Endurazyme Trials on Unsealed Roads in Tararua District, New Zealand

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Executive Summary

Introduction

Endurazyme #388 is a proprietary bioenzyme stabiliser designed to allow greater use of marginal in-situ pavement materials. Tararua District Council investigated the use of Endurazyme #388 as a way to reduce the cost of maintaining their unsealed roads. Four trial sections of road were constructed in 1995 to evaluate the relative effectiveness of adding Endurazyme #388. The sections were monitored from December 1995 to December 1996.

Construction of Trial

Two of the sections were constructed and treated with Endurazyme #388.

The remaining two sections were constructed as control sections to provide a comparison. One of the control sections was constructed exactly the same way but Endurazyme #388 was not added. The second control section was a 50 mm-thick granular wearing course constructed to represent good practice for unsealed roads.

The cost of construction for the Endurazyme #388 sections was about $13,000 per kilometre. This compared favourably with the cost of $16,000 per kilometre to construct the 50 mm granular wearing course section.

Monitoring of Trial

A regular monitoring programme was undertaken, including visual inspections, roughness surveys, pavement wear surveys, dust monitoring, rainfall recording, and traffic counts. Maintenance costs for the trial sections were also recorded.

Originally, a research period of 3½ years had been proposed. Unfortunately, following periods of heavy rain, the pavement surface often became soft and slushy. Concerns about the slipperiness of the pavement, and the safety of motorists, led to the trial being terminated on 23 November 1996, 2½ years earlier than planned.

Performance of Trial Sections

Effect on Potholes and Corrugations

The addition of Endurazyme #338 may have had an affect on reducing potholes because the trial section without Endurazyme had more potholes during the trial. However the evidence is inconclusive because of the difference in the geometry of the two sections. Endurazyme $388 did not appear to have any significant effect in reducing corrugations or rutting in the trial sections of road.

Of the three pavement treatments that were trialled, the 50 mm granular wearing course in the granular wearing course trial section performed the best. Apart from a few potholes and a small area of corrugations, very few surface defects were observed.

Effect on Density (measured by Clegg Impact Values)

The addition of Endurazyme #388 had little or no affect on the density (or stiffness) of the top pavement layers, particularly during winter when the pavement materials were wet.

Effect on Level of Service (Roughness)
Generally, the trial section with Endurazyme #388 provided a better level of service than that without Endurazyme, and also had a lower roughness count. However, the section without Endurazyme had more potholes and corrugations which may be due to different geometry. Therefore the effectiveness of Endurazyme #338 in reducing the roughness is inconclusive.

The granular wearing course trial section provided a better level of service and its roughness remained at approximately 90 NAASRA counts/km, while the roughness of the other sections continued to increase.

Effect on Pavement Wear
An average pavement wear of nearly 25 mm was observed in the trial sections both with and without Endurazyme #388. The conclusion is that the addition of Endurazyme #388 did not appear to have any effect in reducing the amount of pavement wear in these trial sections.

The granular wearing course trial section also suffered a similar degree of pavement wear. As the granular wearing course was initially only 50 mm thick, heavy maintenance may be necessary in the future.

Effect on Dust Emission
Stabilisation of the pavement with Endurazyme #388 had a short-term effect in suppressing dust emission from passing vehicles and, by February 1996 (less than 3 months after construction), there was no noticeable difference in the level of dust between the trial sections with and without Endurazyme #388.

Overall, the 50 mm granular wearing course trial section had the lowest dust emissions from vehicles.

Effect on Safety
Trial sections with Endurazyme #388, and that without Endurazyme #388 all had periods when the safety was unacceptably low. Following rain, the pavement surface of these three trial sections would deteriorate, becoming soft and slushy. Concerns for road user safety led to closing the trial sections with Endurazyme, and to the termination of the entire trial in November 1996 (2½ years earlier than planned).

The granular wearing course section was the only section that provided safe passage for the entire duration of the trials.

Conclusions

It was not possible to conclude from this single study whether or not the addition of Endurazyme #338 had any significant effect on reducing potholes, corrugations or rutting, or reducing pavement wear. The addition of Endurazyme #338 appeared to have only limited short-term effectiveness in suppressing dust emissions from vehicles.

A preliminary cost-benefit analysis was undertaken to determine the relative cost-effectiveness of the three treatments that were trialled. However, as the trial ended after only 12 months, assumptions had to be made, including estimating the maintenance costs and level of service over the next two years.

The maintenance costs for the trial sections with and without Endurazyme #388 were found to be almost identical and, apart from a short-term reduction in dust emissions, their performance did not differ.

Overall, the 50 mm granular wearing course trial section, constructed to represent good practice for unsealed roads, performed the best having the lowest roughness and lowest long-term dust emissions.

It also gave a higher benefit/cost ratio than the Endurazyme #388-treated sections, and the maintenance cost for it was less than the other trial sections. Furthermore, the 50 mm granular wearing course was the only trial section that provided safe passage for the entire duration of the trials.

Abstract

Endurazyme #388 is a proprietary bioenzyme stabiliser designed to allow greater use of marginal in-situ pavement materials. Tararua District Council investigated the use of Endurazyme #388 as a way to reduce the cost of maintaining their unsealed roads. Four trial sections of road were constructed in 1995 to evaluate the relative effectiveness of adding Endurazyme #388. The sections were monitored from December 1995 to December 1996.

Two of the trial sections were treated with Endurazyme #388, one section was treated in the same way but without adding Endurazyme #388, and one section was a 50 mm-thick, granular wearing course constructed to represent good practice for unsealed roads.

Following periods of heavy rain however, the pavement surface on some of the trial sections became soft and slushy. Safety concerns resulted in the trials being terminated in late 1996, some 2½ years earlier than planned. It was not possible to conclude if the addition of Endurazyme #338 had any significant effect on reducing potholes, corrugations or rutting, or reducing pavement wear, except that it did reduce dust for a short period. The 50 mm granular wearing course trial section (without Endurazyme) had the lowest long-term dust emissions and the lowest roughness, and was the only section that provided safe passage for the entire duration of the trial.

1. Introduction

At 1995, 40% of New Zealand's public road network was unsealed, equating to nearly 37 000 kilometres (Transit New Zealand 1995). Unsealed roads are estimated to have an annual road maintenance cost in excess of $50 million. In addition to this there are increased road-related vehicle operating costs.

Many chemicals and proprietary products are claimed to enhance the performance of unsealed roads but have not been formally trialled in New Zealand. Examples of these include Polyroad, calcium sulphate (gypsum), calcium chloride, and sodium chloride (common salt). Some of these have undesirable side effects.

Another family of non-traditional stabilisers is the bioenzymes. Endurazyme #388 is an example of a bioenzyme soil stabiliser, which is developed as a by-product of the enzyme industry. The mechanisms of proprietary bioenzyme stabilisers such as Endurazyme #388 are commercially secret.

1.1 The Tararua District Situation

Tararua District, southern North Island, New Zealand, has nearly 2000 kilometres of public roads, of which over 40% are unsealed. Most of the roads in the Akitio (eastern) part of Tararua District are unsealed. There are few sources of aggregate in this region, and it is understood from preliminary examinations that the aggregate is generally of weathered argillites which may not be ideal for unsealed roads.

As at 1997, in the Akitio area, to supply and place a 50 mm layer of aggregate costs $10,400/km and, as re-metalling is usually undertaken annually, aggregate production and cartage costs are high. This has meant that alternative methods have been investigated by Tararua District Council to reduce the maintenance costs for their unsealed roads. In particular, the Council investigated means of modifying local materials, or in-situ pavement materials.

One of the alternatives investigated by Tararua District Council is a clay modifier known as Endurazyme #388. In April 1994, Tararua District Council trialled Endurazyme #388 on 1.5 kilometres of unsealed road. The performance of the Endurazyme #388-treated pavement appeared promising, so Tararua District Council sought Transit New Zealand subsidy for further Endurazyme #388 work in 1995. The Council's submission was considered in November 1994, and the following resolutions were passed to approve:

(a) *the request from Tararua District Council to carry out trials with the soil stabilisation product Endurazyme on selected sections of unsealed road (totalling some 10km), as eligible for financial assistance (based on estimated expenditure of $104,000) from within the currently approved basic programme;*

(b) *expenditure from the 1994/95 Research and Development budget to engage a researcher for this project; and*

(c) *the inclusion of World Enzymes Australia Ltd as the sole supplier of Endurazyme #388 to the Tararua District Council for the purposes of their trial of this material for stabilisation, in the competitive pricing procedures under Section 19 of the Transit New Zealand Act.*

1.2 Endurazyme #388

Endurazyme #388 is a proprietary bioenzyme stabiliser marketed in New Zealand by World Enzymes Australia Ltd. Endurazyme #388 is a liquid preparation, designed to allow greater use of marginal in-situ pavement materials by manipulating the chemistry of the clay particles. From the technical information provided by World Enzymes Australia Ltd, Endurazyme #388 is understood to :

- promote the formation of strong ionic bonds between clay particles;
- control the hydration/dehydration cycle by waterproofing the soil matrix against water infiltration;
- temporarily increase the workability of the soil.

1.3 Objectives

The purpose of this research project was to evaluate the relative effectiveness of the use of Endurazyme #388 on unsealed roads in the Tararua District. In particular, the trial investigated:

- the practicality of Endurazyme #388 construction;
- the relative costs of pavement maintenance;
- the relative cost-effectiveness of the trial sections of road;
- the effect on the level of service (roughness); and
- relative dust suppression.

1.4 Scope of Work

The scope of work for this project was as follows:

- to identify a length of unsealed road within the eastern Tararua District suitable for trial sections;

- to construct the trial sections in accordance with the instructions of the Endurazyme #388 manufacturer, and with good practice for unsealed road construction;
- to monitor the trial sections for 3½ years by regular visual inspections, roughometer surveys, recording of rainfall, survey of pavement wear, and traffic counts;
- to prepare a report addressing the objectives described in section 1.3.

2. Review of Current Practices for Unsealed Roads

2.1 Introduction

The usual materials used for unsealed road pavements are unbound aggregates. However, an increasing range of stabilisation options is becoming available for unsealed roads, and a review of road stabilisation was carried out by Hudson in 1996.

2.2 Unbound Aggregates

Traditionally, unsealed roads have been constructed using unbound aggregates (i.e. aggregates that have no added chemicals). The wearing course, and frequently also the basecourse, should comprise a well-graded crushed aggregate containing a proportion (e.g. 10%) of moderately plastic clay. The well-graded property provides stability, while the clay provides both cohesion against wearing under tyres and "waterproofing" of the surface. Smaller maximum aggregate sizes have been found to lower road roughness, and steeper crossfalls (up to 6%) are acknowledged to be important in reducing pothole development.

These aspects have been investigated and researched, including a range of trials, carried out in the mid to late 1980s, such as RM/14 (Vincent 1989), AEL 87/54 (Harrison 1987), RM/15 (NRB 1990), and RM/18 (Troon et al. 1989).

2.3 Lime Stabilisation

Experiences with lime-stabilised unsealed roads have been reported at the 1978 Stabilisation Seminar (Pickens 1979, Inglis 1979, Shapcott 1979). More recently Cook County has reported results from lime stabilisation of many of their unsealed roads (Elliot 1991, McDonald 1991).

2.4 Non-traditional Stabilisers

Heat stabilisation was used in New Zealand last century when wood fires were used to stabilise mudstones. It is no longer practised for roading as it needs cheap fuel, and the low thermal conductivity of clay makes it difficult to treat any substantial volume at one time (Ingles & Metcalf 1972).

Lignin derivatives have an affinity to silica surfaces, and form strong bonds with soils, particularly clays. Weslig 120 is a proprietary product based on lignin sulphonate. Although laboratory tests indicate that Weslig 120 is rapidly leached from treated soils, a number of trials on unsealed roads suggest Weslig 120 reduces pavement maintenance costs (e.g. Vincent 1986, Matheson 1989, Nolan 1989).

Reynolds Road Packer was trialled on unsealed roads in the late 1970s with little success (Dunlop c.1980). Arquad 2HT was also trialled, again with little success.

Numerous other chemicals and proprietary products have been claimed to enhance the performance of unsealed roads, but they have not been formally trialled in New Zealand. Examples of these include Polyroad, calcium sulphate (gypsum), calcium chloride, and sodium chloride (common salt). Some of these have undesirable environmental effects.

2.5 Bioenzymes

Another family of non-traditional stabilisers is the bioenzymes. Endurazyme #388 is an example of a bioenzyme soil stabiliser, which is developed as a by-product of the enzyme industry. The mechanisms of proprietary bioenzyme stabilisers such as Endurazyme #388 are commercially secret.

The general nature of bioenzyme stabilisers is to provide bacterial culture in an enzyme solution. When exposed to the carbon dioxide in the air, the bacteria multiply rapidly and produce large organic molecules which the enzyme attaches to the clay molecules in the aggregate, blanketing ion exchange points in the clay. This action prevents further absorption of moisture and results in a stable construction material. During the hydration that follows compaction, ion exchanges form linkages between the closely packed soil particles, providing the cementing bond. Full strength is reached within 4 to 5 days (Scholen & Coghlan 1991).

Some clay content is essential for the bioenzyme to react, and a well-graded aggregate with some clay provides the best performance. Clean crushed rock with no fines will not react (Scholen & Coghlan 1991).

3. Preparation for Trial

3.1 Site Selection

River Road, near Akitio (east of Pahiatua), Tararua District, was chosen as the site of the trial. While two sets of four trial sections were initially considered, each at a different location, the final decision to use only one set of four was dictated by financial constraints.

The site for the trial was chosen because:

- the road incorporating the four trial sections is relatively uniform in terms of gradient, alignment, width, climate, and traffic;
- the areas of road shaded from the sun by trees or cuttings are limited;
- the site had been programmed for Endurazyme #388 treatment by Tararua District Council.

The site for the trials was confirmed after World Enzymes Ltd had inspected both the site and the in-situ materials, and had formally confirmed the suitability of the soils for stabilisation with Endurazyme #388.

3.2 Specification and Contract

A comprehensive performance-based specification was prepared for the construction of the trial sections on River Road. The specification defined the factors to be controlled and measured by the Contractor during construction, and upper and lower limits on items such as the depth of stabilised material. The Contractor was responsible for monitoring construction and ensuring compliance with the specification.

The specification also detailed a significant amount of testing and verification to be done during and after construction. All testing was required to be undertaken by a TELARC-registered laboratory. Verification forms were provided which were to be completed on the site by the lab technician. These worksheets record details on the method of construction, and provide verification of compliance with the specification. Full details on the specification and specified verification are included in an earlier WCS report (WCS 1996a).

The contract was tendered and awarded in compliance with Transit New Zealand's Competitive Pricing Procedures (TNZ 1991). The contract was awarded to Tararua Roading Limited on 20 June 1995.

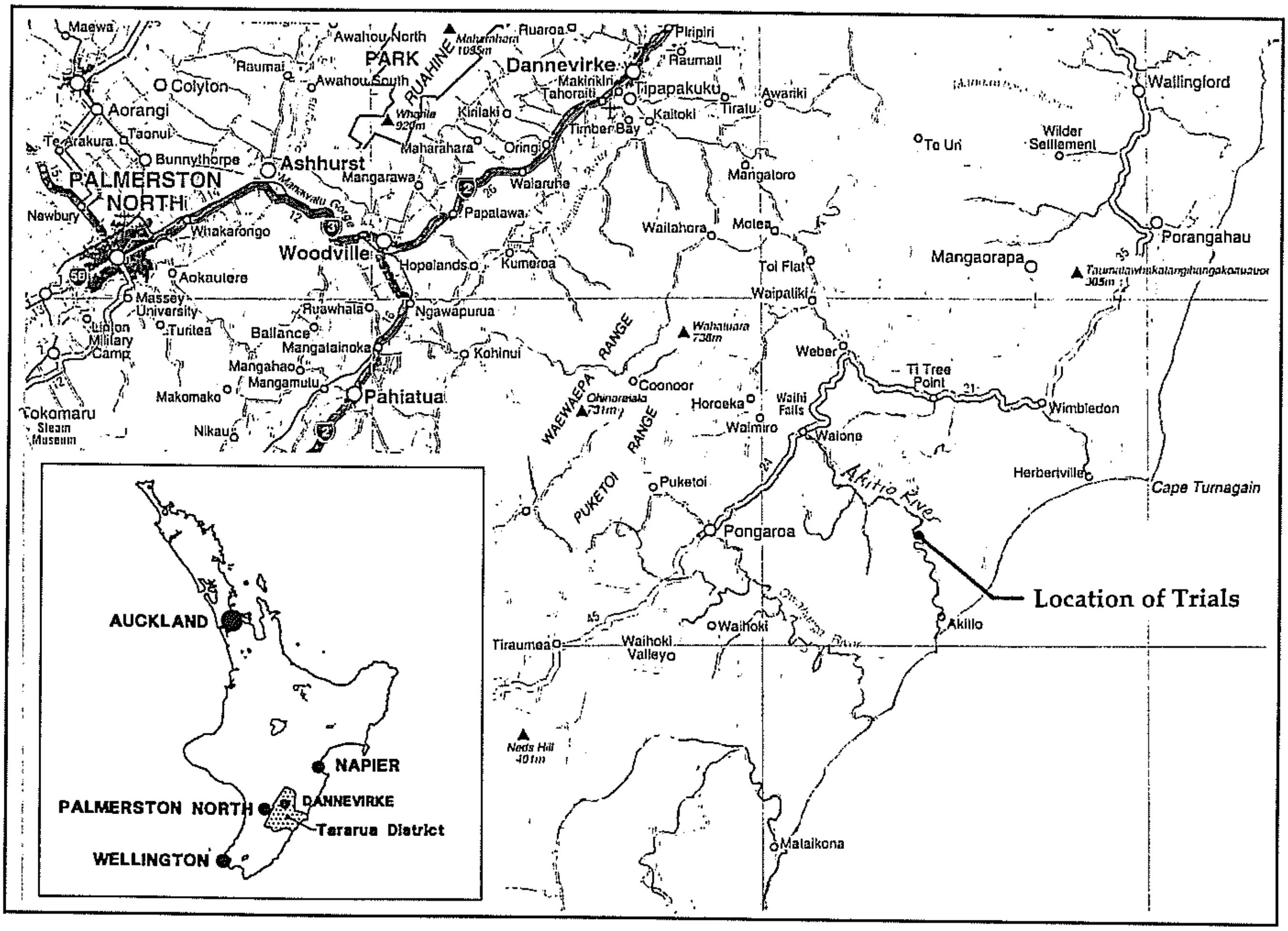

Figure 3.1 **Location of Endurazyme #388 trial sections on River Road, Akitio, in Tararua District, North Island, New Zealand.**

4. Construction of Trial Sections

4.1 Trial Sections

Four trial sections were constructed on River Road, Akitio, Tararua District, in November and December 1995. Full details on the construction of the trial sections are contained in a previous report (WCS 1996a). Table 4.1 lists the trial sections constructed as part of this research project.

Table 4.1 Details of road sections constructed for the trials.

No.	Location	Length	Width	Treatment
1	River Road RP 16.40 - 16.90 km	500 m	6.8 m	Endurazyme #388
2	River Road RP 16.90 - 17.40 km	500 m	6.8 m	No Endurazyme #388
3	River Road RP 17.40 - 17.90 km	500 m	6.8 m	Endurazyme #388
4	River Road RP 17.90 - 18.40 km	500 m	6.8 m	50 mm well-graded granular wearing course

RP - Reference Point

Trial sections 1 and 3 were stabilised with Endurazyme #388. As well as these two stabilised sections, two unsealed road control sections were also constructed for comparison. Construction of trial section 2 was identical to sections 1 and 3, except that Endurazyme #388 was not applied to the pavement material. Trial section 4 was re-shaped and overlaid with 50 mm of well-graded clay-bound granular aggregate, to represent good practice for an unbound, unsealed pavement.

The weather during construction was hot and dry. Although no specific data are available, the air temperatures were estimated to be well in excess of 20°C.

4.2 Construction of Trial Sections 1, 2 & 3 (with & without Endurazyme #388)

Construction of the first three trial sections took place on the 22nd, 23rd, and 24th of November 1995. The sequence of work followed for the construction of trial sections 1 and 3 was as follows:

1. form road to required crossfalls;
2. re-rip pavement to 150 mm depth;
3. apply Endurazyme #388 – water mix;

4. mix Endurazyme #388 – water mix into pavement;
5. compact and shape pavement;
6. apply running course (not carried out).

The construction sequence for trial section 2 was identical to that used for sections 1 and 3 except that the Endurazyme #388 was not mixed with the water that was applied. All technical requirements, testing and quality control requirements were identical* for the first three trial sections.

The Endurazyme #388 used in the trial was supplied by Tararua District Council who had purchased the product from World Enzymes Australia. It had a best-before-date of November 1996. A representative of World Enzymes was present during the construction of the Endurazyme #388 trial sections to ensure they were correctly constructed.

Details of the construction methodology are described below. For details on the machinery used during the construction, see the photographs in Appendix I.

4.2.1 Form Road to Required Crossfalls

During this initial stage of construction, the existing pavement was ripped and contoured with a grader to the finished levels and required crossfall. The surface was then lightly rolled and compacted using a pneumatic-tyred roller (PTR) and large vibrating roller.

Good crossfalls were recognised as essential to the performance of these trial sections, as they are to any unsealed road. Crossfalls of 5-6% on straight sections of road were specified, with a centre-peaked (non-flat) crown. On horizontal curves, a superelevation of at least 5% on the inside of the curves, but less than 10% on the outside of the curves, was specified. Transitions into curves were to be short but not abrupt.

4.2.2 Re-Rip Pavement to 150 mm Depth

After shaping the existing pavement to the specified crossfalls, the pavement was re-ripped to a depth of 150 mm with the grader to break up the lumps, and to provide a uniform pavement layer suitable for stabilisation.

4.2.3 Apply Endurazyme #388 & Water to Trial Sections 1 & 3

Once the pavement was formed to shape and re-ripped, an Endurazyme #388 and water mix was applied using water tankers fitted with pressurised water-spraying equipment. Special care had to be taken to ensure that the correct amount of Endurazyme #388 was applied uniformly over the whole pavement area. The correct application of Endurazyme #388 was the most challenging part of the construction sequence, requiring careful calculation and application of the Endurazyme #338 and water mix.

* No monitoring of Endurazyme #388 application rate was carried out for trial section 2 however.

The specified rate of application of Endurazyme #388 was 0.29ℓ/m³ **. The required quantity of Endurazyme #388 for each trial section was calculated, and then mixed with water for ease of application. The Endurazyme #388 was added to the pavement material in one application.

The Contractor was required to determine the optimum moisture content of the pavement material. For ease of workability during construction, and to ensure full compaction was achieved, the moisture content was to be kept 1%-2% below the optimum moisture content. This was recommended by World Enzymes and was easily achieved as the hot dry weather and intensive mixing of the material with the rotovator quickly dried the pavement material. Sufficient water was added and sprayed with the Endurazyme #388 to obtain this desired moisture content.

Before applying the Endurazyme #388–water mix, the Contractor undertook spraying trials to calibrate the spray rate of the tankers to ensure that the correct amount of Endurazyme #388 was applied. This was done by spraying a known volume of water and then measuring the area that volume covered. As the only way of adjusting the application rate was by changing the travelling speed of the tanker, several trial runs were required to determine the correct speed to achieve the desired application rate.

The actual application rate of Endurazyme #388 to trial section 1 was 0.25ℓ/m³, which is slightly lower than the specified 0.29ℓ/m³. However, as discussed below, the thickness of pavement material stabilised was only 140 mm, 10 mm less than that specified (150 mm). Consequently, the slightly lower than specified application rate was in part compensated as less material was stabilised. This resulted in an actual Endurazyme application rate of 0.27ℓ/m³. Although this is slightly lower than the specified application rate of 0.29ℓ/m³, the difference is less than 7%, which is considered to be well within the level of accuracy for this work.

The application of Endurazyme #388 to the first 250 m of trial section 3 was at exactly the correct rate. The second 250 m of trial section 3 was slightly over-dosed with Endurazyme #388 (0.31ℓ/m³ v the specified 0.29ℓ/m³). While the literature supplied by World Enzymes does not indicate the accuracy required for the application rate, their representative present during construction did not seem overly concerned about the lower and higher application rates achieved.

4.2.4 Mix Endurazyme #388–Water Mix into Pavement

Following the application of Endurazyme #388, the pavement material and Endurazyme #388–water mix were thoroughly mixed to a target depth of 150 mm using a rotary mixer.

During mixing, the pavement material was pulverised to a friable state by the rotovator to ensure maximum penetration of Endurazyme #388. This mixing by the rotovator

** 1 litre of pure Endurazyme #388 treats 3.5 cubic metres of compacted soil material.

ensured that the Endurazyme #388–water mix was uniformly distributed through the pavement material to the required depth.

Untreated material was not introduced to the stabilised pavement material during the mixing, and subsequent compaction and shaping.

4.2.5 Shape and Compact Pavement

Following mixing of the pavement material, the pavement was re-shaped with a grader and compacted. Compaction was carried out with a pneumatic-tyred roller and steel vibratory rollers. Because of the very warm weather, the pavement was lightly watered at regular intervals during the shaping and compaction phase. This kept the pavement material at the desired moisture content and helped bring the fines to the surface. The surface was not slurried.

The depth of stabilised material after compaction was also measured. The depth measurements were recorded for each 500-m section and compared with the specified depth of 150 mm ± 15 mm. The stabilised depth was calculated by measuring the difference in level between the undisturbed subgrade material (determined after mixing but before compaction) and the level of the final compacted and shaped pavement surface. An offset from a reference peg located on the shoulder enabled the two level measurements to be accurately determined.

Test results indicate that the average depth of stabilisation obtained was only 140 mm. While this was less than the target of 150 mm, it was still within the specified limits. At two locations (one in trial section 1, the other in trial section 2), the stabilisation/mixing depth was found to be only 130 mm. This was less than the minimum specified depth of 135 mm.

In the first 250 m of trial section 1, the pavement was mixed and compacted in approximately 2 m-wide strips. This methodology resulted in areas of poor compaction in the 'v' between each strip. This was caused by placing too much compactive effort in each of the rotary hoed lengths before mixing the adjacent length. The roller then bridged these areas to the adjacent compacted sections (Figure 4.1). Further trimming by grader and compaction was required to rectify the problem in this section.

Following this compaction, a Clegg Hammer was used to check for compaction consistency across the width of the road and, in particular, to confirm that the final compaction between the strips was similar to other parts of the road. Results of the Clegg Hammer testing showed that the grader trimming and compaction did rectify the initial compaction problem of trial section 1A. For further details refer to the detailed construction report (WCS 1966a).

Because of these problems, the construction sequence was adjusted in subsequent sections so that the whole width of the road was mixed by the rotary hoe before compaction commenced.

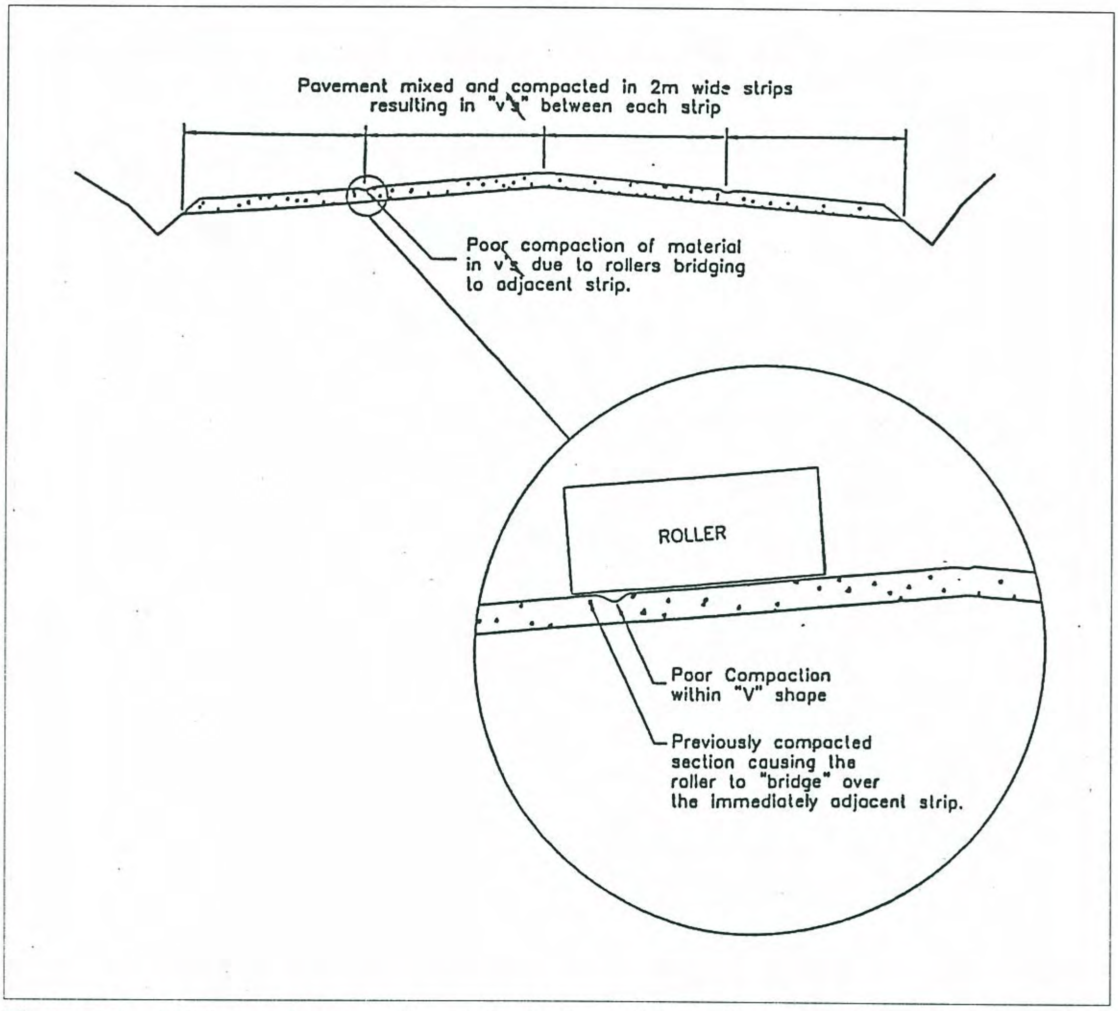

Figure 4.1 Mixing and compacting strips before mixing adjacent strip resulted in areas of low compaction between the strips.

Using the pneumatic-tyred roller directly after the first cut by the grader was found to give the best result. The pneumatic-tyred roller appeared to "knead" the pavement material, giving a better finished surface, and it also sealed in the moisture in the pavement.

The specification called for the pavement to be compacted to at least 95% of maximum dry density. The target maximum dry density of the in-situ soil for each trial section was to be determined from a series of single point compaction tests in conjunction with a full compaction test curve (NZS 4402:1986, SANZ). Full details on the process used is given in the construction report (WCS 1996a).

The purpose of the single point compaction test was to enable the laboratory technician to more accurately estimate the target dry density to be achieved before compaction started. To confirm that the target dry density had been achieved, a nuclear densimeter operating in back-scatter mode was used to monitor compaction effort. World Enzymes had previously advised that the presence of Endurazyme #388 does not influence the readings of the nuclear gauge. Testing was required at a frequency of not less than 3 tests per 50 m of road.

Table 4.2 summarises the compaction results. Field density measurements were taken immediately after compaction and again on 1 December 1995 (approximately a week after construction) to ensure the compaction target was achieved.

Table 4.2 Summary of compaction results for trial sections 1A, 1B, 2 and 3.

Soil Property	Section 1A§	Section 1B§	Section 2	Section 3
In-situ Moisture Content (%) (before hoeing)	6.85	6	5.7	5.3
Target Dry Density (t/m^3)	1.87	1.9	1.9	1.93
Actual Dry Density (t/m^3) (at construction)	1.84 (93%) (22/11/95)	1.90 (95%) (23/11/95)	1.84 (92%) (24/11/95)	1.83 (91%) (23/11/95)
Actual Dry Density (t/m^3) (following construction)	1.95 (99%) (1/12/95)	2.01 (100%) (1/12/95)	1.97 (99%) (1/12/95)	1.97 (97%) (1/12/95)

§ For practicalities of construction, trial section 1 was split into trial section 1A (first 250 m), and trial section 1B (second 250 m).

The target density of 95% of the maximum dry density was not achieved immediately following construction on any of the trial sections, except on section 1B. However, after one week, the density of the pavement materials had increased by 5% to 7% from those measured immediately following construction, and all trial sections finally achieved the specified minimum density.

Grader trimming and shaping of the pavement continued during compaction to ensure that the road profile was correct. Some areas with loose aggregate material on the surface were evident, especially in trial section 1. Fine cutting passes by the grader followed by re-compaction of this cut material and the application of extra water helped bed this material in.

Surface shape tolerances were specified to ensure that there was no point in the finished surface that varied more than 25 mm from a 3 m-straight edge placed either parallel to the centre line of the road (except within a vertical curve section), or at right angles to the centre line of the road. This was achieved throughout the four trial sections.

The crossfalls achieved following construction were measured using a "smart level". Crossfalls along straight sections of the road complied with the specified limits of ±5% to

6%. However, it was difficult to compare the measured values with the specified limits at curves, and at transitions to curves, given the changes in superelevation at these locations. In hindsight, a full survey and geometric design should have been undertaken so that the final crossfalls could be compared directly with the design crossfalls, including those at curves and at transitions to curves. While this may be beneficial for future research projects, the additional cost may be restrictive. Verification results are summarised in the earlier detailed construction report (WCS 1996a).

Based on a visual assessment, the surface was hard and smooth, and complied with the surface shape requirements. Overall the crossfalls appeared to be adequate.

4.2.6 Apply Running Course

The specification originally called for the application of a running course of Grade 4 sealing chip during final compaction of the pavement. However, following advice from the representative from World Enzymes, this stage was deleted from the contract as it was felt that sufficient granular material existed within the pavement to provide the grip and wearing characteristics necessary. Also there was concern that any loose chip would cut the surface under traffic and cause unnecessary wear.

4.3 Construction of Trial Section 4 (Granular Wearing Course)

Trial section 4, granular wearing course, was constructed on 7-8 December 1995. The sequence of work followed during its construction was as follows:

1. form road to required crossfalls, and compact;
2. supply well-graded aggregate;
3. place well-graded granular wearing course material, and compact.

The granular wearing course was intended to replicate good practice for unsealed roads, based on RRU Technical Recommendation TR8 *Unsealed Roads* (Ferry 1986). Further details on each stage of the work are given below.

4.3.1 Form Road to Required Crossfalls, and Compact

During this initial stage of construction, the existing pavement surface was shaped to 50 mm below the finished levels and crossfall, with a grader. The surface was then lightly watered and compacted using a steel vibratory roller.

As for trial sections 1 to 3, crossfalls of 5-6% on straight sections of road were specified, with a centre peaked (non-flat) crown. On horizontal curves, a superelevation of at least 5% on the inside of the curves, but less than 10% on the outside of the curves, was specified. Transitions into curves were to be short but not abrupt.

Before placement of the wearing course material, the crossfall and the superelevation on curves were checked using an electronic smart level.

4.3.2 Supply Well-graded Wearing Course Material

The specification called for a granular wearing course material having the properties that are recommended in RRU TR8 (Ferry 1986). A number of local sources of aggregate were investigated for their ability to produce a well-graded aggregate suitable for granular wearing courses. Following a number of trials and adjustments to the crusher at the Akaroa Quarry at Akitio, a material that almost fully complied with the RRU TR8 specification was achieved. Background to the selection and initial testing of the wearing course material is given in Appendix J.

4.3.3 Place Granular Wearing Course Material, and Compact

The granular wearing course was placed using truck and trailer units. In some areas the required 50 mm aggregate depth was achieved in one lift, while in other areas 3 to 4 lifts were required.

For the trial sections with Endurazyme #388 and without Endurazyme #388, the Contractor was required to verify the depth of granular wearing course. The tolerances on the wearing course depth were 50 mm ± 10 mm. The depth of the wearing course material placed was found to range from 45 to 60 mm (i.e. within the specified range), with an average depth of 50 mm.

The first 250 m of trial section 4 was compacted with the steel vibratory roller, then cut with the grader to achieve the desired crossfalls and overlay depth, and rolled again. On the second 250 m, the aggregate was spread evenly with the grader and then compacted with the steel vibratory roller. A watercart spread water almost continuously during grading and rolling of the wearing course.

In-situ compaction testing using a nuclear densimeter in backscatter mode found the average dry density of the wearing course to be 2.02 t/m^3.

Some segregation of the aggregate occurred. A seam of larger aggregate particles with insufficient fines to bind them was observed on the centre line. However, after several fine passes by the grader and plenty of water and rolling, the aggregate appeared to bed in.

5. Practicalities of Construction with Endurazyme #388

5.1 Experience and Advice

The Contractor had had experience with Endurazyme before these trials, as he had constructed nearly 6 kilometres of Endurazyme #388-stabilised unsealed roads in the Tararua District over the previous two summers. The representative from World Enzymes was on site for the construction of the two Endurazyme #338 trial sections (sections 1 and 3), and he provided valuable advice on construction with Endurazyme #338. Such advice is desirable for any contractor using Endurazyme #338 for the first time.

5.2 Determining Endurazyme #388–Water Mix

Construction of the two Endurazyme #338 trial sections was straightforward. The most difficult part of the construction sequence was determining the amount of Endurazyme #338 to add to the watercarts, and ensuring that Endurazyme #388 was added to the pavement at the correct rate and uniformly.

The volume of Endurazyme #338 to be mixed with water and applied to the pavement was not always easy to calculate. This was complicated during the construction of the trial sections by the decision to mix a full tank, but only use part of a tank for each section being constructed. Because the amount of Endurazyme #338–water mix left in the tank varied, the quantity of water and Endurazyme to be added to fill the watercart had to be estimated. This made it difficult to ensure that each portion of the road received the required dosage of Endurazyme #338.

5.3 Equipment

Except for the Sakai rotovator, all equipment used for construction was conventional road construction equipment that is owned and used by all roading contractors. It is understood that a grader can be used for mixing the pavement material instead of the rotovator.

5.4 Environmental Effects

According to the technical literature provided by World Enzymes, Endurazyme #388 has no effect on the environment, and has an insignificant level of toxicity making it harmless to humans, animals and plants. For these reasons no special precautions were taken, and no protective equipment was used when handling and working with Endurazyme #388, apart from rubber gloves and safety goggles. None of the people who worked with the Endurazyme #338 experienced irritations or any discomfort from the product.

6. Monitoring the Trial Sections

6.1 Monitoring Programme

Following construction of the trial sections, a regular monitoring programme was implemented to monitor, observe and record their performance. This included regular visual inspections, roughometer surveys, record of rainfall, survey of pavement wear, dust monitoring, and traffic counts. Maintenance costs were recorded separately for each section.

6.2 Time Line of Events

A number of significant events occurred in the first 12 months after construction of the four trial sections. These events led to trial section 3 being withdrawn from the trial in April 1996, and the termination of the complete trial in November 1996 (2½ years earlier than planned). A list of the significant events that occurred during the trial period follows.

24/11/95	Construction of trial sections 1, 2 and 3 completed.
24/11/95	Heavy rain caused deterioration of the running surface. Top surfaces of parts of trial sections 2 and 3 became very soft and very slippery. Deep wheel tracks, some over 25 mm, observed. Some minor softening of the pavement surfaces observed in parts of trial section 1, but not to the same extent as in sections 2 and 3.
25/11/95	Fine, warm weather dried the pavement sufficiently to allow the top surface to be re-compacted with a PTR and steel drum roller.
1/12/95	After a week of fine weather, the pavement surface had dried out completely and was again hard and smooth.
8/12/95	Construction of trial section 4 wearing course completed.
24-29/1/96	Period of steady rain. Pavement surfaces of trial sections 1, 2 and 3 again became soft and slushy (the last 100 m of section 2 and the first 200 m of section 3 were worst affected). Soft layer on the pavement surface was estimated to be 40 mm deep. Underneath this, the base still seemed to be reasonably hard. Concern for safety was expressed by locals. School bus was escorted through trial sections by a grader. Trial section 4 remained firm.
29/1/96	Decision made to spread grade 3 chip on trial sections 1, 2 and 3 to provide an armouring layer.

30-31/1/96	Trial sections 1, 2 and 3 re-graded to ensure 5% crossfalls, and re-compacted. Grade 3 armouring layer was placed at a rate of $5m^3/1000m^2$. Pavement re-rolled to embed the chip into the surface.
21-23/2/96	Period of heavy rain. Again, surfaces of parts of trial sections 1, 2 and 3 became soft and slushy; complaints received from the public. Trial section 4 remained firm.
23/2/96	Decision made to overlay the worst affected parts from RP 17.35 to 17.55 (i.e. last 50 m of section 2, and first 150 m of section 3).
11/3/96	Overlay of trial sections 2 and 3 from RP 17.35 to 17.55 completed. Overlay depth 50 mm. No further monitoring of this 200 m length was undertaken.
11/3/96	Heavy rain left the remainder of trial section 3 slushy and slippery. Again concern for motorists' safety. Trial section 1 and remainder of trial section 2 not affected to the same degree. Trial section 4 remained firm.
18/3/96	Decision was made to overlay the whole of trial section 3.
3/4/96	Overlay of trial section 3 completed. Trial section 3 withdrawn from the trial.
19/6/96	Maintenance of trial sections 1, 2 and 4 carried out: pothole patching in trial sections 1 and 4, and normal grading of trial section 2 to remove corrugations and potholes.
26/8/96	Maintenance of trial sections 1, 2 and 4 carried out: potholes patched in all 3 sections, and cut-off drains constructed at strategic locations in trial sections 1 and 4.
13/11/96	Trial section 1 was noted to be deteriorating. Rutting had increased to a significant level, and potholes and corrugations were developing. School bus driver concerned about the slipperiness of trial section 1 after bus had slid off the road and into the water table.
18/11/96	Due to concerns for safety, decision was made to overlay all of trial section 1 and the remainder of trial section 2.
23/11/96	Overlay of trial sections 1 and 2 completed. Trial terminated.

6.3 Rainfall

Rainfall seemed to be the biggest single factor influencing the performance of the Endurazyme #388 trial sections. Throughout the trial, rainfall data were collected at Akitio, approximately 2km from the trial sections (see Appendix A for details).

Overall, 1996 was a reasonably average year with a total rainfall of 1384 mm recorded at Akitio, compared with an average rainfall over the previous 10 years of 1397 mm. The winter and spring of 1996 were much drier than normal, with under half the average rainfall occurring. The exception to this was July which was an exceptionally wet month with rainfall well above average. The rainfall during the first half of 1996 (summer and autumn) was close to the average rainfall for these months recorded over the previous 10 years.

6.4 Traffic Volume

Traffic counts were carried out over four periods in 1996-1997, using automatic counters to determine the number of vehicles using River Road during the trial. In addition to the automatic counts, manual traffic counts were undertaken while on site for visual monitoring. These manual counts provide an indication of the composition of the traffic stream. The average daily traffic using River Road was found to be 72 vpd (vehicles per day) (see Appendix B for details).

7. Performance of Trial Pavements

7.1 Visual Monitoring

Visual monitoring of the trial sections was carried out every 2 months. Details of the visual monitoring procedure are recorded in a WCS report (1996b), and Appendix I contains photographs showing the performance of the trial sections.

Pavement conditions that were identified and noted during the visual monitoring of the trial sections included the following items:

1. Road surface moisture,
2. Pavement surface ravelling,
3. Potholes,
4. Wheel track definition,
5. Corrugations,
6. Camber.

During the visual monitoring, shoulders, water tables, and nearby paddocks were inspected for any environmental effects. Clegg Impact Hammer readings were also taken, and the road camber was measured. The following sections summarise the pavement performance over the trial period. Full details are in the summary report (WCS 1997).

7.1.1 Road Surface Moisture

For the first two months and again near the end of the trial, the surfaces of parts of trial sections 1, 2 and 3 were sufficiently soft and slushy to cause concerns for the safety of motorists. Trial section 3 was particularly soft, which led to it being overlaid and withdrawn from the trial only two months after construction. The wearing course on trial section 4 remained firm throughout the trial and appeared to be unaffected by moisture.

7.1.2 Pavement Surface Ravelling

Immediately following construction (December 1995), the pavement surface throughout the four trial sections was hard and very smooth. The grader driver commented, for example, that the Endurazyme #388-treated pavement was difficult to move when dry.

For the first 6 to 8 months of the trial, very little exposed aggregate was observed on the surfaces of the trial sections. The aggregate that was exposed had an average exposed stone height of 3-5 mm. By November 1996, exposed aggregate was present on the surfaces of all trial sections, with an average exposed height of 5-10 mm.

Very little ravelling was observed during the first 6 months of the trial. Areas of ravelling that were observed at one inspection were not necessarily present at the next inspection. Towards the end of the trial, the amount of ravelling that was present depended on the level of recent rainfall, and the amount of moisture within the pavement surface. When the pavement has hard and dry, ravelling of the surface was observed, but once the pavement became wet, any loose material became embedded into the surface again.

7.1.3 Potholes

Potholes were the most common defect requiring maintenance work in all four trial sections and were generally present in the transitions to curves where little or no crossfall existed. The number, and size, of potholes generally increased from one inspection to the next, until they reached a level where intervention was required and the potholes were repaired. Between the September and November 1996 inspections, the badly corrugated area within trial section 2 had changed to a badly potholed area.

Overall, trial section 2 (without Endurazyme) was the worst affected by potholes (e.g. in July over 70 potholes were counted, compared with 33 in trial section 1, and only 7 in trial section 4). However whether the difference in the number of potholes between trial sections 1 and 2 was related to the presence of Endurazyme #388, or to other factors such as geometry, is difficult to conclude. For example, trial section 2 had more curves, and hence more areas with no crossfall at the transitions into these curves where water could pond. The number of potholes within trial section 4 was always very low compared to trial sections 1 and 2.

7.1.4 Corrugations

Of the four trial sections, section 2 exhibited the greatest number and extent of corrugations. Within the first three months following construction, corrugations had developed over a 80-m length within trial section 2. These corrugations occurred in the left-hand outer wheel path, on the inside of a left-hand bend.

These corrugations were repaired by grading of the surface in June 1996. However by September, the corrugations were evident again, extending over the first 250 m of trial section 2, with an average depth of 15-20 mm. This gave a very uncomfortable riding surface. By November 1996 only 100 m of corrugation were observed, but the rest of the length that had been corrugated had developed into a badly potholed area.

Corrugations were also observed in trial section 4 during the September inspection. These corrugations were present over a 50-m length in the right-hand outer wheel path, on the inside of a left-hand bend. By November these corrugations had developed further, extending over a 70 m length of road, with an average depth of 25 mm.

No corrugations were observed in trial section 1.

Given that corrugations only occurred at locations where the road had a curve, it may be concluded that the development of corrugations is more dependent on the geometry than the pavement material. However, it may equally be argued that trial section 1 had fewer corrugations because of the addition of Endurazyme #338.

7.1.5 Wheel Track Definition

During the first 6 to 8 months of the trial, only minor rutting was observed and only in localised areas. By September 1996, rutting had become more serious and had occurred in all sections. Between the inspections in September and November, rutting increased significantly, and the maximum observed rut depth in November was 50 mm (an increase from only 25 mm in September). Almost all rutting occurred in the outer wheel tracks.

The November 1996 inspection found trial section 1 out of shape. The failure was not strictly rutting (i.e. it was not caused by non-recoverable compression of the subgrade), but was rather extensive shallow shear failures. Following recent heavy rain, the surface had become very soft and had been re-worked by passing vehicles.

7.1.6 Camber

Changes in the surface crossfall or camber were monitored every two months during the visual monitoring. Results showed that the camber did not change significantly between each visit.

7.2 Environmental Effects

The trial sections were monitored for any environmental effects that may have been caused by the three pavement treatments. The monitoring involved observations for:

- excessive dust which can cause reduced agricultural and horticultural productivity, and cause a nuisance for residents;
- silt which can harm aquatic life if washed into nearby streams;
- other effects on flora and fauna.

No effects on the environment were observed.

7.3 Clegg Impact Hammer Results

During visual monitoring, Clegg Impact Hammer testing was taken at three locations across the trial sections (left outside wheel path, inside (or middle) wheel path, and right outside wheel path). This was done at 100-m intervals within the middle 400 m of each trial section (see Appendix C for details).

The Clegg Impact Value (CIV) is dependent on the pavement moisture content. This was evident in all four trial sections as the measured CIVs reduced significantly between March and June 1996 due to additional pavement moisture.

While the CIV results do not provide an absolute measure of the pavement density or stiffness, they do, nevertheless, provide a useful comparison between the trial sections. In particular, it was anticipated that the CIV tests would highlight those sections that are more sensitive to moisture and hence show a greater reduction in surface density or stiffness.

Results showed no obvious difference in the CIV measured in trial sections 1 and 2, after the initial settling-down period following construction, indicating that the addition of Endurazyme #388 had little affect on the CIVs. The CIVs in trial section 4 were consistently higher than those for trial sections 1 and 2 (the only exception being one outside wheel path on 18 November 1996).

As a general rule, the CIVs measured in the inner wheel path were higher than the CIVs measured in the outer wheel paths. A possible explanation for this is that the pavement material in the inside (or middle) wheel paths was drier because of the migration of moisture towards the edge of the road.

7.4 Pavement Wear

Pavement wear was measured by surveying the middle 200 m of each trial section. Levels were initially taken on 17 January 1996 and then again on 19 November 1996. The difference in the levels gives the wear in the pavement. An additional survey was carried out on 2 April 1996 to measure the wear that had occurred before trial section 3 was overlaid and withdrawn from the trial (Appendix D gives details).

Table 7.1 summarises the average pavement wear that occurred in the three trial sections over the 12 month trial period. This assumes that the measured wear is in fact true wear, and not just settlement or consolidation of the pavement and subgrade layers. Wear was measured using standard survey methods and has an accuracy of ± 5 mm.

Table 7.1 Average pavement wear for trial sections 1, 2 and 4.

Section (treatment)	Average Pavement Wear	
	17/1/96 - 2/4/96	17/1/96 - 19/11/96
1 (with Endurazyme #388)	12 mm	23 mm
2 (without Endurazyme #388)	11 mm	26 mm
4 (with 50 mm granular wearing course)	9 mm	22 mm

There is little difference in pavement wear between trial sections 1 and 2, indicating that the addition of Endurazyme #388 has had no effect on reducing aggregate loss. A significant portion (approximately 50%) of the pavement wear occurred in the first 3 months. This is probably related to the initial settling down. No single wheel path suffered worse wear than the others. The measured pavement wear appears to be slightly higher than that predicted by the TRRL wear model (ARRB 1993), which suggests 12 to 19 mm wear can be expected for pavements with longitudinal gradient 1% to 5%.

Trial section 4 also suffered wear to a similar degree as trial sections 1 and 2. Assuming that the above measured wear results are not significantly influenced by settlement and consolidation, the depth of wearing course remaining in trial section 4 may now be minimal in places given that original wearing course depth was only 50 mm. Heavy maintenance would probably have been necessary on this section in the future.

7.5 Roughness

Roughness surveys of the trial test sections were conducted every 2 months using a calibrated NAASRA roughometer*** (Appendix E gives further details).

The roughness immediately following construction was remarkably low, averaging less than 60 counts per km. In the 12 months after construction the roughness increased steadily. (The only exception to this was the reduced roughness following the repair of potholes and corrugations in June 1996.) The October roughometer survey results show that trial sections 1 and 2 had an average roughness of nearly 120 counts per km (i.e. roughness had doubled in only 10 months). The roughness of trial section 4 had not increased to quite the same extent, averaging under 100 counts per km (up from 65 counts in February). Table 7.2 summarises the roughness data.

Table 7.2 Roughness counts for trial sections 1 (with Endurazyme), 2 (without Endurazyme), and 4 (50 mm granular wearing course).

Date of Count	Average Roughness (NAASRA counts per km)		
	Trial section 1	Trial section 2	Trial section 4
12 December 1995	47	70	*
26 February 1996	61	89	65
10 April 1996	80	100	81
17 June 1996	93	119	90
22 August 1996	111	105	86
14 October 1996	112	126	93
Ave Feb 96 - Oct 96	91	108	83

* Roughness of trial section 4 was not measured in December 1995 as the wearing course was not completed.

*** Roughometer calibrated in December 1994 by Works Central Laboratories (now Opus Central Laboratories) against a laser-fitted vehicle. Verification is carried out quarterly.

7.6 Dust Monitoring

To assess any reduction in dust resulting from the addition of Endurazyme #388 to the pavement, dust monitoring was carried out during the first 3 months of the trial (Appendix F gives details). Further dust monitoring was to have been conducted at 12, 24 and 36 months after construction, but this was not undertaken because the trials were prematurely terminated.

The level of dust given off by a passing vehicle was assessed by photographing an approaching car travelling in the usual wheel paths, at a constant speed of 70 km/h. The same car was used every time and the photographs were taken from the same position. Monitoring was conducted after at least 3 days with no rain, and only on days with little or no wind.

The amount of dust being produced by the passing vehicle was measured using visual assessment of photographs. The dust level was ranked as either nil, low, medium or high.

The addition of Endurazyme #388 to the pavement initially appeared to have some palliative action, as trial sections 1 and 3 had a lower level of dust than trial section 2. However, by February 1996 the dust palliative was no longer effective and no noticeable difference in the level of dust was observed between trial sections 1 and 3 with and without Endurazyme #388. Overall, the 50 mm aggregate wearing course of trial section 4 produced the lowest level of dust.

8. Costs of Trial Treatments

8.1 Construction Costs

An indication of the cost of construction of the trial sections is given in Table 8.1. These costs are based on an estimate of the number of hours operated, and typical plant hire rates (in NZ$ 1995). These costs are for the construction of a 500 m section.

Construction of each 500-m trial section took approximately 12 hours (1½ days) to complete.

The costs of establishment on site, traffic control, surveying and setting out, and testing of materials have not been included. The cost associated with the verification and testing which was undertaken during the construction of these trial sections is also not included.

Table 8.1 Costs of constructing the 500-m trial sections.

Section (treatment)	Construction Cost (NZ$ 1995)/500 m
1 & 3 (with Endurazyme #388)	**$6,600**
2 (without Endurazyme #388)	**$4,200**
4 (with 50 mm granular wearing course)	**$8,060**

8.2 Maintenance Costs

To investigate the relative cost-effectiveness of adding Endurazyme #388 to an unsealed pavement, records were kept of all maintenance carried out on the trial sections, and the associated costs (Appendix G gives details). This allows a comparison of the relative cost of pavement maintenance for the three different pavement treatments.

The repair of pavement defects within the trial sections were carried out in accordance with strict maintenance procedures (Duffill Watts & Tse Ltd 1995). Maintenance was only undertaken after approval from the Manager of Tararua Consultancy, and was always supervised by a representative from Tararua Consultancy.

Table 8.2 summarises the costs incurred in maintaining the three trial sections from December 1995 to November 1996. The addition of Endurazyme #388 to the pavement in trial section 1 had little or no affect on the level of maintenance expenditure.

Table 8.2 Costs of maintaining the trial sections.

Section (treatment)		Annual Maintenance Cost (NZ$ 1995) for entire section
1	(with Endurazyme #388)	**$1,001.60**
2	(without Endurazyme #388)	**$1,014.45**
4	(with 50 mm granular wearing course)	**$ 715.75**

Placing too much emphasis on these relative costs would be unwise, as they represent the maintenance costs for only the first year. In our opinion, maintenance costs need to be recorded over several years before any conclusions could be made regarding the relative cost of pavement maintenance of these trial sections.

8.3 Cost-Benefit Analysis

A cost-benefit analysis was undertaken in an attempt to compare the cost-effectiveness of applying Endurazyme #338 with constructing a granular wearing course to represent good unsealed road practice in New Zealand. Ideally, in order to accurately predict true life-cycle costs, the cost-benefit analysis should be based on pavement performance and maintenance costs that have been recorded over several years. Because these trials were terminated after only 1 year, full life-cycle costs are not available.

To maximise the use of information collated over the year-long trial and to help assess the cost-effectiveness of Endurazyme #338, the pavement performance and maintenance cost were estimated for future years. While this provides an indication of the benefit/cost ratio, the results are dependent on the assumed performance and costs over future years and costs, and is therefore somewhat subjective.

The addition of Endurazyme #388 to the pavement was found to have a benefit/cost ratio of 0.1. Construction of the trial section 4 granular wearing course, representing good unsealed road practice, achieved a benefit/cost ratio of approximately 0.3.

A sensitivity analysis was also undertaken to check the sensitivity of the assumptions that were made regarding the future roughness and maintenance costs. The benefit/cost ratios were re-calculated with vehicle operating cost savings and maintenance costs within a ± 25% range. The calculated benefit/cost ratios were found to be relatively insensitive to these changes in cost, and the granular wearing course consistently had the highest benefit/cost ratio.

Details of the benefit/cost ratio is given in Appendix H, including details of the assumptions made for ongoing maintenance costs and pavement performance.

9. Summary

9.1 Introduction

The trials described in this report were established to evaluate the relative effectiveness of the use of Endurazyme #388 on unsealed roads in the Tararua District, North Island, New Zealand. As the trials had to be terminated early because of safety concerns, no information on the long-term behaviour and effectiveness of adding Endurazyme #388 could be obtained. No attempt has been made within this report to examine or explain the reasons for the failure, as this was beyond the brief of this research project.

Nevertheless, the following conclusions about the effectiveness of Endurazyme #338 are drawn from the limited trials that were undertaken as part of this project. These conclusions may or may not apply to other unsealed roads in the Tararua District or other parts of New Zealand.

9.2 Performance of Trial Sections

Effect on Potholes and Corrugations
The addition of Endurazyme #338 may have had an affect on reducing potholes because trial section 2 (without Endurazyme #338) had more potholes during the trial. Trial section 2 also had more curves than section 1, and consequently had more areas with little or no crossfall, and hence areas where water could pond and lead to potholes. However the evidence for Endurazyme #338 in reducing potholes is inconclusive because of the difference in the geometry of the two trial sections.

Endurazyme did not appear to have any significant effect in reducing corrugations or rutting in the trial sections of road.

Of the three pavement treatments that were trialled, the 50 mm granular wearing course in trial section 4 performed the best. Apart from a few potholes and a small area of corrugations, very few surface defects were observed.

Effect on Density (measured by Clegg Impact Values)
CIVs measured on trial sections 1 and 2 indicate that the addition of Endurazyme #388 had little or no affect on the density (or stiffness) of the top pavement layers, particularly during winter when the pavement materials were wet.

Effect on Level of Service (Roughness)
Generally, trial section 1 provided a better level of service than trial section 2. Except in August 1996, it also had a lower roughness count than that of trial section 2. However, the higher roughness count in trial section 2 can be attributed to the higher occurrence of potholes and corrugations which, as discussed above, could be related to its geometry.

It is therefore inconclusive whether the addition of Endurazyme #338 reduced the roughness during these trials.

Trial section 4 also provided a better level of service. Although for the first 7 months of the trial the average roughness of trial sections 1 and 4 were similar, in the last 5 months of the trial, the roughness of trial section 4 remained at approximately 90 NAASRA counts/km, while the roughness of the other sections continued to increase.

Effect on Pavement Wear

An average pavement wear of nearly 25 mm was observed in both trial sections 1 and 2. The conclusion is therefore that the addition of Endurazyme #388 did not have any effect in reducing the amount of pavement wear in these trial sections.

Trial section 4 also suffered a similar degree of pavement wear. One of the wheel tracks within it showed an average of 33 mm wear. As the granular wearing course was initially only 50 mm thick, it is predicted that heavy maintenance may be necessary in the future.

Effect on Dust Emission

Stabilisation of the pavement with Endurazyme #388 had a short-term effect in suppressing dust emission from passing vehicles. The photographs of an approaching vehicle show that trial sections 1 and 3 produced a lower level of dust than trial section 2. However, the palliative action was only short term. By February 1996 (less than 3 months after construction), there was no noticeable difference in the level of dust between the sections with and without Endurazyme #388.

Overall, the 50 mm granular wearing course in trial section 4 had the lowest dust emissions from vehicles using the road.

Effect on Safety

Trial sections 1 and 3 with Endurazyme #388, and trial section 2 without Endurazyme #388 all had periods when the safety was unacceptably low. Following rain, the pavement surface of these three trial sections would deteriorate, becoming soft and slushy. Concerns for road user safety led to trial section 3 being withdrawn from the trial in April 1996, only 4 months after construction. Similarly, pavement deterioration and safety concerns led to the closure of trial section 1, and the termination of the entire trial in November 1996 (2½ years earlier than planned).

Trial section 4 was the only section that provided safe passage for the entire duration of the trials.

9.3 Economics

Almost no difference in the cost of maintaining trial sections 1 and 2 was recorded over the period of the trial. It is concluded that the addition of Endurazyme #388 to the pavement in trial section 1 had no affect on the level of maintenance expenditure. The granular wearing course of trial section 4 had the lowest maintenance cost.

A preliminary cost-benefit analysis was undertaken to determine the relative cost-effectiveness of the three trial treatments. As the trial ended after only 12 months, a number of assumptions had to be made, including estimating the maintenance costs and level of service over the next two years. The 50 mm granular wearing course treatment was found to have a higher benefit/cost ratio than treatment. While the assumptions made are somewhat subjective and alternative assumptions could also be justified, the analysis does nevertheless provide an indication of the likely cost-effectiveness of using Endurazyme #388 had the trial sections lasted more than one year.

9.4 Construction Verification & Monitoring Programme

The research programme devised for this project provides useful material for future researchers. Particularly relevant are the methods adopted for verifying pavement construction, including stabilising depth and pavement density.

Also of interest to future researchers was the monitoring programme. Although not required by our original brief, the report has indicated areas where these construction and monitoring procedures could be improved in future projects. Overall however, the methods adopted were both practicable (in terms of collecting data) and useful in drawing conclusions about the performance of the trial sections.

If the monitoring programme suffered in any way, it was the premature termination of the trials, leading to inconclusive comparisons on the economic performance of the trial sections. Improved methods for measuring, verifying, and comparing surface camber should be investigated.

While the trials were intended to investigate the costs and performance of Endurazyme #388 for unsealed roads, they also provided useful insights into the costs and performance of unsealed roads in general, and of unsealed roads representing good practice in particular.

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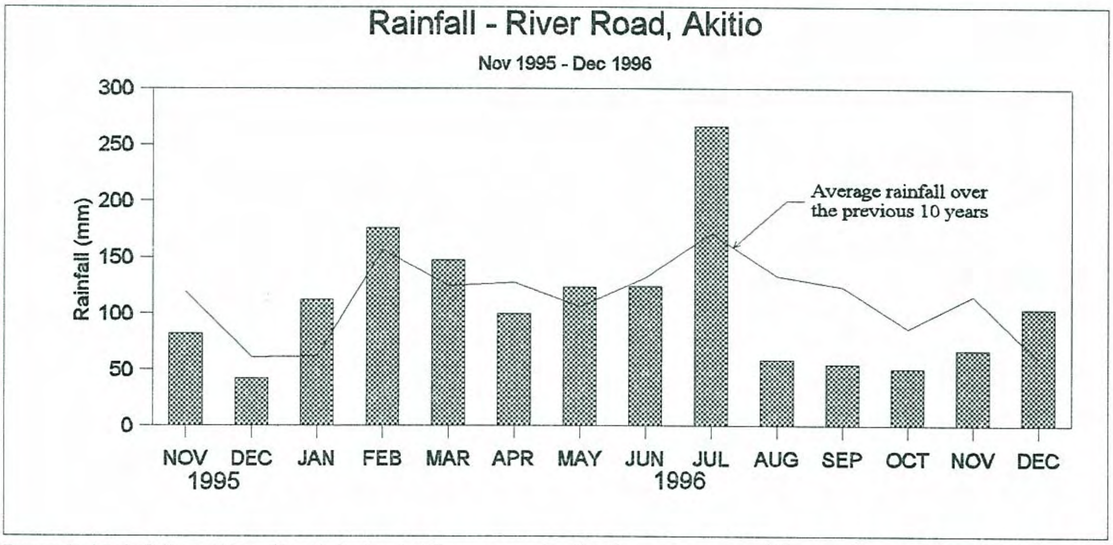
Appendices

Appendix A Rainfall Data

Rainfall Data			
Date	**Total Rainfall (mm)**	**No. of days with 5+ mm of rain**	**No. of days with no rainfall**
November 1995	82.0	5	21
December 1995	42.5	2	29
January 1996	112.0	7	17
February 1996	176.0	7	17
March 1996	147.5	6	18
April 1996	99.5	7	21
May 1996	123.5	7	17
June 1996	124.0	10	14
July 1996	266.5	17	7
August 1996	59.0	5	17
September 1996	54.5	7	19
October 1996	50.5	4	24
November 1996	67.0	4	18



Recorded rainfall on River Road during trial, compared with the average rainfall over the previous 10 years

Appendix B Traffic Count Data

1. Automatic Traffic Counts

Date	Duration of Count	Average Traffic Volume
May 1996	7 days	66 vpd
September 1996	7 days	84 vpd
November 1996	4 days	66 vpd
December 1996 - January 1997*	25 days	130 vpd
*Although this count was done outside the monitoring period, it gives a good indication of likely traffic volumes over the December 1995 / January 1996 holiday period.		

2. Manual Traffic Counts

In addition to the automatic counts, manual traffic counts were undertaken while on site for visual monitoring. These manual counts allowed the composition of the traffic stream to be determined. Vehicles were categorised as either cars, buses and rigid trucks, or articulated trucks and truck and trailers. The results of the manual traffic counts are given in the following table.

Date	No. of Hours on Site	Traffic Passing
December 1995	3.5	8 x cars
March 1996	2.5	5 x cars 1 x rigid truck 1 x articulated truck
June 1996	3.5	4 x cars 1 x rigid truck
July 1996	2.5	1 x cars
September 1996	2.0	2 x cars
November 1996	2.5	5 x cars 2 x rigid trucks

Appendix C Clegg Impact Values (CIV)

Wheelpath	Average Clegg Impact Value					
	21/12/95	28/03/96	13/06/96	24/07/96	23/09/96	18/11/96
SECTION 1						
OWP	37	51	24	27	49	46
IWP	48	50	25	25	55	47
OWP	33	39	23	22	49	40

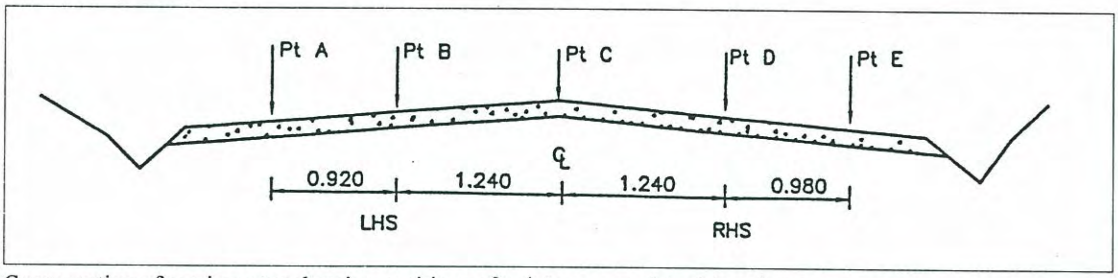
	21/12/95	28/03/96	13/06/96	24/07/96	23/09/96	18/11/96
SECTION 2						
OWP	49	52	25	25	50	35
IWP	53	52	25	25	46	34
OWP	49	50	21	22	49	36

	21/12/95	28/03/96	13/06/96	24/07/96	23/09/96	18/11/96
SECTION 4						
OWP	54	63	35	36	57	43
IWP	64	66	37	36	66	48
OWP	55	58	30	36	56	49

OWP outer wheelpath
IWP inner wheelpath

Appendix D Pavement Wear

Pavement wear was measured by surveying the middle 200 metres of each trial section. Survey benchmarks were established at 20 metre intervals, and 5 points across the road at each cross-section were levelled. The position of the 5 survey points is shown in the figure below. Levels were initially taken on 17 January 1996 and then again on 19 November 1996. The difference in the levels gives the wear in the pavement. An additional survey was carried out on 2 April 1996 to measure the wear in trial section 3 before this section was overlaid and withdrawn from the trial.



Cross section of carriageway showing positions of points surveyed to determine pavement wear.

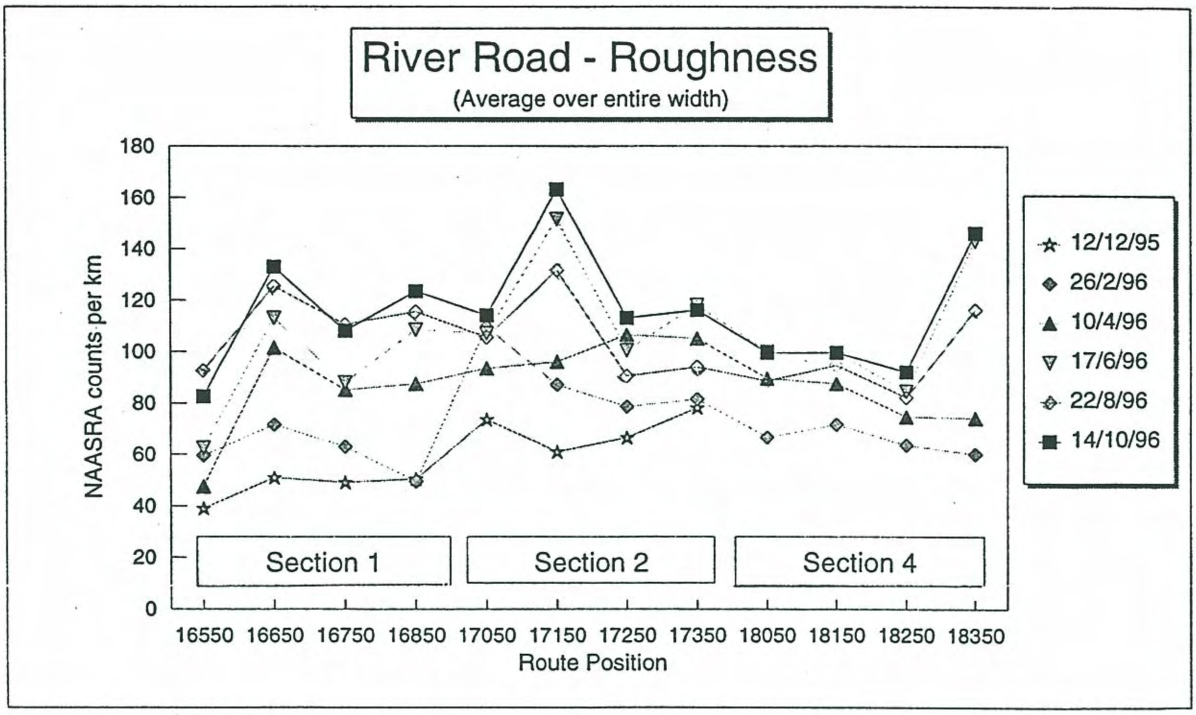
The following tables summarise the average pavement wear that has occurred at the five different locations across the carriageway.

Average Pavement Wear (17/1/96 - 2/4/96)				
Position	**Section 1**	**Section 2**	**Section 3**	**Section 4**
Point A (LHS)	8 mm	8 mm	10 mm	10 mm
Point B (LHS)	10 mm	14 mm	16 mm	13 mm
Point C (CL)	14 mm	14 mm	20 mm	12 mm
Point D (RHS)	16 mm	11 mm	15 mm	8 mm
Point E (RHS)	12 mm	8 mm	11 mm	4 mm

Average Pavement Wear (17/1/96 - 19/11/96)			
Position	**Section 1**	**Section 2**	**Section 4**
Point A (LHS)	14 mm	39 mm	14 mm
Point B (LHS)	22 mm	27 mm	33 mm
Point C (CL)	25 mm	24 mm	28 mm
Point D (RHS)	29 mm	21 mm	16 mm
Point E (RHS)	29 mm	19 mm	19 mm

LHS left hand side
RHS right hand side
CL centre line

Appendix E Roughness



Progression of roughness on River Road trial sections

Notes:

1. Section 4 was not surveyed on 12/12/95 as it was yet to be completed.
2. The roughness of the last 100 metres of section 4 is uncharacteristically high when compared to the rest of section 4. One possible explanation for this is that the running course from the adjoining pavement, outside the trial length, has migrated onto the granular wearing course section. Because of the uncertainty of the accuracy of this data, the roughness readings over the last 100 metres of section 4 should be discarded.

Appendix F Dust Monitoring

The amount of dust produced by the passing vehicle was "measured" through a visual assessment of photographs taken of an approaching vehicle travelling at 70km/h.

The dust level was ranked as either nil, low, medium or high.

The assessed dust level measurements are given in the table below:

Section	Position of Photograph	Assessment of Dust Level		
		21/12/95	9/1/96	16/2/96
Section 1 Endurazyme #388	RP 16.55 LHS	Low	Low	Low
	RP 16.78 RHS	Low	Low	Moderate
Section 2 No Endurazyme #388	RP 17.02 LHS	Moderate	Moderate	Moderate/High
	RP 17.16 RHS	Low/Moderate	Low/Moderate	Moderate
Section 3 Endurazyme #388	RP 17.57 LHS	Low	Low	Moderate
	RP 17.72 RHS	Low	Low	Moderate
Section 4 50mm granular wearing course	RP 18.05 RHS	Low	Low	Low
	RP 18.15 LHS	Nil	Nil	Low

RP reference point
LHS left hand side
RHS right hand side

Appendix G Maintenance Costs

The tables below summarise the costs incurred in maintaining the three trial sections.

Section 1		
19/6	Pothole Patching	$230.75
26/8	Pothole Patching	$770.85
	TOTAL	**$1001.60**

Section 2		
19/6	Grading Corrugations	$624.00
26/8	Pothole Patching	$390.45
	TOTAL	**$1014.45**

Section 4		
19/6	Grading Corrugations	$172.45
26/8	Pothole Patching	$543.30
	TOTAL	**$715.75**

Appendix H Benefit-Cost Analysis

This Benefit-Cost Analysis was undertaken to determine the relative cost-effectiveness of the three pavement treatments trialled.

To provide a better indication of the cost-effectiveness, the analysis was extended to cover a three year period. This required us to assume that the Endurazyme sections did not fail after only 12 months. It was also necessary to estimate the level of future maintenance and also to estimate the likely progression of roughness.

While such assumptions do not represent the true situation, they do provide a better indication of the likely cost-effectiveness of applying Endurazyme #388, rather than estimating the benefit/cost ratio for only the single year of the trial. The assumptions made are based on best estimates, and there are other assumptions which could be made which may be equally valid. For this reason, the assumptions were tested by a sensitivity analysis.

Some of the assumptions which have been made in this analysis include:

- Future maintenance costs for the sections with and without Endurazyme will be identical. It is assumed that maintenance (pothole repairs, grading, etc.) will be required on average every four months.
- Cost of any rehabilitation which may be required, and the cost of repairing the road following softening of the surface is not included.
- Other costs (e.g. safety concerns/accidents due to slippery surface) are not considered.
- Vehicle operating costs are based on 70 vehicles a day. No traffic growth is predicted.
- Roughness has been assumed to increase linearly. Maximum roughness of 200 NAASRA counts/km is assumed (as per TNZ Project Evaluation Manual, 1991).
- A discounting factor of 10% has been used in the analysis.

It must be noted that this benefit-cost analysis is based on a single application of Endurazyme #388 and a single application of wearing course. In reality, this is unlikely to be the case as a good maintenance strategy would ensure the wearing course had a top-up application of aggregate before the wearing course wore through to the underlying pavement structure.

DO MINIMUM OPTION
Reconstruction of Pavement Without Adding Endurazyme

Month	Months Since Construction	MAINTENANCE COST: Activity	Cost ($)	NPV	VEHICLE OPERATING COSTS: NAASRA Counts	Cost/km	Operating Cost	NPV
Nov 95	0	Construction	4,200.00	4,200.00	70	0.2	2.10	2.10
Dec 95	1				70	0.2	2.10	2.08
Jan 96	2				80	0.7	7.35	7.23
Feb 96	3				89	1.6	16.80	16.40
Mar 96	4				95	2.25	23.63	22.89
Apr 96	5				100	2.8	29.40	28.26
May 96	6				110	3.9	40.95	39.04
June 96	7	Maintenance	624.00	590.25	119	4.89	51.35	48.57
July 96	8				110	3.9	40.95	38.43
Aug 96	9	Maintenance	390.45	363.51	105	3.35	35.18	32.75
Sep 96	10				105	3.35	35.18	32.49
Oct 96	11				126	5.75	60.38	55.32
Nov 96	12	Maintenance	350.00	318.18	130	6.25	65.63	59.66
Dec 96	13				135	6.875	72.19	65.11
Jan 97	14				140	7.5	78.75	70.46
Feb 97	15				145	8.175	85.84	76.20
Mar 97	16	Maintenance	500.00	440.33	150	8.85	92.93	81.84
Apr 97	17				155	9.525	100.01	87.38
May 97	18				160	10.2	107.10	92.83
June 97	19				165	10.925	114.71	98.64
July 97	20	Maintenance	500.00	426.56	170	11.65	122.33	104.36
Aug 97	21				175	12.375	129.94	109.98
Sep 97	22				180	13.1	137.55	115.50
Oct 97	23				185	13.85	145.43	121.14
Nov 97	24	Maintenance	500.00	413.22	190	14.6	153.30	126.69
Dec 97	25				195	15.35	161.18	132.15
Jan 98	26				200	16.4	172.20	140.07
Feb 98	27				200	16.4	172.20	138.96
Mar 98	28	Maintenance	600.00	480.36	200	16.4	172.20	137.86
Apr 98	29				200	16.4	172.20	136.77
May 98	30				200	16.4	172.20	135.69
June 98	31				200	16.4	172.20	134.62
July 98	32	Maintenance	600.00	465.34	200	16.4	172.20	133.55
Aug 98	33				200	16.4	172.20	132.50
Sep 98	34				200	16.4	172.20	131.45
Oct 98	35				200	16.4	172.20	130.41
Nov 98	36	Maintenance	600.00	450.79	200	16.4	172.20	129.38
				$8,148.56				**$3,148.76**

OPTION 1
Treatment of Pavement with Endurazyme

Month	Months Since Construction	MAINTENANCE COST Activity	Cost ($)	NPV	VEHICLE OPERATING COST NAASRA Counts	Cost/km	Operating Cost	NPV
Nov 95	0	Construction	6,600.00	6,600.00	47	0	0.00	0.00
Dec 95	1				50	0	0.00	0.00
Jan 96	2				60	0	0.00	0.00
Feb 96	3				61	0.02	0.21	0.21
Mar 96	4				70	0.2	2.10	2.03
Apr 96	5				80	0.7	7.35	7.06
May 96	6				86	1.3	13.65	13.01
June 96	7	Maintenance	230.75	218.27	93	2.03	21.32	20.16
July 96	8				102	3.02	31.71	29.76
Aug 96	9	Maintenance	770.85	717.67	111	4.01	42.11	39.20
Sep 96	10				111	4.01	42.11	38.89
Oct 96	11				112	4.12	43.26	39.64
Nov 96	12	Maintenance	350.00	318.18	120	5	52.50	47.73
Dec 96	13				125	5.625	59.06	53.27
Jan 97	14				130	6.25	65.63	58.72
Feb 97	15				135	6.875	72.19	64.08
Mar 97	16	Maintenance	500.00	440.33	140	7.5	78.75	69.35
Apr 97	17				145	8.175	85.84	75.00
May 97	18				150	8.85	92.93	80.55
June 97	19				155	9.525	100.01	86.00
July 97	20	Maintenance	500.00	426.56	160	10.2	107.10	91.37
Aug 97	21				165	10.925	114.71	97.09
Sep 97	22				170	11.65	122.33	102.71
Oct 97	23				175	12.375	129.94	108.24
Nov 97	24	Maintenance	500.00	413.22	180	13.1	137.55	113.68
Dec 97	25				185	13.85	145.43	119.24
Jan 98	26				190	14.6	153.30	124.70
Feb 98	27				195	15.35	161.18	130.07
Mar 98	28	Maintenance	600.00	480.36	200	16.4	172.20	137.86
Apr 98	29				200	16.4	172.20	136.77
May 98	30				200	16.4	172.20	135.69
June 98	31				200	16.4	172.20	134.62
July 98	32	Maintenance	600.00	465.34	200	16.4	172.20	133.55
Aug 98	33				200	16.4	172.20	132.50
Sep 98	34				200	16.4	172.20	131.45
Oct 98	35				200	16.4	172.20	130.41
Nov 98	36	Maintenance	600.00	450.79	200	16.4	172.20	129.38
				$10,530.73				$2,813.98

OPTION 2
50mm Granular Overlay

Month	Months Since Construction	MAINTENANCE COST: Activity	Cost ($)	NPV	VEHICLE OPERATING COSTS: NAASRA Counts	Cost/km	Operating Cost	NPV
Nov 95	0	Construction	8,060.00	8,060.00	50	0	0.00	0.00
Dec 95	1				60	0	0.00	0.00
Jan 96	2				60	0	0.00	0.00
Feb 96	3				65	0.1	1.05	1.03
Mar 96	4				72	0.3	3.15	3.05
Apr 96	5				81	0.8	8.40	8.07
May 96	6				85	1.25	13.13	12.51
June 96	7	Maintenance	172.45	163.12	90	1.7	17.85	16.88
July 96	8				90	1.7	17.85	16.75
Aug 96	9	Maintenance	543.30	505.82	95	2.25	23.63	22.00
Sep 96	10				95	2.25	23.63	21.82
Oct 96	11				92	1.92	20.16	18.47
Nov 96	12	Maintenance	250.00	227.27	100	2.25	23.63	21.48
Dec 96	13				105	3.35	35.18	31.72
Jan 97	14				110	3.9	40.95	36.64
Feb 97	15				115	4.45	46.73	41.48
Mar 97	16	Maintenance	350.00	308.23	120	5	52.50	46.23
Apr 97	17				125	5.625	59.06	51.60
May 97	18				130	6.25	65.63	56.88
June 97	19				135	6.875	72.19	62.08
July 97	20	Maintenance	350.00	298.59	140	7.5	78.75	67.18
Aug 97	21				145	8.175	85.84	72.65
Sep 97	22				150	8.85	92.93	78.03
Oct 97	23				155	9.525	100.01	83.31
Nov 97	24	Maintenance	350.00	289.26	160	10.2	107.10	88.51
Dec 97	25				165	10.925	114.71	94.05
Jan 98	26				170	11.65	122.33	99.50
Feb 98	27				175	12.375	129.94	104.86
Mar 98	28	Maintenance	450.00	360.27	180	13.1	137.55	110.12
Apr 98	29				185	13.85	145.43	115.51
May 98	30				190	14.6	153.30	120.80
June 98	31				195	15.35	161.18	126.00
July 98	32	Maintenance	450.00	349.01	200	16.4	172.20	133.55
Aug 98	33				200	16.4	172.20	132.50
Sep 98	34				200	16.4	172.20	131.45
Oct 98	35				200	16.4	172.20	130.41
Nov 98	36	Maintenance	450.00	338.09	200	16.4	172.20	129.38
				$10,899.67				$2,286.51

BENEFIT-COST ANALYSIS

Option 1 : Treatment of Pavement with Endurazyme

$$B/C = \frac{\text{VOC Savings}}{\$\text{ option} - \$\text{ do min}} = \frac{3148.76 - 2813.98}{10530.73 - 8148.56}$$

$$= 0.14$$

Option 2 : 50 mm Granular Wearing Course

$$B/C = \frac{\text{VOC Savings}}{\$\text{ option} - \$\text{ do min}} = \frac{3148.76 - 2286.51}{10889.67 - 8148.56}$$

$$= 0.30$$

SENSITIVITY ANALYSIS

Option 1 : Treatment of Pavement with Endurazyme

VOC Savings	= \$334.78
± 25 %	= \$251.10 → \$418.48
Maintenance Cost Difference	= \$2,382.17
± 25 %	= \$1,786.63 → \$2,977.71

VOC Sensitivity : *B / C* $= \frac{251.10}{2382.17} \rightarrow \frac{418.48}{2382.17}$

$= 0.11 \rightarrow 0.18$

Maintenance Cost Sensitivity : *B / C* $= \frac{334.78}{2977.71} \rightarrow \frac{334.78}{1786.63}$

$= 0.11 \rightarrow 0.19$

Combined Sensitivity : *B / C* $= \frac{251.10}{2977.71} \rightarrow \frac{418.48}{1786.63}$

$= 0.08 \rightarrow 0.23$

SENSITIVITY ANALYSIS

Option 2 : Wearing Course

VOC Savings	=	\$862.25
± 25 %	=	\$646.69 → \$1,077.81
Maintenance Cost Difference	=	\$2,751.11
± 25 %	=	\$2,063.33 → \$3,438.89

VOC Sensitivity : $B/C = \frac{646.69}{2751.11} \rightarrow \frac{1,077.81}{2,751.11}$

$= 0.24 \rightarrow 0.39$

Maintenance Cost Sensitivity : $B/C = \frac{862.25}{3,438.89} \rightarrow \frac{862.25}{2,063.33}$

$= 0.25 \rightarrow 0.42$

Combined Sensitivity : $B/C = \frac{646.69}{3438.89} \rightarrow \frac{1,077.81}{2,063.33}$

$= 0.19 \rightarrow 0.52$

Appendix I Photographs

Photo 1 (upper): Section 1 22/11/95
Close up of rotary hoe (Sakai PM170 fitted with carbide tines) mixing Endurazyme into pavement material. Note very fine tilth behind hoe.

Photo 2 (lower): Section 3 24/11/95
Reshaping of road with grader (14 tonne Faun F156A) following application of Endurazyme and mixing with rotary hoe.

Photo 3 (upper): Section 1 23/11/95

Final shaping of surface - several light passes by the grader were required to bring sufficient fines to the surface. Photo shows grader followed by vibrating roller (Sakai SU700, 7.2 tonne).

Photo 4 (lower): Section 1 23/11/95

Water cart applying water during the final shaping and compaction. PTR (Bros 7 tonne) following behind water cart.

Photo 5 (upper): Section 4 — 7/12/95
Placement of granular wearing course using truck and trailer units.

Photo 6 (lower) : Section 4 — 7/12/95
Spreading of aggregate and shaping of road. Compaction was carried using 7.2 tonne vibrating roller, and water was regularly applied to maintain aggregate moisture content during compaction.

Photo 7 (upper): Section 1 5/12/95
General view of section 1, 1 week following construction. Pavement surface is hard and smooth.

Photo 8 (lower) : Join between sections 3 and 4 24/1/96
Following period of heavy rain. Section 4 in good condition. Section 3 is extremely soft on the surface with some ruts up to 25mm. Concern about motorists' safety due to slipperiness of surface.

Photo 9 (upper): Section 1 16/2/96
General view of section 1. Pavement is hard, dry and smooth, providing an excellent riding surface.

Photo 10 (lower) : Short rise between sections 2 and 3 11/3/96
Following period of rain. Pavement surface very slushy and extremely slippery. Safety for motorists was a real concern.

Photo 11 (upper): Section 1 18/11/96
General view of section 1 after half an hour of rain. Note wheel tracks on LHS where school bus slid off the road.

Photo 12 (lower): Section 1 18/11/96
Same view of section 1, 1 hour later. Rain has changed the road surface from hard and dry to soft and slushy in only 1½ hours.

Photo 13 (upper): Section 1 18/11/96
Shallow shear failures causing severe loss of shape within section 1.

Photo 14 (lower): Section 4 18/11/96
General view of section 4. Granular wearing course remained in good condition, and was not affected by rainfall. Some corrugations and ruts present on the inside of the bend are evident. Water flowing down LHS due to rut development in the wheel track and gravel build-up on the edge of the pavement.

Appendix J Properties of Wearing Course (Background to Aggregate Selection)

prepared by K. Hudson, Duffill Watts & Tse Ltd, Wellington, 1996[1]

1. Background

The aggregate traditionally used in the River Road area of Tararua District came from the Akaroa Quarry. Historically this has been a clay-bound aggregate containing some 16% passing the 75μm sieve. Local experience suggested this aggregate contained too much clay or was poorly graded, and so tended to become slippery and soft during winter.

For the aggregate sourced from the Akaroa quarry over the period November 1994 to November 1995, the clay was scalped out prior to crushing, giving a silty-feeling clean aggregate containing some 10% passing the 75 μm sieve. From Duffill Watts & Tse observations, partly confirmed in discussion with Trevor Bennett and Les Hines, the clean material lacks cohesion and when truck-spread tends to ravel off under traffic. There is also some doubt if this aggregate when compacted forms a waterproof layer, hence exposing the entire pavement structure to excess moisture.

Clearly neither of the two types of aggregate sourced from Akaroa were ideal for the 50 mm overlay section (section 4) of the Endurazyme trials.

2. Good Practice

The aggregate for the 50 mm of Well-Graded Aggregate overlay section was to replicate good practice for unsealed roads.

The basis of New Zealand good practice for wearing courses was taken for RRU Technical Recommendation TR8 (1986) *Unsealed Roads. A Manual of Repair and Maintenance for Pavements* by Alan Ferry. In broad terms this required:

- a well-graded aggregate with top size between 9.5 mm and 19 mm, and with between 10% and 21% passing the 75 μm sieve;
- linear shrinkage ≤5%;
- plasticity index 6 to 20;
- crushing resistance ≥ 100 kN.

The specification requirements for the aggregate for the section 4 overlay were developed from this.

1 Hudson, K.C. 1996. Endurazyme trials: Tararua: 50 mm overlay section, aggregate selection. Duffill Watts & Tse Ltd, Wellington.

3. Aggregate Sources

In liaison with Trevor Bennett and Les Hines, and with assistance from Works Consultancy and Duffill Watts & King, other potential sources of aggregate for the 50 mm overlay section were investigated. The sources investigated were:

3.1 Waitohora Pit (near Dannevirke)

Initial samples tested were too coarse. Screening to all passing 19 mm, then crushing gave an aggregate with a grading (particle size distribution) close to that desired, but with very few fines and insufficient clay content.

3.2 Kittows Pit (near Waipawa)

A well-graded aggregate but with insufficient fines and clay. Plasticity and linear shrinkage were both higher than desirable. While an adequate aggregate, for unsealed roads it did not approximate TR8 good practice.

3.3 Te Awe Awe Road Pit (near Eketahuna) Clay

Test results gave a linear shrinkage of 11 and a plasticity index of 22. Although linear shrinkage was higher than desirable, this may reduce if the clay was blended with an aggregate. Blending would require several spells of fine weather so the contractor could "shave" off layers of dry clay to enable it to be mixed with the aggregate.

3.4 Pongaroa Rubbish Tip Clay

The linear shrinkage was higher than desirable. Quantities of this clay appear to be limited, which is likely to restrict any long-term use.

Test results gave a linear shrinkage of 14 and a plasticity index of 28. Both of these were higher than desirable.

3.5 Glenora Road Clay

There were only small quantities of clay in a bank (4.4 km up Glenora Road from River Road). Most of the material was rotten rock. The clay appeared to be very plastic, so linear shrinkage could be of concern. For these reasons this material was not tested.

3.6 Akaroa Quarry

As discussed above, this quarry has been the source of wearing coarse aggregate for the River Road area for many years. The old clayey aggregate and the recent clean aggregate were both tested for particle size distribution, Atterberg limits, and linear shrinkage.

The particle size distribution results and Atterberg limits and linear shrinkage results are given in the following tables.

Particle Size Distribution for Old and Recent Akaroa Aggregates

Sieve Size	Old Clayey Aggregate % passing	Recent Clean Aggregate % passing
37.5 mm	100	100
26.5 mm	98	99
19 mm	83	91
13.2 mm	70	81
9.5 mm	60	71
4.75 mm	46	54
2.36 mm	40	44
1.18 mm	34	33
600 micron	29	25
425 micron	27	22
300 micron	26	19
150 micron	21	14
75 micron	15.5	10.4
63 micron	14.2	8.9

Property	Old Clayey Aggregate	Recent Clean Aggregate
Atterberg limits		
Liquid limit	26	25
Plastic limit	17	17
Plasticity index	9	8
Linear shrinkage	6	5

Comparing these results with the RRU TR8 good practices showed the old clayey aggregate was not very well graded, with the plasticity index slightly lower and linear shrinkage slightly higher than desirable. The recent clean aggregate was deficient on sands and the plasticity index was lower than desirable.

4. Options

None of the options offered an aggregate that fully met good practice.

The options involving blending of clay with an aggregate were not favoured as they were dependent on a period of fine weather and it was wished to construct the trials early in the construction season, so this could have delayed the trials.

While Kittow's pit aggregate has a track record of good performance, it did not comply with the desired good practice, and the cart of over 100 km would have made it very expensive. Also, it would have been unlikely to have been used again on Tararua roads in the future.

Sourcing the aggregate from Akaroa Quarry was the favoured option for a number of reasons:

- Test results indicate changes to quarry production techniques may give an aggregate close to good practice.
- It was the closest quarry so would provide the cheapest aggregate on-the-road.
- This quarry was the traditional source of aggregate for unsealed roads in the Akitio area, so any improvements to the material would offer long-term benefits to Tararua District.

5. Akaroa Quarry

Modifying the Aggregate

It was decided to use the Akaroa Quarry as the source of aggregate and modify the production. The quarry owners, I D Loader Limited of Wanganui, were very helpful and willing to trial various crusher/screen settings and select aggregate from specific parts of the quarry. This lead to a cycle of modify the crusher, produce a quantity of aggregate, sample for stockpile, then laboratory test.

This took time and by 30 November 1995 led to a material produced using a 30 mm screen, with the following properties:

Sieve Size	Percent Passing
37.5 mm	100
26.5 mm	98
19.0 mm	84
13.2 mm	70
9.50 mm	60
4.75 mm	46
2.36 mm	39
1.18 mm	30
600 μm	24
425 μm	22
300 μm	20
150 μm	17
75 μm	13
Plasticity index not less than 12	

These test results are appended to this report.

This material was close to the RRU TR8 good practice requirements, but the top size was larger than desirable, and generally the grading was coarser than desired and deficient in sand sizes.

These test results were available on 30 November 1995. Construction of sections 1, 2 and 3 had been completed, and it was wished to construct section 4 immediately so all sections would be subjected to the same environmental conditions and traffic.

While one further cycle of crusher/screen modifications, aggregate production, sampling, then testing would have been desirable, there was not time.

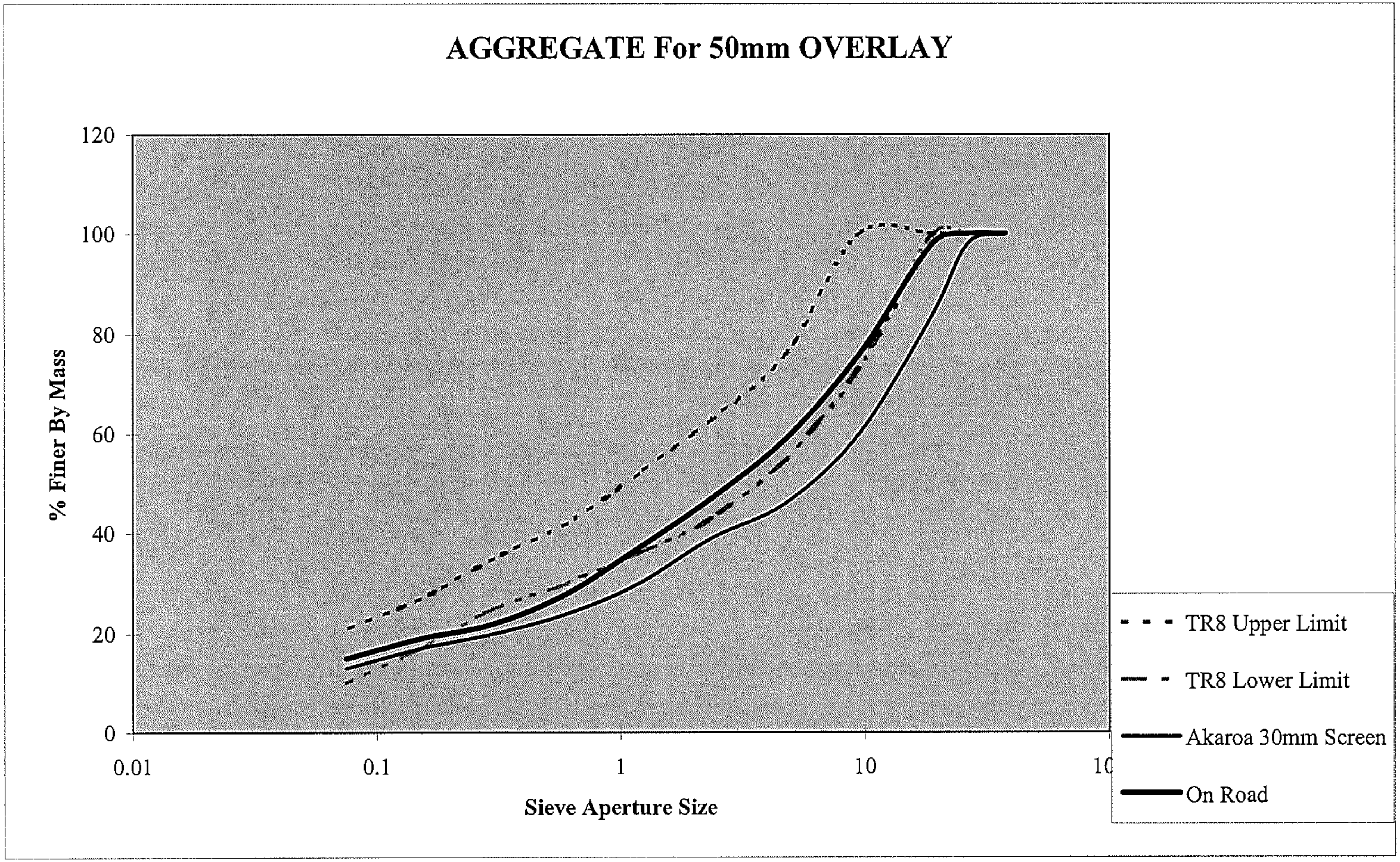
Accordingly, I made the decision to change the screen size from 30 mm to 20 mm, keep all other aspects of the aggregate production as for the previous production and produce aggregate. This aggregate was used as the overlay on section 4 with no further testing prior to construction.

Post-Construction Testing

The properties of this aggregate have since been shown by post-construction sampling from the road, and testing by Works,to be close to RRU TR8 good practice.

Future Refinement

It is likely that a better wearing course could be produced from Akaroa Quarry. However, this would take a programme of fine tuning of the quarry production, laboratory testing, observation, and on-the-road trials. Really, this is considered to be a matter separate from the Endurazyme trials, as the aggregate used is close enough to TR8 good practice for the purpose of comparison in the trials.


AGGREGATE For 50mm OVERLAY
120
100
80
60
40
20
0
% Finer By Mass
0.01
0.1
1
10
10
Sieve Aperture Size
TR8 Upper Limit
TR8 Lower Limit
Akaroa 30mm Screen
On Road

Appendix K Properties of In-situ Pavement Material

Particle Size Distribution	
Sieve Size	**Cumulative % passing**
63.0	100
53.0	97
37.5	96
26.5	94
19.0	89
13.2	84
9.5	78
6.7	73
4.75	68
2.36	59
1.18	52
0.600	47
0.300	43
0.150	38
0.075	30
From lab report PC053.00, (9/11/1994). Sample taken from RP 16.5.	

California Bearing Ratio			
	Dry Density as compacted	**Swell**	**CBR at depth of penetration**
Sample as received	1.92 t/m^3	0.6 %	2.5 at 2.5mm
Sample after addition of Endurazyme #388	2.04 t/m^3	0 %	14 at 5.0mm
From Lab Report 95/M0811 (18/1/95). Soaked CBR tests conducted on remoulded specimen. Sample taken from RP 18.80. Although sampled from outside the test sections, sampled believed to be indicative of in-situ pavement material within trial. Sample was treated with Endurazyme and re-tested to determine the increasing in bearing ratio following treatment.			

Atterburg Limits	
Liquid Limit	25
Plastic Limit	15
Plasticity Index	10
From Lab Report 95/M1441 (15/3/96). Sample taken from RP 17.35 (section 2) at a depth of approx 150mm.	

Physical Description of Pavement Material
Greyish Brown Sandy Silty GRAVEL

Heavy Compaction Test
Heavy compaction test was carried out on the minus 19mm fraction of a sample taken from RP 19.5. Results are shown on the following page.

Hutt Park Road, P.O. Box 30-845, Lower Hutt, New Zealand
Phone (04)5683-119, Fax (04)5683-169

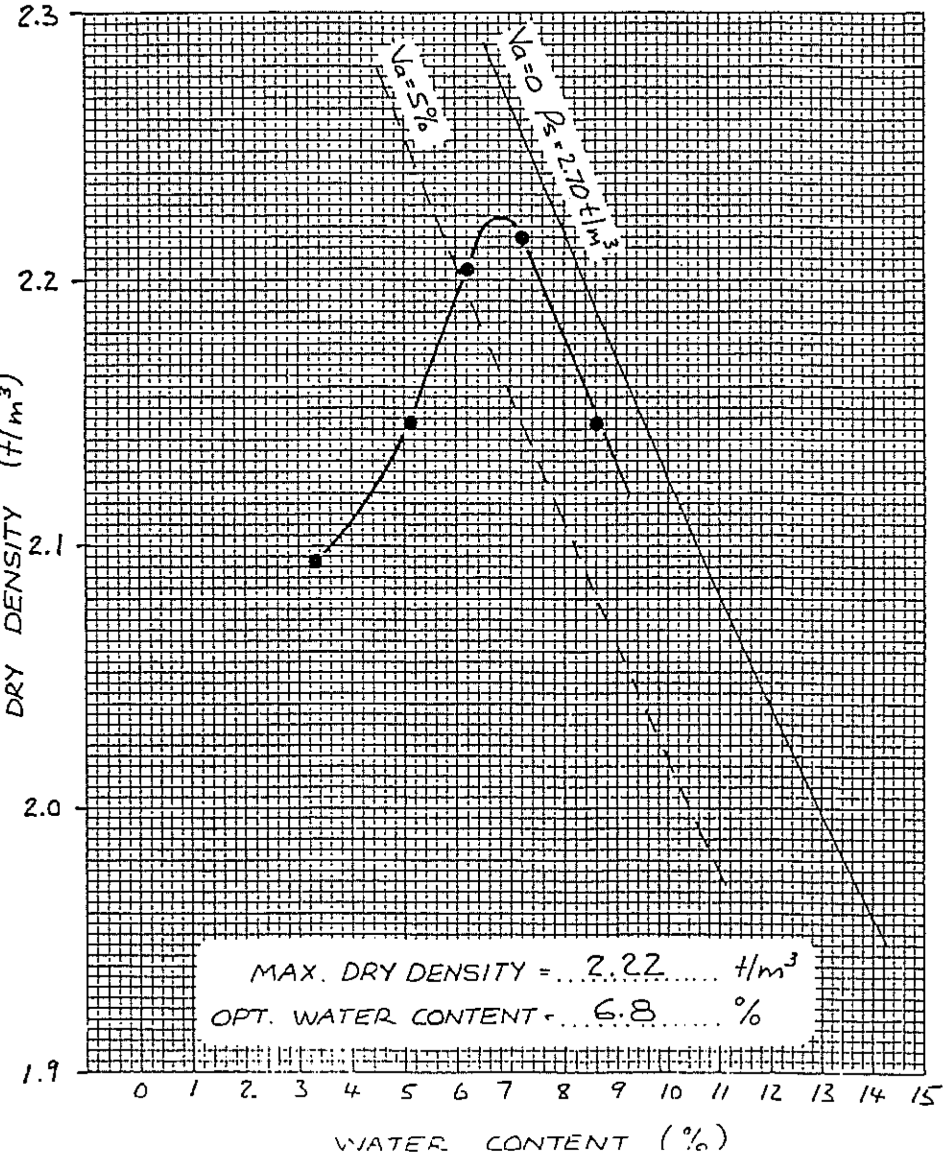
WORKS Consultancy Services

Report No PC053.00

NZS STANDARD/HEAVY/VIBRATING COMPACTION
NZS 4402 1986: test 4.1.1, 4.1.2, 4.1.3

CLIENT .... WCS P. NORTH .... SAMPLE NO. 2-94/94
PROJECT .... ENDURAZYME .... TESTED BY MJM
SOURCE ..... RIVER RD 19.5 km (I.D.) .... DATE 15.11.94
DESCRIPTION Silty Sandy GRAVEL: f-c, some clay ... CHECKED BY AJS
TEST DETAILS (Delete non-applicable) DATE 18.11.94

COMPACTION USED: ~~N.Z. STD (test 4.1.1)~~, N.Z. HEAVY (test 4.1.2), ~~N.Z. VIBRATING (test 4.1.3)~~
SAMPLE FRACTION: ~~WHOLE~~ / PASSING 19.0mm / ~~37.5mm~~ TEST SIEVE % PASSING = 93
HISTORY: NATURAL / AIR DRY / ~~OVEN DRY / UNKNOWN~~
SOLID DENSITY: ρ_s = 2.70 t/m³ ~~MEASURED~~ / ASSUMED



MAX. DRY DENSITY = 2.22 t/m³
OPT. WATER CONTENT = 6.8 %

All tests reported herein have been performed in accordance with the laboratory's terms of registration

APPROVED SIGNATORY: MJ
DESIGNATION: TECHNICAL OFFICER
DATE: 17.11.94

These test results relate only to the samples as received. Their true representation of source material is neither stated nor implied by Central Laboratories.

Page 1 of 1

CL 2218 3.94

WORKS Consultancy Services

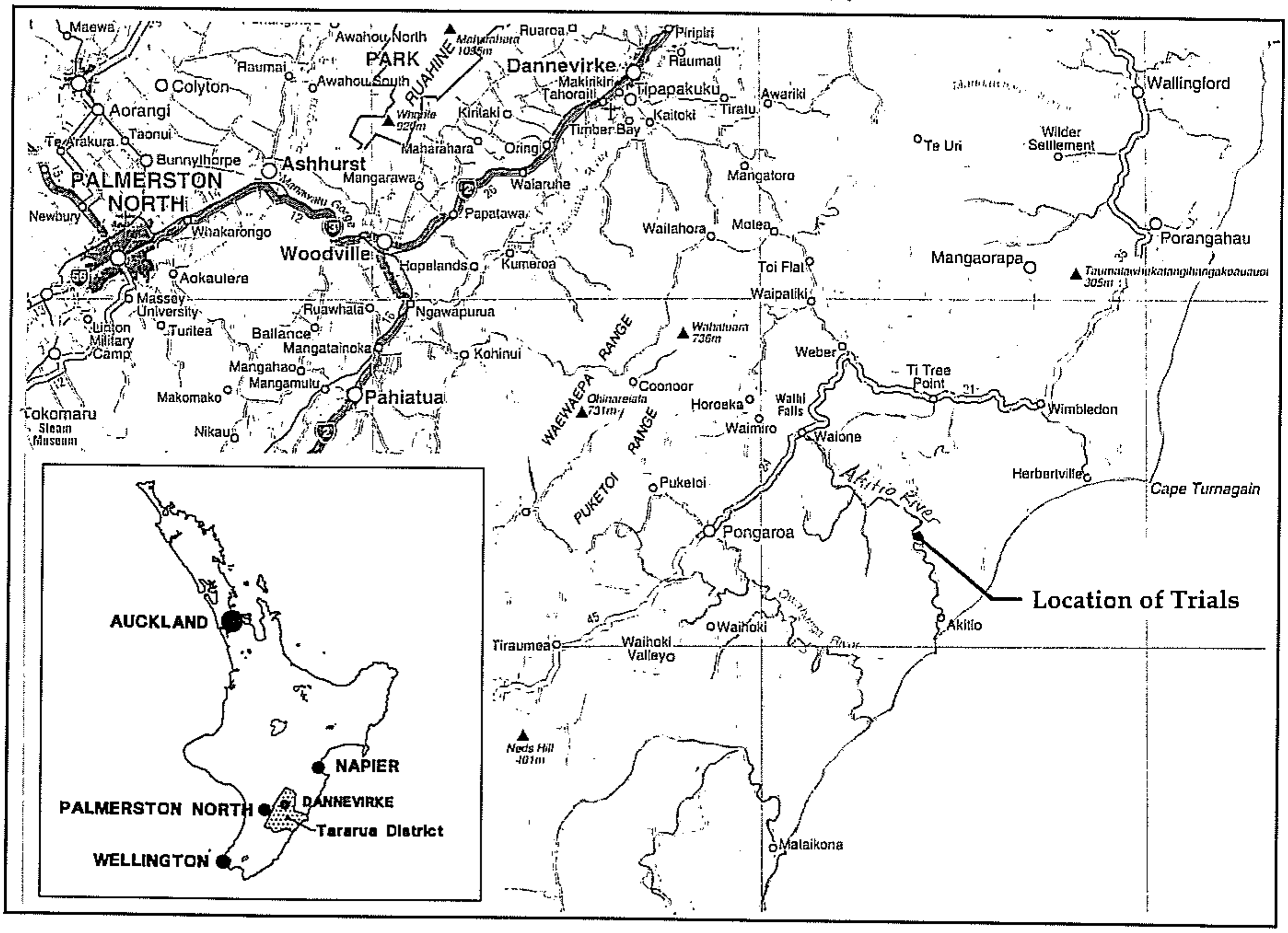


Figure 3.1 Location of Endurazyme #388 trial sections on River Road, Akitio, in Tararua District, North Island, New Zealand.

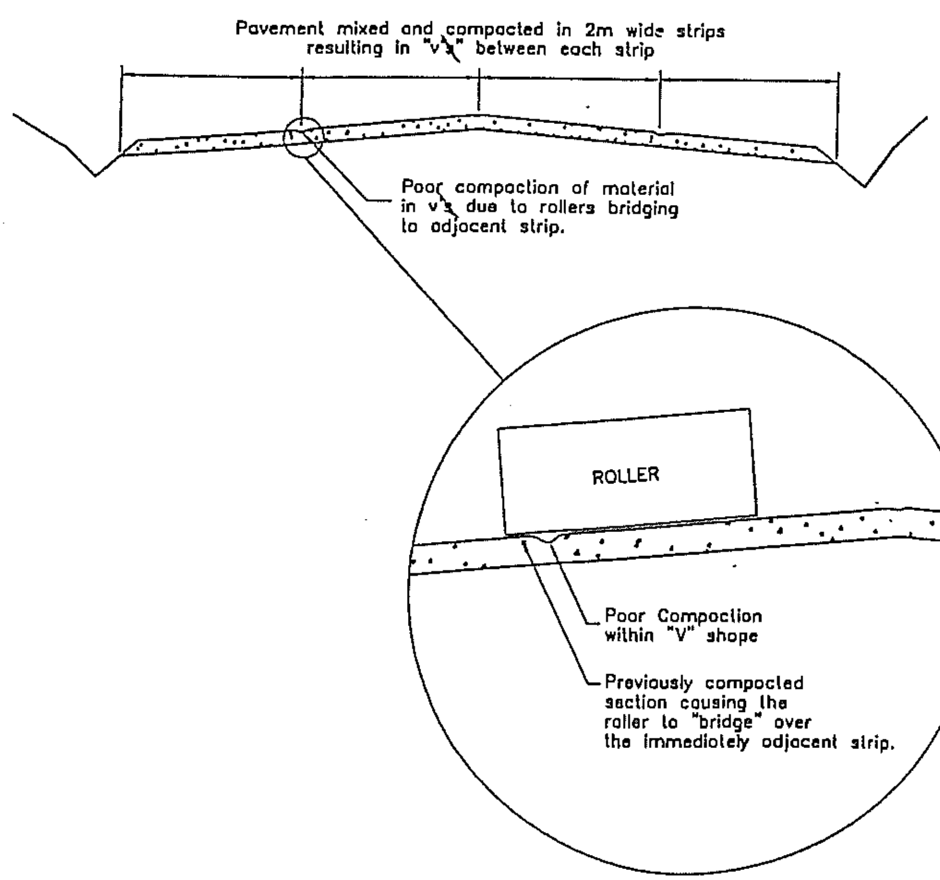


Figure 4.1 Mixing and compacting strips before mixing adjacent strip resulted in areas of low compaction between the strips.

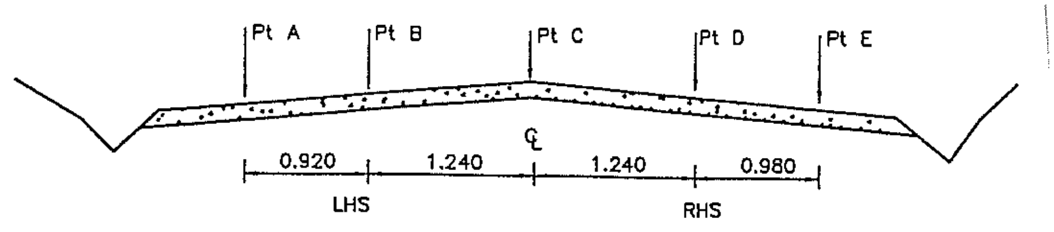
Using the pneumatic-tyred roller directly after the first cut by the grader was found to give the best result. The pneumatic-tyred roller appeared to "knead" the pavement material, giving a better finished surface, and it also sealed in the moisture in the pavement.

The specification called for the pavement to be compacted to at least 95% of maximum dry density. The target maximum dry density of the in-situ soil for each trial section was to be determined from a series of single point compaction tests in conjunction with a full compaction test curve (NZS 4402:1986, SANZ). Full details on the process used is given in the construction report (WCS 1996a).

The purpose of the single point compaction test was to enable the laboratory technician to more accurately estimate the target dry density to be achieved before compaction started. To confirm that the target dry density had been achieved, a nuclear densimeter

Appendix D Pavement Wear

Pavement wear was measured by surveying the middle 200 metres of each trial section. Survey benchmarks were established at 20 metre intervals, and 5 points across the road at each cross-section were levelled. The position of the 5 survey points is shown in the figure below. Levels were initially taken on 17 January 1996 and then again on 19 November 1996. The difference in the levels gives the wear in the pavement. An additional survey was carried out on 2 April 1996 to measure the wear in trial section 3 before this section was overlaid and withdrawn from the trial.



Cross section of carriageway showing positions of points surveyed to determine pavement wear.

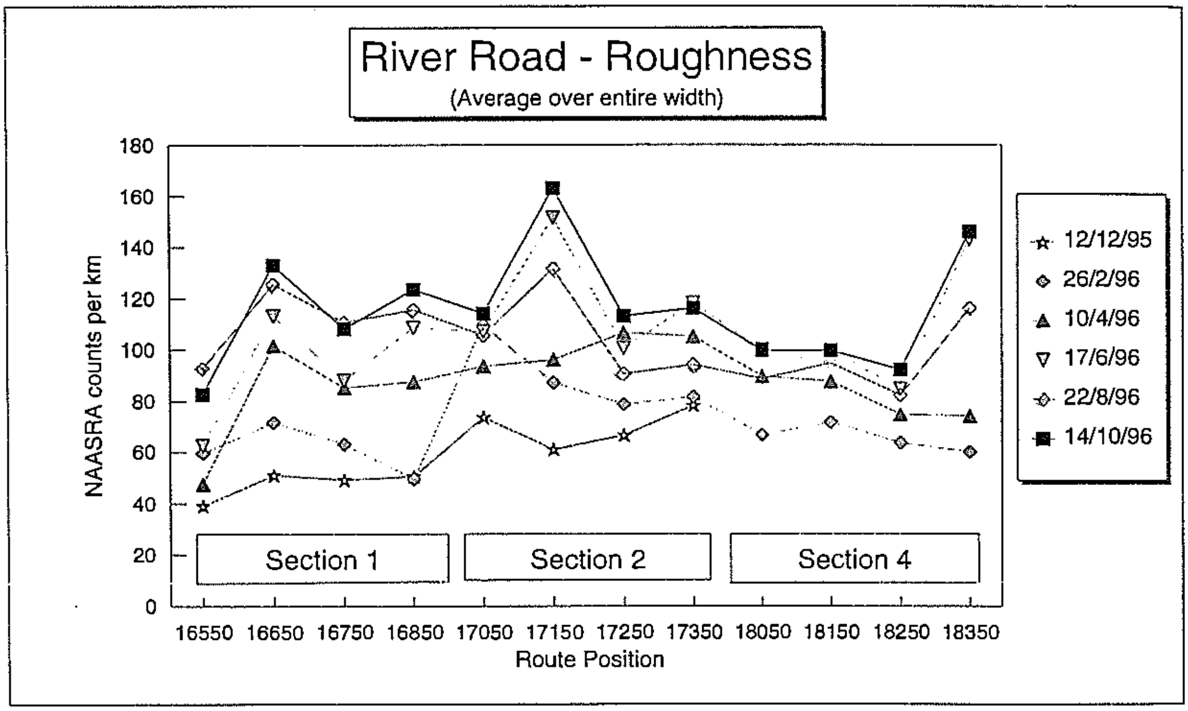
The following tables summarise the average pavement wear that has occurred at the five different locations across the carriageway.

Average Pavement Wear (17/1/96 - 2/4/96)				
Position	**Section 1**	**Section 2**	**Section 3**	**Section 4**
Point A (LHS)	8 mm	8 mm	10 mm	10 mm
Point B (LHS)	10 mm	14 mm	16 mm	13 mm
Point C (CL)	14 mm	14 mm	20 mm	12 mm
Point D (RHS)	16 mm	11 mm	15 mm	8 mm
Point E (RHS)	12 mm	8 mm	11 mm	4 mm

Average Pavement Wear (17/1/96 - 19/11/96)			
Position	**Section 1**	**Section 2**	**Section 4**
Point A (LHS)	14 mm	39 mm	14 mm
Point B (LHS)	22 mm	27 mm	33 mm
Point C (CL)	25 mm	24 mm	28 mm
Point D (RHS)	29 mm	21 mm	16 mm
Point E (RHS)	29 mm	19 mm	19 mm

LHS left hand side
RHS right hand side
CL centre line

Appendix E Roughness



Progression of roughness on River Road trial sections

Notes:

1. Section 4 was not surveyed on 12/12/95 as it was yet to be completed.
2. The roughness of the last 100 metres of section 4 is uncharacteristically high when compared to the rest of section 4. One possible explanation for this is that the running course from the adjoining pavement, outside the trial length, has migrated onto the granular wearing course section. Because of the uncertainty of the accuracy of this data, the roughness readings over the last 100 metres of section 4 should be discarded.

DO MINIMUM OPTION
Reconstruction of Pavement Without Adding Endurazyme

Month	Months Since Construction	MAINTENANCE COST: Activity	Cost ($)	NPV	VEHICLE OPERATING COSTS: NAASRA Counts	Cost/km	Operating Cost	NPV
Nov 95	0	Construction	4,200.00	4,200.00	70	0.2	2.10	2.10
Dec 95	1				70	0.2	2.10	2.08
Jan 96	2				80	0.7	7.35	7.23
Feb 96	3				89	1.6	16.80	16.40
Mar 96	4				95	2.25	23.63	22.89
Apr 96	5				100	2.8	29.40	28.26
May 96	6				110	3.9	40.95	39.04
June 96	7	Maintenance	624.00	590.25	119	4.89	51.35	48.57
July 96	8				110	3.9	40.95	38.43
Aug 96	9	Maintenance	390.45	363.51	105	3.35	35.18	32.75
Sep 96	10				105	3.35	35.18	32.49
Oct 96	11				126	5.75	60.38	55.32
Nov 96	12	Maintenance	350.00	318.18	130	6.25	65.63	59.66
Dec 96	13				135	6.875	72.19	65.11
Jan 97	14				140	7.5	78.75	70.46
Feb 97	15				145	8.175	85.84	76.20
Mar 97	16	Maintenance	500.00	440.33	150	8.85	92.93	81.84
Apr 97	17				155	9.525	100.01	87.38
May 97	18				160	10.2	107.10	92.83
June 97	19				165	10.925	114.71	98.64
July 97	20	Maintenance	500.00	426.56	170	11.65	122.33	104.36
Aug 97	21				175	12.375	129.94	109.98
Sep 97	22				180	13.1	137.55	115.50
Oct 97	23				185	13.85	145.43	121.14
Nov 97	24	Maintenance	500.00	413.22	190	14.6	153.30	126.69
Dec 97	25				195	15.35	161.18	132.15
Jan 98	26				200	16.4	172.20	140.07
Feb 98	27				200	16.4	172.20	138.96
Mar 98	28	Maintenance	600.00	480.36	200	16.4	172.20	137.86
Apr 98	29				200	16.4	172.20	136.77
May 98	30				200	16.4	172.20	135.69
June 98	31				200	16.4	172.20	134.62
July 98	32	Maintenance	600.00	465.34	200	16.4	172.20	133.55
Aug 98	33				200	16.4	172.20	132.50
Sep 98	34				200	16.4	172.20	131.45
Oct 98	35				200	16.4	172.20	130.41
Nov 98	36	Maintenance	600.00	450.79	200	16.4	172.20	129.38
				$8,148.56				**$3,148.76**

OPTION 1
Treatment of Pavement with Endurazyme

Month	Months Since Construction	Maintenance Cost: Activity	Maintenance Cost: Cost ($)	Maintenance Cost: NPV	Vehicle Operating Cost: NAASRA Counts	Vehicle Operating Cost: Cost/km	Vehicle Operating Cost: Operating Cost	Vehicle Operating Cost: NPV
Nov 95	0	Construction	6,600.00	6,600.00	47	0	0.00	0.00
Dec 95	1				50	0	0.00	0.00
Jan 96	2				60	0	0.00	0.00
Feb 96	3				61	0.02	0.21	0.21
Mar 96	4				70	0.2	2.10	2.03
Apr 96	5				80	0.7	7.35	7.06
May 96	6				86	1.3	13.65	13.01
June 96	7	Maintenance	230.75	218.27	93	2.03	21.32	20.16
July 96	8				102	3.02	31.71	29.76
Aug 96	9	Maintenance	770.85	717.67	111	4.01	42.11	39.20
Sep 96	10				111	4.01	42.11	38.89
Oct 96	11				112	4.12	43.26	39.64
Nov 96	12	Maintenance	350.00	318.18	120	5	52.50	47.73
Dec 96	13				125	5.625	59.06	53.27
Jan 97	14				130	6.25	65.63	58.72
Feb 97	15				135	6.875	72.19	64.08
Mar 97	16	Maintenance	500.00	440.33	140	7.5	78.75	69.35
Apr 97	17				145	8.175	85.84	75.00
May 97	18				150	8.85	92.93	80.55
June 97	19				155	9.525	100.01	86.00
July 97	20	Maintenance	500.00	426.56	160	10.2	107.10	91.37
Aug 97	21				165	10.925	114.71	97.09
Sep 97	22				170	11.65	122.33	102.71
Oct 97	23				175	12.375	129.94	108.24
Nov 97	24	Maintenance	500.00	413.22	180	13.1	137.55	113.68
Dec 97	25				185	13.85	145.43	119.24
Jan 98	26				190	14.6	153.30	124.70
Feb 98	27				195	15.35	161.18	130.07
Mar 98	28	Maintenance	600.00	480.36	200	16.4	172.20	137.86
Apr 98	29				200	16.4	172.20	136.77
May 98	30				200	16.4	172.20	135.69
June 98	31				200	16.4	172.20	134.62
July 98	32	Maintenance	600.00	465.34	200	16.4	172.20	133.55
Aug 98	33				200	16.4	172.20	132.50
Sep 98	34				200	16.4	172.20	131.45
Oct 98	35				200	16.4	172.20	130.41
Nov 98	36	Maintenance	600.00	450.79	200	16.4	172.20	129.38
				$10,530.73				$2,813.98

OPTION 2
50mm Granular Overlay

Month	Months Since Construction	MAINTENANCE COST: Activity	Cost ($)	NPV	VEHICLE OPERATING COSTS: NAASRA Counts	Cost/km	Operating Cost	NPV
Nov 95	0	Construction	8,060.00	8,060.00	50	0	0.00	0.00
Dec 95	1				60	0	0.00	0.00
Jan 96	2				60	0	0.00	0.00
Feb 96	3				65	0.1	1.05	1.03
Mar 96	4				72	0.3	3.15	3.05
Apr 96	5				81	0.8	8.40	8.07
May 96	6				85	1.25	13.13	12.51
June 96	7	Maintenance	172.45	163.12	90	1.7	17.85	16.88
July 96	8				90	1.7	17.85	16.75
Aug 96	9	Maintenance	543.30	505.82	95	2.25	23.63	22.00
Sep 96	10				95	2.25	23.63	21.82
Oct 96	11				92	1.92	20.16	18.47
Nov 96	12	Maintenance	250.00	227.27	100	2.25	23.63	21.48
Dec 96	13				105	3.35	35.18	31.72
Jan 97	14				110	3.9	40.95	36.64
Feb 97	15				115	4.45	46.73	41.48
Mar 97	16	Maintenance	350.00	308.23	120	5	52.50	46.23
Apr 97	17				125	5.625	59.06	51.60
May 97	18				130	6.25	65.63	56.88
June 97	19				135	6.875	72.19	62.08
July 97	20	Maintenance	350.00	298.59	140	7.5	78.75	67.18
Aug 97	21				145	8.175	85.84	72.65
Sep 97	22				150	8.85	92.93	78.03
Oct 97	23				155	9.525	100.01	83.31
Nov 97	24	Maintenance	350.00	289.26	160	10.2	107.10	88.51
Dec 97	25				165	10.925	114.71	94.05
Jan 98	26				170	11.65	122.33	99.50
Feb 98	27				175	12.375	129.94	104.86
Mar 98	28	Maintenance	450.00	360.27	180	13.1	137.55	110.12
Apr 98	29				185	13.85	145.43	115.51
May 98	30				190	14.6	153.30	120.80
June 98	31				195	15.35	161.18	126.00
July 98	32	Maintenance	450.00	349.01	200	16.4	172.20	133.55
Aug 98	33				200	16.4	172.20	132.50
Sep 98	34				200	16.4	172.20	131.45
Oct 98	35				200	16.4	172.20	130.41
Nov 98	36	Maintenance	450.00	338.09	200	16.4	172.20	129.38
				$10,899.67				**$2,286.51**

WORKS Consultancy Services
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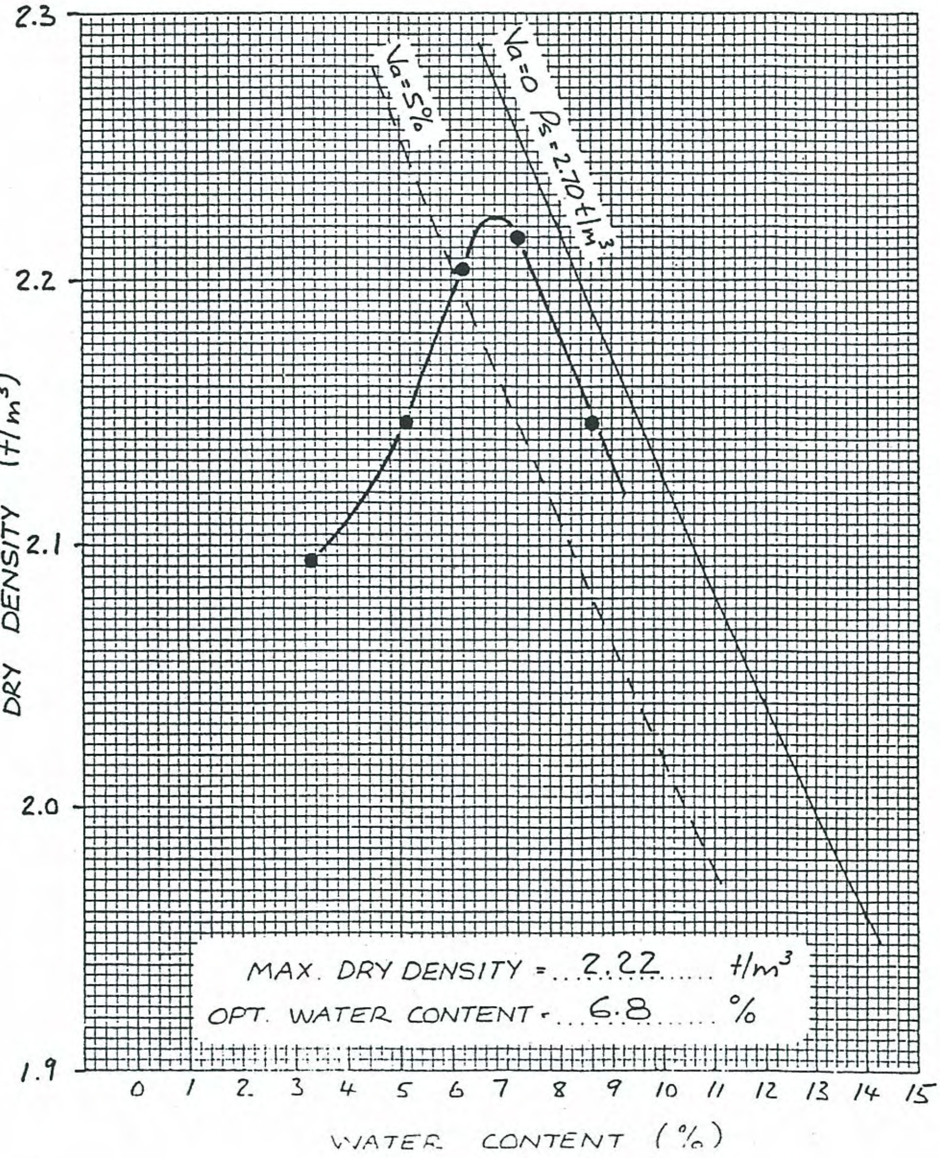
Report No PC053.00

NZS STANDARD/HEAVY/VIBRATING COMPACTION
NZS 4402 1986: test 4.1.1, 4.1.2, 4.1.3

CLIENT	WCS P. NORTH	SAMPLE NO.	2-94/94
PROJECT	ENDURAZYME	TESTED BY	MJM
SOURCE	RIVER RD 19.5 km (I.D.)	DATE	15.11.94
DESCRIPTION	Silty Sandy GRAVEL: f-c, some clay	CHECKED BY	AJS
TEST DETAILS (Delete non-applicable)		DATE	18.11.94

COMPACTION USED: ~~N.Z. STD (test 4.1.1)~~, N.Z. HEAVY (test 4.1.2), ~~N.Z. VIBRATING (test 4.1.3)~~
SAMPLE FRACTION: ~~WHOLE~~ / PASSING 19.0 mm / ~~37.5 mm~~ TEST SIEVE % PASSING = 93
HISTORY: NATURAL / AIR DRY / ~~OVEN DRY / UNKNOWN~~
SOLID DENSITY: ρ_s = 2.70 t/m³ ~~MEASURED~~ / ASSUMED



All tests reported herein have been performed in accordance with the laboratory's terms of registration

APPROVED SIGNATORY: [signature]
DESIGNATION: TECHNICAL OFFICER
DATE: 17.11.94

These test results relate only to the samples as received. Their true representation of source material is neither stated nor implied by Central Laboratories.

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