ECONOMIC DISBENEFITS OF DUST FROM UNSEALED ROADS

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AN IMPORTANT NOTE FOR THE READER

Amendment to Report

Page 7, November 1993.

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EXECUTIVE SUMMARY

Almost one half of the New Zealand network of public roads is unsealed. Economic studies have shown that completing sealing of the network is not justified, primarily because of the low volumes of traffic using such roads. Nevertheless, while traffic volumes may be relatively low, such roads are usually of strategic significance, whether directly to ensure delivery of primary produce or indirectly to provide alternative routes. In addition, some unsealed roads are popular tourist routes.

As well as the tangible costs (such as increased accident risk, damage to crops), there is a need to improve recognition of intangible costs (such as dust deposits on clothing, general discomfort).

As a first step in the process of improving the quantification of the disbenefits of dust, a literature survey of relevant overseas research has been carried out, and with reference to research conducted by Lincoln University in New Zealand.

The review of overseas literature shows that relatively little work has been done on calculation of disbenefits accruing from dust on unsealed roads. The most helpful work is that on the effects of dust on agriculture in New Zealand.

Within New Zealand, the most significant disbenefits apply to crops and possibly to vehicle operating costs.

ABSTRACT

Potential economic disbenefits of dust emission from unsealed roads impact on crop production, animal food supply and health, accident potential, property values and maintenance costs, vehicle operating costs and personal health.

A literature survey concentrating on overseas literature has found that very little information of a quantified nature is available. Moreover, transferring the results of some of the work on dust generation carried out in developing countries is difficult because of differences in climate and road materials. By including some New Zealand studies, it was concluded that the most significant potential disbenefits from dust emissions arise from a reduction in crop yield and possibly [an increase] to vehicle operating costs.

1. INTRODUCTION

Dust is inherently a product of all unsealed roads at some stage and for various periods of time. The disbenefits to roads can vary from very large to quite modest and of little consequence. The degree of dust emission is often associated with environmental factors, and can be modified by the skill and knowledge of the practitioner in charge of the road maintenance.

The problem of wind-blown particles is a major one in many developing countries. In Nigeria, the annual atmospheric particle loading has been estimated (Funso 1989) at 2.75 x 10^6 kg with contributions as follows:

Activity	Percentage Contribution
Bush burning	31.7
Fugitive dust from roads	**29.1**
Fuel wood burning	21.3
Harmattan* dust (*wind pattern unique to Nigeria)	13.8
Solid waste incineration	2.1
Stationary sources	1.6
Automobile exhaust	0.2
Gas flares	0.1

Visser and Hudson (1980) comment that, with respect to developing countries:

> *"Dust is often considered as a nuisance, but it is difficult to express comfort in monetary terms, because road users are not willing to pay for this sort of comfort. The effect of dust on crops and livestock has been mentioned, but apparently little has been quantified. For example, in cotton-growing areas, gravel roads are sometimes paved because the dust affects the cleanliness of the cotton, which may then render it unacceptable. The influence of dust on crops and livestock is an aspect that requires further attention. If the impact is significant, it could greatly reduce the traffic volume at which a road should be paved."*

The above report was prepared in 1980, and it is evident that quantitative values on the disbenefits of dust towards crops and livestock are still lacking.

Relatively little literature on the subject of the economic disbenefits of dust from unsealed roads has emerged from developed countries, and economic disbenefits are generally speculative.

In the USA, the Environmental Protection Agency (Transportation Association of Canada 1987) has estimated that emission of particulate matter is distributed as follows:

Source	**Percentage Contribution**
Unsealed roads	**80**
Construction activities	8
Wind erosion	8
Paved roads	2
Wildfires	0.6
Agricultural tilling	0.6
Mineral extraction	0.6

Clearly, unsealed roads are the prime contributors to dust levels in the USA, and the study identified in particular those unsealed roads near cities.

Research undertaken by the Transportation Association of Canada (1987) does not quantify disbenefits but merely asserts that "untreated gravel roads" have the greatest environmental and social impact in the following areas:

- Safety
- Aesthetics
- Health

- Vegetation
- Soils
- Aquatic resources, and
- Vehicle costs

In New Zealand, even though approximately 44% of the total road network is unsealed, the roads are in better condition than those in developing countries. The rate of production of dust is less because:

- the climate is less arid than in developing countries such as those on the African continent,

- relatively low volumes of traffic operate on New Zealand's unsealed roads, and

- the supply of rock aggregate is more readily available for constructing the road (both the foundation and surface) than in many developing countries.

In evaluating the economics of amelioration, both the cost of this operation and the reduction of disbenefits (i.e. accrual of benefit) need to be weighed. This paper focuses on the significance of disbenefits. Various palliative measures are discussed in Appendix 1, but costs have not been discussed.

Dust is a road maintenance problem because it results in the loss of material from the road surface which has to be replaced. It also pollutes the atmosphere. It reduces visibility and is therefore a potential cause of accidents. People, animals and crops within the range of the dust clouds are affected. In this study, the effect of dust from unsealed roads is considered in terms of these issues.

2. RATIONALE FOR COMMITTING EXPENDITURE TO REDUCE DUST

To justify removing or reducing the dust nuisance, the disbenefits of dust need to be significantly in excess of the cost of remedial measures which means the Benefit:Cost ratio needs to be significantly in excess of 1.0.

The measures themselves might generate new disbenefits, and the "cure be worse than the disease." For example, in the application of a lignin by-product to roads in Whakatane (c.1985), it was reported that:

> *"the lignin by-product, as well as being described as 'hot, sticky, black and smelly,' was found to leach significantly, kill pasture and stick to vehicles."*
> (RRU Memo 1985)

But these effects were temporary.

A study of the cost of *noise, dust and vehicle emissions* in Finland, in 1987, indicated that dust contributed to between 10 and 28% of the sum of these three disbenefits (Himanen

1989). The dust-related component of cost was estimated to be about 0.7% of the annual cost of surface dressing of all gravel roads. This relatively small ratio implies that further effort to reduce the dust nuisance would not be justified. Moreover, not all dust was contributed by unsealed roads. The use of studded tyres on frozen paved roads, and the practice of road sanding in freezing conditions also contributed significantly. This further reduces justification to address the problem of dust emission from unsealed roads in Finland.

Of course, the Finnish experience cannot be translated to all developed countries, including New Zealand. The agricultural/horticultural use of land in Finland is very different from that in New Zealand because of the more severe winters, and the benefit of taking remedial measures is therefore likely to be considerably greater in New Zealand.

In calculating Benefit:Cost ratios, the result needs to be qualified when robust data are lacking. In the case of economic disbenefits of dust from unsealed roads, individual opinion is the basis for many of the disbenefit values asserted in the literature. Although quantification of these gives the appearance of reliability, no account is taken of the variability that may be forthcoming from different "expert opinions". If rigorous estimates of disbenefit are to be obtained, then control data are needed, which are measurements of the same item (crop quality, animal weight etc.) in conditions which, except for the absence of dust from unsealed roads, are similar. This would enable the marginal disbenefit, i.e. the disbenefit caused solely by the effect of dust, to be calculated.

3. DUST LOSS

Most of the literature on this topic accrues from studies made of roads in developing countries, often by personnel from developed countries.

A relatively recent report has been produced by Jones (1984a), following a study in Kenya. Concerning dust loss, this relatively up-to-date report states:

> *"The emission of fine particles from the surface arises from a loosening of the soil structure and a reduction in the cohesion of the gravel wearing course by the action of traffic and climate. This loss of material increases the permeability of the surface layer and results in the early development of potholes, all of which accelerates the need for regravelling. Furthermore, the coarser surface texture brought about by the removal of the finer fractions often leads to higher levels of surface irregularity which in turn give rise to increase in vehicle operating costs."*

Clay is a significant component of the running course of an unsealed road because it is the "binder" between the aggregate. Loss of the fine clay particles as dust or by water scour leads to a loss of cohesion and stability in the running course. As a result, windrows of coarse aggregate develop. These are a major cause of accidents on unsealed roads.

Mulholland (1972) has produced the following empirical gradation of dust concentration.

Grade	Concentration
10	Dust-free
9	Very little dust, rising one to two feet
8	Small amount of dust, rising to fender level
7	Thin cloud, easily seen through, no impaired vision
6	Cloud thickens and thins, visibility restricted in flashes, normal driving speeds maintained at all times, no uncertainties in manoeuvres
5	Dust causes driver to be uncertain momentarily because of poor visibility in meeting or passing
4	A blast of dirt taking one to five seconds to clear, visibility restricted during this time if meeting; forced to drop back a short distance if following or to take a risk if passing
3,2,1	Concentration of dust and time between 0 and 4
0	Dust is suspended and concentrated; next-to-zero visibility for 800m

Although various formulae are available to predict dust emission (e.g. McCrea 1984), disparity between them may reflect the effectiveness or otherwise of design of the particular unsealed road. There is also a climatic factor associated with dust production which, as for steep roads in areas of high rainfall, can increase rate of lost of fine surfacing material. The effect of both climate (rainfall) and longitudinal gradient is included in a model formulated by Paterson (1991).

A convenient estimation (in imperial units) given by Hoover (1981) (also reported in McCrea 1984) is "one ton per mile per vehicle per year" or about 500 kg per vehicle per kilometre. However, for the reasons given above, this should not be regarded as universally valid.

A variety of estimates is given by Jones (1984a), citing various sources:

Location/Author/vpd	**Quantity of Dust Loss**
Kenya (Jones 1984a) 100vpd	25 tonnes/km/year- 1981 trial[a]
Seattle USA (Roberts et al. 1975)	73 tonnes/km/year
Sehmel USA	8 tonnes/km/year[b]
Other reports from TRRL	60-300 tonnes /km/year
Kenya (Jones 1984a) 105 vpd (1983 trial)	33 tonnes /km/year[c]
Kenya (Jones 1984a) 111 vpd (1983 trial)	37.5 tonnes /km/year[c]
Kenya (Jones 1984b) no traffic	7mm wear/year due to rain and wind

Note:
vpd vehicles per day
a. 25-45% was retained on BS 10mm sieve
b. Possibly a paved road
c. All material passing 10mm sieve

Van Barneveld (1985) has summarised a variety of measurements from dustfall, including some of the results presented above. A wide range of values is evident, up to several hundredfold. Clearly, the characteristics of the road surfacing including the gradation and mineralogical properties of the dust are needed to more completely describe the rate of loss.

The OECD Working Group (Reichert 1987) find that, in Nigeria, Cameroon and Kenya for annual daily traffic (ADT) of 140, wear (loss of unsealed road surfacing materials) is between 1 and 3 cm per year.

A serious problem noted in Kenya (and applicable in other parts of the world) is the failure of the road maintenance authorities to recognise the extent of the losses caused primarily through dust. Generally the extent of necessary regravelling has been under-estimated, and the losses have not been fully recognised and quantified. The Kenya study (Jones 1984a) attempts to remedy this situation.

Figure 1 shows a measured relationship between vehicle speed and the total amount of dust deposited by the passing vehicle on a grid of trays adjacent to a Kenyan roadside. There is strong dependence on vehicle speed. Nearly all material fell within 7 metres of the roadside, but no significant wind was blowing during the trial. The report does not detail the dust particle size distribution.

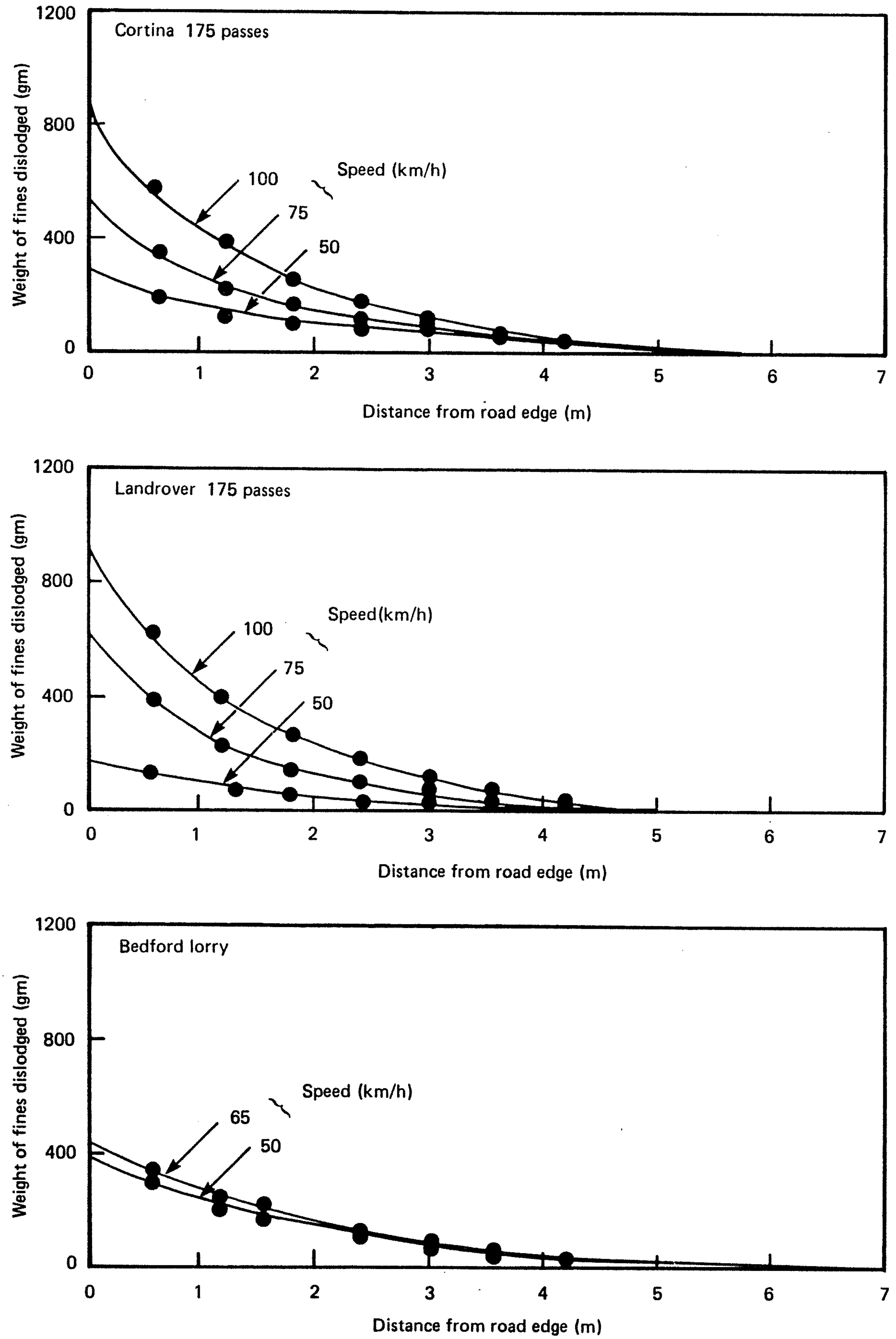

Figure 1. Distribution of dust generated by vehicles in Kenya (from Jones 1984a).

A note of caution is sounded by Paige-Green and Visser (1991) concerning the transportability of dust loss models that have been developed in a different environment.

The World Bank (1989) believes that the problem of dust loss is widespread and that the total cost runs into billions of dollars.

4. EFFECTS ON CROP YIELD

4.1 Effects on Horticulture in New Zealand

Within New Zealand, the distribution (Heinemann 1987) of specific horticultural crops is broadly as follows:

Fruit	Location
Apples, peaches, nectarines	Hawke's Bay
Citrus	East Coast and northwards
Cherries	Marlborough
Apricots	Central Otago
Wine grapes	Auckland, Poverty Bay, Hawke's Bay, Marlborough, Nelson
Kiwifruit	Bay of Plenty

In a study of the effect of dust in agriculture, McCrea (1984) considered the effectiveness on insect pest control, weed control, pollination, stomatal interference and plant disease. None of these effects was considered to be of significant economic consequence.

An indirect effect on yield is likely through dust interfering with the retention of sprays, most of which are designed to be effective when retained on leaf surfaces.

In developing a model for the deposition of dust on plant surfaces, McCrea (1987) recognises the following factors as important:

- seasonality
- rainfall
- proportion only of dust which is intercepted by plant surfaces
- leaf type (hairy versus smooth)
- shelterbelts
- calculation of photosynthetic yield loss

However, it is possible that in some cases the effect of dust deposits on leaves is actually beneficial. Brown and Berg (1980) cite work by Everett (1977-78) in which the effect of road dust was shown to increase the plant leaf temperature. The resulting increase in productivity was postulated. McCrea (1984) notes that road dust in some instances may contain nutrients which can be taken up by plants through leaf surfaces. However it is considered that overall these fertiliser effects will be negligible on crop production.

Likewise, McCrea (1984) reports a result obtained in Israel (by Stanhill et al. 1976) which identified beneficial effects from dust. A deposit of kaolin (a clay mineral) on crop foliage during a drought over a three year period, reduced plant reflectivity and consequently reduced the ability of the foliage to release water vapour to the atmosphere.

On the other hand, a coating of road dust can lead to overheating of plant leaves (Eller 1977). This is in part related to a change in the spectrum of radiation able to be absorbed by the leaves. Only a small part of absorbed global radiation is used for photosynthesis and, if excess heat remains, the plant has to increase respiration. Respiration may increase much faster with rising temperature than does photosynthesis, so that the net photosynthesis and productivity are lowered.

Clearly, the effect of dust on plant productivity may or may not be beneficial and depends on:

- ambient temperature,
- nature of dust coating,
- the plant species.

The effect of dust on the dollar yield of crops in New Zealand is apparent when government regulations for export produce are considered (McCrea 1984). All produce for export, and its packaging, must be clean and free from disease and dirt. In general, there is the additional requirement that produce must meet prescribed standards as regards **colour**, among other things.

Colour is obviously affected if dust is deposited and not all fruit can be cleaned of dust by washing. For example, kiwifruit which is primarily an export crop has a hairy skin which cannot be washed in water or treated in any heavy handed manner to remove dust after harvesting. If the fruit is dusty it is rejected.

Ministry of Agriculture and Fisheries (MAF) have identified three levels of dust contamination: 20% rejected, 50% rejected, and over 80% rejected (Underwood and Sale 1990). The net loss to the grower given for each of these three levels per block of area equal to 0.4 hectares, is reported as $2070, $4675 and $7260, or 2, 5 and 7% respectively, in 1990 figures. However estimates of loss vary widely.

McCrea (1984) carried out an exercise to consider loss of production in a variety of horticultural industries, resulting from dust deposition where the road is adjacent to the productive strips. Results are in the order of 3% for the pipfruit industry but upwards of 10% for other fruit. McCrea found that predictions of kiwifruit loss can vary tenfold, but that a predicted loss of about 5% (near the bottom of the range) is probably more realistic. A similar estimate (5%) is deduced for blueberry production. The proximity of the garden to the unsealed road, and the depth of the plot near the unsealed road has to be postulated in producing such estimates. A loss of 1.8% is estimated for asparagus production, 3% for summer lettuce and 2% for winter lettuce production.

A summary table from McCrea (1984) (Table 47) is reproduced here as Table 1. A range of plot shapes (hectare per kilometre of adjacent unsealed road), and a range of dispersion of dust were considered. The results were an estimated five- to tenfold range of losses per kilometre.

Table 1. Possible costs per kilometre to major rural horticultural enterprises in Tauranga County

Horticultural Enterprise	Costs per kilometre		
	High	Medium	Low
Avocado	67,974	14,766	6,709
Kiwifruit	33,520	6,625	3,938
Blueberry	17,200	4,568	2,720
Orange	12,446	3,022	1,231
Winter Lettuce	11,532	2,388	838
Apple	7,238	2,078	848
Peach	6,548	1,676	690
Asparagus	5,244	1,417	651
Summer Lettuce	4,123	1,039	801
Pumpkin	910	306	-
Maize	722	240	78

McCrea (1984, p.61) reports an apple grower's estimate that 30% of his crop close to an unsealed road either could not be sold or was heavily downgraded by the Fruit Marketing Board. Inability to control mites and rot in the stem cavities was considered to contribute to this downgrading as well. McCrea cites work by Alexandrakis et al. (1979) which showed that dust inhibits the activity of beneficial insects (predators and parasites of insect pests) and resulted in an increase in the pest population near unsealed roads.

Another independent assessment results from an inspection carried out in 1981 by an advisory officer of the Fruitgrowers Federation and the Ministry of Agriculture (Waipa District Council 1981). Apple production from the first 4 rows of trees adjacent to an unsealed road was estimated at only 40%. A loss of between \$4000 and \$5000 per year was estimated. The loss per hectare depends on the shape of the hectare (long dimension parallel to adjacent road versus long dimension perpendicular to road) but, in any event, it is significant. Production loss was less from trees in rows more distant from the road.

The effect of dust settling on the leaves was considered to

- inhibit growth,
- reduce light absorption,
- prevent spray fixing.

As a result of dust being generated during construction of a road realignment in Nelson (Nelson Evening Mail, 7 April 1992), an orchardist reported that some apples were engrained with dust, with the result that some of the fruit may not have been able to be processed.

In order to mitigate the effect of dust on crops, NZ Railways Corporation was required by the Planning Tribunal (Butterworths Current Law 1991) to prepare a management plan that would enable it to quarry, with reduced dust emission, high quality stone ballast year-round on the Kapiti Coast in the vicinity of orchards.

At present, shelterbelts are widely used to protect crops such as kiwifruit and grapes from prevailing winds. These also serve to partially screen dust from the crops. In a recent advertisement in *New Scientist* (1992), it was noted that

> *"Tree leaves .. trap airborne dust particles which are then washed to the ground by rain.* ***It has been estimated that a beechwood extracts nearly five tonnes of dust per hectare per annum.*** *"*

4.2 Lead Emission - A Greater Hazard than Dust

On the densely trafficked motorways in the UK, Watkins (1991) reports evidence that suggests the highest accumulations of lead would be on median strips and up to 5 metres adjacent to the carriageway. These areas receive the most serious damage by lead. In an earlier publication, Watkins (1981) notes that, in the case of roadside plants in the UK, experiments have shown that 30-95% of lead may be removed by washing the leaves. Moreover, most lead is present merely as an inert surficial coating. Watkins considers that high levels of lead in the soil are likely to have much greater effect, since much greater quantities can be taken up into plants by their roots. However, the distribution of lead declines very rapidly with both distance from the road (tenfold within 5 metres) and with increasing soil depth.

4.3 Summary

In summary, the economic disbenefits of dust on crop yield are significant, and it would be reasonable to suggest that relative losses with crop type are as indicated in Table 1.

The economic disbenefits of dust are greater than of lead, particularly when the relatively low volumes of traffic operation on unsealed roads in New Zealand are considered.

5. EFFECTS ON ANIMALS

5.1 Effects on Animal Production

Probable losses in animal value reported by McCrea (1984) are:

- bovine pneumonia,
- lower weight gain related to ingestion of dust,
- worn teeth,
- pinkeye (blindness),

but he considers that none of these is likely to be economically significant.

McCrea suggests that milkfat yield can be reduced as a result of

- depressed pasture yield, and
- reluctance of cows to eat contaminated pasture,

and that a 1-2% reduction in yield results.

He speculates that a 1% loss in lambing rate also results for similar reasons. Reduction in yields for animal production are summarised in Table 2 taken from McCrea.

Table 2. Possible costs per kilometre to major rural animal enterprises in Tauranga County

Animal Enterprise	Costs per kilometre		
	High	Medium	Low
Dairying	712	356	144
Sheep	250	150	50
Beef	250	150	50

These reductions are clearly of a much lower order of loss than those estimated for fruit (Table 1).

5.2 Animal Distress during Transit

The possible economic loss caused by animals becoming distressed during transit on unsealed roads in Australia has resulted in wind tunnel testing to improve the transport environment (Town and Lapworth 1990). Distress of animals is considered to result from progressive dust inhalation. Stress shows through an increase in meat pH (alkalinity), causing "dark cutting" meat), and reducing the economic return. Animals become agitated and in some cases go down causing bruising. Under extreme conditions, there are mortalities, further reducing the meat yield.

Although the authors do not estimate the proportion of the reduction of yield from dust per se, a total loss of $A47million is cited for bruising and "dark cutting" from all sources. The problem in Australia is exacerbated by the fact that animals are often conveyed in road trains, and the more remote the trailer is from the tractor the more dust is ingested by the animals carried in it.

It is considered that the economic loss of stock in New Zealand caused by ingestion of dust is much less severe than in Australia, as stock is not conveyed in road trains and distances travelled on unsealed roads are much less.

A separate estimate has been made of the disbenefit of dust on a basis of semi-trailer (and road train) per kilometre (Both and Bailey 1976). For the semi-trailer (applicable to New Zealand), a saving from the absence of dust on a sealed road is assessed as $A0.11 per vehicle kilometre. Assuming a haul of 80 km and 50 head of cattle per load, then the disbenefit per beast is $0.23 head[1]. This is hardly significant.

6. EFFECTS ON PEOPLE

"Respirable" dust is taken as less than 7μm and "total" dust as less than 60μm. Sampling carried out in 1985 at Handleys Road, Wanganui, showed that 22% of collected dust was respirable (van Barneveld 1985).

The Environmental Protection Agency were considering "passing 10 microns" as a standard mark for testing ambient air pollution in USA (Rosbury and Zimmer 1983).

In a study of dust suppression on mine haul roads (Rosbury and Zimmer 1983), the benefits included

> *"Improvement in air quality, resulting in fewer worker days lost and a cleaner environment."*

However, the benefit of improved air quality was considered "difficult or impossible to cost".

A study was undertaken of dust produced by road traffic in Seattle's industrial valley where about one quarter of the weight per unit volume of dust produced by vehicles was found to be respirable (Roberts et al. 1975). Both unpaved roads and dusty paved roads were studied.

The most significant benefit considered to arise from application of dust control was a US$1.9million saving in *cleaning costs*, and about one tenth of this figure would also be saved through reduced health costs. The increase in property values was about the same as the reduction in cleaning costs.

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1 Assuming an unsealed road of gradient 3% and roughness 150 NAASRA counts per km, then the cost of operating a semi-trailer in New Zealand is about $1.10/km (Transit New Zealand Project Evaluation Manual 1991). The disbenefit to the stock carried as a result of dusty conditions is therefore 13% of the vehicle operating cost.

Unfortunately, no population figures are given, and published census statistics do not identify the "Industrial Valley." Assuming a population of about 500,000 (US Dept of Commerce 1977), cleaning costs equate to about $US3.60 per person per year, and the health component a further $US0.40 per person per year.

This is a conservative estimate of the unit cost given that the range of potential population to be affected by dust is 500,000 to 1.4 million. Therefore, the health cost is not perceived as a major issue.

The disbenefit of lack of cleanness was reported (Nelson Evening Mail, 7 April 1992) during construction of the O'Connors Bridge to Maisey Road realignment in Nelson. Dust was reported to spread right through an adjacent house, and washing was hung inside to avoid the effects of dust. It should be noted, however, that the soil generating the dust was a natural soil, not the clay-bound granular material that normally is used to surface a sealed road. Further, the intensity of heavy traffic was greater than would normally be expected.

There is an absence of reliable data to indicate the level of economic cost to persons as a result of living and working in an environment containing dust from unsealed roads. However, the results from the study in Seattle, and the sparseness of the New Zealand population living adjacent to unsealed roads, indicate that the health disbenefit is not significant.

7. DUST COMPOSITION

7.1 Mineralogy

The effect of dust deposition depends to a degree on the composition of the dust. McCrea (1984) reports the observation made in Israel (by Stanhill et al. 1976) where application of kaolin dust to crop foliage during a drought period actually increased crop yield by 7 - 20% over a three year period.

If the "dust" is in the form of deposits of vehicle exhaust lead emission, then most of it (Section 3) does not act on the plant, once deposited.

7.2 Particle Size Gradation

Figure 2 compares the gradation of dust recommended by the US Bureau of Mines (1977) with that recommended in Road Research Unit Technical Recommendation TR8 (Ferry 1986). The similarity is striking. Of relevance in the context of this study is the recommended quantities of "dust", or material finer then 75 μm. Between 10 and 20% of the total quantity is recommended. This contains the clay fraction considered necessary to bind the granular material together but which clearly contributes to dust. The contribution is particularly significant when this clay-size material is non-plastic. Hence, the perceived need to confirm plasticity in preparing a surface course for unsealed roads using the Plasticity Index.

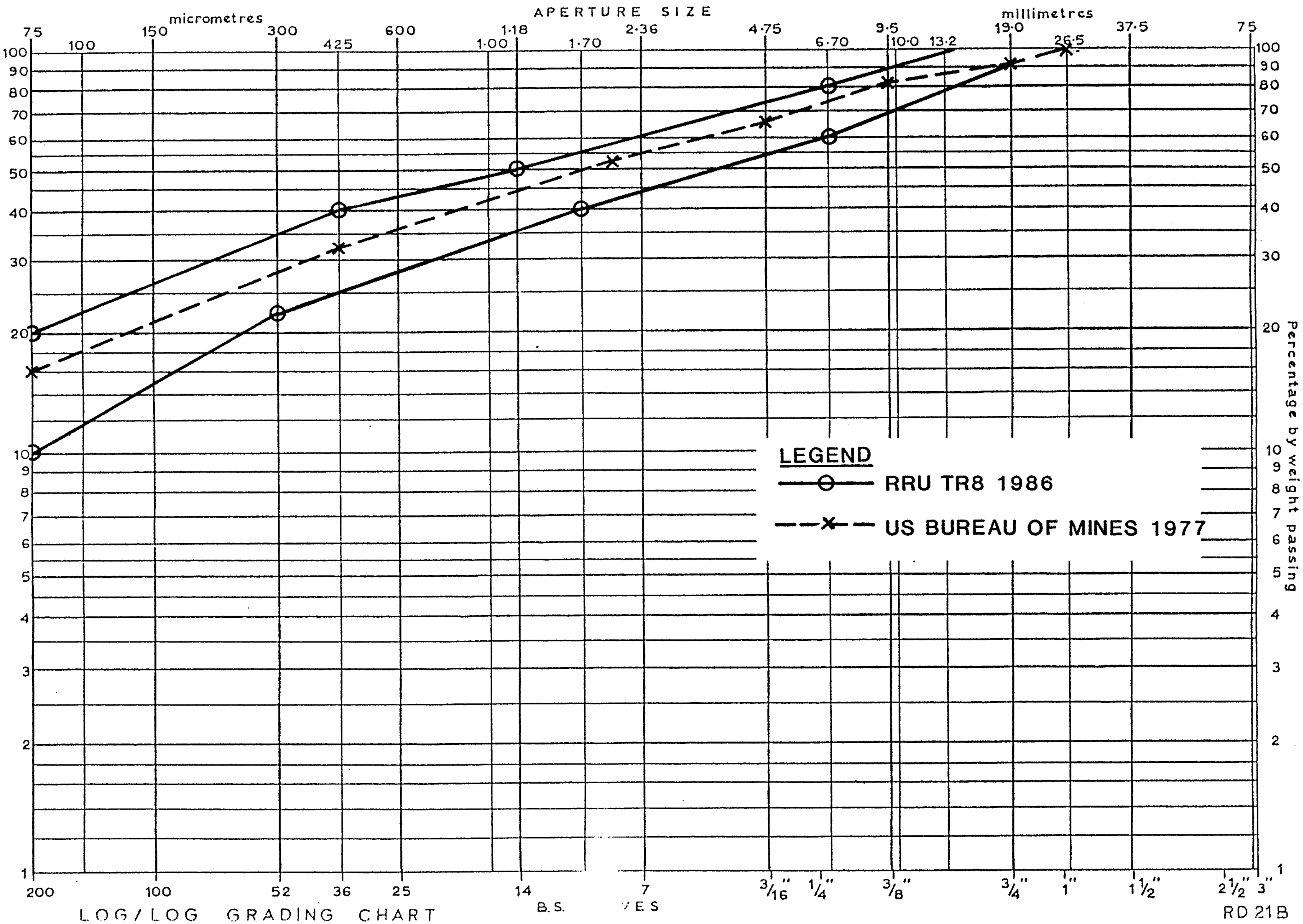

Figure 2. Comparison of surface course gradations for unsealed roads.

Walker (1991) considers that the severity of dusting is affected by grade of gravel, weather and traffic. The removal of fines from the road as dust can be an indicator of future maintenance problems and the presence of loose large aggregate on unsealed roads is attributed to the loss of fines. This is a driving hazard and affects drainage.

Handy et al. (1975) concluded that relatively dustless construction results from:

- the soil aggregate including clay binder,
- carefully proportioned grading of the crushed rock and fines to give good mechanical interlock.

Aggregate replacement needs are considered to be an indirect measure of dusting. Handy et al. (1975) believe that 80% of 15 tonnes per kilometre of crushed stone are used as replacement material annually in USA for an estimated ADT averaging 40. This traffic figure is considered to be close to the ADT average for New Zealand's unsealed public roads, too. There are very few unsealed public roads in New Zealand where the ADT exceeds 100.

Jones (1984a), in considering cost-effective ways to mitigate the disbenefits of dust, observes:

> *"In most developing countries there are likely to be insufficient funds for surface dressing or chemical treatment on a large scale for many years and* ***any solution to the problem is more likely to be derived from improvements to the design specification of the gravel surfacing material.*** *In particular, on roads in arid areas more emphasis must be placed on ensuring that there is sufficient plasticity in the fines to achieve adequate cohesion with minimal reduction in strength."*

An OECD Working Group (1987) found that:

> *"the dry season favours ... the loss of fines and once the road materials has thus lost its cohesiveness it becomes more susceptible to corrugation."*

Both observations are complementary, and point to the need for plasticity in the fines component of surfacing course, achieved either by the use of cohesive clay minerals, or by retention of adequate water.

Hoover (1981) found that top course aggregate with an appropriate particle size distribution either with or without additives can reduce dust and thus reduce wear to low levels. At the same time it can reduce maintenance costs of blading and gravel replacement to the point where the benefit:cost ratio is attractive.

The foregoing references point to the prospect of benefits applicable to New Zealand unsealed roads if more constraint is placed on the performance of the materials specified for road maintenance.

Rosbury and Zimmer (1983) observed that variables affecting dust emission rates included the silt content of the surface material. It has also been found (Muleski and Cowherd 1987) that road surface silt loading is a reliable indicator of the relative effectiveness of some dust-suppressant chemicals, although most suppressants were relatively ineffective if the silt content was high.

8. EFFECTS ON STANDARD OF LIVING

The most evident effect on standard of living revealed is in the increase of household cleaning effort required (Section 6). This is particularly applicable to soft furnishings and to clothes.

The frequency of house painting does not appear to be affected by dust. While houses near unsealed roads often need repainting because of dirt deposits and the reduction in gloss after they are washed down, such problems also exist for urban dwellings away from unsealed roads. Thus, whether or not a house is near an unsealed road, a time of around five years is usual for the house-painting cycle.

The effect of dust on people's standard of living is therefore considered to be of only minor significance. The only data quantifying the effect on additional cleaning effort were the data from Seattle discussed in Section 6.

9. INSURANCE CLAIMS

Contacts with several agencies[2] elicited the information that no separable effect of dust has been perceived necessary in setting premiums for vehicle use on unsealed roads.

10. LOSS OF VALUE OF HOUSING AND LAND

The issue of reduction of land yield is considered in Sections 4 (Crops) and 5 (Animals) and is not further considered here, to avoid "double counting". Likewise, the cost of household cleaning (Section 6) is not considered.

The consideration remains whether or not a buyer of land and house would be deterred because access to the property was by a dusty road. The buyer most likely to be affected by such considerations is the purchaser of a "rural lifestyle" block. These blocks have grown in popularity in recent years. Indeed, it could be argued that, for some, the unsealed road is part of the attraction, possibly symbolising a desirable remoteness.

It is suggested that the presence of an unsealed road in the vicinity is not going to significantly reduce the benefits otherwise perceived by the buyer.

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[2] NZ Automobile Association, NZ Insurance Council; Royal Automobile Club of Queensland; Royal Automobile Association of South Australia; National Roads and Motorists' Association, Sydney

11. EFFECTS ON VEHICLE-OPERATING COSTS

Several organisations in other countries were contacted to find out if separate identification had been made of the effect of road dust on vehicle operating costs. No information was available from the New Zealand Insurance Council or the New Zealand Automobile Association.

Neither Australian Road Research Board Ltd nor the Canadian Automobile Association had persons knowledgeable on the subject.

Automobile associations in two Australian states also held no data, but indicated that dust would affect vehicle-operating costs in the following ways (Weller 1992, Simons 1992):

- increased damage and wear to tyres, suspensions, underbodies and exhausts,
- entry into vehicle boots and/or cabin areas causing more frequent cleaning and earlier deterioration of interior trims,
- ingestion by engine giving rise to more frequent replacement of the air filter and premature engine wear,
- entry into underbody and brake friction components, causing increased wear.

The National Roads and Motorists' Association (NRMA 1992) noted the difficulty of quantifying the severity of dust conditions. However, they considered that vehicle manufacturers normally recommended a more frequent servicing of particular components in dusty conditions. Specifically, oil changes should be made at 5,000 km intervals instead of at 10,000 km; servicing of the air filter could be reduced from a 40,000 km cycle to a 20,000 km cycle; and the effect was calculated to be an additional $A0.09 per kilometre in running costs.

Commenting on the effect of insurance and rental rates, NMRA believes that this is not a factor and, in fact, insurance rates in the rural environments (where dusty conditions can apply) are significantly lower than for City and Urban areas.

In New Zealand, the cost of running a car on rural roads (3% gradient, 70 kph) is 25.2 cents per km (Transit New Zealand 1991). This figure includes no provision for dust and most of the running is done on sealed roads. For exclusive use of unsealed roads, if a further 6 cents per km is added because of roughness (150 NAASRA counts per km - op cit, Table A2.15), a total running cost of 31 cents per km results.

If the Australian analysis is applied to the New Zealand situation, a dusty environment adds about 40% to vehicle operating costs because of the need for additional oil changes and air filters.

Further consideration of this very high figure is needed. In translating to the situation in New Zealand, recognition would need to be given to the fact that significant running in the rural environment is on sealed roads. In addition, the quantity of dust generated from

Australian roads is likely to be greater owing to the arid climate and the presence of ungravelled, unsealed roads.

12. EFFECTS ON TRAVEL TIME

The presence of air-borne dust can lead to reduction in speed, with consequent increase in travel time. However, much of the work done in this area relates to driving in *fog*. A summary of research on driving in fog is contained in Appendix 1.

There are two components which sum to affect the rate of loss of visibility of an object with distance in fog. These are reflected in formulae as a *scattering coefficient* and an *absorption coefficient*. The latter is relatively very low for fog, but higher for dust. On balance, there will be similarities between fog and dust on travel time.

These similarities will be particularly marked when the dust is present during several minutes of the drive, and when the dust is unlit from the sides of the road. This situation arises when an unsealed road is located between a tree line or in a gorge, to a lesser extent when there is no wind to disperse the dust (which will usually apply in the two situations described), and when driving at night.

Thus in some circumstances, dust will have a significant effect on vehicle travel time. However, we consider that the speed selected by the driver will be governed often by the relative lack of skid resistance on the road, a result of the unbound aggregate surfacing course, rather than by the presence of dust.

13. EFFECTS ON ACCIDENT POTENTIAL

A significant difference noted between fog and dust is that fog is not a suddenly occurring hazard: it is present over significant time, and arguably the driver has time to adjust to the conditions.

The reaction time of a reasonably alert driver in fog is about 1.4 seconds, but AASHO recommends 2.5 seconds as the total perception time for highway design use (this is for unalerted drivers, and includes a 1 second reaction time). Because drivers are presumably somewhat more alert when driving in fog, a perception reaction time of 1.8 seconds can be justified.

Statistics suggest that 1 - 3% of all accidents might have been prevented if fog could have been eliminated. For example, in 1969 1.7% of all casualties occurred in fog, and 0.8% occurred at night in fog.

The effect of fog causing fatal and serious accidents is not clear because the incidence of accidents in fog is relatively small. However the figures available show that the incidence of slight accidents in fog is significantly increased. Similarly, day-time accidents in fog are significantly **increased** while night-time accidents are **decreased**.

The increase in risk of accidents occurring because of dusty conditions is difficult to deduce from the studies in fog. As above, the incidence of accidents in dust is relatively small. Driving conditions on dusty unsealed roads include a lesser skid resistance than for sealed roads, and less predictable geometry. Hence, the speed of the vehicle is already limited, and the driver is likely to be more vigilant than when driving on sealed surfaces. Speeds therefore are likely to be less than when driving on sealed roads in foggy conditions.

On the other hand, the likelihood of **overdriving** (when the distance required to react and come to a stop is greater than the visual range) may be greater on a dusty unsealed road.

Conclusions about the increased risk of accidents because of dusty conditions are difficult to draw. The increase is likely to be small, particularly when traffic volumes and speeds are low as is normally the case. Moreover, insurance companies are not including an increased risk for lack of visibility in their calculation of premiums.

14. UNSEALED ROADS AND THEIR ENVIRONMENT IN NEW ZEALAND

Most of the literature reviewed in this study has been drawn from overseas, as required in the brief for the project. There are two main differences between the overseas situation and that applying in New Zealand:

1. New Zealand is a developed country, with relatively good unsealed roads compared to, say, many African countries.

2. The population density of New Zealand in rural areas is low.

Published data from New Zealand (Department of Statistics 1992) and the National Roads Board (1989) enable an approximate calculation of some areas where orcharding, market gardening and farming are important activities and could conceivably be subject to disbenefit from dust. The evaluation of the potential disbenefit of dust in these areas is shown in Table 3.

The "estimated" length of unsealed road included in Table 3 incorporates a reduction to account for remote areas where people, horticulture or animal stocks are sparse. The effects of dust on population, crops and stock in the areas identified depend on assumptions concerning proximity to unsealed roads as follows:

- 50% of population live near an **unsealed** road
- 20% of orchard areas are adjacent to unsealed roads
- 20% of stock have potential to be affected because of proximity to unsealed roads.

Within the limits of the assumptions above, the following observations can be made:

- A higher probability that people will be affected by dust in Bay of Plenty region than in any of the other regions considered.

- Crops have the highest risk of being affected in Bay of Plenty and in Nelson-Marlborough.

- Although fewer animals are in proximity of unsealed roads in Bay of Plenty, they are generally more expensive stock (town supply herds). Thus, there is no significant regional difference in the economic cost of dust to animals.

15. CONCLUSIONS

- Substantiated and quantified information concerning the economic disbenefit of dust is lacking.

- The disbenefit of dust on people's health is not considered significant in New Zealand.

- The disbenefit of dust on farm animals is not considered significant.

- Crop yield is significantly disadvantaged by dust.

- Vehicle-operating costs may be significantly affected by operating vehicles in a dusty environment.

- Accident risk is not likely to be significantly increased by dusty conditions.

Table 3. Important Areas of Productive Land in New Zealand[1]

Regions	Unsealed Road	Regional Population **Population affected per kilometre of unsealed road[2]**	Crop Type and Land Area **Crop land affected per kilometre of unsealed road[3]**	Stock Totals, Farm Area and Stock Units per hectare **Stock affected per kilometre of unsealed road[4]**
Bay of Plenty	1112 km	544,337 **Population affected: 224 persons/km**	Kiwifruit, horticulture, and subtropical horticulture established on former high quality dairy land. 15,000 ha **Cropland affected: 2.7 ha/km**	Stock: 1,406,000 Farms: 810,000 ha Stock Units/hectare: 1.7 **Stock affected: 252 stock units/km**
East Coast	3000 km (est)	196,022 **Population affected: 32 persons/km**	Market gardens and orchards near Gisborne, Napier and Hastings. Also important for pip fruit production and vineyards. 17,000 ha **Cropland affected: 1.1 ha/km**	Stock: 8,168,000 Farms: 1,670,000 ha Stock Units/hectare: 4.9 **Stock affected: 544 stock units/km**
Nelson-Marlborough	1000 km (est)	125,827 **Population affected: 63 persons/km**	Orcharding and market gardens. 10,000 ha **Cropland affected: 2.0 ha/km**	Stock: 1,541,000 Farms: 1,258,000 ha Stock Units/hectare: 1.2 **Stock affected: 308 stock units/km**
Central Otago and lower Taieri	2000 km (est)	190,245 **Population affected: 47 persons/km**	Orcharding especially stone fruit in Central Otago basins. Irrigation necessary. Market gardening in lower Taieri. 2,000 ha **Cropland affected: 0.2 ha/km**	Stock: 6,507,000 Farms: 2,121,000 ha Stock Units/hectare: 3.1 **Stock Affected: 650 Stock Units/km**

[1]FOOTNOTES:

1. Assumptions:
   a. 50% of population live near unsealed roads
   b. 20% of orchard areas are adjacent to unsealed roads
   c. 20% of stock have potential to be affected because of proximity to unsealed roads

2. Affected Population per km of unsealed road: $\frac{\text{50\% of population}}{\text{length of unsealed road}}$

3. Affected Cropland per km of unsealed road: $\frac{\text{20\% of land area}}{\text{length of unsealed road}}$

4. Affected Stock per km of unsealed road: $\frac{\text{20\% of stock}}{\text{length of unsealed road}}$

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APPENDIX 1. FOG

(i) Effect on a light source (Moore and Cooper 1972)

Allard's Law: $E = I/R^2 * \exp\{-\sigma R\}$
where E = illumination
I = intensity of light source
R = distance, and
σ = extinction or attenuation coefficient of fog

For example, the light source may be a headlight or tail light.

If $\sigma = 0.09$, this corresponds to dense fog where there is a 9% loss per metre travelled. A very large increase in light intensity is needed to substantially increase the visibility distance of a light source in such conditions.

$$\sigma = b + k$$

i.e. the sum of a *scattering coefficient* and an *absorption coefficient* (the latter is relatively very low for fog).

Fog may be considered as numerous small spheres blocking the path of the light source:

$$b = n\, k\, \pi\, d^2 / 4$$

where n = number of droplets per unit volume (usually 1 - 50 /cm^3)
k = scattering area ratio (normally $6 < d < 12\ \mu m$)

(ii) Effect on the visibility of a large object

Let the *object* luminance = B_o
the *background* luminance = B_o'
when effect of fog is negligible

Let the *object* luminance = B_R
the *background* luminance = B_R'
when the object is viewed from distance R in fog of attenuation coefficient σ

Then the *apparent contrast* (viewed from a distance R) is

$$C_R = \{B_R - B_R'\} / B_R'$$

and is obtained from the *inherent contrast* (the contrast viewed from close range)

$$C_o = \{B_o - B_o'\} / B_o'$$

from the equation

$$C_R = C_o * B_o'/B_R' * \exp\{-\sigma R\}$$

In daylight, when the background against which the object is seen is the fog itself, the latter equation reduces to

$$C_R = C_o * \exp\{-\sigma R\}$$

(When the object is a black object seen against the horizon sky, $C_o = -1$)

An attentive driver probably requires a contrast of at least 5% to detect a fairly large object. Then the value of R is known as the "meteorological viewed range," V, and

$$V \approx 3/\sigma$$

But predicting the viewed range of an object seen by a driver in the headlamp or foglamp beam is a complex procedure, involving

- the actual illumination on the object and its background (so as to derive the inherent contrast),
- the effect of the intervening fog in reducing the effective contrast as seen by the driver, and
- the effect of the back scatter from the headlight beam which produces a luminous veiling effect, further degrading the contrast.

It has been found that seeing distance with a fog-lamp cannot be increased indefinitely by simply increasing the intensity of the beam, for the effect of the scattered light becomes predominant.

It has been found (Kocmond and Perchonok 1970) that drivers reduce speeds in fog, but that the incidence of *overdriving* (when the distance required to react and come to a stop is greater than the visual range) increases. On the other hand vigilance increases, and a driver suspicious of an object ahead can probably reduce the time to react to about 1 second.

The authors do not find that the net effect of fog reduces the accident rate:

> *"The only source of germane information shows accidents to be less likely in fog. Even if one were to generalize these results, this still does not imply that accidents in for constitute a negligible problem."*

Interviewed drivers generally claimed that vehicles which they struck did not suddenly appear. The problem reduces to the quantum of information that the driver's decision-making process needs.

It was found that the visibility of tail-lights and turn signals is poor in daytime fog. In a night fog having a visual range of about 200 ft, the distance at which tail-lights can be seen is over 500 ft; the combination of tail-lights and turn signals can be seen at 670 to over 800 ft, depending on the lighting of the following vehicle. Visual distance is far more sensitive to vehicle lighting than to the lighting of the observer's vehicle.

(iii) **Effect of thick fog on traffic flow** (Codling 1971)

On the A4 near London Airport, traffic was 20-40% below normal on four foggy weekdays, and 40-60% below normal on a foggy Saturday and Sunday respectively. Similar reductions were observed on other roads.

The effect of fog on fatal and serious accidents is not clear because of the small numbers involved. Incidence of slight accidents significantly increased: day-time accidents significantly **increased** while night-time accidents **decreased**.

APPENDIX 2. MEANS OF REDUCING DUST LOSS

Several studies have been carried out exploring the effectiveness of various dust palliatives. A relatively recent and major study is of interest because it has been undertaken in a developed country (Hoover 1981). This study is directed particularly towards local unpaved roads in Iowa of which 70,000 miles were then unpaved. Various trials are described in some detail. Some 28 pages are given over to reviewing past work in US and by TRRL. One report quoted frequently was HR 151 dated 1973, which included the finding that "average dust generation from unpaved roads was found to be one ton/mile/vehicle of average daily traffic within a 1000-ft-wide corridor centred on the roadway".

Two primary application methods for treatments were reported from earlier work:
1. surface or topographically sprayed,
2. mix-in-place.

The relative merits of these two methods were investigated and in most cases and with most additives the mix-in-place method proved more effective. This not only achieved palliation but provided improved roadway surfacing, resulting in reduced maintenance costs.

It was reported (p.8):

> *"Of the projects constructed and observed during HR-151,* ***dusting was reduced from approximately one-third to more than 80% of that of untreated surfaces****, depending on method of treatment (see above).*
>
> *"**Aggregate pullout** (loose surface aggregate) was reduced to as little as one-fourth of that of the untreated soil/aggregate test road surface...., with the mix-in-place application effecting the greatest improvement. Thus, it was illustrated that dust could be controlled and annual aggregate replacement could be reduced by a factor of 2 to 4, the latter alone offering a potential annual cost saving of several thousand dollars per mile.*
>
> *"Reduction of dust and aggregate losses were also coupled with significant reduction of normal weekly to monthly blade grading for the palliation sections, and generally no blade operations were required on the mixed-in-place applications, a definite maintenance cost saving."*

As regards rate of loss of aggregate:

> **"The best mix-in-place section lost rock at the rate of 3.3kg/km/vpd/year, while the worst surface applied aggregate section lost 2185 kg/km/vpd/year or more than 600 times as much."**

This would appear to be a strong economic as well as environmental argument for improving aggregate surface roads by mixing aggregate and stabilising agent. The report notes that this treatment might have to be repeated every five years.

Clouston (1987) asserts that the economic effects of dust from unsealed roads "remain somewhat unknown and are best described as an intangible in any project evaluation". He reports that preliminary analysis being carried out by RRU Pavements Committee (1985) suggested that different gravel roads surfaces may vary by almost an order of magnitude in dust generation. Large variations are confirmed in the observations quoted above.

It should be noted that that is not sufficient to merely measure dust loss. A competent evaluation requires the use of control sections that are identically constructed except for the single variable, "non-treatment", because only then can the variable be evaluated. Where proper controls have been used, some surprising conclusions result: for example, *"the discovery that mixing in rock alone without any chemical additives is an effective palliation measure"* (Hoover 1981).

Thus, several techniques are available for reducing dust loss, not all of them chemical, and some have been tried with notable success in New Zealand.