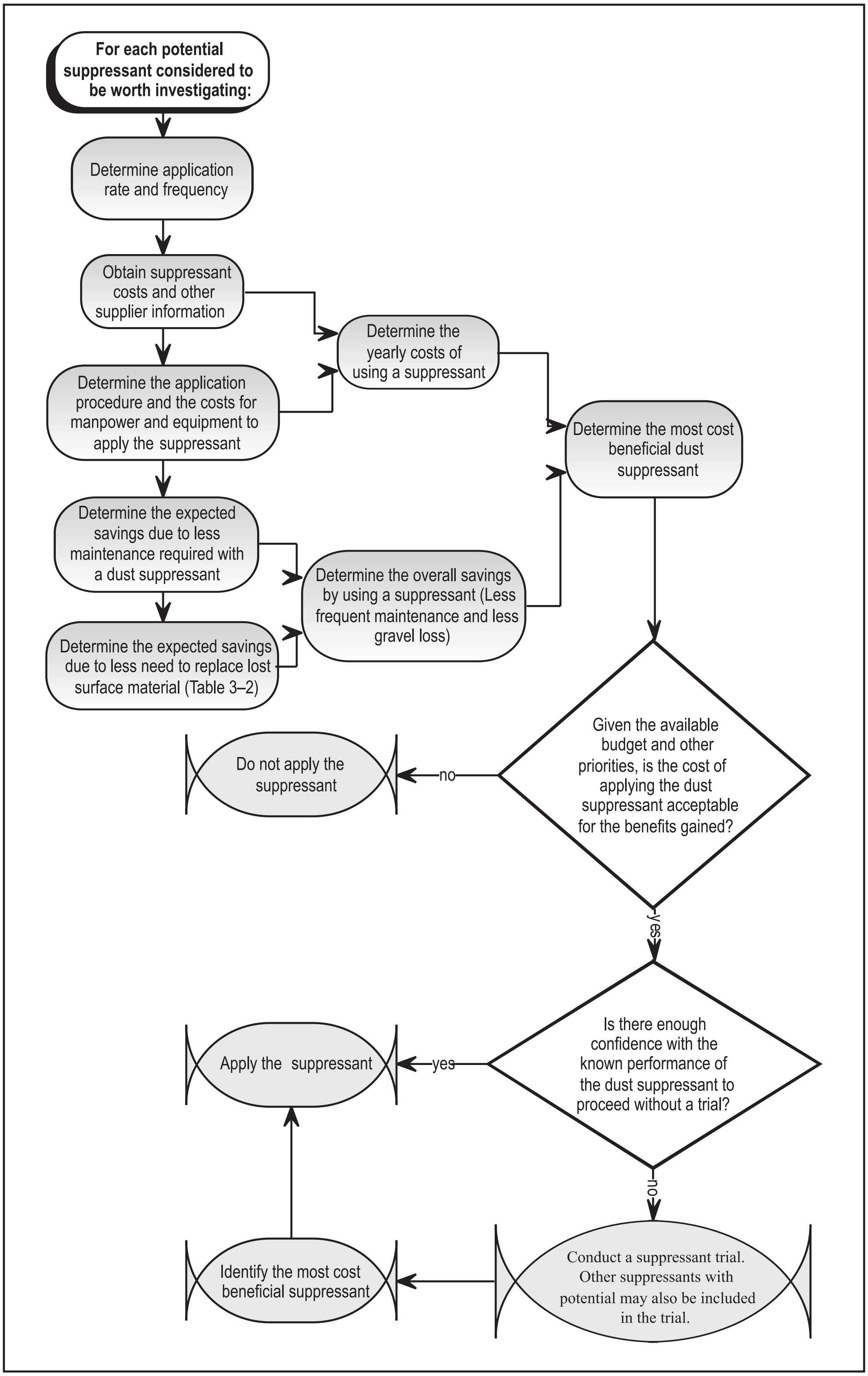


Figure 3–1
Dust suppressant
selection process (cont'd)

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



3.1 Road Construction

The use of a dust suppressant to control the amount of dust emitted from unpaved roadways should only be considered after it has been determined that the road has adequate bearing capacity, drainage, and that the surface-wearing materials have proper gradation and compacted.

3.1.1 Bearing Capacity

A road is structurally stable if it resists lateral displacement and permanent deformation when subjected to loading. The natural forces of cohesion and internal friction provide this resistance. Cohesion occurs as a result of the attraction of fine silt and clay particles when compacted, while internal friction is the resistance to movement due to a lattice of surface contact between the coarser particles. Too high a fine content may keep the coarser particles apart, not allowing proper interlocking, and may lower the aggregate internal friction.

The sub-grade, base, and surface layer must be designed to have sufficient strength to achieve mechanical stability, or else the

Table 3–1: Product Selection Chart

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

Legend: ✓✓ = Good ✓ = Fair × = Poor

NOTES:

(1) May require higher or more frequent application rates, especially with high truck volumes.

(2) Greater than 20 days with less than 40 percent relative humidity.

(3) May become slippery in wet weather.

(4) SS-1 or CSS-1 with only clean, open-graded aggregate.

(5) Road mix for best results.

Source: Bolander and Yamada (1999).

surface-wearing layer of the road can be expected to deform. This will rapidly lead to breakup and disintegration of the road, and dust suppressants will have little or no effect on the rate of such deterioration. Unpaved roads with low bearing capacity are cheaper to build, but if their bearing capacity is insufficient for the applied traffic load, maintenance costs will be very high.

3.1.2 Road Drainage

If the road profile or drainage system is not properly designed, water can float the finer particles out of the surface-wearing layer and wash them away. This can happen if the road does not have a suitably shaped crown to divert water to the side of the road. Vehicle tires splashing through pools of rain on the road surface produce a pumping action that flushes out the fines. Ruts develop in which water can collect and, in turn, the ruts can develop into potholes. Fines can also be washed out if flooding occurs due to poor road drainage design or failure to clear blocked ditches and culverts. Dissolvable dust suppressants will also be leached out of roads that are subject to flooding or rainwater pooling. Poor ditch drainage can lead to poor road performance. More information on road drainage can be found in InfraGuide's best practice for road drainage (InfraGuide, 2003).

3.1.3 Gradation of the Surface-Wearing Layer

Roads that have been constructed with sufficient bearing capacity can deteriorate by another mechanism other than deformation. Ravelling occurs after the fines in the road surface material that binds the larger aggregate together are blown away by wind or the air turbulence created by vehicles. Fines may also be washed out of the surface layer by rainfall and poor drainage. The larger aggregate can then be easily loosened from the road surface layer by traffic.

Loss of road surface materials and emissions of dust can be considerably reduced if the surface materials have the proper gradation. This will ensure that the larger aggregate particles are in contact with each other and the spaces between them are completely filled with smaller particles. Usually, road surface aggregate gradation consists of fractured (crushed) coarse aggregate (40 to 60 percent) including 8 to 10 percent fines. Appropriate aggregate gradation of the materials will achieve a high density and shear strength if compacted at optimum moisture content. Clay consists of very fine particles and can be very adhesive when moist. The inclusion of a small proportion of such material in the surface layer can greatly enhance stability. The type of aggregate used in the surface layer is also important and should have a high crushing resistance. Crushed gravel performs better than uncrushed, because the high angularity of the aggregate provides better interlocking strength.

It should be noted that excessive fines in the road surface may be caused by repeated blading or by the inclusion of shoulder topsoil and sub-grade material. Fines may also be drawn to the surface of the road by compaction when it is still wet after the application of a suppressant.

3.1.4 Prediction of Road Surface Material Performance

The grading coefficient is a measure of how well the road surfacing material is graded. It is calculated from the amount of road surfacing material passing through a number of different-sized sieves. If there is insufficient material to fill the voids between the coarse aggregates, the aggregate will ravel. If there is too much, the coarse aggregate will not be able to interlock and the road will be susceptible to erosion.

Materials with low plasticity lack adequate cohesion to resist ravelling, or the formation of corrugations, under traffic. The shrinkage product is a measurement of the plasticity of the road material and is the product of the bar linear shrinkage test and the percentage amount of fines in the surfacing material. The bar linear test measures the amount of shrinkage of the fines from a saturated state to a completely dry state.

Unpaved roads with low bearing capacity are cheaper to build, but if their bearing capacity is insufficient for the applied traffic load, maintenance costs will be very high.

Figure 3–2 shows the expected performance of the surfacing material with respect to plasticity and gradation.

Although the tests for the shrinkage product and grading coefficient are relatively easy to perform, road maintenance authorities may wish to send samples to materials testing laboratories which, in addition to performing these tests, may also be able to provide advice on the addition or deletion of material to improve road surface performance by reaching optimal gradation.

Figure 3–2: Expected road conditions based on plasticity and gradation

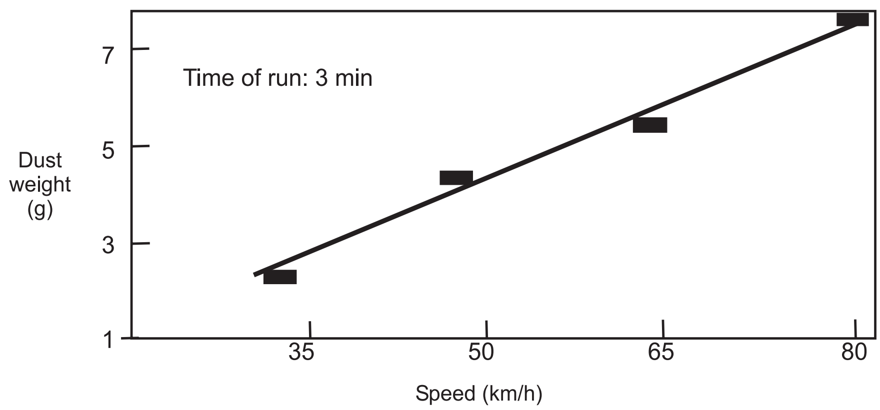
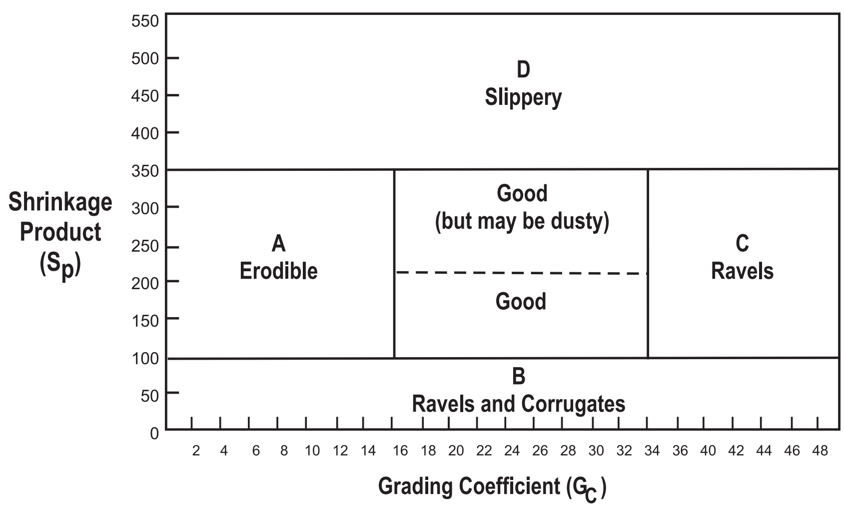


Figure 3–3: Dust generated as a function of speed



Source: Addo and Sanders (1993).

3.1.5 Vehicle Speed Reduction

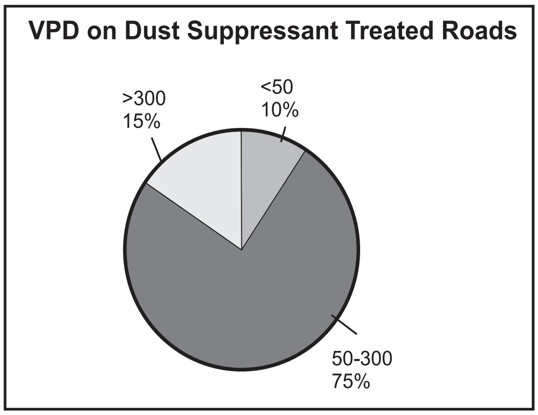
The amount of dust emission from an unpaved road is directly related to the speed and type of vehicles using the road, shown in Figure 3–3. If dust levels are unacceptable only along relatively short sections of a road, such as residential areas, and dust suppression activities have not produced the desired dust control, consider introducing vehicle speed restrictions.

3.2 Decision to Use a Suppressant

If the road is well designed and constructed, the next step is to determine if it may be worth conducting a cost-benefit analysis to decide if a suppressant should be applied or if the road should be sealed or paved. The average vehicles per day (vpd) traffic volume and how much of this traffic consists of commercial vehicles is often a good indicator of whether this analysis should be done (see section 3.1). If the vpd is high, or the percentage of commercial vehicles is above 15 percent, it may be economical to consider upgrading to a sealed or paved road. The limit at which sealing or paving should be considered will vary depending on several economic variables, such as the cost of paving or sealing. Some studies give a limit of greater than 250 vpd and others give a limit of greater than 500 vpd (UMA 1987). The limit at which sealing or paving should be considered will depend on local factors, such as costs and availability of materials. Each jurisdiction usually determines this limit by financial analysis of trials using suppressants and comparing the costs to maintaining untreated roads and sealing or paving them. One frequent observation that should be considered in this calculation is that when road performance improves due to use of suppressants, sealing or paving, more people will use the road.

Studies indicate that it is not economical to use suppressants on roads with a range of fewer than 50 vpd (Foley et al., 1996). Again, the actual figure will vary within each jurisdiction. After performing cost analyses a number of times, each road maintenance authority will be able to estimate the vpd economic cut-off limits for use of dust suppressants, and a detailed cost analysis will no longer be necessary. Results from the study questionnaire are illustrated in Figure 3–4.

Figure 3–4: Average vehicles per day on dust suppressant-treated roads



3.3 Cost-Benefit Analysis

The yearly cost of using a dust suppressant depends on the cost of the suppressant, the application frequency, and the cost of applying the suppressant. This can be calculated using information from the supplier on dust suppressant. The supplier will likely also have different costs for delivery to different areas and for the supplier applying the suppressant or it being delivered to the road authority stores.

The cost of applying the suppressant will depend on the cost of watering, scarifying, shaping, grading and compacting. It will also depend on the frequency with which these operations will be performed, which should be minimized with the use of suppressants.

To calculate and compare the cost of obtaining and applying various dust suppressants, it may be advantageous to produce a table similar to that shown below. It would also be useful to include the costs involved in not applying a suppressant (i.e., the cost of maintaining the road without the use of a suppressant). Without the use of a suppressant, shaping and grading will likely need to be done more frequently (See Table 3–2 below).

There may also be an up-front capital cost if any additional application equipment or suppressant storage facilities are required. After determining costs, the final step is to consider the less quantifiable characteristics of the suppressants, such as environmental impact, difficulty in reworking the surface layer during maintenance or reapplication, corrosive effects, and leaching during rainfall. Dust suppressants have been in use for decades and road authorities spend considerable money to obtain and use them. It is, therefore, rather surprising that there has been so little research described in the literature to quantify the effectiveness of various dust suppressants. It is known that road authorities do perform trials on different suppressants, but information on these trials rarely appears to reach publication. The following provides a description of a few of the larger studies that have been performed.

After determining costs, the final step is to consider the less quantifiable characteristics of the suppressants, such as environmental impact, difficulty in reworking the surface layer during maintenance or reapplication, corrosive effects, and leaching during rainfall.

Table 3–2: Template for the Cost-Benefit Evaluation of Dust Suppressants

Suppressant Price $ / kg or Litre	Application rate Kg or Litre / m^2	Application Frequency per Year	Yearly Cost of Suppressant per Km	Application Labour and Equipment	Costs per Km/ Year	Total Dust Control Costs / Km / Year
$CaCl_2$ Pellet						
$CaCl_2$ Flake						
$CaCl_2$ liquid						
No suppressant						

It is more difficult to put a price on factors such as improved safety and health, reduced vehicle wear, and reduced environmental impacts, but they must be considered when deciding if a suppressant should be used.

In a field study conducted at Colorado State University, three dust suppressants were evaluated, including calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$) (Addo and Sanders 1995). The results indicated that the use of road suppressants reduces the emissions of fugitive dust from unpaved road surfaces by 50 to 70 percent. It was also found that at later stages the amount of dust generated increases and the amount of fines in the road surface material influences the amount of traffic-generated dust. A cost analysis indicated a 30 to 46 percent reduction in total annual maintenance costs for the treated test sections compared to the untreated test section.

In 2000, the US Department of Agriculture, Forest Service (Region 1, Materials Engineering Section, Missoula) conducted an evaluation of alternate chemical stabilization treatments on a road that had a history of dusting up in the summer and severe washboarding, even though the road was bladed, watered, and recompacted three times each year. The following table lists the costs of the various suppressants tested.

In order to maintain a smooth road surface, for every 2 weeks of poor road quality a grading application would be required ($600). The grading cost over the study duration (1 year) is added to the treatment cost. As can be seen from the costs, the use of some suppressants can result in considerable savings purely in terms of roadway maintenance costs. It is more difficult to put a price on factors such as improved safety and health, reduced vehicle wear, and reduced environmental impacts, but they must be considered when deciding if a suppressant should be used.

3.4 Dust Suppressant Selection

There are a number of factors to consider when selecting a chemical dust suppressant, including:

- regulations and provincial guidelines;
- effectiveness in controlling dust at the required location;
- road stabilization benefits;
- cost of suppressant, delivered to storage or point of use:
- equipment and labour costs for applying suppressant at the required frequency; and
- costs for replacing gravel and road maintenance before and after suppressant application.

Table 3–3: Evaluation of Dust Control Methods

Treatment Description	# of Poor Weeks	Treatment Cost/Mile	Cost to Maintain Smooth Road Surface
Traditional blading, watering, and compaction	44	$3,600	(22 x $600) + $3,600 = $16,800
Mixing 6 cm to 7 cm deep with in-place processor	42	$4,240	(21 x $600) + $4,240= $16,840
Bentonite clay mixed 6 cm to 7 cm deep with in-place processor	38	$4,940	(19 x $600) + $4,940= $16,340
0.6 kg/sq m flake CaCl2 on surface for dust abatement	35	$3,900	(17 x $600) + $3,900= $14,100
Bentonite clay mixed 6 cm to 7 cm deep with in-place processor plus 0.6 kg/sq m flake $CaCl_2$ on surface	34	$5,840	(17 x $600) + $5,840= $16,040
0.8 kg/sq m flake $CaCl_2$ mixed 6 cm to 7 cm deep with in-place processor	14	$4,540	(7 x $600) + $4,540= $8,740
1.6 kg/sq m flake $CaCl_2$ mixed 6 cm to 7 cm deep with in-place processor	0	$5,140	$5,140

NOTE: Units have been converted to metric measure.
Source: US Department of Agriculture (2001). Dust, Washboards, Deep Stabilization, and Erosion Control. Joe Althouse, April 2001.

3.4.1 Regulations and Provincial Guidelines

Several provinces and territories have restrictions on the types of dust suppressants that may be used. Before selecting a dust suppressant, the provincial departments of transportation and the environment should be consulted to ensure the selected suppressant is either approved for use or has not been banned. In addition, there may be location specific prohibitions that require special attention — environmentally sensitive wetlands. The list of approved and banned suppressants will vary with time. The following are examples of approvals and restrictions at the time of writing this best practice.

British Columbia (B.C.)

BC Ministry of Transportation Recognized Products List, July 2004 Edition. Only those products containing the chemicals listed below and conforming to the B.C. Ministry of Environment, Lands, and Parks' Environmental Standards shall be considered for use as a dust suppressant.

- Proven Products: magnesium chloride, calcium chloride, calcium lignosulphonate, and sodium lignosulphonate.
- Tentative Products: BA 65 (under evaluation, summer 2003) and DC–40 (827).

Northwest Territories (N.W.T.)

Used oil cannot be used as a dust suppression/road stabilizing product or added to other dust suppression products. Calcium chloride, Bunker C and DL10 are the only approved dust suppressants in the Northwest Territories. Other products cannot be used until the NWT Environmental Protection Service has approved them. Regulations also exist for notifying various parties that the use of a dust suppressant is intended. These parties include the relevant road authority, adjacent property owner, the local renewable resource officer, and the public.

Ontario (Ont.)

Only dombind and used oil are banned through regulation in Ontario. The Ontario Ministry of Transportation (MTO) has a designated sources list (DSL), which identifies products evaluated and approved by the MTO. Calcium chloride, lignosulphonate, and water are the only materials on this list. In addition, the MTO will accept dust suppressants approved by the Ontario Ministry of the Environment.

3.4.2 Types of Dust Suppressants

Chloride Salts

Salts, such as calcium chloride and magnesium chloride, are ionic compounds and, in solution, each ion can be considered analogous to a powerful single pole magnet. Each ion attracts, and is surrounded by, the weakly magnetic water molecules. This attraction will decrease the rate at which water molecules escape into the air, lowering the water vapour pressure and the rate of evaporation of the solution. Surface tension and the boiling point will also increase. If two dust particles are placed together and coated in a chloride salt solution instead of just water, the greater surface tension will bind the particles together more strongly. The decrease in the evaporation rate will also prevent the road from drying out as quickly. Calcium and magnesium salts also have one other advantage in that they can absorb moisture from the atmosphere at relatively low levels of humidity. These salts can, therefore, regenerate their moisture content by themselves without the need to apply water manually.

Brine made from these salts will absorb water until the rate of absorption is the same as the rate of losing water (evaporation). If the air is at 100 percent relative humidity, the brine solution can continue to absorb water from the air indefinitely. Usually air is at less than 100 percent relative humidity, so the process of absorbing water molecules at a greater rate than losing them will stop once the water vapour pressure of the salt solution equals the water vapour pressure in the air. For example, at 25°C and at a relative humidity of 30 percent, calcium chloride will adsorb more than twice its own weight in water. At the same temperature with a relative humidity of 95 percent, it will attract more than

17 times its own weight in water. In Canada the relative humidity lies between 60 and 90 percent all year, so it can be expected that calcium and magnesium salts will always contain moisture when used in Canada.

As well as controlling dust, the moisture captured by calcium or magnesium chlorides will help compact the road aggregate. Although reapplication will likely be required once a year, usually some salt will still be retained and the amount of salt required for reapplication will be less than the initial application. Many agencies in Canada, however, are only applying one application per year, with a performance period ranging from 8 weeks to 15 weeks.

Many agencies in Canada, however, are only applying one application per year, with a performance period ranging from 8 weeks to 15 weeks.

There are a few potential disadvantages to using salt as a dust suppressant. The road may become slippery when wet and it will cause vehicle corrosion. With poorly designed roads, prolonged contact with rainwater can occur, which will leach out the salt and may pose an environmental hazard.

Water-attracting chemical dust suppressants are recognized for providing the best combination of application ease, durability, cost, and dust control for semi-arid, semi-humid, and humid climates. They can have significant impacts on the reduction of dust (e.g., 30 to 80 percent), but require frequent reapplication to maintain long-term dust suppression performance. Environmental impacts of chlorides include metal corrosion, degradation to nearby vegetation, surface water, groundwater, and aquatic species.

The chlorides are effective with road surface materials that have a moderate fines content and higher plasticity indices, and are located in a humid environment.

Sodium chloride does not have the same properties as calcium or magnesium chloride. It will not extract moisture from the atmosphere to the point that it turns into a solution. It will also not attract moisture from the atmosphere unless the relative humidity is greater than about 75 percent. In comparison, calcium and magnesium chloride will absorb moisture with humidity levels below 40 percent. Sodium chloride is the cheapest of the chloride salts and will improve the mechanical stability of a road. However, when it goes into solution, due to rain, it disperses fines or clay particles. When these particles dry out they shrink and so become susceptible to wind erosion. Sodium chloride can be used to stabilize a road, but a suitable dust suppressant, such as calcium chloride, should be applied on the surface for dust control.

Consumption and Availability of Chloride Salts

Calcium chloride dust suppressants are consumed across Canada, with the majority of consumption concentrated in central Canada. Ontario and Quebec are estimated to represent approximately 60 percent of the annual demand for these dust suppressants. The remainder is distributed among the provinces/territories, with British Columbia consuming the next largest quantity. Magnesium chloride is only produced at three sites in the United States (no production in Canada), each of which is in the west. As a result, the small amount of magnesium

Table 3–4: Consumption of Chloride-Based Dust Suppressants in Canada, 2000 (Kilotonnes — 100% basis)

Jurisdiction	Calcium Chloride	Magnesium Chloride	Total
British Columbia	11	3	14
Alberta	6	< 1	6
Saskatchewan	4	< 1	4
Manitoba	3	2	5
Ontario	41	< 1	41
Quebec	22	< 1	22
New Brunswick	3	0	3
Nova Scotia	2	0	2
Prince Edward Island	1	0	1
Newfoundland and Labrador	1	0	1
Territories	4	0	4
Total	**98**	**5**	**103**

Note: Quantity of calcium chloride and magnesium chloride is on 100% basis.

Source: Environment Canada (2000).

chloride consumed as a dust suppressant in Canada is concentrated in the western provinces. Manitoba and British Columbia are the leading consumers of magnesium chloride, see Table 3–4 and Table 3–5.

Table 3–5: Suppliers of Chloride-Based Dust Suppressants in Canada

Company	Location	Estimated Annual Production Kilotonne's (100% basis)
General Chemical	Brooks, AB	4
Tiger Calcium	Smith, AB Mitsue, AB	39
Ward Chemical	Calling Lake, AB	23
Total		**66**

Note: Quantity of calcium chloride and magnesium chloride is on 100 percent basis. Greater quantities are applied, which contain water and other ingredients.

Research conducted for this study did not identify the use of sodium chloride or potassium chloride in Canada for dust suppression.

Organic Non-Bituminous Dust Suppressants

(Lignosulfonates, Sulphite Liquors, Tall Oil Pitch, Pine Tar, Vegetable Oils, Molasses)

Lignosulphonate and Resins

Lignin is a component of wood and is a natural polymer. It imparts strength to wood cells and binds them together. The lignin must be removed to make paper pulp. In the sulphite paper-pulping process, the lignin is digested and made soluble using a solution of sodium, calcium, ammonium, or magnesium bisulphate. Depending on the type of bisulphate used, the waste liquor from the pulping process contains calcium, sodium, ammonium, or magnesium lignosulphonate. The waste liquor also contains some sugars, which attract moisture from the atmosphere if the air is humid enough. These lignosulphonates have been used extensively as a road dust suppressant, but not as extensively as calcium and magnesium chlorides. Lignosulphonates bind particles together due to a combination of chemical and physical interactions.

There are resin products available under various commercial names. The basic composition of resins is lignosulphonate. These products work best when incorporated into the surface gravel under arid and semi-arid conditions and with medium to high fines in the surface layer. As with most dissolvable suppressants, they are unlikely to provide sufficient dust control for a second year, but subsequent applications may be made at reduced rates, because of residual effects.

Some commercial products in this category may be visually unappealing, odorous, or very sticky on application. This may preclude their use, depending on the location of the area to be treated.

Lignosulphonates do not impart much mechanical stabilization to the road, if any. As a component of wood, they have a high biological oxygen demand (BOD) during decomposition, and spills into surface waters should be avoided. Due to their solubility, rainfall can leach lignosulphonates out of, or deeper into, the road where they are ineffective for dust suppression. A single rainfall event can seriously impair or completely eliminate the effectiveness of lignosulphonates as a dust suppressant. It is reported (Jones and Michley, 2001) that with reapplications the product concentration can build up below the road surface over several years, which reduces the rate of downward leaching.

Lignosulphonates are corrosive to aluminum and its alloys. If calcium carbonate slurry is added, the corrosive effects are neutralized. Another benefit from adding this slurry is that it also reduces the solubility of the lignosulphonate, reducing the rate at which it leaches out of the road.

In summary, lignosulphonates have a useful duration of six months and work best with surface materials that have high fine content and high plasticity indices in a dry environment.

Table 3–5
Suppliers of Chloride-Based Dust Suppresants in Canada

Magnesium chloride is only produced at three sites in the United States (no production in Canada), each of which is in the west. As a result, the small amount of magnesium chloride consumed as a dust suppressant in Canada is concentrated in the western provinces.

Vegetable Oils

These suppressants include soybean, cottonseed, and linseed oils, and soap stock. They are susceptible to oxidation and can form brittle surfaces. Their effectiveness in suppressing dust is often less than desired, and these suppressants are only available in limited quantities.

Petroleum-Based Binders

(Bitumen Emulsions, Asphalt Emulsions, and Waste Oils)

Cutback Asphalts

Historically, cutback liquid asphalts were used extensively as a dust suppressant on unpaved roads. However, the hydrocarbon solvents used to liquefy the asphalt are toxic and very mobile in the environment. As a consequence, they have been banned in many places.

Emulsified Asphalts

Asphalt emulsion consists of asphalt cement suspended in water with the help of an emulsifying agent and is available as either a cationic or anionic type. For dust control, the slowsetting anionic types, such as SS–1, are preferred, although the slow-setting cationic types, such as CSS–1, also can be used. It is preferable to use the asphalt emulsions undiluted. On contact with road surface materials, the water and asphalt in the emulsion separate. On a porous road surface, the asphalt phase penetrates and cures in several hours under favourable conditions. On an impervious or tight road surface, an asphalt film will remain on the surface.

The dust suppressants in this category can be effective for a broad range of road surface material types and climate, and have been approved for use in various Canadian jurisdictions, such as DL10 in the Northwest Territories. They are relatively expensive compared to other product types, and may be visually unappealing, odorous, or very sticky on application. This may preclude their use, depending on the location of the area to be treated.

Emulsified asphalts can also pose a threat to the environment, but are less of a concern than cutback asphalts. The product must be applied with special asphalt application equipment. After application, maintenance crews may find the surface difficult to rework.

DL10

DL10 is an asphalt product that is mixed with water and a soap solution. DL10 should be applied to one side of the road at a time, and then allowed to set for about three hours.

Braking may be difficult on freshly treated road, so a pilot car may be necessary to direct traffic during the application to ensure slow speeds. Vehicles should travel no faster than 20 km/hr through areas where the application has not set.

Fresh DL 10 can be washed off using soap and water. If it is allowed to dry, a solvent may be required.

Bunker C

Bunker C is the heaviest viscosity oil that refineries produce, with an asphalt content varying between 7 and 25 percent. Bunker C must not contain contaminants not normally found within the virgin product (i.e., tank bottom sludge, other fuels or oils, used oil, PCBs, or solvents). It must be bladed or otherwise incorporated into the road immediately on application.

Containment Bunker C must not be applied to sections of the road that are subject to flooding and must not be allowed to enter water bodies due to potential hydrocarbon contamination.

Waste Oil

Even clean off-the-shelf engine oil contains additives (such as zinc compounds). During its use in engines, it becomes contaminated with the by-products of combustion, and metals from engine wear and tear. These contaminants can include carcinogenic (cancer causing) polycyclic aromatic hydrocarbons (PAHs) and metals, such as aluminum, cadmium, chromium, lead, and copper. The application of used oil as a dust suppressant is prohibited by legislation for several Canadian provinces and in all 50 U.S. states.

Electro-Chemical Stabilizers

(Sulphonated Petroleum, Ionic Stabilizers, Bentonite)

These products work over a wide range of climatic conditions and do not easily leach out. A large variety of these materials are available. When they are applied under highly specific trafficked-surface and aggregate conditions, they reduce dust generation dramatically. Their performance can, however, be variable, and pilot tests should be done before any large-scale application.

Bentonite appears to be effective for up to two years and works well with surface materials having low fines and plasticity, and with limestone aggregate. If paving is contemplated in the future, the use of bentonite clay is not advisable.

Polymers

(Polyvinyl Acrylics and Acetates)

These products bind road surface particles together and form a semi-rigid film on the surface layer. Most polymer products are supplied in concentrated form and require dilution with water before application. With slight variations in dilution and final application rates, polymers are generally suitable for use under a wide range of road surface materials and climatic conditions.

Most polyvinyl acrylics and acetates are considered non-toxic and environmentally friendly when used according to manufacturers' recommendations. They are most effective on lightly trafficked surfaces, such as helicopter landing surfaces in areas that receive between 200 mm and 1000 mm of precipitation per year.

Microbiological Binders

(Cryptogams, Blue-Green Algae Inoculants, and Enzyme Slurries)

Many products in this category are under development. They are most effective in arid climates. Many enzymes are adsorbed by clay particles, resulting in a compression of the pore space that aids in compaction and reduces dust generation. As with those in the electro-chemical stabilizer category, these products have been very successful under highly specific trafficked-surface and aggregate conditions. Without standard testing procedures to predict their performance under field conditions, small-scale trials should be initiated and evaluated before large-scale application.

Table 3–6
Comparison of Dust Suppressant Characteristics

Table 3–6: Comparison of Dust Suppressant Characteristics

Types	Source	Functional Mechanism	Application	Performance Advantages	Performance Limitations	Environmental Considerations
Lignin derivatives	Paper-making industry by-product containing lignin and carbohydrates in solution. Specific composition depends on chemicals and processes used to extract cellulose.	Act as adhesives, binding road surface particles together.	■ Usually one to two treatments per year. ■ 10–25% solution 2.3–4.5 l/m^2.	■ Greatly increases dry strength of road surface materials. ■ Imparts some plasticity to road surfaces; lowers freezing point of road surface and base. ■ Effectiveness retained after reblading.	■ Can be leached out of the road during heavy precipitation ■ ($CaCO_3$ added ingredient, can neutralize acidity). ■ Proper aggregate mix (4%–8% fines) is important to performance. ■ Becomes slippery when wet, brittle when dry.	■ Lignin products have a high BOD (biological oxygen demand) in aquatic systems. ■ Spills or runoff into surface or groundwaters may create low dissolved oxygen conditions that are detrimental to aquatic life.
Synthetic polymer emulsions	Synthetic formulations composed of polyvinyl acetates, vinyl acrylic copolymers, copolymer methacrylates, polybutadiene.	Binds road surface materials together by adhesion.	■ Usually one treatment lasts two years. ■ 40%–50% solution ■ 1.4–4.5 l/m^2.	■ Applicable to a range of emission sources ■ Functions well in sandy road surface materials. ■ Some types allow seeded vegetation to grow through the polymer matrix.	■ Require proper weather conditions and time to cure; may be subject to UV (sunlight) degradation. ■ Application equipment requires timely cleaning ■ No residual effective-ness after reblading.	None.
Bitumens, tars, and resins ■ Residual fuel oil ■ Technical white oils ■ Fuel oils #4, #5, #6	Petroleum, coal, and plastics industry by-products.	■ Asphalt and resinous products are adhesive. ■ Petroleum oil products coat road surface particles, increasing their mass.	■ Refer to manufac-tures guidelines.	■ Water insoluble when dry; provide a degree of surface waterproofing. ■ Good residual effectiveness.	■ Surface crusting, fracturing, and potholes may develop. ■ Long-term application may cause road to become too hard for reblading. ■ Will not prevent frost heave.	■ Application of used oils is prohibited. ■ Some petroleum-based products may contain PAHs.
Water	From surface, groundwater or potable sources.	Moisture wets surface particles, binding them together by the surface tension of the water.	■ Usually only effective from 1 to 12 hours.	■ Usually readily available, low material cost, easy to apply.	■ Evaporates readily and usually controls dust for less than 12 hours.	No environmental hazard, if not applied excessively.
Seawater	Sea	Moisture stabilizes fines. Contains small quantities of salt (mostly $MgCl_2$), which retain moisture in road surface.	■ Usually only effective for one day.	■ Low material cost. ■ Performs better than freshwater. ■ Need for reapplication is less than with freshwater.	■ Only available in coastal areas.	Repeated applications and long-term use may harm nearby vegetation and aquatic life

Table 3–6: Comparison of Dust Suppressant Characteristics (cont'd)

Types	Source	Functional Mechanism	Application	Performance Advantages	Performance Limitations	Environmental Considerations
Calcium chloride	Three forms: flake, ■ Type I, at 77% to 80% purity pellet, ■ Type II, at 94% to 97% purity. ■ Clear liquid at 35% to 38% solids.	■ Attracts and retains moisture at a relative humidity of 29% at 25°C and 20% humidity at 38°C. ■ Assists compaction. ■ Treated road can be regraded and recompacted with less concern for losing moisture and density.	■ Usually one to two treatments per year. ■ Initial application, flake: at 0.5 to 1.1 g/m^2. ■ Typical application 0.9 kg/m^2 liquid: 35% to 38% solution at 0.9 to 1.6 l/m^2. ■ Typical application is 38% concentrate applied at 1.6 l/m^2. ■ Follow-up: apply 1/2 to 1/3 initial dosage.	■ Retains moisture and attracts moisture from the air. ■ Lowers freezing point of water minimizing frost heave and reducing freeze-thaw cycles. ■ Increases compacted density of road material. ■ Effectiveness retained after reblading.	■ Slightly corrosive to metal, highly to aluminum and its alloys. ■ Rainwater tends to leach out highly soluble chlorides. ■ If high fines content in treated material, the surface may become slippery when wet.	■ Repeated applications and long-term use may harm nearby vegetation and aquatic life. ■ Water quality impact: generally negligible if the proper buffer used. ■ Plant impact: some species are susceptible, such as, pine, hemlock, poplar, ash, spruce, and maple.
Magnesium chloride	■ Produced from natural salt brine. ■ By-product of potash production .	■ Attracts and retains moisture at a relative humidity equal to or greater than 32% independent of temperature. ■ More effective than calcium chloride solutions for increasing surface tension, resulting in a very hard road surface when dry. Treated road can be regraded and recompacted with less concern for losing moisture and density.	■ Usually one to two treatments per year. ■ Initial application: 28%– 35% solution. ■ Typical application 1.4 to 2.3 l/m^2 ■ Follow-up: 1/2 initial dosage	■ Reduces evaporation rate of moisture in the road. ■ Lowers freezing point of water minimizing frost heave and reducing freeze-thaw cycles. ■ Increases compacted density of road material, more so than $CaCl_2$.	■ Corrosive to steel, though inhibitors can be added. ■ Solubility results in leaching during heavy precipitation.	■ Repeated applications and long-term use may harm nearby vegetation and aquatic life.

12. Temperatures in the range of 50 to 70 °C are common. Emulsions should not be heated above 85 °C.

4. Applications and Limitations

4.1 Applications

Once a dust suppressant has been chosen the following section provides advice on when and how the suppressant should be applied.

4.1.1 When to Apply

Dust suppressants work best when applied to damp road materials. Chlorides and lignosulphonates should be applied in late spring, after the seasonal rains so sub-grade and surface materials will not have dried.

Chloride dust suppressants and, to a lesser extent, lignosulphonates can be leached out of a road by heavy rain during and just after application. These suppressants should, therefore, not be applied during a heavy rainfall or if rain is forecast in the next few days. Application during light rain can help, so long as the rainfall is not running off the road.

The selection of the application rate will vary with the type of gravel being treated, amount of traffic, and the length of time dust control is needed. Suppressant suppliers will provide general guidelines on application rates and experience will fine-tune these estimates.

4.1.2 How to Apply

Before applying the suppressant, the road surface layer should be tested to ensure proper gradation (see section 3.1.3). If the road surface material does not have proper gradation, consideration should be given to adding material. Dust suppressants will not work as well on poor quality roads.

If the road surface is tight and penetration of liquid suppressant is poor, the road surface layer should be loosened (scarified) a minimum of 25 mm to 50 mm to permit in-place penetration of water and suppressant. This must also be done for in-place mixing of solid suppressants such as chloride flakes. If the road surface layer material is not damp, a water truck should be used to spray the road. Cooler and more humid periods reduce evaporation and provide a greater period of time during which the material may be worked. To avoid rapid evaporation of water from the road, it is preferable to wet the road in the early morning or evening, especially during hot weather.

The road should be shaped to ensure a good crown and good shoulder drainage. Before applying the suppressant, ensure that there are no pools of water on the surface. Pools will cause weak spots in the surface layer and potholes will develop.

It is important that the equipment used to apply the suppressant (in liquid or solid form) can do so in a uniform manner across the width of the road and can be calibrated to deliver the required application rate. Ideally, traffic should be kept off the road for up to two hours after application.

Treatment should vary in width depending on the traffic volume. Depending on traffic volume, 75-80% surface coverage may achieve the same dust control as with 100% coverage. Rolling will assist compaction and is recommended for high traffic-volume roads. Rolling is not so essential for low traffic-volume roads. If rollers are used, pneumatic ones are preferred. If the roller picks up gravel, let the suppressant cure longer and then complete rolling.

When using chlorides as a dust suppressant, the application equipment should be cleaned quickly after use, because of the corrosive nature of these salts. These salts corrode aluminum and its alloys very rapidly. When the salts are incorporated in the road, they are much less corrosive to vehicles. Chlorides are very corrosive to concrete cement; do not spread chloride suppressants over bridge decks.

Restrict application of chlorides within eight metres of a body of water (Environment Canada, 2004) to avoid potential contamination of surface or groundwater. In areas of shallow groundwater, determine if significant migration of the chloride would reach the groundwater table. Restrict the use of chlorides if low salt-tolerant vegetation is within eight metres of the treated area. Typical low-tolerant vegetation includes varieties of alder, hemlock, larch, maple, ornamentals, and pine.

The road surface layer, to which a dust suppressant has been applied, may be reworked to remove potholes and ruts, and the suppressant will still work as well as before or will still have a significant residual effect. Most dust suppressants fall into this category, but there are a few suppressants whose dust controlling ability will be completely destroyed by reworking. The suppressant supplier should be consulted to establish the effect of reworking the surface of the road. Grading should be performed only when necessary, and this will be difficult to do unless the road surface material is thoroughly moist. Grading should be performed at minimal depth; only deep enough to rework imperfections and allow the mixing in and reduction of float gravel. Grading should never be deeper than 100 mm to prevent excessive dilution of the suppressant. The graders should blade lightly from the edges toward the centre and then feather the material back toward the edges. It is a good practice to blade in short sections so the area can be compacted before it dries out. The road crown should still be retained.

It is preferable to apply emulsified asphalts at an ambient temperature of 27°C or above and should not be applied at temperatures below 10°C. If the ambient temperature is low, then the emulsion should be heated to a temperature between 24°C and 54°C. Heating the emulsion above 85°C will cause the asphalt and water to separate. Emulsions generally cure in about eight hours.

It is of interest to note that of the 14 road maintenance agencies responding to a survey performed for this study, 57 percent indicated they had guidelines or standards for the application of dust suppressants.

For more information on the application of chloride salts review Environment Canada (2004).

4.1.3 Test Sections

For some dust suppressants, such as electro-chemical suppressants, it is difficult to predict what level of performance might be achieved. It is, therefore, advisable to test the suppressant on a small section of road. More than one suppressant and different application rates are often tested at the same time for comparison. An untreated section is also usually included to provide a baseline from which to evaluate the effectiveness of the suppressants.

Supplier recommended application rates are included in Table 3–6.

4.2 Limitations

4.2.1 Environmental Considerations

In 1995, road salts were placed on the federal government's Priority Substances List 2 for assessment to determine toxicity under the Canadian Environmental Protection Act (CEPA). The scientific assessment concluded that because of the high releases around storage and snow disposal sites and through runoff and splash from roadways into soils, streams, and rivers, road salts pose a serious threat to the aquatic environment, and plants and animals.

A large proportion of the salt used for road maintenance is applied for de-icing purposes. However, salt used for dust suppression also enters the environment, and sensitive areas should be considered when determining the suitability of the dust suppressant. When considering areas that may be vulnerable, take note of significant wetlands or areas that drain into lakes and ponds with long residence times (slow to fill and drain), and watercourses that experience cumulative effects of many nearby roads. Other areas of concern include those that drain into sources of drinking water and critical habitats that are necessary for the survival or recovery of a wildlife species listed as at risk (Schedule 1 of the *Species at Risk Act*).

Areas adjacent to salt-sensitive native or agricultural vegetation, where the addition of road salt has the potential to reduce growth and flowering, should also be identified or flagged requiring special attention/consideration when choosing the dust suppressant. It is best to check with local authorities to ensure the appropriate action is taken.

Open Bodies of Water and Drinking Water Wellheads

The use of organic petroleum products, deliquescent/hygroscopic salts, and ligninbased suppressants is highlydiscouraged within six metres of open bodies of water, including lakes, streams, canals, and drinking water wellheads. This buffer zone is intended to prevent leachate from these suppressants from reaching an open body of water or a groundwater aquifer.

Natural Washes and Flood Control Channels

Use of organic petroleum products, deliquescent/hygroscopic salts, and ligninbased suppressants are highly discouraged within six metres of natural washes and flood control channels. This buffer zone is intended to prevent leachate from these suppressants from reaching a natural wash or flood channel, and subsequently being flushed into surface waters or drinking water supplies.

4.2.2 Humidity

Calcium and magnesium chloride salts are effective dust suppressants, because they attract and retain moisture either from rainfall or directly from the atmosphere. This moisture keeps dust fines wetted and prevents them from becoming airborne. These salts can only draw moisture from the atmosphere if the relative humidity is above 40 percent. Fortunately, the relative humidity in Canada is invariably above 40 percent, and usually lies in the range of 60 to 90 percent all year round.

4.2.3 Precipitation

Some dust suppressants, such as chlorides and lignosulphonates, are dissolvable in water and are, therefore, not so suitable for use in areas that receive heavy rainfalls. Figure 4–1 shows the regions in Canada that receive an annual average rainfall of greater that 800 mm.

Figure 4–1: Areas Exceeding 800 mm of Rainfall per Year

Source: Based on information from the *Atlas of Canada*, 3rd Edition. Canada. Department of Mines and Technical Surveys, Geographical Branch, 1957 (Canada, 1957).

5. Evaluation

The measures used by road maintenance authorities to evaluate the success of a dust control method are currently limited to visual observation and personal experience. Comparative testing of dust control methods is popular and can provide good information on their effectiveness. Observation records of application rates, road surface material characteristics, climatic conditions, vehicle traffic, and dust emissions should be kept over the trial period and for future comparison to other suppressants trials. Photographs of dust emissions from the same type of vehicle traveling at the same velocity at intervals during the trial may prove very helpful in subsequent assessments. Some research institutes have attempted to quantify the performance of dust suppressants by measuring the amount of dust falling out of the air near treated and untreated road sections over time. The amount collected depends on a relatively large number of variables, and the reliability of such measurements are questionable.

Another instrument devised to measure dust consists of an infrared emitter and receiver (Jones, 1999). A drop in the intensity of the received signal indicates the amount of dust in the air between the emitter and receiver.

Static dust measuring devices have been described that employ photometric devices that depend on light scattering or interference between a light source and a sensor (Sanders and Addo, 2000).

It has been suggested that mobile measurement of dust emissions would be more accurate than using static instruments at points along a road. Mobile devices mounted behind the rear wheels of a moving vehicle have been developed to measure dust generated by the vehicle along a length of road. These devices employ infrared sensors (Jones, 1999) and cyclones that collect the dust in a container or on filter paper (Sanders and Addo, 2000). The accuracy of mobile measuring devices can be affected by vehicle aerodynamics, speed variations, and road roughness.

Another type of mobile instrument (Sanders and Addo, 1993) consists of a quarter-ton pickup truck, an electric generator, and a standard high-volumetric suction pump connected by a tube to a dust filter attached to the bumper of the truck.

6. Areas for Future Research

Research continues in developing new dust suppressants, application methods, and ambient dust measuring instruments.

In the current literature, there does not appear to be any standard method or instrumentation to take quantifiable dust emission measurements to compare the effectiveness of one trial dust suppressant study to another. A number of instruments have been developed based on the decrease of light transmission (at various wavelengths), due to the interference of dust between a light emitter and receiver. These methods, however, do not provide a standard light wavelength or standard interference devices, such as filters, with which to calibrate instruments with each other. The accuracy of these methods has also been affected by difficulty filtering out sunlight.

One possibility is to use a low-powered laser as the emitter and a laser power meter or light meter as the receiver. Optical interference filters are available that will only allow the transmission of light on a very specific wavelength, and these filters are available for the wavelengths of light produced by various types of lasers. This arrangement would eliminate the effect of sunlight, because a laser beam is millions of times more intense than sunlight at the same wavelength. Other standard optical filters could then be used to calibrate the instrument, or adjust the readings, to give the same measurement for the same level of dust in the air. In this manner, dust emission levels could be accurately measured with instrumentation that is relatively cheap, the emitter and receiver/datalogger being only a few hundred dollars each. If such instrumentation is developed in the future, it is important to note that long wavelength lasers (red, infrared) penetrate through dust much more easily that higher wavelength lasers (green, blue), so using a shorter wavelength laser will probably result in a more sensitive instrument.

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