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ENVIRONMENTAL STEWARDSHIP

Icy Road Management with Calcium Magnesium Acetate to meet Environmental and Customer Expectations in New Zealand

ALAN BURKETT
Transit New Zealand

NICK GURR
Opus International Consultants

Because of public concerns, the use of salt as a deicer for roads in New Zealand was discontinued more than 20 years ago, and icy roads have been managed since without the use of chemical deicers. In more recent years however, increasing customer expectations have demanded improvements to icy road management beyond the application of just grit or sand.

A proposal to reintroduce salt as a deicing chemical was rejected by road users and environmental groups.

Following investigations of alternatives, calcium magnesium acetate (CMA) was chosen as a suitable deicer and anti-icer that could meet the environmental concerns and be accepted by the road user.

CMA has been introduced gradually in various parts of the country and has been closely monitored for any effects on the environment. In particular, monitoring has taken place over the past 5 years in the central North Island, where operations are within a national park and world heritage area. During that time extensive testing of streams, soil, and vegetation has been carried out, and no significant effect has been observed.

CMA is a high-cost product, and so ice prediction technology is now being introduced to assist with managing its use on a just-in-time and in-the-right-place philosophy to ensure it is cost-effective, improves safety and efficiency for the road user, and minimizes any environmental concerns.

This paper summarizes the environmental monitoring of CMA in the central North Island, the results obtained, the benefits and costs involved, and management practices.

INTRODUCTION

New Zealand's temperate climate provides winter temperatures that generally do not remain below freezing during the day. This climate provides sometimes daily freeze-thaw cycles during the winter season with temperatures hovering around 0°C.

In 1995 storms closed a section of State Highway 1, the main north-south highway, in the central North Island for 9 consecutive days due to snow and ice. This section of highway is known as the Desert Road, and although closures each winter are common, the extended length of this closure raised substantial public concern. The previous winter, because of a fatality caused by ice, criticisms were levelled on the basis that the Desert Road was not closed soon enough.

Traffic volume on the main highways continues to increase, and more goods are being transported by road as a result of reducing regulation in the transport industry. Consequently, road users and communities have in recent times increased their expectation for higher levels of service on the country's highways.

Transit New Zealand's ability to manage winter storms better has been constrained by its existing ice management practices. Salt had been used in past years in some areas, although not extensively. However, its use was stopped in the late 1970s or early 1980s as a result of concerns, mainly from motorist groups.

Ice management practices were therefore restricted to the use of mechanical means to remove snow and cut down the ice layer as far as possible to the road surface. Abrasives in the form of grit or sharp sand were applied to improve traction until rising temperatures were able to melt the ice.

Gritting, however, has its own limitations in its effectiveness. There have been concerns over safety issues; under some circumstances this material can be just as dangerous as ice on the road to unsuspecting motorists.

As a result of public concerns following the mid-1990 storms, investigations into winter maintenance operations for the Desert Road were commenced and included a study of overseas practices. Among other things, this investigation recommended the use of a chemical deicer as being the most effective method of managing ice.

Consequently the reintroduction of salt was recommended. However the various motoring organizations expressed total opposition to the use of any chloride-based salt. The location of the Desert Road within a national park and world heritage area also meant that there was significant concern for the environment.

Following extensive research in to the various deicing chemicals available, it was found that calcium magnesium acetate (CMA) was the best suited because of its reduced effect on the environment and its noncorrosive properties.

New Zealand's environmental law (1) meant that formal consents were necessary to allow the use of a chemical for deicing purposes on the highway. The process also requires recognition of any cultural and spiritual concerns of indigenous Maori. Natural waterways and landforms are particularly significant to Maori.

Consents, covering discharge to water and land, were granted in October 1997 for a 5-year period covering five sites on the Desert Road. These were the most prone to icing and were frequently the sites that caused problems for motorists. The consents were to enable trials to be carried out, including extensive field monitoring, to determine the effects on the streams, soils, and vegetation. Further consents have been obtained since for extensive areas in the South Island based on the work undertaken on the Desert Road.

This paper outlines the environmental monitoring undertaken on the Desert Road over the 5-year trial period and discusses the results obtained.

CMA is a relatively high-cost, imported product. To ensure that it is used effectively and improves safety and efficiency for the road user and that the environmental concerns are minimized, managing its use on a just-in-time and in-the-right-place basis is important. The directions being taken and the technology being introduced also are reviewed.

POTENTIAL EFFECTS

In order to support the application for consent to use a chemical deicer, extensive investigations and consultation were carried out and an effects assessment was prepared. This work highlighted the following potential effects.

Soils and Groundwater

In normal agricultural soils, there are usually high levels of calcium and magnesium but in contrast, the generally volcanic soils of the Desert Road region have low levels of calcium and magnesium. The Desert Road soils also are low in organic matter and phosphorous and are acidic. CMA could therefore be expected to increase soil fertility with increases in calcium and magnesium as well as potentially increasing phosphorous levels. [Production-grade CMA is contaminated with phosphorous (2).] In addition there could be an expected increase in phosphorous and soil organic matter. Overall the effects of CMA on soils could be expected to be beneficial; however, the effects of any increased soil fertility on vegetation existing in the lowly fertile Desert Road alpine areas were unknown.

Terrestrial Vegetation

The Desert Road area experiences a relatively windy climate and therefore makes vegetation potentially susceptible to damage by airborne contaminants. It had been reported that CMA application on a number of plant species showed no discernible effects (2, *3).* It was considered that CMA applications at the levels expected were unlikely to cause any detrimental effects on roadside vegetation.

Streams

The depletion of dissolved oxygen (DO) from the degradation of the acetate component of CMA was the major water quality concern. Studies had shown that CMA decomposition exerted a significant biochemical oxygen demand on receiving waters *(3).* Stream life could be affected by depleted DO, and there was also concern about potential bacteria and fungi growth that could smother the streambed and increase the oxygen demand. This was of concern as the streams are nearly pristine and feed an internationally acclaimed trout fishery.

Although there was some concern over the potential effects on both soils and vegetation in the area, monitoring over time to determine cumulative effects was considered to be the most appropriate method for determining changes due to CMA application. The more significant concerns, however, were the apparent risks to streams.

DISSOLVED OXYGEN MODELING

As a consequence of the possible adverse effects identified by the investigation, a simple DO modeling exercise was carried out to determine stream responses for the five areas identified on the Desert Road for chemical applications. There are various guidelines available that discuss DO levels in natural waters. In particular, environmental legislation requires that for water classified to be managed for aquatic ecosystems, fishery, or fish-spawning purposes, the concentration of dissolved oxygen shall exceed 80% of saturation concentration (J).

The streams in the national park have not been classified under the legislation, but because of their particular location it was considered that this level of protection was appropriate.

The results of the modeling suggested that at lower rates (10 gm/m^2) of CMA delivery to streams, the risk of DO depletion causing adverse effects on aquatic biota was negligible. However, with higher application rates, the model indicated that severe oxygen depletion might occur (4).

As a consequence of this assessment, further work was necessary to refine the inputs of the model.

Four streams on the Desert Road were chosen for the refined modeling study and site-specific information on temperatures, DO, stream depths, velocities, and background biological oxygen demand (BOD_5) was obtained.

The worst-case theoretical scenario providing the greatest risk to the streams was considered to be where multiple applications of chemical had been applied and was followed by a relatively short-duration, high-intensity rainfall event. The resulting runoff would then tend to slug dose the streams giving the greatest potential for any effect.

The total mass of chemical that would cause a 20% drop in DO under this scenario was determined as the critical burden. When the cumulative critical burden was reached, a significant run-off event would need to occur before further CMA applications could resume.

The smallest stream with a base flow less than 0.05 m^3/s indicated some risk of significant DO reductions with an estimated critical burden of just 35 gm/m^2 (4).

There was however a high uncertainty of two critical model parameters:

- The proportion of CMA applied to the road that washes into the stream and
- The time taken (duration) for the CMA to reach the stream.

To obtain realistic estimates of these criteria and to calibrate the DO model further, field-testing involving the application of CMA directly on the road was necessary. At this point a consent was required for on-road trials.

It was considered that with a precautionary approach adopted by commencing testing on the catchments of the larger streams, monitored information could be gathered to estimate the crucial model parameters. The testing also would monitor DO response in the streams and the results used to calibrate the model. Further model simulations could them be made to set safe application limits for the smaller streams and allow full-scale trials to be carried out on all catchments.

CONSENT APPROVEL

On the basis of the investigation and specific modelling analysis, consents were sought to initially carry out model calibration tests followed by a controlled trial at the five identified sites. Accepted as an integral part of the consent approval, an environmental management plan was prepared to cover the test and trial procedures, including the monitoring and operational requirements. In addition a community liaison group was established with representation invited from the major interest groups, including the Maori.

The purpose of the group was to receive information of the testing and trial monitoring results and provide feedback. This provided a forum for discussion of important issues, so that the interested parties could gain a greater understanding of the trial and appreciate others points of view. The consent was granted for a 5-year period to carry out model calibration tests initially and then full-scale on-road trials based on critical burdens derived from the modeling.

FIELD CALIBRATION

The calibration test criteria required that ground temperatures be below zero (freezing) to minimize the loss of chemical due to infiltration into the soils on the flow paths to the stream. CMA was then to be applied over a measured road area at a predetermined rate and then washed from the road by water tankers simulating a short high intensity rainstorm.

Stream samplers and DO probes were placed downstream of the test site, and measurements were taken following the washing of CMA off the road ( ). The measured drop in DO as a result of the CMA inflow would be used to calibrate the model and then refine the determination of the critical burden for each stream catchments. Should the test not provide the required results, then-based on the precautionary approach-the stream with the next lowest flow rate would be the subject of testing and so on until a result was achieved and the model able to be calibrated.

The tests on the larger streams indicated that the prediction of critical burden was conservative. As a result the smallest stream was then tested but with changes to the test procedure. To avoid having to spread the CMA on the road and then wash it off, the CMA was poured directly into the stream.

Testing began with 5 kg of solid CMA discharged directly to the stream over a 30-min period. Monitoring was unable to detect any discernible decrease in DO within the stream *(5)*. A second test was carried out with 12 kg over a 30-min period. Again there was no evidence of DO depletion.

Two further tests were carried out. The first involved 15 kg of dissolved CMA applied over a 15-min period, and the second, 32 kg of dissolved CMA applied over a 10-min period. Neither test indicated any effect on stream DO (6).

All four direct tests on the stream were carried out in the summer period, stream bacterial populations normally would be expected to be at their highest and with the greatest effect on oxygen demand.

The tests carried out did not provide the results required to enable the DO model to be calibrated and therefore provide a confident assessment of the CMA critical burden that would ensure that the DO depletion in each stream would not exceed the 20% limit set by the resource consent.

With the lack of results it was thought that there were insufficient bacteria in the streams to consume the CMA to the extent required to affect DO. The streams are of pristine nature with relatively cool water temperatures measured at a maximum of 12 degrees during midsummer and therefore suppressing the BOD_5 decay rate.

Feedback from the liaison group, however, gave the opinion that the bacteria needed to acclimate to the introduction of CMA as a food source, and the tests so far were insufficient in duration to allow this to take place.

The model was then refined assuming that an actual DO depression in the final test of 5% was reached given that the DO probes were accurate to ±3%. The BOD_5 decay rate was altered in the model to force it to predict a DO depression of 5% for the test.

The revised model then was used to predict the critical burden for the smallest stream. This resulted in a total application of 500 kg, equivalent to a rate of 110 gm/m^2 on the road, which could be applied safely before requiring a significant runoff event to wash the accumulated CMA from the road and surrounding soils. This maximum rate allowed realistic CMA applications on this area for the full-scale trials. The larger streams could therefore receive proportionally larger critical burdens.

This provided confidence that the risk of significant effect on the streams for the full-scale trials would be negligible.

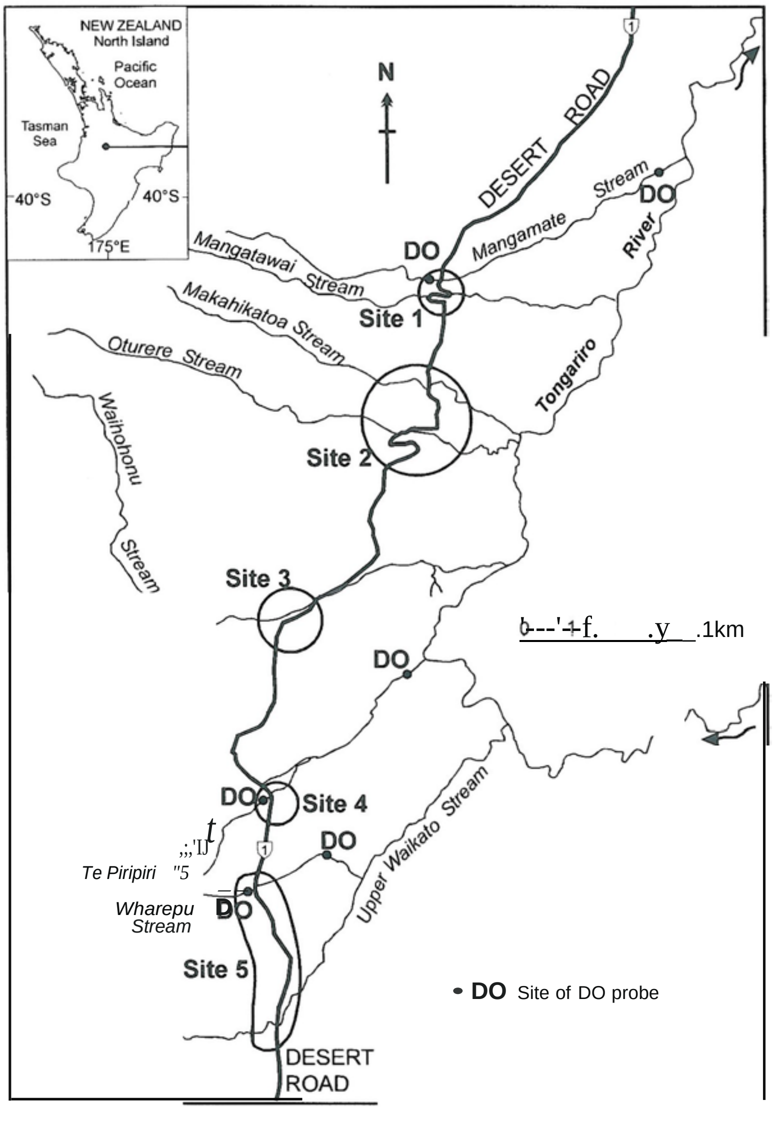

FIGURE 1 Locality plan, showing CMA trial areas (sites 1 through 5) and location of DO probes.

FULL SCALE ROAD TRIALS

Stream Monitoring

The first full-scale trials of CMA began in the winter of 1999. When snow fell or ice formed on the road, CMA was applied to the five trial sites. A range of monitoring was carried out, including the following:

- Continuous DO and phosphorous measurements upstream and downstream from the road on three different streams,
- TOC measurements in two streams during three separate rainfall runoff events (to provide further information on the concentrations of CMA entering the streams),
- Monthly assessments of invertebrates and periphyton and heterotrophic film cover on three streams upstream and downstream from the road, and
- Ancillary information gathering, including rainfall and stream flow recording.

Relatively mild winters were experienced in 1999 and 2000, and CMA was applied only on three and four occasions per year, respectively. Colder winters were experienced in 2001 and 2002, and a total of 13 and 12 applications were made each year, respectively (average application rate of 30 gm/m^2; total mass of 23 tons and 22 tons applied each year, respectively). It was concluded that in the monitored streams over the trial period there were

- No reductions in DO below the consent limit of 80% of saturation (DO concentrations remained above 90% of saturation throughout the study period). A typical result is shown in
- No detectable effects on benthic growths.

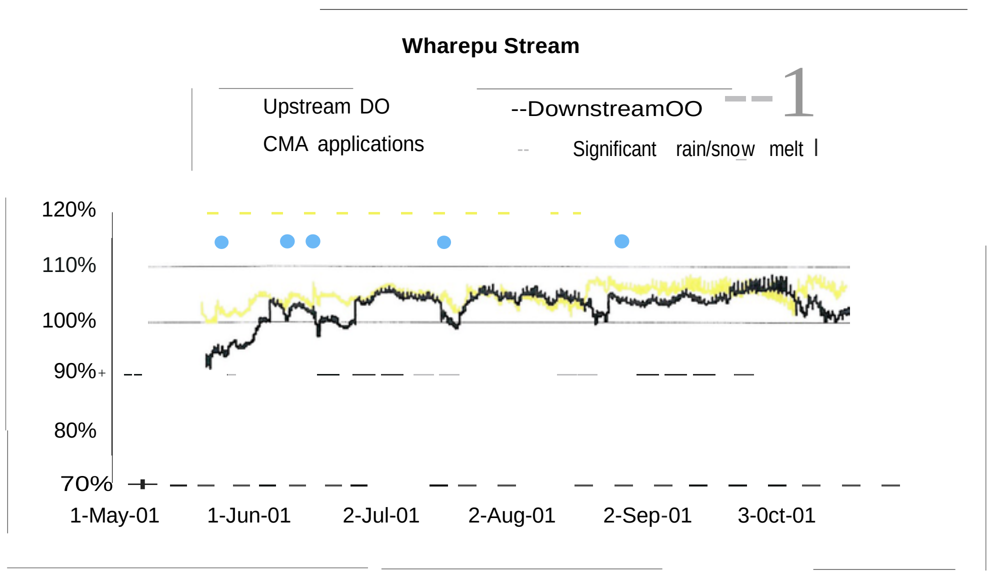

FIGURE 2 Typical result of DO monitoring at the smallest stream.

- No ecologically significant effects on aquatic invertebrates.
- Some short-term increases in TOC concentrations downstream from the road after rainfall (7).

Vegation and Soil Monitoring

Vegetation monitoring involved the establishment of 30-m transects at right angles to the highway on both sides of the road with one site in each of the four distinct vegetation areas within the trial areas, including beech forest, shrub-grassland, and fernland vegetation. The vegetation was checked monthly during the trial, and photographic records were kept. Soil samples were analysed annually for physiochemical changes.

No consistent pattern of change was evident in measured parameters in beech or tea tree forest or in fern land or grassland. Changes found in some plots in beech and tea tree forests were likely to reflect natural dynamic processes rather than the application of CMA to the adjacent highway. There has been no evidence that the application of CMA to the highway since 1999 has affected the health of the four monitored plant communities or of the individual species monitored within them (*8*).

No significant effect has been found in the soil chemistry. Increases in phosphorous and exchangeable calcium and magnesium were insignificant and decreases in values were as common as increases (*9*).

COSTS AND BENEFITS

The use of CMA provides substantial benefits over the traditional use of grit in terms of safety and effectiveness. Grit application is relatively inexpensive (US$63 per lane km per application), but there have been concerns raised regarding its use as it can create hazardous situations and expose motorists to additional or unnecessary risk. It also requires multiple applications to overcome the disbursement by vehicles and wind and the embedment into ice as the surface re-freezes.

CMA, conversely, is a high-cost, imported product. Application cost is about five times the cost of grit. CMA does, however, have the ability to maintain a residual effect; therefore the number of applications and the amount applied reflect this.

To provide a comparison of the cost and benefits of using CMA against grit, an assessment of the relative economic differences has been undertaken using a 25-year analysis period.

In the case of CMA these benefits are obtained through

- Reduction in accidents. The analysis of accident reductions is difficult because of the variability of the winters. To allow for this in a benefits analysis, the effectiveness of CMA at reducing ice-related accidents was treated as a variable.
- Decrease in travel time. The replacement of grit with CMA results in a net decrease in travel time when icy conditions are prevalent because of increased speed. Skid-resistance tests indicated a 24% increase in grip when CMA was used in place of grit and therefore provided a safer surface for motorists.

• Reduction in road closure durations. The most significant benefit to the road users is obtained through reductions in road closures. A network model to determine the effects on road users when the Desert Road is closed has been developed *(10)*. The model considered

- Vehicle operating costs,
- Vehicle occupant time, and
- Benefits lost because of canceled trips.

The reduction in road closures due to the use of a deicer or anti-icer is difficult to quantify, and so this factor also was adopted as a variable.

The benefit-cost ratio (BCR) of CMA is the ratio of the combined benefit streams (travel time reductions, accident reductions, and reductions in road closure durations) over the differential cost of CMA compared with gritting. In looking at the BCR of using CMA as a replacement for grit ( ), it is evident that CMA's greater costs can be offset by the increased benefits to the road users with just a small reduction in accidents or closures.

MANAGEMENT PRACTICES

The demand for improved levels of service and the use of a high-cost, imported deicer, necessary to meet the environmental and motorist concerns, has driven the need to introduce better management practices. As the affected areas of highway in New Zealand are dispersed widely throughout the network, varying levels of service are appropriate taking the use and remoteness of the highways into consideration.

The focus will be to keep high-volume tourist routes and strategic state highways open as a first priority level of service. It has been considered that because of the cost in terms of resources and consent compliance monitoring for the use of the deicer, only the first priority routes will receive chemical treatment. Other routes will continue with the traditional grit applications.

TABLE 1 Benefits-Cost Ratio Matrix

	Reduction in Ice and Snow Accidents with the Road Open											
[illegible]		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
	0%	0.38	0.42	0.49	0.57	0.64	0.72	0.79	0.87	0.94	1.02	1.09
	10%	2.18	2.21	2.29	2.37	2.44	2.52	2.59	2.67	2.74	2.82	2.89
	0%	3.97	4.01	4.09	4.16	4.24	4.32	4.39	4.47	4.54	4.62	4.69
	80%	5.77	5.81	5.89	5.96	6.04	6.11	6.19	6.27	6.34	6.42	6.49
	40%	7.57	7.61	7.69	7.76	7.84	7.91	7.99	8.06	8.14	8.22	8.29
	50%	9.37	9.41	9.49	9.56	9.64	9.71	9.79	9.86	9.94	10.01	10.09
	60%	11.17	11.21	11.29	11.36	11.44	11.51	11.59	11.66	11.74	11.81	11.89
	70%	12.97	13.01	13.09	13.16	13.24	13.31	13.39	13.46	13.54	13.61	13.69
	80%	14.77	14.81	14.89	14.96	15.04	15.11	15.19	15.26	15.34	15.41	15.49
	90%	16.57	16.61	16.69	16.76	16.84	16.91	16.99	17.06	17.14	17.21	17.29
	100%	18.37	18.41	18.49	18.56	18.64	18.71	18.79	18.8€	18.94	19.01	19.09

Getting resources to the right place at the right time is also an important factor in improving the levels of service. All highway maintenance services have been contracted out since 1989, and there has been a reliance on the experience and judgment of the contractors to determine when and where treatment was required. The specification for snow and ice treatment traditionally has been method-based. The use of a chemical also means that advantage can be taken of its ability as an anti-icer to improve safety and route availability in a more efficient and effective manner.

To assist road managers, road weather information stations, thermal mapping, and ice prediction forecasting now are being introduced.

Using such systems will provide road managers with real-time information about their network, an analysis of the various factors that give rise to icy conditions, and specific predictions for the network. This knowledge ensures that better-informed decisions will be made as to where and when to act and that the appropriate treatment will be applied at the right time at the right place.

These systems will be applied not only to the management of chemical application but also to gritting use, thereby minimizing the exposure of motorists to hazards.

Variable message signs and automated road open and close signs also have been installed to provide motorists with accurate and timely road condition information.

CONCL

Environmental monitoring of CMA use on the Desert Road has indicated that there have been no discemable effects on DO concentrations or biological attributes in the streams during the 5-year trial period.

There has been no evidence that the application of CMA has affected the health of vegetation and no significant effect has been found in the soil chemistry.

The environmental liaison group has not raised any significant issues of concern, and the success of the trial has been acknowledged through the granting of a further consent for an 11-year period.

In that time monitoring for an additional 5 years on a much-reduced scale will be undertaken to ensure that there will be no long-term cumulative effects.

So far the changes to management practices have been well received by the contractors and supported by the motorist organizations.

For the future every opportunity to stay informed about various initiatives in operations, products, research studies, and trials should be taken and every opportunity to keep aware of changing customer expectations should be implemented.

Benchmarking with others and applying best practices suitable for the New Zealand situation should contribute to obtaining acceptance by customers and society as a whole that this management of snow and icy roads is reasonable and effective and saves lives.

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