SEASONAL AND WEATHER NORMALISATION OF SKID RESISTANCE MEASUREMENTS

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EXECUTIVE SUMMARY

The principal objective of this research was to develop a procedure for adjusting values of wet road skid resistance measured on a given day under given weather conditions to a different day with different environmental conditions. The research was conducted in two phases. The first involved field measurements to establish the influence of air, road, water and rubber temperature on British Pendulum Tester and GripTester derived values of skid resistance. In the second phase, statistical methods, including regression analysis, were applied to existing skid resistance databases involving long term GripTester and British Pendulum Tester measurements made at frequent intervals in different regions of New Zealand. The purpose was to identify environmental factors, other than temperature, which had the greatest influence on skid resistance. From this it was hoped to develop a predictor model that permitted the reliable estimation of the minimum skid resistance value of a road surface from a single measurement. This minimum value is an essential input to the provision of safe roads and the effective allocation of available maintenance funds.

The following conclusions and associated recommendations have been derived from the research findings.

1. Adequacy of Temperature Correction Procedures for the British Pendulum Tester

The amplitude of daily fluctuation in skid resistance was shown to be comparable to that observed for seasonal fluctuation, suggesting that the underlying cause of long and short term variability in British Pendulum Tester derived skid resistance measurements was, in the main, temperature related. Application of the temperature correction procedure put forward by the manufacturers of the British Pendulum Tester, and presented in Road Note 27, was only partially successful in reducing the amplitude of daily fluctuation. However, it was apparent from measurements of road temperature, air temperature and water temperature, made at the time of each skid resistance reading, that a more appropriate correction procedure could be derived.

1.1 Recommendation

If the British Pendulum Tester continues to be used for measuring the skid resistance characteristics of New Zealand road surfaces it is essential that:

(a) Given the range of macrotexture levels on New Zealand roads, a more appropriate temperature correction than presented in Road Note 27 needs to be derived that specifically accounts for texture effects, thereby enabling more reliable skid resistance readings to be made;

(b) To assist the valid comparison of BPN readings, details of the time and temperature (air, dry road surface, wet road surface) when the skid resistance measurement is taken should be recorded until such time a temperature correction procedure, validated for New Zealand road surfaces, becomes available.

2. Mechanisms Causing Long and Short Term Variations in Skid Resistance

Statistical analysis suggests that an improved understanding of how road surface skid resistance changes with rainfall is first required before progress can be made in deriving a predictor model that adequately accounts for weather factors.

2.1 Recommendations

2.1.1 Yearly Seasonal Fluctuation

The most appropriate model for estimating yearly seasonal fluctuation in skid resistance about a terminal value is

$$C1 \cos(2\pi y) + S1 \sin(2\pi y)$$

where y = Julian calendar day / 365.25, and y = 0 corresponds to 1 January.

The constant terms C1 and S1 are a function of aggregate type, climatic region and skid tester. The model may be simplified with a negligible loss in precision if S1 is set to zero. An additional simplifying assumption can be made by holding the amplitude of the seasonal adjustment (C1) at a conservative value, leading to the formulation of the following models:

For the British Pendulum Tester,

$$BPN = BPN_{terminal} - 5\cos(2\pi/365.25 \times JDay)$$

where BNP = British Pendulum Number

For the GripTester,

$$GN = GN_{terminal} + 0.002\cos(2\pi/365.25 \times JDay)$$

where GN = Grip Number when obtained in tow mode

The proposed model for estimating seasonal effects on Grip Number should be treated with caution as it is derived from data covering one climatic region (Wellington) and one aggregate type (greywacke). However, more confidence can be attached to the model pertaining to the British Pendulum Tester because a broad range of climatic conditions and two aggregate types (greywacke and basalt) have been considered.

2.1.2 Skid Resistance Measurements Before and After Rainfall

Although the occurrence of rainfall is generally accepted as the reason for short term variations in skid resistance, the mechanism by which the variations are produced is not yet sufficiently well understood to permit reliable modelling. For example, is a cloudburst of, say, an hour's duration during daylight less effective in restoring skid resistance than light rain through the night when traffic is light and the evaporation rate is low. Therefore, to address this knowledge gap, it is recommended that a limited investigation be carried out to determine the skid resistance time histories of a chipseal pavement for different rainfall levels and durations, traffic levels and the length of the dry spell preceding the rainfall. This would require a rainfall gauge to be located beside the test section, and a skid tester that can make measurements at traffic speeds so traffic flows are not affected. The resulting "before" and "after" rainfall skid resistance measurements will allow the formation of a model that accounts for short term variations in skid resistance better than the dirt-buildup and rain days factors utilised as part of the study and derived on the basis of reviewed overseas literature.

2.1.3 Increased Frequency of Readings at Whangarei

The scope of the Whangarei monitoring programme on State Highway 1 between RP 165/6.97 and RP 173/0.0 involving three monthly British Pendulum Tester skid resistance and sand circle texture depth readings should be expanded to include increased frequency of readings, every 10 to 14 days, at one of the six test strips. The readings should be supplemented with humidity, air temperature and dry road surface temperature measurements. A rainfall gauge should also be installed adjacent to this test strip and monitored. This would address the major reservation of the existing analysis that localised, site-specific climatic effects had not been appropriately accounted for as a consequence of employing weather data from meteorological stations that were some distance from the test sites.

The resulting database would be invaluable for validating proposed modelling approaches for accounting for rainfall.

3. Relationship Between Amplitude of Seasonal Variation and Aggregate Type

Overseas research suggests that the amplitude of seasonal variations depends on aggregate type. The more polish-susceptible the aggregate, the more pronounced are the seasonal and short term variations in skid resistance. However, analysis of long term data obtained as part of a National Roads Board funded study to investigate the comparative skid resistance performance of Christchurch and Palmerston North sourced greywacke (polished stone value ≈ 55) and Dunedin sourced basalt (polished stone value ≈ 44) gave the opposite result. The more polish-resistant greywacke aggregates displayed larger seasonal fluctuations over a range of traffic levels and climatic regions.

3.1 Recommendation

To resolve the anomaly between overseas and New Zealand research findings, pertaining to the comparative performance of different aggregate types with respect to seasonal and short term variation in skid resistance related to rainfall, a monitoring programme similar to the "Three Cities" study undertaken by the National Roads Board should be repeated with the following refinements. Firstly, all commonly used aggregate types should be used in the construction of test strips which would be laid adjacent to each other as part of a normal chipsealing operation of a trafficked road. The influence of chip size should be additionally investigated by constructing two groups of test strips: one from coarse textured grade 2 and the other from fine textured grade 4 chip. Secondly, a weather station should be installed adjacent to the test site to obtain local meteorological data, in particular humidity and rainfall. Thirdly, the test strips should be at least 50 m in length to allow monitoring by a vehicle-based skid tester so that the results could be directly related to state highway SCRIM surveys. Each of the test strip groupings, therefore, would have to be preceded by a 400 m length of chipseal surface of the same grade as the grouping to allow for the conditioning of the skid tester's measuring wheel. It is envisaged that one test site, located on a straight section of a state highway would be sufficient and that the monitoring should extend for a minimum period of two years.

The resulting database will identify the need or otherwise to calibrate seasonal adjustment models for aggregate type and size.

4. Significance of British Pendulum Tester and GripTester Measurements in Relation to Actual Car Tyre Performance

On the basis of the databases analysed, it appears that the seasonal variations observed in the long term British Pendulum readings are partly temperature related, whereas those for the GripTester are not. Therefore, it is necessary to establish the significance of this result.

4.1 Recommendation

A series of comparative measurements involving wet and dry GripTester, British Pendulum and locked wheel braking measurements using an instrumented vehicle should be undertaken first thing in the morning when the road surface temperature is close to its minimum and repeated in mid afternoon when the temperature is at its maximum. The resulting change in braking distance can then be correlated with the observed changes in the Grip Number and British Pendulum Number values. In order to perform the wet measurements, the road surface would need to be artificially wetted.

This comparatively straightforward experimental programme will assist in establishing which device better represents the behaviour of car tyres on wet road surfaces, and provide a better understanding as to how road surface temperature affects the braking performance of vehicles.

ABSTRACT

This report presents the results of a research programme involving two phases. The first involved limited field measurements to quantify the relationship between wet pavement skid resistance, as measured by the GripTester and British Pendulum Tester, and temperature for a limited range of road surfaces. In the second phase, statistical methods, including analysis of variance (ANOVA), were applied to three long-term skid resistance databases to establish whether models could be developed to predict variations in skid resistance due to rainfall conditions, temperature effects and time of year. A significant finding was that existing temperature correction procedures for the British Pendulum Tester were inadequate. Furthermore, the skid resistance readings displayed temperature sensitivities that appeared to be a function of the road surface texture.

1. INTRODUCTION

1.1 Overview

Skid resistance of road surfaces has been observed to change appreciably due to short and long term variations of weather conditions (Oliver *et al* 1988, Dickinson 1989, Kennedy *et al* 1990). Efforts to determine the trends of these changes have pointed to a seasonal cycle where the skid resistance generally decreases in the summer through autumn, and is rejuvenated in the winter months. Furthermore, pavement skid resistance has been found to vary from week to week, and even day to day, particularly where weather conditions vary significantly.

UK researchers Maclean and Shergold (1958) suggest two opposing mechanisms are operative:

(a) During dry spells, abrasive material (grit) lying on the road or embedded in vehicle tyres is very fine and polishes the exposed aggregate surfaces of a pavement; and

(b) In the wet, these aggregate surfaces are roughened by natural weathering due to chemical action of rainwater (and oxygen). The grit becomes coarser and therefore has an abrasive rather than a polishing action.

Seasonal wet and dry periods correspond to cycles of rising and lowering skid resistance. Furthermore, different materials and road surface designs respond differently to the polishing and rejuvenation mechanisms resulting in lesser or greater variations in skid resistance.

Based on previous research summarised in Henry *et al* (1984), the following factors appear to be significant:

(1) <u>Surface age.</u> There is a general decrease of skid resistance with time and traffic. The decrease after construction is rapid but then slows, and eventually levels out at a fairly steady average value. Cyclic changes (2-6) are superimposed on this basic pattern.

(2) <u>Seasonal changes.</u> During winter, skid resistance rises to reach a maximum value in early spring. It then decreases until it attains a minimum value in late autumn.

(3) <u>Rainfall.</u> During rain, pavements recover some skid resistance which is lost again during the following dry period. Greatest changes appear to be caused by the duration of the dry period preceding the measurement of skid resistance.

(4) <u>Daily changes.</u> The effect of temperature on rubber resilience exerts a perceptible influence in all skidding resistance measurements. It shows itself as a fall in skid resistance as the temperature rises. In addition, the magnitude of the variation of skid resistance with temperature varies considerably from road to road, mainly because of the influence of the road surface profile. Therefore, skid resistance is likely to vary with daily temperature cycles.

(5) Aggregate type. Surfaces composed of aggregates having differential wear (e.g. greywacke) exhibit relatively small variation in skid resistance. In contrast, surfaces composed of polish-susceptible aggregates, such as dolomites and Dunedin basalt, undergo pronounced seasonal and short term variations in skid resistance which are related to changes in rainfall.

(6) Contamination. Contaminants such as oil and dust can influence the measured skid resistance. However, these factors are not necessarily of a cyclic nature. Contamination of surfaces by vehicle oil droppings and tyre detritus has been ruled out as a source of skid resistance variation, as a gentle detergent wash was found ineffectual in improving skid resistance (Giles and Sabey 1959, Oliver 1987).

Safe, skid resistant street and highway pavement surfaces are expected by the travelling public. However, variations in skid resistance make it difficult for roading agencies to reliably identify sections in their road systems that are at, or below, investigatory skid resistance levels so that corrective measures can be undertaken.

1.2 Research Need

Because it is impossible to always conduct measurements in the period in which the skid resistance of roads is expected to be at its lowest value, there is a need to establish and validate analytical procedures that provide corrections to the measured skid resistance for measurable seasonal and short term variations in test conditions. The three most common measurement methods for determining the skid resistance of New Zealand roads are the:

- Sideways Force Coefficient Investigation Machine (SCRIM),
- GripTester, and
- British Pendulum Tester.

At present, only the SCRIM state highway survey data is processed to account for seasonal variation effects via the mean summer SCRIM coefficient (MSSC) method. This requires restricting the survey season from mid November to mid April, and by obtaining the mean of at least three SCRIM coefficients measured at fairly equal intervals over the whole testing season at a number of regional control sites. From this a suitable datum mean summer value can be calculated. The seasonal correction factor applied to any routine single survey measurement is that which is obtained by the mean summer value at the nearest control site divided by the skid resistance measurement taken at the control site at the closest date to the survey (Kennedy *et al* 1990).

As is clearly evident, the MSSC approach has a number of serious limitations. It is time consuming, expensive, takes into account only seasonal variations, and cannot be readily applied to other measurement methods without first establishing correlation to SCRIM. The research presented in this report, therefore, is concerned with the development of a predictor model derived from a statistical analysis of existing skid resistance databases involving long term GripTester and British Pendulum Tester measurements made at frequent intervals in different regions of New Zealand.

The need for this research has been identified as part of Transit New Zealand Research Project PR3-0134, Frictional Interaction Between Tyre and Pavement, (unpublished). It seeks to address the major problem of comparing skid resistance measurements, taken at different times of the year, with each other and recommended investigatory levels.

1.3 Objectives

The programme of research had two main objectives:

(1) To quantify the relationship between wet pavement skid resistance, as measured by the GripTester and British Pendulum Tester, and temperature for a range of road surfaces, thereby verifying existing temperature correction procedures.

(2) To establish whether or not a predictor model could be derived to:

  (a) adequately describe the effects of seasonal and weather factors; and

  (b) provide a basis for adjustment of skid resistance measurements, irrespective of measurement device, to standard seasonal and weather conditions.

The ultimate goal was the development of a validated procedure for adjusting values of wet road skid resistance measured on a given day of the year and under given weather conditions, to a different day of the year and a different set of environmental conditions. Such a procedure would enable identification of environmental factors which had the greatest influence on skid resistance, and the prediction of the likely minimum skid resistance value of a road surface from a single measurement.

1.4 Scope of the Report

This report presents the results of a detailed statistical analysis performed on data collected for the determination of seasonal variation of the skid resistance of New Zealand friction course and chipseal surfaced roads. Chapter 2 describes a series of controlled on-road trials undertaken to quantify the extent of daily changes in measured skid resistance that is solely attributable to temperature effects. The observed temperature sensitivities are analysed and compared with previously published temperature correction factors for the British Pendulum Tester and GripTester. In Chapter 3, the time series skid resistance and climate databases created for the statistical analysis are presented in terms of time series plots. Chapter 4 summarises the statistical analysis carried out and associated significant findings. These findings are compared and contrasted with previous modelling efforts. Finally, conclusions and recommendations drawn from the research are given in Chapter 5.

2. INVESTIGATION OF TEMPERATURE EFFECTS

2.1 Background

The raw skid resistance value is not a good indicator of the general skid resistance level of a site since the particular conditions at the time of testing affect the temperature of the rubber slider or tyre used to make the measurement. Rubber resilience increases and hysteresis losses become smaller as temperature rises (Kennedy *et al* 1990). These effects combine to reduce the measured value of skid resistance as temperatures increase. The effect can be significant for skid resistance measuring systems with non-continuous type of operation (e.g. British Pendulum Tester or GripTester in manual push mode). However, systems with continuous measurement of skid resistance (e.g. SCRIM or GripTester in tow mode) need only to ensure that equilibrium working temperatures have been reached, as temperature effects are not particularly significant over the expected range of working temperatures. Normally this is achieved by utilising a conditioning run of about 500 m length, prior to recording on the survey lengths.

Skid resistance measurements may be adjusted to a standard temperature, typically 20°C, or alternatively may be recorded as measured, with any temperature effects being considered to be part of the seasonal variation. Since large temperature variations can occur in New Zealand between regions, and also in any locality within a test day, it is desirable to apply a temperature correction to the measured skid resistance values.

When testing, four different temperatures may be distinguished which could affect the results. These are:

(a) water temperature,
(b) air temperature,
(c) rubber temperature, and
(d) road surface temperature.

In practice, it is very difficult to continuously measure rubber temperature at the point of contact with the road. Fortunately good correlations have been established with the other temperature measures.

For the British Pendulum Tester, the manufacturer provides a suggested temperature correction factor based on the water lying on the road (i.e. wet road temperature) immediately after the test. The effect of the water temperature on the resulting skid resistance measurement is shown to be greatest at temperatures below 10°C. Oliver (1980) has proposed two alternative temperature correction factors for the British Pendulum Tester, one based on dry road surface temperature, and the other on air temperature. The temperature correction for SCRIM is based on the mean of the air temperature and dry road temperature. The manufacturers of the GripTester, Findlay Irvine, believe temperature effects to be negligible once the working temperature of the measuring tyre has been reached, and so no temperature correction is recommended.

Because previous research has identified that temperature correction is dependent on road surfacing type (Meyer and Kumer 1969), some doubt existed as to whether or not seasonal changes observed in British Pendulum Tester skid resistance measures were masked or exaggerated by inappropriate correction procedures. Accordingly, the following controlled test programme was performed to determine:

(a) the change in measured skid resistance during a typical daily temperature cycle; AND

(b) the appropriateness of overseas derived temperature correction factors for the British Pendulum Tester and GripTester when applied to coarse textured New Zealand chipseal surfaces.

2.2 Experimental Design and Procedures

GripTester and British Pendulum Tester measurements were made on three very lightly trafficked sites over an extended (11 hours) period. Two sites were outdoors (one having a coarse textured chipseal surface and the other a smooth textured asphaltic concrete surface), and the other indoors (having a very smooth concrete surface). This indoor test site acted as a control to highlight any changes in the skid resistance measurements that could be attributable to factors other than temperature, such as surface water buildup, tester wear, operator variability, etc. Figures 1 and 2 show views of the outdoor sites which were vehicle accessways located around the perimeter of Opus Central Laboratories Shed 13.

To minimise the cleaning effect of repeated measurements, all test surfaces were scrubbed with a broom and water the evening before the measurements took place. The GripTester was operated in a push mode (survey speed of approximately 5 km/h). This enabled a test length of 5 m to be surveyed for each site. In comparison, readings were taken at three separate locations per site with the British Pendulum Tester and then averaged.

The skid resistance measurements were made in summer during daylight hours (8.00 am to 6.30 pm) at approximately half hourly intervals under conditions of minimal cloud cover. The two outdoor surfaces were therefore free of moisture and exposed to high solar radiation leading to a significant daily surface temperature cycle. Measurements over the first two hours of testing were repeated a few days later under similar conditions to establish whether or not the observed temperature dependency of the British Pendulum Tester and GripTester skid resistance values were repeatable.

The British Pendulum Tester readings for each test site were temperature corrected by the graphical relationship presented in Road Note 27 (HMSO 1969) and Oliver's road surface temperature based mathematical relationship (Oliver *et al* 1988). The GripTester readings were left uncorrected per standard practice.

In order to apply and evaluate the temperature correction procedures, readings of dry and wet bulb air temperature, road surface temperature, water temperature and rubber slider/measuring tyre surface temperature were also made immediately after each skid resistance measurement.

Figure 1. GripTester survey of asphaltic concrete site about to commence.

Figure 2. British Pendulum Tester measurement in progress at chipseal site.

2.3 Results

The daily variation of British Pendulum Tester and GripTester derived skid resistance measurements obtained over an 11 hour period on 3 March 1998 and a 2 hour period on 10 March are shown in Figures 3 and 4 respectively. The data used to generate these figures is tabulated in Appendix 1. Particular features of note are:

- The measured skid resistance reduces as the dry road surface temperature increases. This effect is observed for both skid testers.
- The variability of the skid resistance measurements is considerably greater for the chipseal surface than for the smooth textured asphaltic concrete and concrete surfaces. This is in agreement with an earlier study involving the British Pendulum Tester which showed the repeatability of this device to be clearly a function of the measuring surface profile (Dravitzki *et al* 1997).
- With reference to the outdoor test sites, the difference between the minimum and maximum dry road surface temperature during daylight hours is almost double that of the air temperature, indicating that solar radiation effects are significant.
- The skid resistance measurements performed indoors were relatively constant compared to those outside, the difference between the highest and lowest reading falling within the measurement repeatability of both devices on smooth surfaces (i.e. ±0.06 units in the case of the GripTester (Lund 1997), and ±4.8 units for the British Pendulum Tester (Dravitzki *et al* 1997)). This result suggests that skid resistance variations observed for the outside sites are, in the main, temperature related rather than test procedure related.
- The second series of skid resistance measurements performed on 10 March demonstrate the same temperature dependency. Furthermore, when the surface temperatures are equivalent to the 3 March measurements, there is reasonably good agreement between the two sets of skid resistance values. Any slight differences can be explained by the fact that 3 March was less humid than 10 March (45% relative humidity compared with 66%). This result further confirms that observed variations in the skid resistance measurements with temperature are real and not brought about as a consequence of the testing procedures.

Figures 5 and 6 show the effect of applying Road Note 27 and Oliver's temperature correction procedures. With reference to Table 1, the difference between the lowest and highest uncorrected skid resistance values recorded over the 11 hour measuring period is 22.7 BPN units for the chipseal site and 16.4 BPN units for the asphaltic concrete site. Because the test sites were not exposed to traffic during the measuring programme, the expectation was that temperature corrected BPN values should converge to a constant value. From the actual measurements, inferred constant values are BPN = 80 for the chipseal surface and BPN = 74 for the asphaltic concrete surface. Application of the suggested correction procedures results in maximum changes to the measured BPN values of 2 BPN units for Road Note 27 and 5 BPN units for Oliver, whereas changes in the order of 14-16 BPN units are required.

Figure 3. Observed daily variation in British Pendulum Tester derived skid resistance readings.

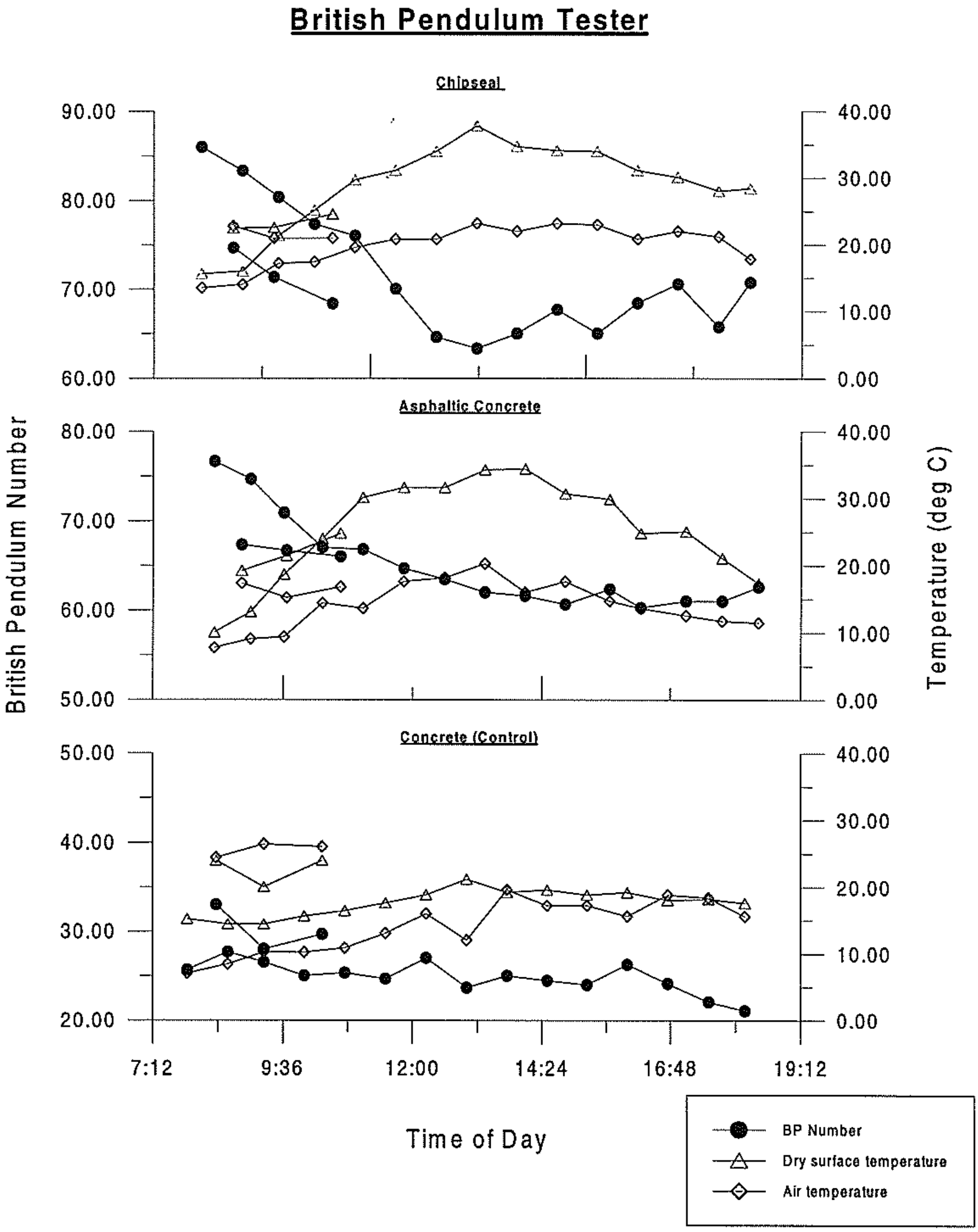


Figure 4. Observed daily variation in GripTester (push mode) derived skid resistance readings.

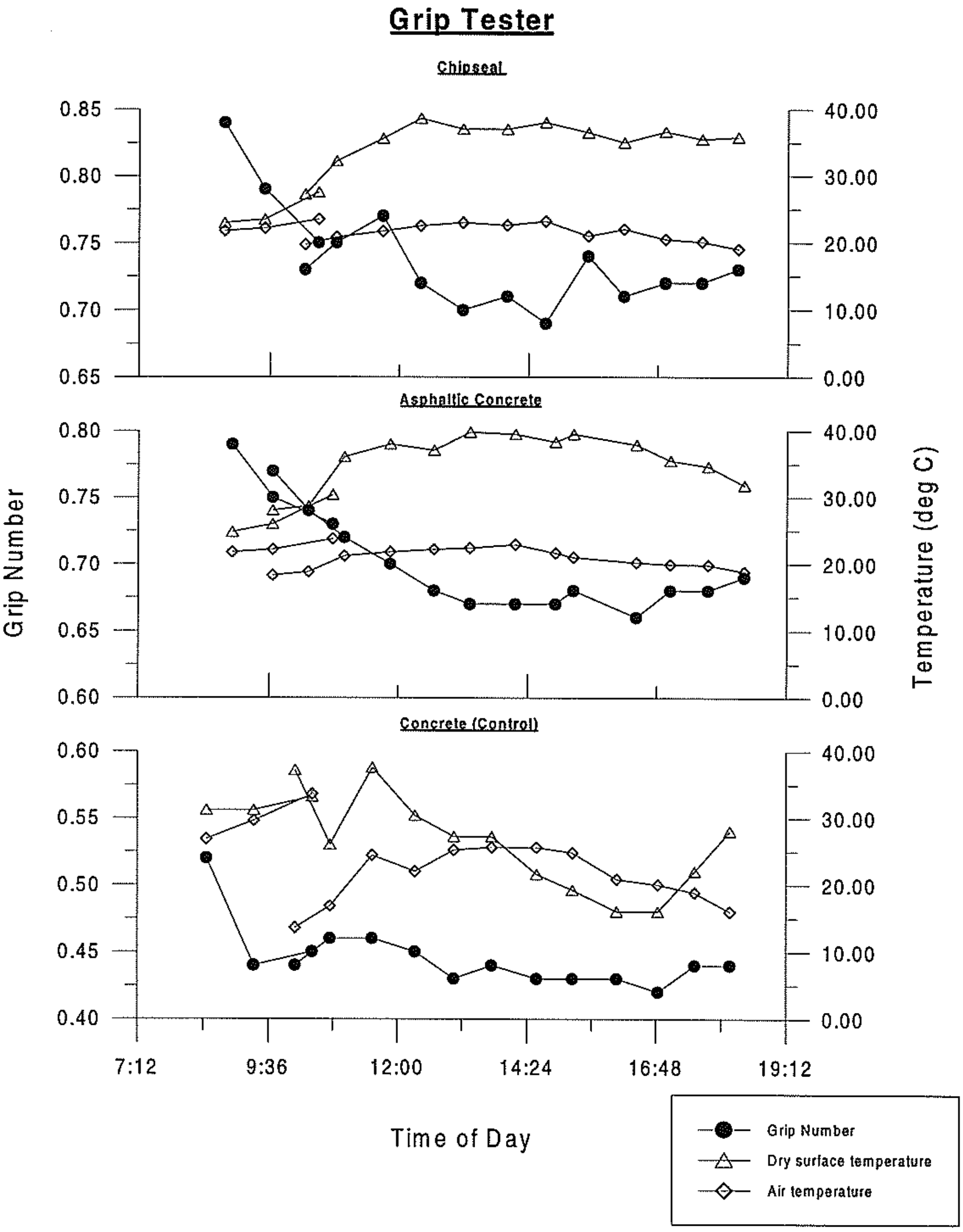


Figure 5. Temperature corrected BPN variation for chipseal site.

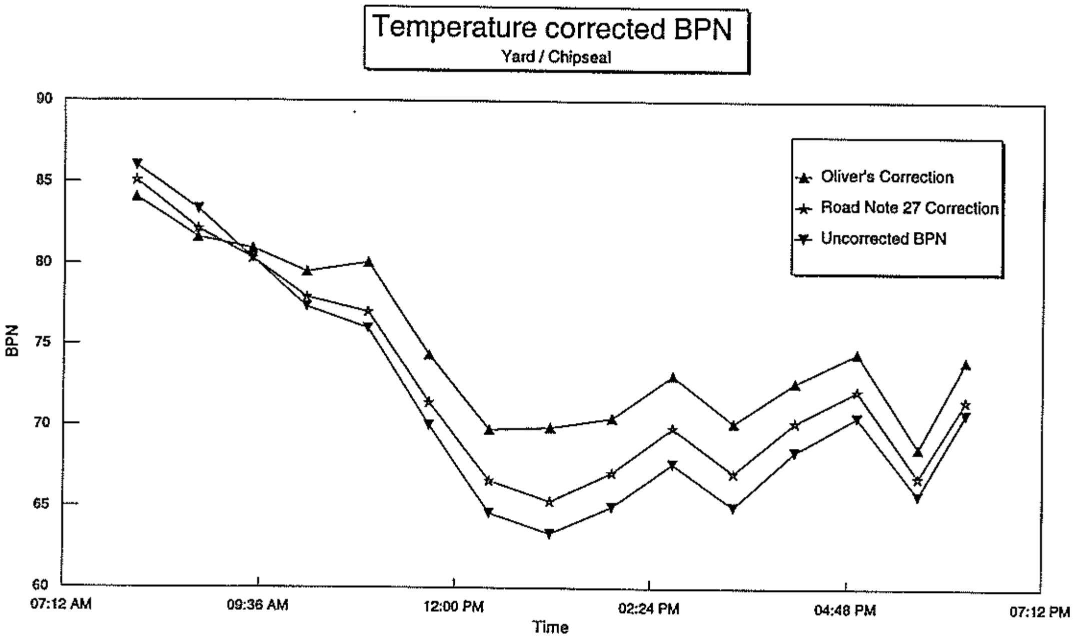


Figure 6. Temperature corrected BPN variation for asphaltic concrete site.

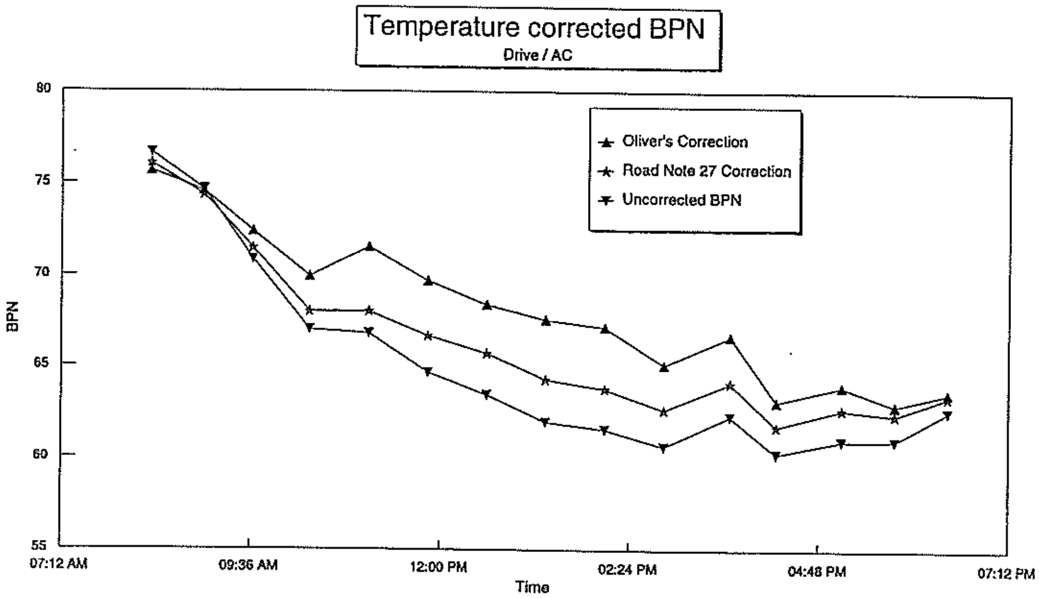


Table 1. Differences between daily maximum and minimum BPN readings for chipseal site.

Δ BPN	Test site surface	
	Chipseal	**Asphaltic concrete**
Uncorrected	22.7	16.4
Road Note 27 correction	20.5	14.2
Oliver's correction	19.7	12.6

The GripTester derived skid resistance measurements showed a difference of 0.11 Grip Number (GN) units between the highest (0.77) and lowest (0.66) values recorded over the 11 hour monitoring period for the chipseal test site, and 0.08 for the asphaltic concrete site. These variations are about half that of the British Pendulum Tester measurements and are partly attributed to smaller fluctuations in the temperature of the GripTester's measuring tyre (21.6-27.7°C) when compared to the British Pendulum Tester's high resilience rubber slider (15.6-24.8°C). This was achieved by utilising a short run-up length to condition the GripTester's measuring tyre, as can be seen in Figure 1.

A linear regression analysis was performed to establish the degree of correlation between the measured skid resistance values and the average of the air and the dry road surface temperatures. This temperature parameter was selected over others primarily because it forms the basis of the temperature correction factor for SCRIM readings. Also being a composite temperature measure, it is less likely to experience significant variations due to random events such as passing cloud cover, localised surface hot spots, etc. The resulting correlation equations are given in Table 2. With reference to the standard deviation values of the regression slope coefficients, it is apparent that the British Pendulum Tester readings display a different temperature sensitivity for the coarse textured chipseal surface than for the smooth textured asphaltic concrete surface (–1.41 BPN/°C c.f. –0.95 BPN/°C). This is graphically shown in Figure 7. By comparison, this surface texture effect is not evident in the GripTester readings. Combining the asphaltic concrete and chipseal Grip Number values results in a temperature sensitivity of about –0.0113 GN/°C. Figure 8 shows the associated regression line which has a coefficient of determination (r^2) of 0.68. Dividing the British Pendulum Number by 100 to give skid resistance values of comparable magnitude to the Grip Number suggests that the GripTester in push mode displays a similar temperature sensitivity to the British Pendulum Tester.

A previous on-road investigation of GripTester measurement sensitivities undertaken by Opus Central Laboratories on Lower Hutt roads showed a temperature sensitivity of about – 0.004 GN/°C for a tow speed of 50 km/h. The reported temperature sensitivity for SCRIM at a survey speed of 50 km/h is very similar at –0.003 SFC/°C (Kennedy *et al* 1990). It therefore can be inferred that the temperature sensitivity of skid resistance measuring devices with intermittent type of operation is a factor of three greater than for continuous measuring devices.

Figure 7. Correlation between British Pendulum Number and temperature as a function of road surface type.

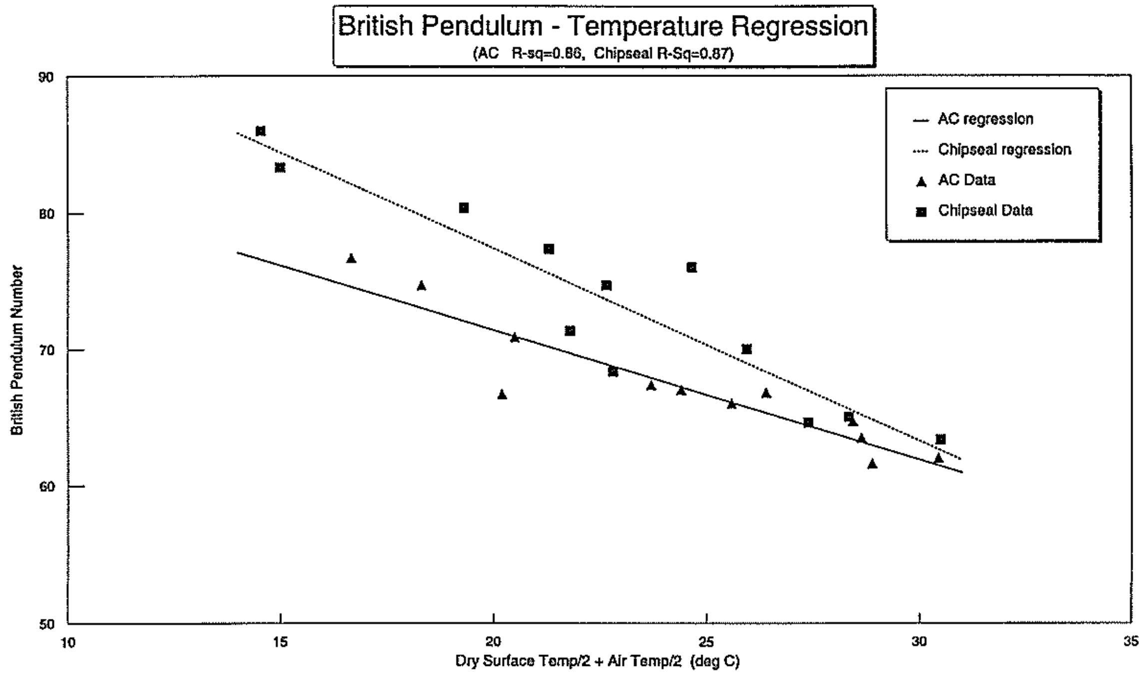


Figure 8. Correlation between Grip Number and temperature.

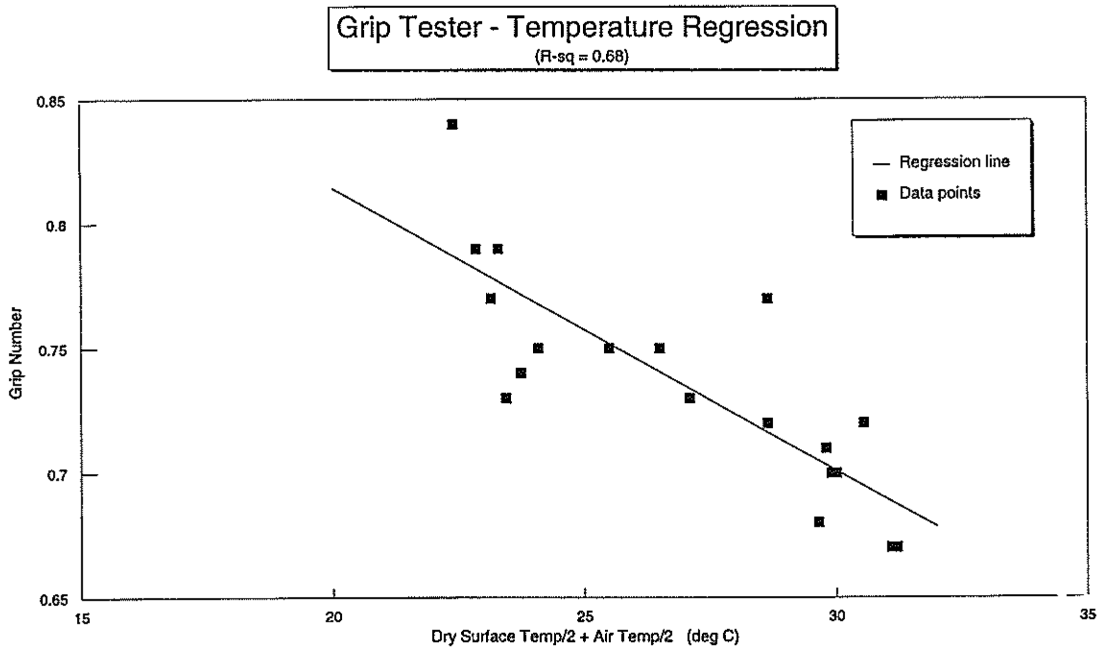


Table 2. Linear correlations between skid resistance reading and temperature.

Device	Regression equation	Surface type	Coefficient of determination (r^2)
British Pendulum Tester	BPN = 90.45 – 0.95T (3.03) (0.12)	Asphaltic concrete	0.86
	BPN = 105.66 – 1.41T (4.09) (0.18)	Chipseal	0.87
GripTester	GN = 1.04 – 0.012T (0.04) (0.001)	Asphaltic concrete	0.89
	GN = 1.02 – 0.010T (0.09) (0.003)	Chipseal	0.54

BPN = British Pendulum Tester
GN = Grip Number @ 5 km/h
T = [air temperature (°C) + dry road surface temperature (°C)] / 2
( ) = standard deviation

2.4 Concluding Remarks

It is readily apparent that presently used temperature correction procedures for the British Pendulum Tester are inadequate. This finding is consistent with a previous New Zealand study undertaken by Royds Garden Ltd on behalf of the National Roads Board (Royds Garden 1989). Therefore any historical data collected with this device to investigate seasonal variations will include a significant temperature component. This will also be the case with the GripTester as no temperature correction is applied.

Based on the 3 and 10 March 1998 measurements, the commonly applied temperature correction procedure given in Road Note 27 for the British Pendulum Tester under-estimates the observed temperature sensitivity by a factor 4. If the British Pendulum Tester continues to be used for testing New Zealand road surfaces, a more appropriate temperature correction than either Road Note 27 or Oliver (1980) needs to be derived which specifically accounts for road surface texture characteristics.

3. CREATION OF TIME SERIES SKID RESISTANCE AND ASSOCIATED CLIMATE DATABASES

3.1 Background

Data from existing skid resistance time series database was extracted and reformatted in a form suitable for inputting in specialised statistical analysis software. The data comprised British Pendulum Tester measurements performed over a number of years in Whangarei, Palmerston North, Christchurch and Dunedin as part of National Roads Board projects, and GripTester measurements performed at six sites in the Wellington region at a frequency of 2-3 weeks over 18 months to obtain seasonal variation correction factors for the 1995 SCRIM state highway survey. The skid resistance data was matched with weather data acquired from the National Institute of Water and Atmospheric Research Ltd (NIWA). This weather data comprised daily averages of maximum and minimum air temperature and rainfall, wind speed and direction, humidity, and barometric pressure. A description of the resulting databases follows.

3.2 Whangarei Database

British Pendulum Tester derived skid resistance readings and associated sand circle derived texture depth readings have been recorded at a minimum of three monthly intervals by Opus Consultancy Services Ltd, Whangarei Laboratory, since February 1988. At time of writing this report, 1998, these measurements were continuing. The measurements are made on seven consecutive test strips, each between 80-100 m in length, located on State Highway 1 between RP 165/6.97 and RP 173/0.0. All the test strips are surfaced with grade 2 greywacke chip. The specific test strip locations and the associated quarry sources of the sealing chip are given in Table 3.

The average traffic volume across all the test strips over the period 1988 to 1997 was an AADT = 4400 (vehicles/lane/day) with a mix of light and heavy vehicles considered to be typical for a state highway. An open road speed zone (100 km/h) applies to all test strips.

For each test strip, the skid resistance measurements were taken at up to six different sites using British Pendulum Tester (Instrument No. 8305) in accordance with procedures specified in Road Note 27 (HMSO 1969). Accordingly this instrument is calibrated once a year. Four different operators have been utilised in making these time series measurements.

Table 3. Route position location of Whangarei test strip sites and sealing chip source.

Test site no.	Location along SH1	Source of grade 2 chip
1	RP 165/7.27-7.37	Warahine Quarry, Wellsford
2	RP 165/7.37-7.47	Maungaturoto Trans., Piroa Quarry
3	RP 165/7.59-7.67	Winstones Otaika Quarry
4	RP 165/7.67-7.75	Titoki Quarry
5	RP 165/7.89-7.97	Puketona Quarry
6	RP 165/7.97-8.05	Lamers Road, Kaitaia
7	RP 165/8.05-8.13	Pukepoto Quarry, Kaitaia

The available weather data was collected at Whangarei Airport, which is approximately 7 km northeast from the test strips.

Figure 9 shows the variation in the average test strip values over the 10 year monitoring period. Important features of note are:

- A decline in skid resistance over the first four years. The rate of decline progressively diminishes and then stabilises. This effect is attributed to the polishing action of accumulated traffic.
- A strong cyclical seasonal influence, with the highest skid resistance in the winter and the lowest in the summer. The difference between maximum and minimum values over a year, once the test strip surfaces have reached their terminal skid resistance value, is 15 BPN units. This is of similar magnitude to the observed daily change in BPN values (refer Section 2.3).
- All test strips exhibit the same degree of cyclical variation once the terminal skid resistance value is reached. This is not unexpected as the surfaces of the test strips are constructed from the same type of aggregate, greywacke.

With reference to Figure 10, the same yearly cyclical variation is present in the wet road surface temperature, recorded immediately after the skid resistance measurements have been taken. This suggests that the observed seasonal variation in the skid resistance readings is in phase with changes in skid resistance due to temperature.

Plots of skid resistance and wet road surface temperature variations at each measurement site within a test strip, from which the average values graphed in Figures 9 and 10 have been derived, are presented in Appendix 2 for reference.

3.3 Three Cities Database

Relevant data was extracted from a National Roads Board funded study undertaken by Royds Garden Ltd to investigate the skid resistance performance of different aggregates under varying climatic conditions and comparable traffic conditions (Royds Garden 1989). This study used two greywacke aggregates, one sourced from Palmerston North and the other from Christchurch, and Dunedin basalt. Relevant characteristics of the aggregates are given in Table 4.

At three sites located in Dunedin, Christchurch and Palmerston North, 2-4 m^2 patches of test aggregate were constructed in December 1982 and January 1983 in a traffic lane as part of a normal road sealing operation. The Christchurch and Dunedin sites had three test patches, each comprising Christchurch, Dunedin and Palmerston North sourced aggregate. The Palmerston North site had only two patches comprising Christchurch and Palmerston North sourced aggregate.

The Dunedin site was located on Hillside Road, between Wesley and Bradshaw Streets. This is an inner city main arterial with a mean traffic flow of 5840 vehicles/lane/day. The wheelpaths on the site were well defined due to kerbside parking restricting the trafficable width of the lane.

Figure 9. Time history of average BPN values for Whangarei test strips.

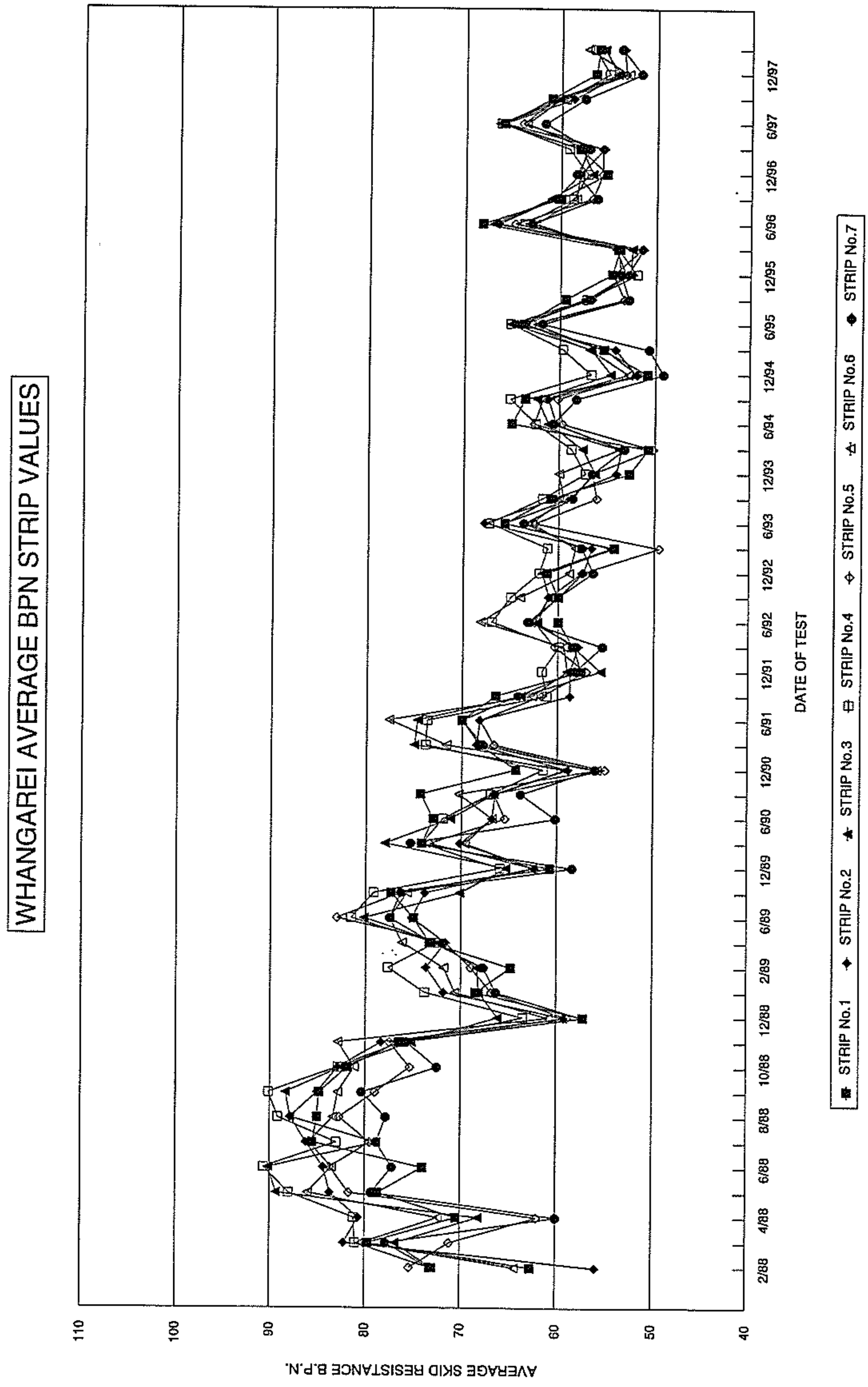
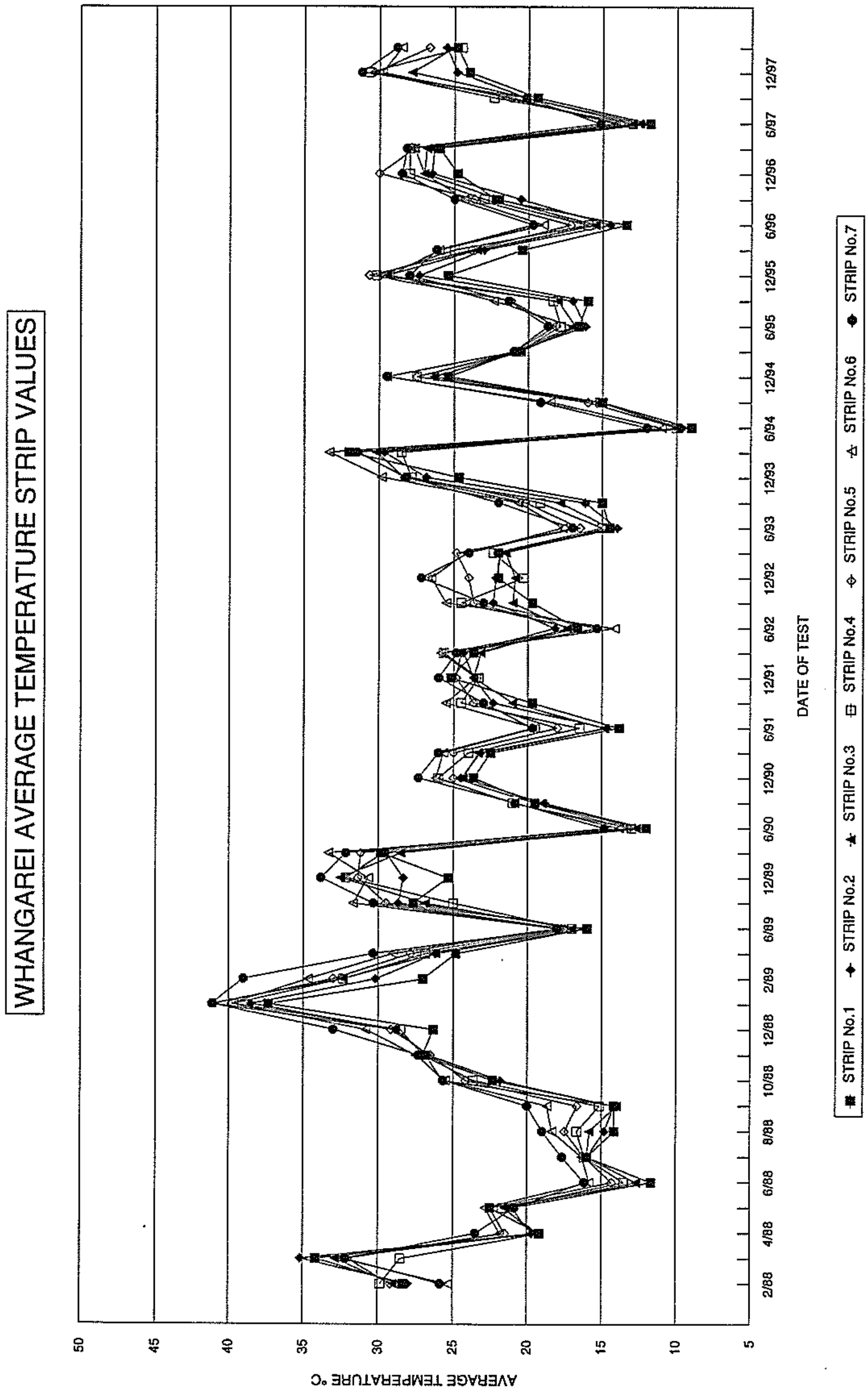


Figure 10. Time history of average wet surface temperature values for Whangarei test strips.



The Christchurch site was located on Yaldhurst Road (State Highway 73, RP 0/1.90). This is an outer city, main arterial with a mean traffic flow of 7384 vehicles/lane/day. Pronounced wheelpaths were not evident as traffic was free to track over a much wider area of pavement than the Dunedin site. The Palmerston North site was located on Milson Line, an outer city arterial with a traffic flow of 2626 vehicles/lane/day. This site was comparatively free of wheeltracking. All three sites were in 50 km/h restricted traffic areas.

Table 4. Sealing chip specifications for Three Cities study.

Aggregate type	**ALD[1] (mm)**	**PSV[2]**	**Source**
Basalt	6.5	39-46	Palmers Quarry, Logan Point North End, Dunedin
Greywacke	7.1	52-57	Pavroc Quarry, Miners Road, Christchurch
Greywacke	6.4	51	Childs Quarry, Palmerston North

1. **ALD** = Average Least Dimension of Chip
2. **PSV** = Polished Stone Value

At all sites, data collection commenced in 1983 within four months of construction. Testing at marked site locations was carried out on a random basis with testing frequency increasing to three and four times a year. Due to flushing, testing was carried out in Dunedin only until 1986, but continued at both Christchurch and Palmerston North sites until 1988.

A British Pendulum Tester (Instrument No. 8244), calibrated on a yearly basis, was used to measure skid resistance. Special care was taken to ensure that the measurements were always carried out at the same location within the test patch. All skid resistance measurements were corrected for air temperature using Oliver's (1980) relationship.

Figures 11 to 18 show the variation in test site skid resistance values at each marked location over the testing period. The frequency of testing at Dunedin was insufficient to show seasonal variations. However, the Christchurch test site results show a strong seasonal variation with the highest skid resistance in the winter and the lowest in the summer. The results for the Palmerston North test site also show a cyclic variation, particularly for the Christchurch aggregate.

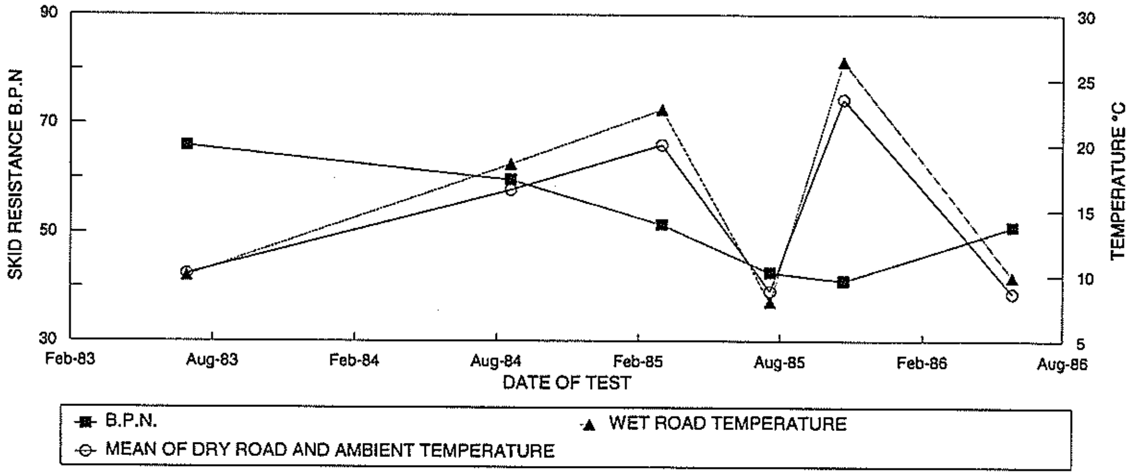
The supplied weather data was collected at the following meteorological stations:

- Musselburgh, except for pressure data which was taken at Dunedin Airport. Musselburgh is approximately 4 km west of the Dunedin test site, while Dunedin Airport is approximately 25 km south.
- Christchurch Airport, which is approximately 2 km southwest of the Christchurch test site.
- Palmerston North Airport, which is less than 1 km west of the Palmerston North test site.

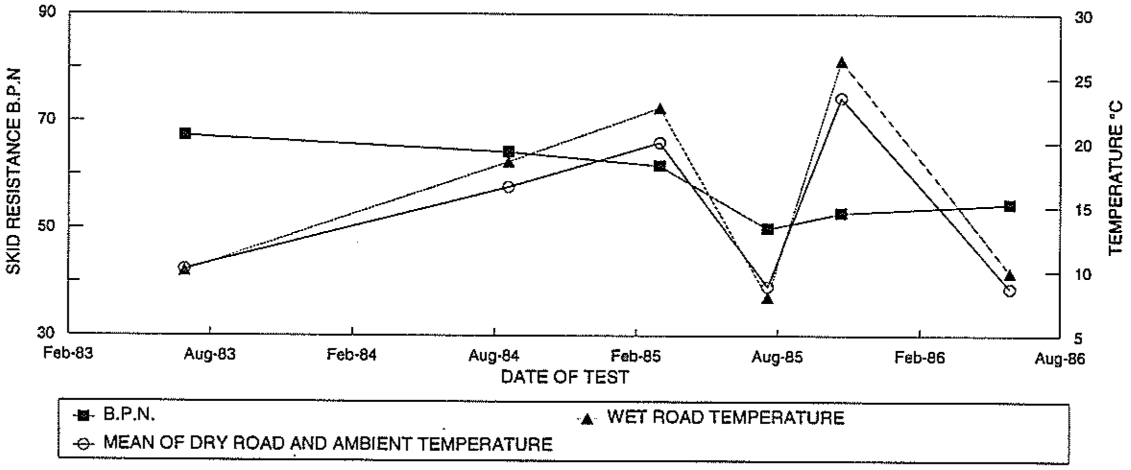
Research undertaken in the UK by Neville (1974) suggested that the amplitude of seasonal variation depends on aggregate type, the lower its polished stone value the more pronounced the effect. The Three Cities database provided an opportunity to test this premise.

Figure 11. Time histories of BPN values for Dunedin test site - locations 1 to 3 (Christchurch chip).

DUNEDIN SITE ONE



DUNEDIN SITE TWO



DUNEDIN SITE THREE

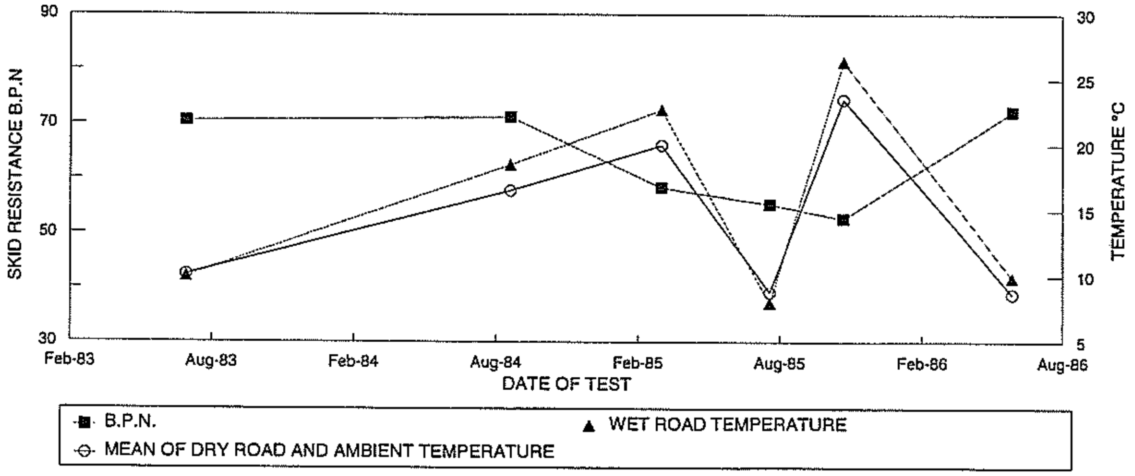
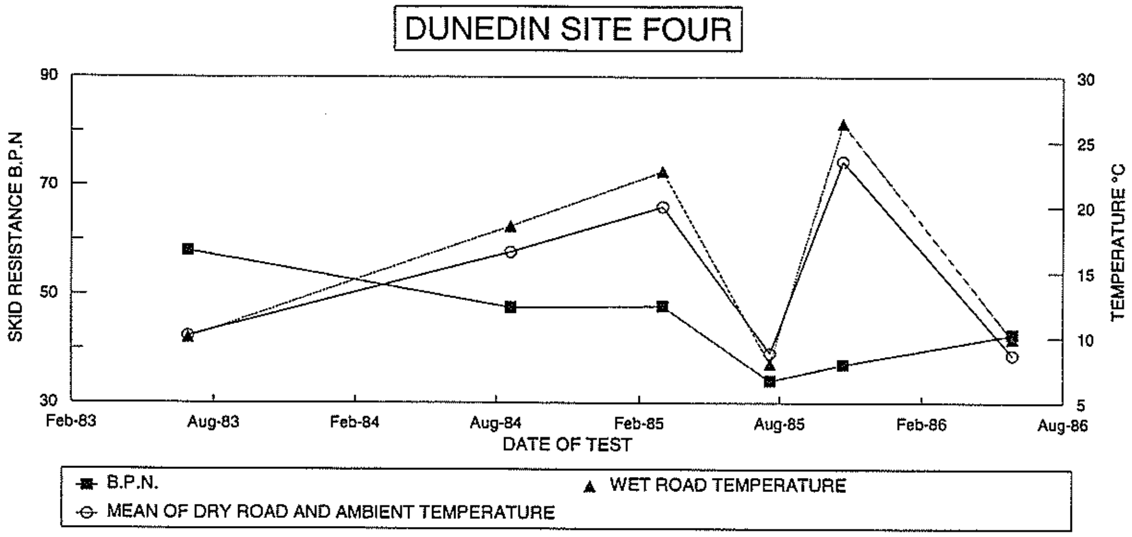
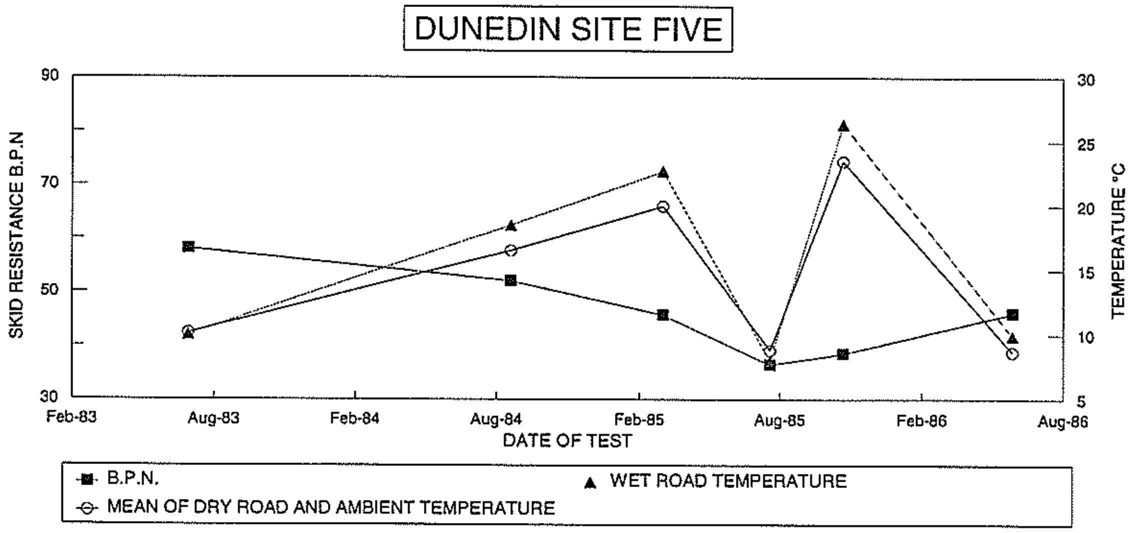


Figure 12. Time histories of BPN values for Dunedin test site - locations 4 to 6 (Dunedin chip).





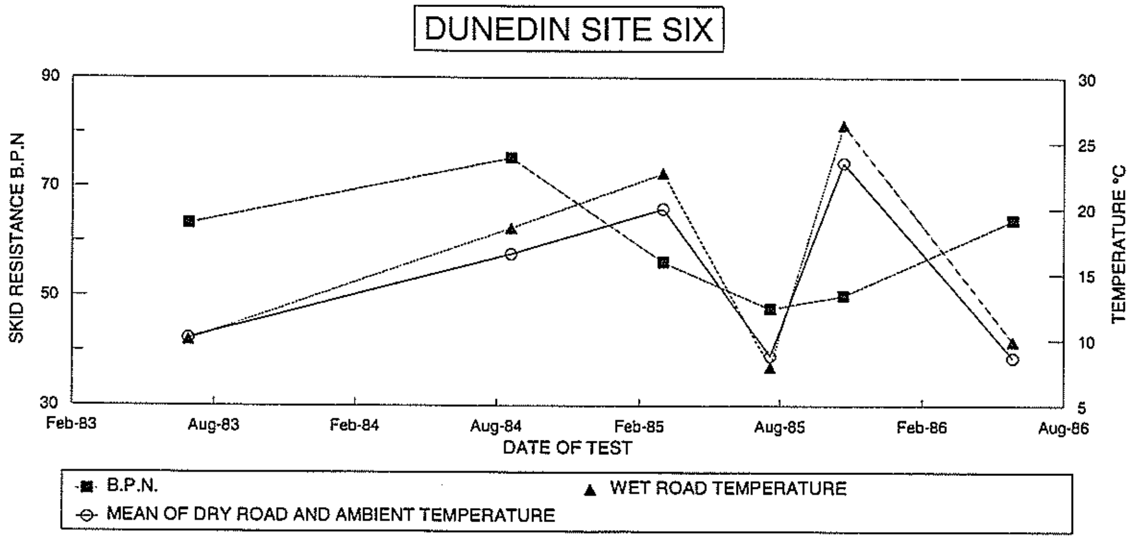
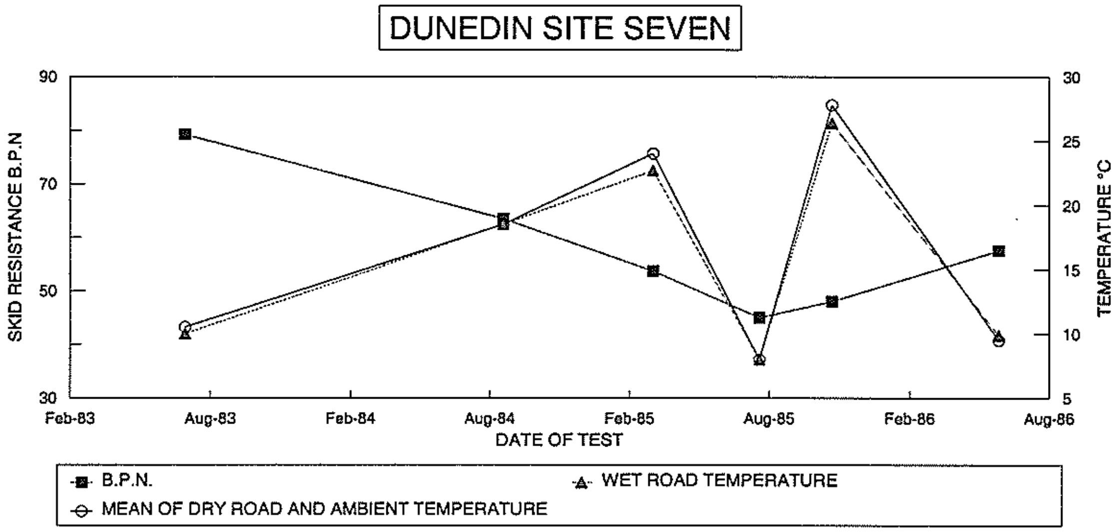


Figure 13. Time histories of BPN values for Dunedin test site - locations 7 and 8 (Palmerston North chip).



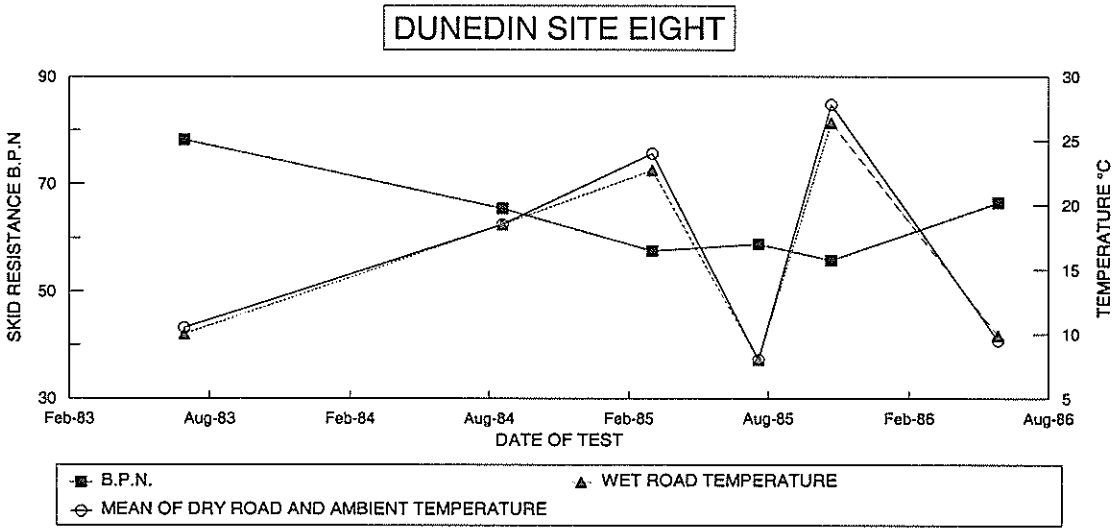
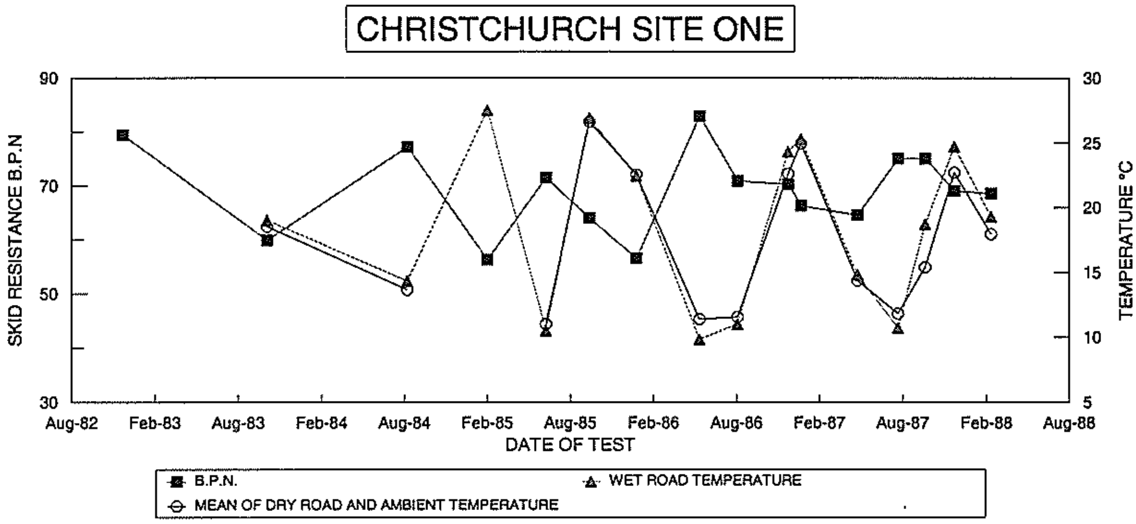
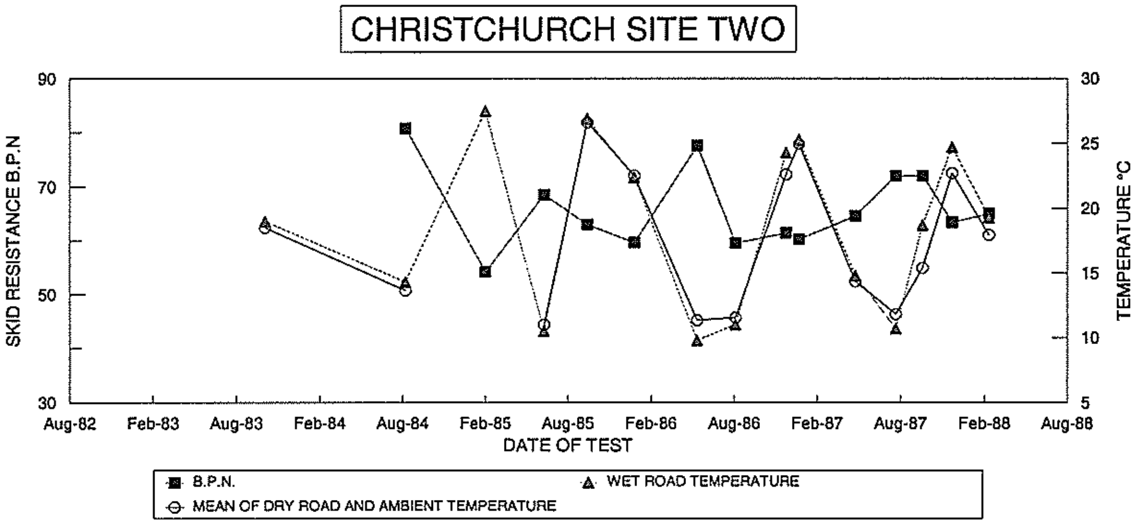


Figure 14. Time histories of BPN values for Christchurch test site - locations 1 to 3 (Palmerston North chip).





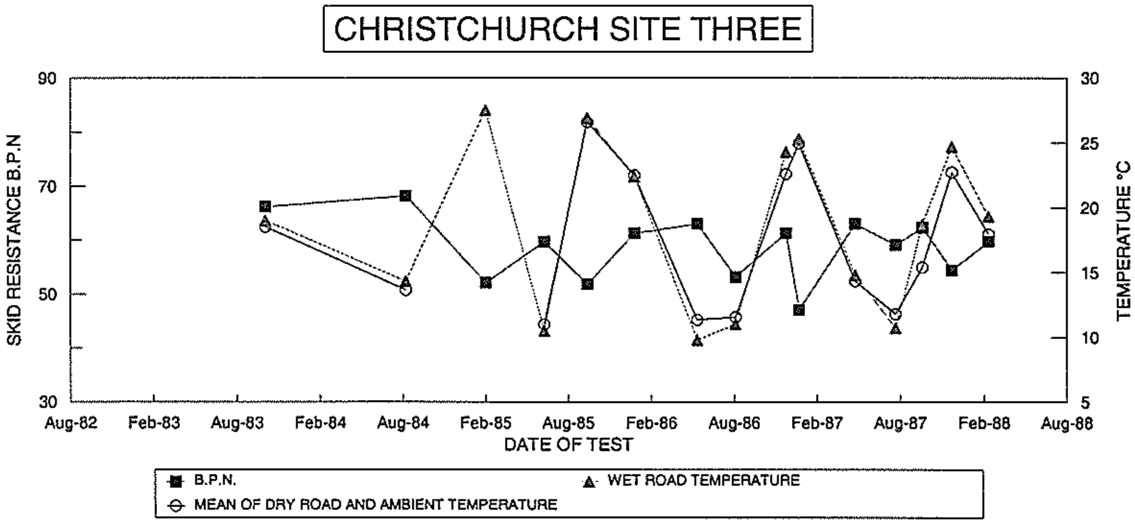
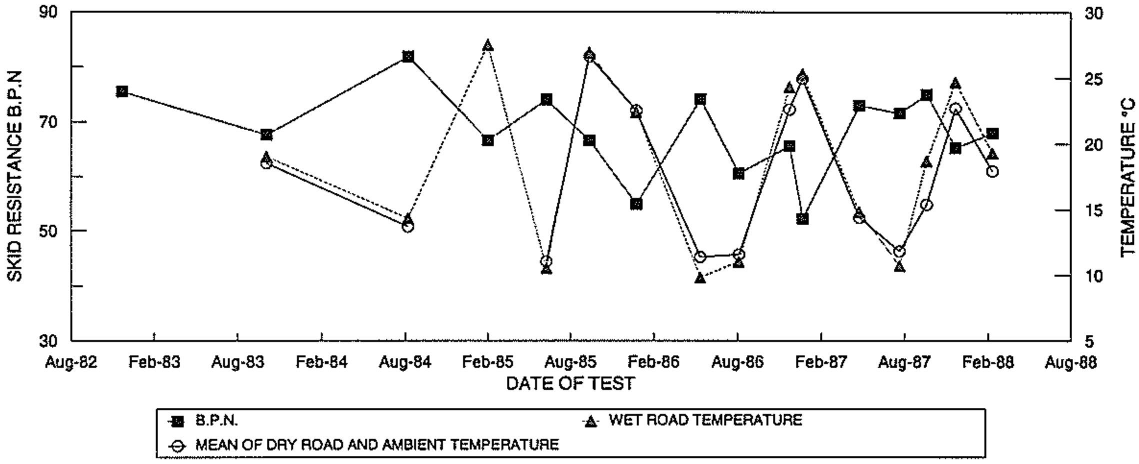
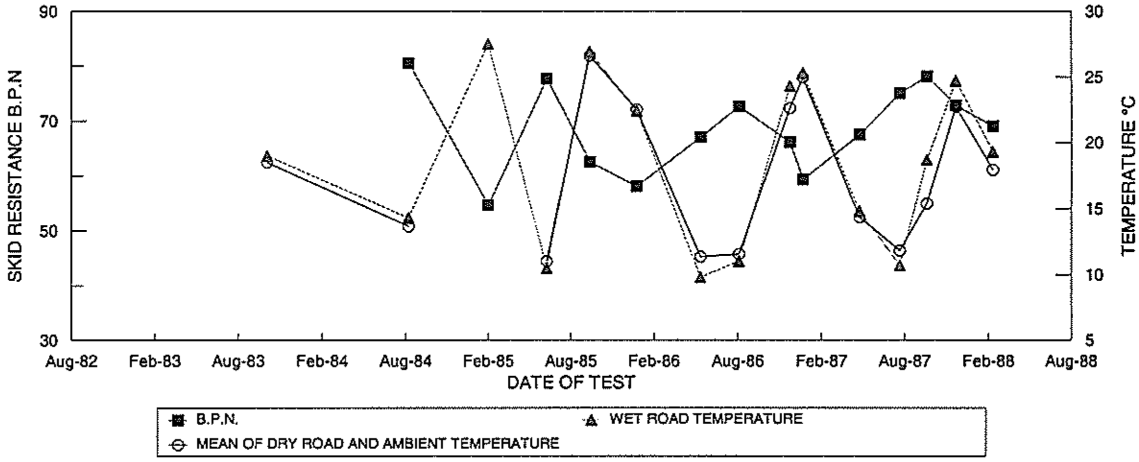


Figure 15. Time histories of BPN values for Christchurch test site - locations 4 to 6 (Christchurch chip).

CHRISTCHURCH SITE FOUR



CHRISTCHURCH SITE FIVE



CHRISTCHURCH SITE SIX

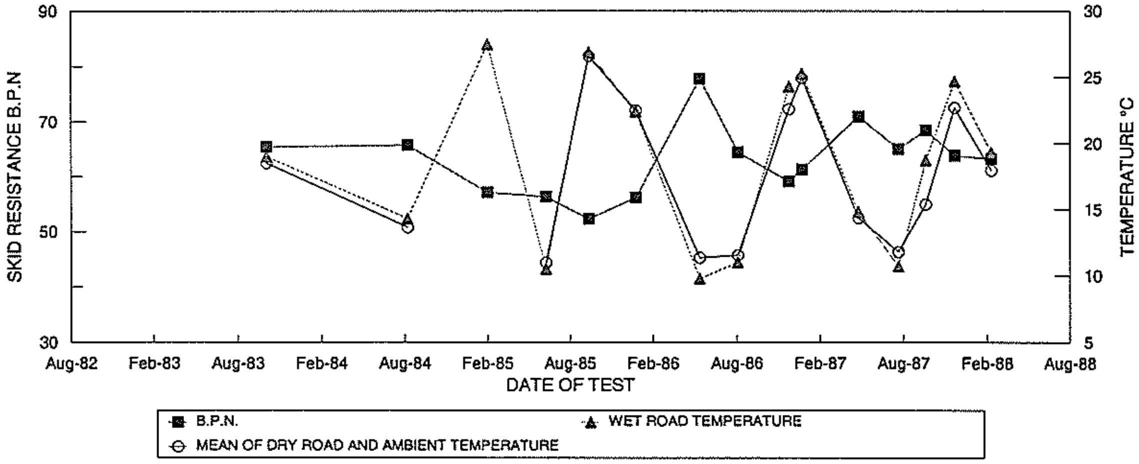
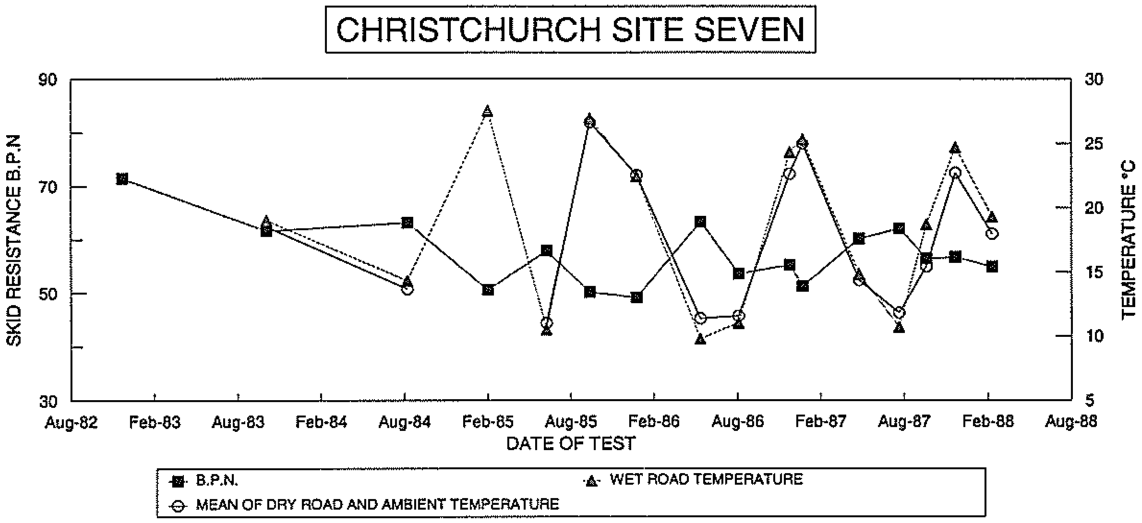
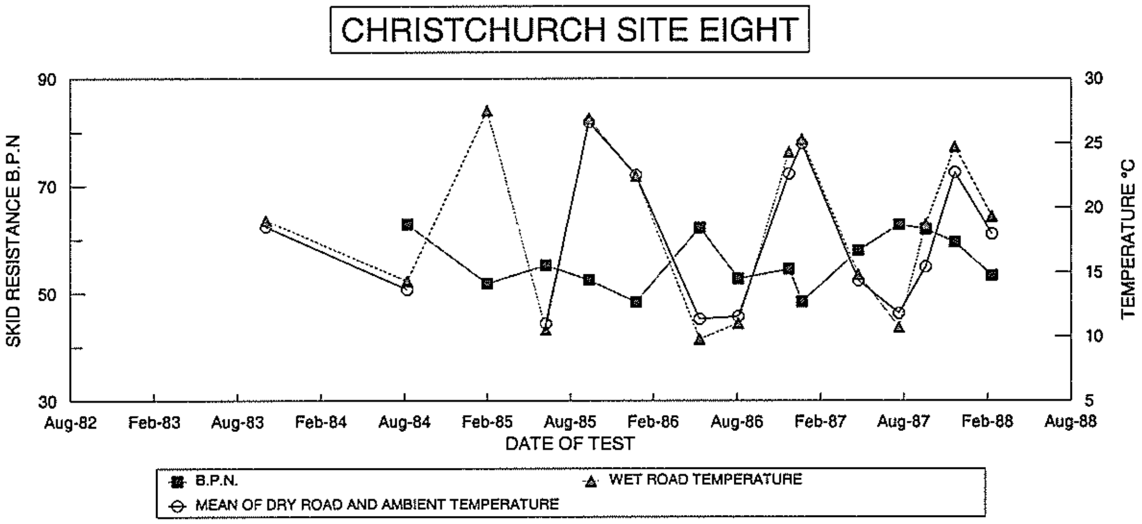


Figure 16. Time histories of BPN values for Christchurch test site - locations 7 to 9 (Dunedin chip).


CHRISTCHURCH SITE SEVEN


CHRISTCHURCH SITE EIGHT

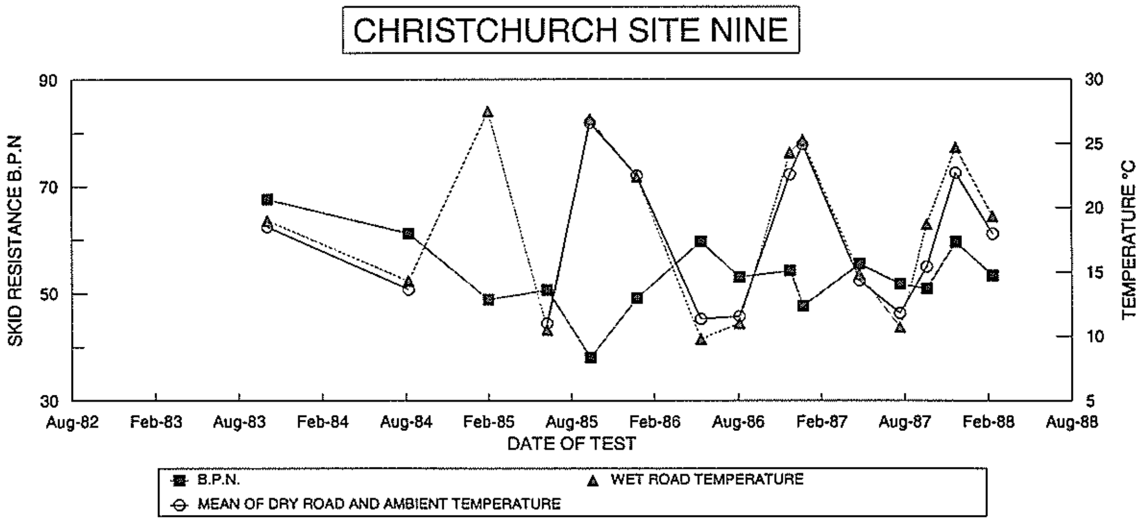
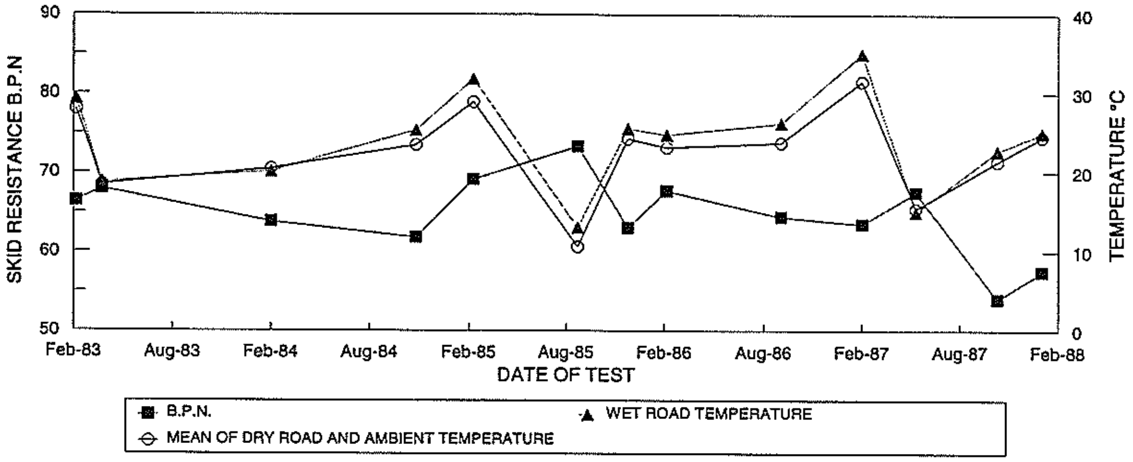
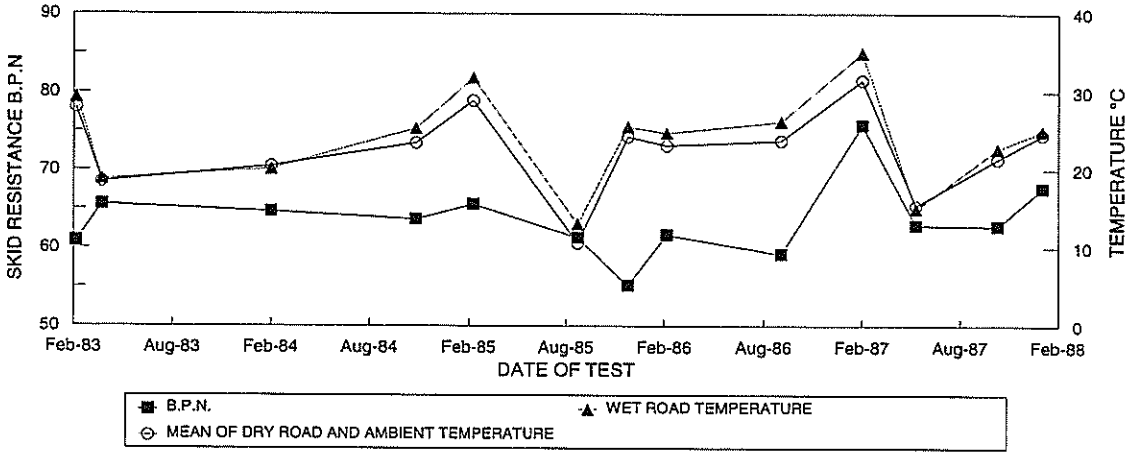

CHRISTCHURCH SITE NINE

Figure 17. Time histories of BPN values for Palmerston North test site - locations 1 to 3 (Christchurch chip).

PALMERSTON NORTH SITE ONE



PALMERSTON NORTH SITE TWO



PALMERSTON NORTH SITE THREE

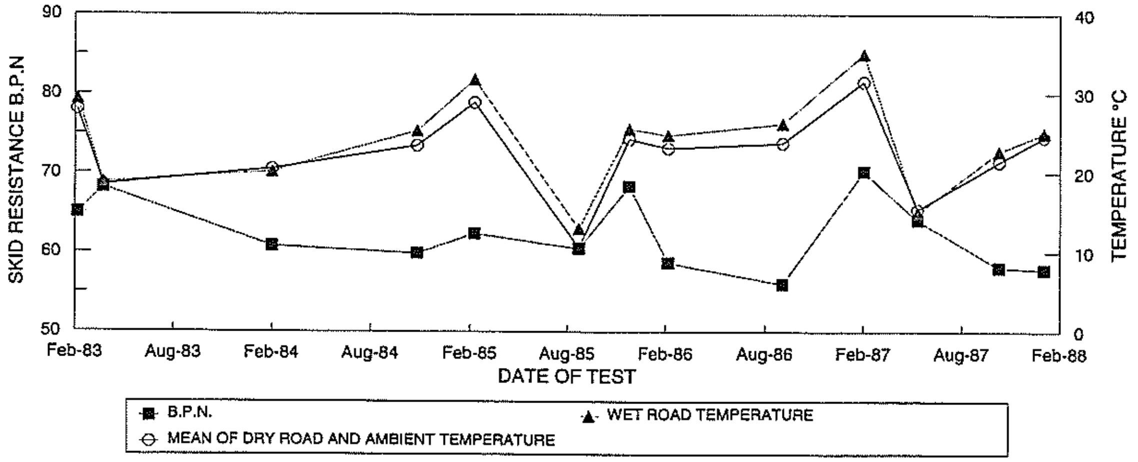
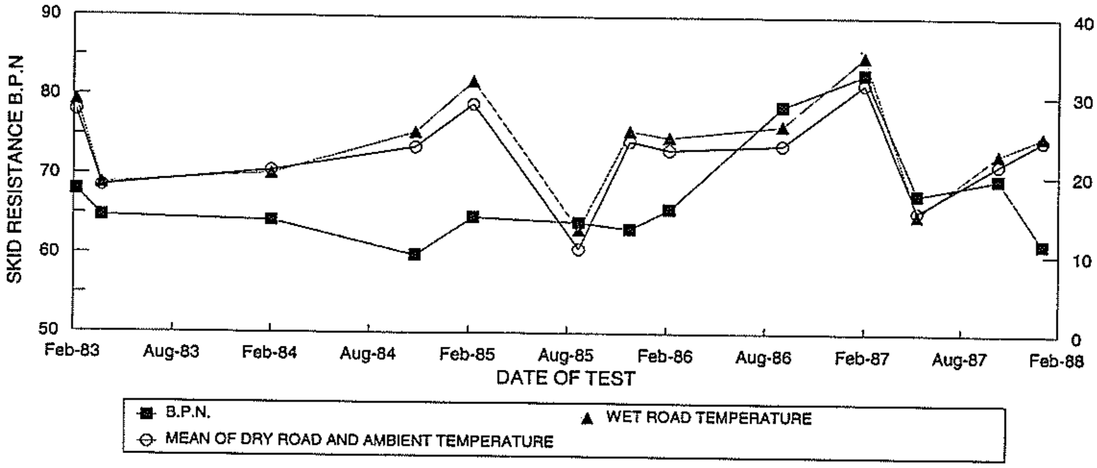
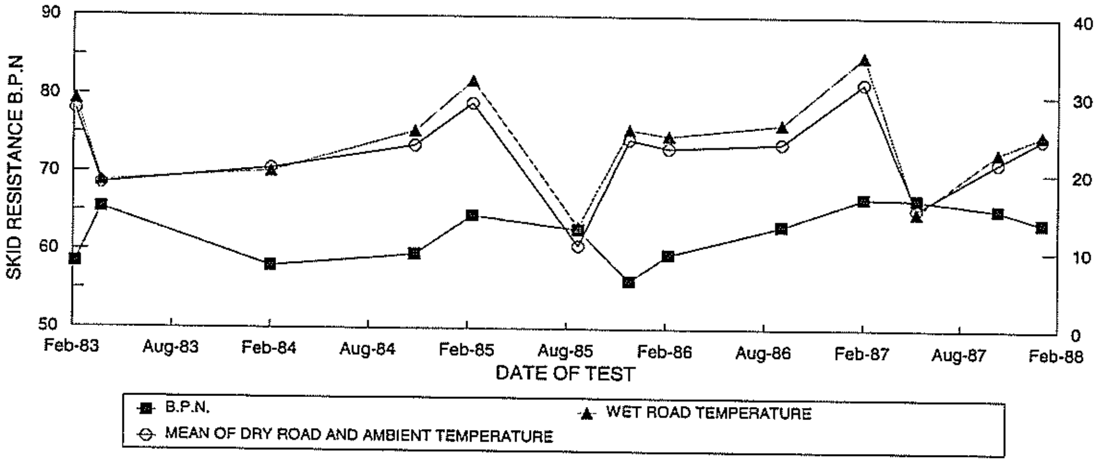
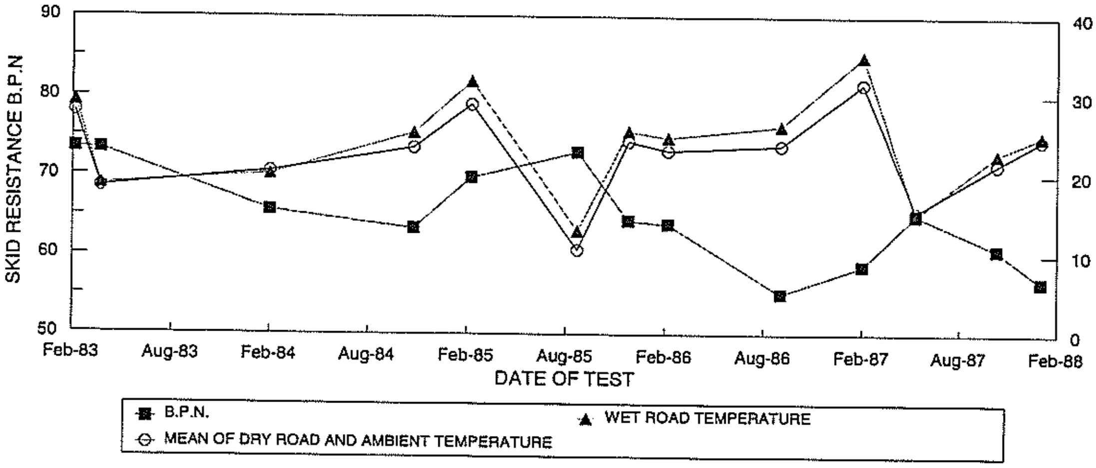


Figure 18. Time histories of BPN values for Palmerston North test site - locations 4 to 6 (Palmerston North chip).


PALMERSTON NORTH SITE FOUR


PALMERSTON NORTH SITE FIVE


PALMERSTON NORTH SITE SIX

3.4 Wellington Database

As part of the 1995 SCRIM survey of the state highway network, the skid resistance of a number of control sites located in the Wellington region were monitored almost on a fortnightly basis over a 20 month period (late December 1994 to late July 1996) to establish seasonal correction factors. Measurement of skid resistance was by Opus Central Laboratories' GripTester operated at a survey speed of 50 km/h and 0.5 mm water film depth. No temperature correction was applied, although readings of on-road temperature, wet and dry bulb temperature, tyre temperature, and barometric pressure were taken on completion of a control site survey.

The control sites satisfied the following selection criteria:

- chipseal surface in sound condition and at least two years old (to ensure that it had passed the initial polishing stage and had reached an equilibrium condition),
- no major change likely in condition or commercial traffic flow over the monitoring period,
- located on straight, level stretches of road,
- structurally sound pavement with little rutting and low to medium roughness,
- free-flowing traffic covering a range of levels,
- well defined wheeltracks,
- minimum length of 500 m,
- reasonably uniform skid resistance along length of site,
- unlikely to be subject to windborne or vehicle contamination from adjoining land.

The locations of the control sites are summarised in Table 5. Originally only six control sites were to be monitored. However, control sites 3 and 5 were replaced three months into the monitoring programme by control sites 7 and 8 respectively in an effort to reduce travel time between the six sites. Unexpectedly, control site 8 was resealed 2½ months later and so GripTester surveying of site 5 resumed after July 1995.

During the monitoring period, the GripTester's tow vehicle was involved in a crash and so measurements were suspended over May-June 1995 and did not recommence until the start of July 1995.

Time histories of the skid resistance values for the eight sites are presented in Figures 19 to 21. These results tend to confirm established theory that, for an aggregate with the same polished stone value, roads with the higher commercial vehicle volumes will have a lower terminal skid resistance value.

Sites 3 and 8 were precluded from statistical analysis because of the limited number of Grip Number readings.

The available weather data were, in the main, collected at the meteorological centre in the Botanic Gardens at Kelburn, supplemented with limited data from the Weather Workshop weather station at Mana, and NIWA weather stations located at Wallaceville and Kaitoke. The distance of the meteorological centre from the control sites is given in Table 6.

Table 5. Seasonal variation control sites - Wellington region.

Control site no.	Site location	Surface type	Chip size/ALD	Traffic volume (v/l/d)	PSV
1	SH1N - RP 969/3.0/2.3 Porirua Ramp intersection to Whitford Brown Avenue (northbound)	Friction course	10 mm	14,000	55
2	SH1N - RP 969/2.0-1.0 Whitford Brown Avenue to Paremata (northbound)	Coarse chipseal	Grade 2/11.77 mm	12,500	54
3	SH1N - RP 953/15.2-14.1 Paremata Esplanade between Paremata Drive and Dolly Varden Crescent	Fine chipseal	Grade 4	~12,500	54
4	SH1N - RP 969/0.4-1.5 Paremata to Whitford Brown Avenue (southbound)	Fine chipseal	Grade 6	12,500	54
5	SH58, RP 0/8.0-7.0 Judgeford straight (eastbound)	Coarse chipseal	Grade 2/10.42 mm	5,000	55
6	SH2, RP 962/9.0-8.0 Dowse Drive to Melling (northbound)	Friction course	10 mm	16,000	55
7	Paekakariki Road Pautahanui straight near restaurant (southbound)	Fine chipseal	Grade 4	3,000	-
8	Cambridge Terrace, Lower Hutt Waterloo Overbridge to Epuni Station	Coarse chipseal	Grade 3	<2,000	-

Table 6. Distance of Kelburn Meteorological Centre from control sites.

Control site no.	Control site location	Distance to where weather data taken
1	SH1, RP 969/3.0-2.3 (Waitangurua)	20 km, south
2	SH1, RP 969/2.0-1.0 (Paremata roundabout)	20 km, south
4	SH1, RP 969/0.4-1.5 (Paremata roundabout)	20 km, south
5	SH58, RP 0/8.0-7.0 (Judgeford)	25 km, southwest
6	SH2, RP 962/9.0-8.0 (Maungaraki-Normandale)	15 km, southwest
7	Paekakariki Road (Pautahanui)	23 km, south

Figure 19. Time histories of Grip Number values for Wellington control sites 1 to 3.

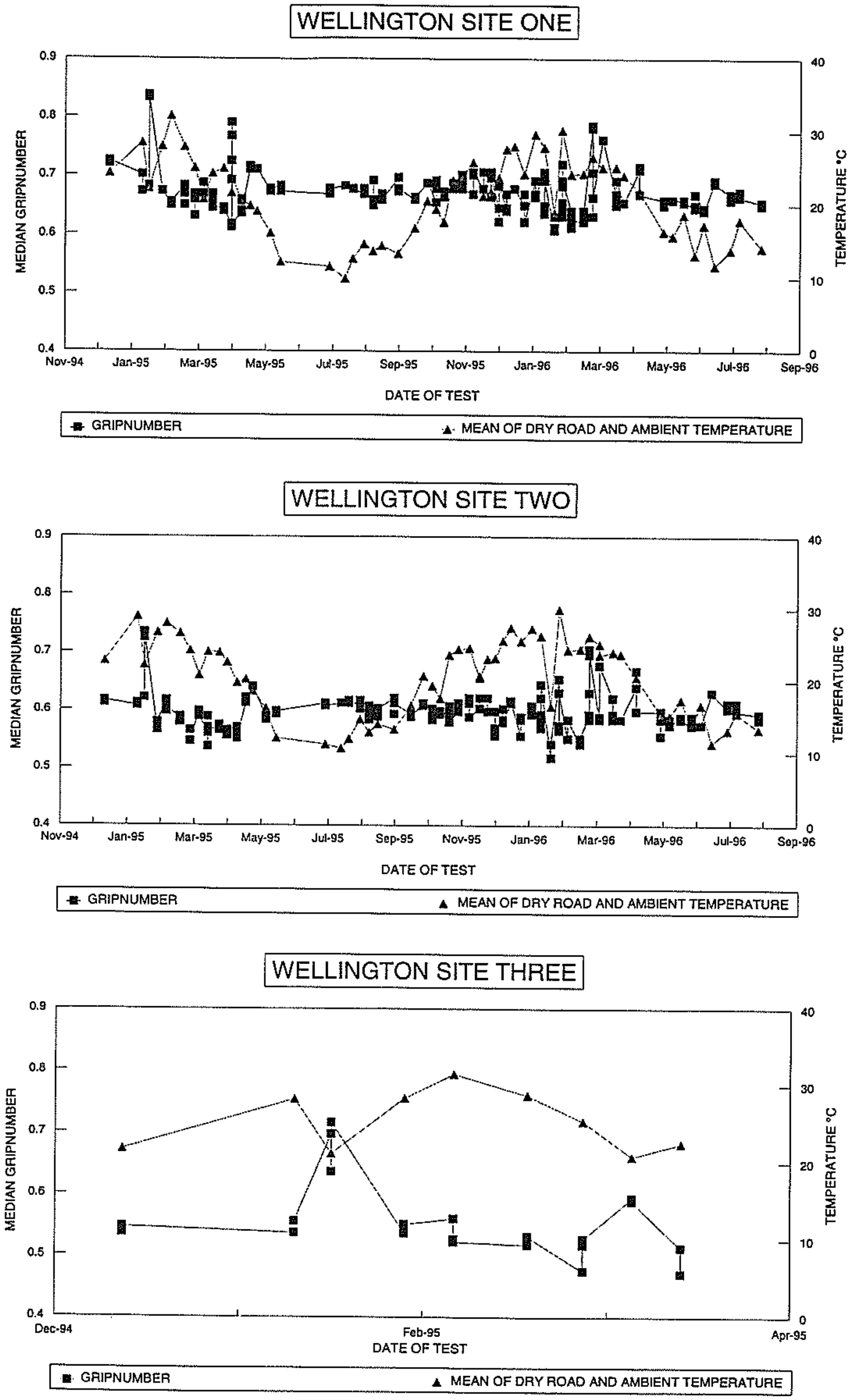
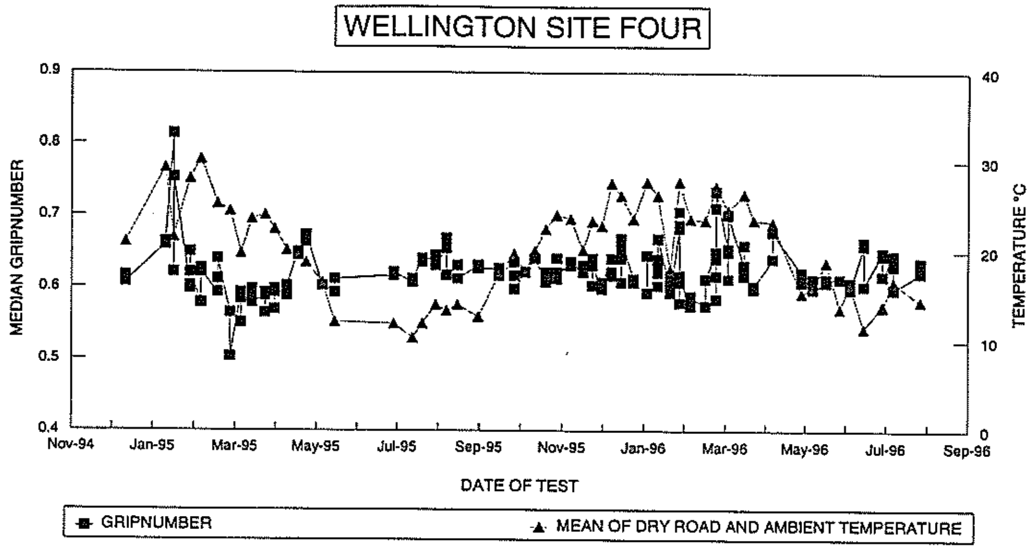
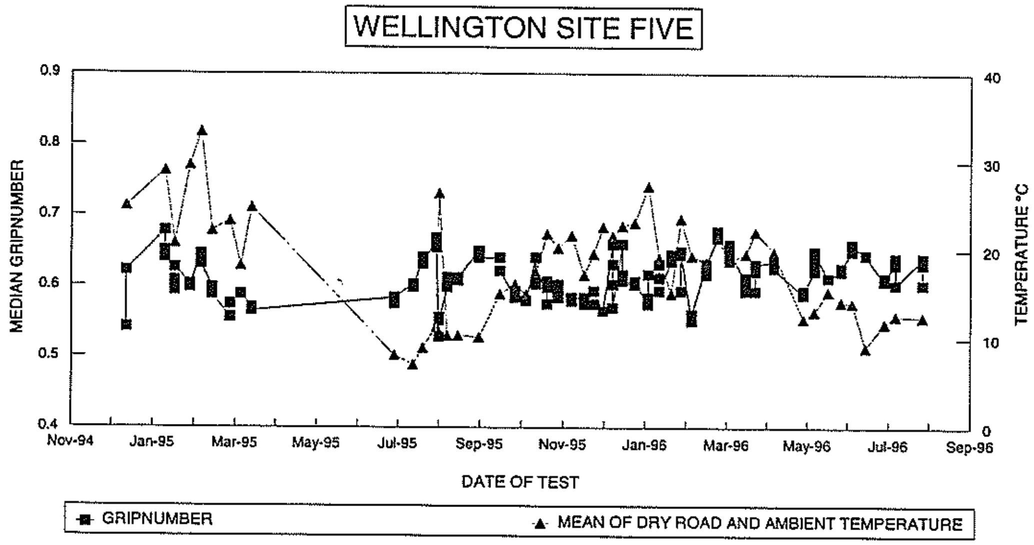


Figure 20. Time histories of Grip Number values for Wellington control sites 4 to 6.





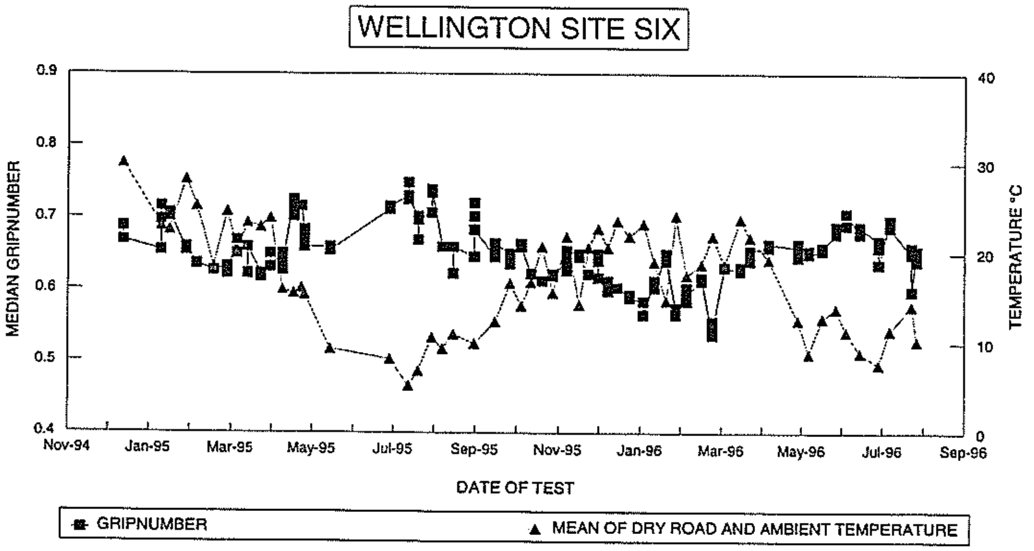
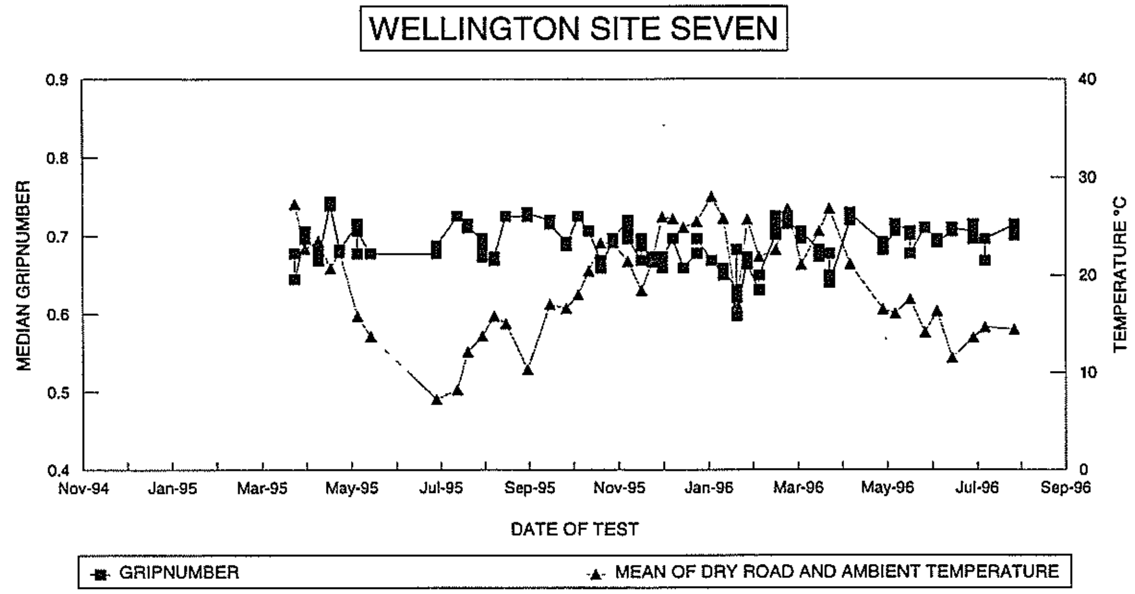
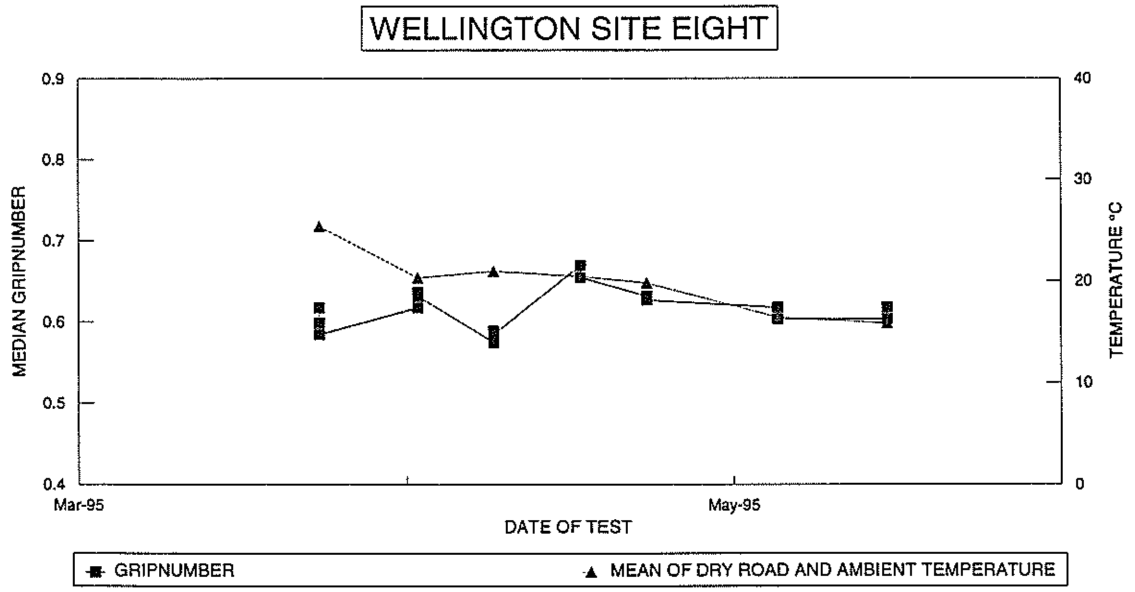


Figure 21. Time histories of Grip Number values for Wellington control sites 7 and 8.





4. STATISTICAL ANALYSIS

4.1 Statistical Packages Utilised

The statistical analyses of the time-series skid resistance data sets described in Section 3 was performed with Genstat and S-Plus. Genstat is produced by the Rothamsted Experimental Station in Harpenden, England, and is distributed by the Numerical Algorithms Group Ltd (NAG). S-Plus is produced by the StatSci Division of MathSoft in Seattle in the USA. It is based on the S package produced by the AT & T Bell Labs (now Lucent Technologies). Both packages provide a wide range of statistical analyses and sophisticated command languages, but with emphases reflecting the different interests of their developers and, to an extent, of the countries of origin.

S-Plus was used for data manipulation, the main statistical analyses and some of the graphical output, whereas Genstat was used to investigate data with complex error structures.

4.2 Interpretation of S-Plus and Genstat Output

4.2.1 Output From S-Plus Linear Model Function (LM)

LM is used for fitting models of the form,

$$Y_i = \beta_0 + \sum_{j=1}^{m} x_{i,j}\,\beta_j + \varepsilon_i$$

for i = 1, ..., n. The Y_i are the observations, the β_j are the unknown parameters to be estimated, and the $x_{i,j}$ form the design matrix (known) that relates the unknown parameters to the observations. The ε_i are random errors which are assumed to have zero mean, the same variance, and be approximately normally distributed.

Two of the tables output by LM are the analysis of variance table and the table of estimates.

The analysis variance table shows the statistical significance of each of the β_j when they are added one after the other. As an example, Whangarei data adjusted for the operator effect averaged across sites and restricted to days where temperature data is available gives the following output:

Response: BPN.Adj
Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
poly (year, 2)	2	176.6668	88.3334	22.50841	0.0000031
T.max	1	322.0947	322.0947	82.07362	0.0000000
C1	1	66.5205	66.5205	16.95022	0.0003918
S1	1	0.0184	0.0184	0.00469	0.9459580
Residuals	24	94.1871	3.9245		

The Y value is the British Pendulum Number adjusted for operator effects. The following effects are considered: a second order polynomial in year (poly (year, 2)), the maximum temperature (T.max), the cosine of 2π (or 360°) × year (C1), and the sine of 2π (or 360°) × year (S1).

The column labelled Df shows number of terms being added in.

The column labelled Sum of Sq shows the reduction in the sum of squares of residuals due to these terms.

The column labelled Mean Sq gives the ratio of the preceding two columns.

The column labelled F Value gives the ratio of the Mean Sq to the residual mean square at the bottom of the Mean Sq column. This is used to test the statistical significance of the effect being fitted. A high value corresponds to a statistically significant effect.

The final column, Pr(F), is the test of significance. A value less than 0.05 is generally considered statistically significant, although if a significant number of tests are carried out a smaller value such as 0.01 or 0.001 may be used.

In this example analysis it can be seen that the first three terms are very significant but the last one is not. However, the terms are added sequentially so that the term T.max is being tested before the sine and cosine terms have been fitted. If the T.max term is fitted last, the following analysis of variance table results:

Response: BPN.Adj
Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
poly (year, 2)	2	176.6668	88.3334	22.50841	0.0000031
C1	1	377.4047	377.4047	96.16728	0.0000000
S1	1	3.2449	3.2449	0.82683	0.3722316
T.max	1	7.9840	7.9840	2.03441	0.1666535
Residuals	24	94.1871	3.9245		

T.max is now no longer significant and so it can be concluded that this term does not provide any useful information once the sine and cosine terms are fitted. Therefore T.max is not included in the final analysis. S1 tends to be included even though it is not a significant variable, because C1 and S1 go together, giving:

Response: BPN.Adj
Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
poly (year, 2)	2	176.6668	88.3334	21.61410	0.0000035
C1	1	377.4047	377.4047	92.34633	0.0000000
S1	1	3.2449	3.2449	0.79398	0.3813949
Residuals	25	102.1710	4.0868		

In the analyses presented in this report, different ordering of variables have been investigated to identify the simplest model consistent with the data.

The second table is the table of estimates.

	Value	Std Error	t Value	Pr (> I t I)
(Intercept)	65.9894763	0.9874250	66.829861	0.0000000
poly (year, 2) 1	–45.8609433	7.3563504	–6.234198	0.0000016
poly (year, 2) 2	18.2303409	5.2055323	3.502109	0.0017562
C1	–4.9760299	0.5209417	–9.551990	0.0000000
S1	–0.4791093	0.5376870	–0.891056	0.3813949

This gives the estimates of the β_j and their standard errors. In most cases the estimates should be within two times the standard error of the true value. The t value is the ratio of the value to the standard error. It is used for telling whether the value is statistically significantly different from zero. The last column gives the significance values. As before, the values less than 0.05 suggest that the corresponding β_j is non-zero.

The line labelled (Intercept) is the constant term, β_0. The two lines labelled poly (year, 2) are for the two terms in the polynomial of year. Interpretation of the values of the individual terms is difficult because S-Plus has transformed them to improve the numerical accuracy. However, both terms are statistically significant, so at least a second degree polynomial is required. The last two lines give the estimates of the C1 and S1 coefficients.

Many of the linear models developed in this report involve factors that can take on one of a small number of values. Examples are the name of a British Pendulum Tester operator or the name of a site. If the factor has p levels, then p-1 terms in the linear equation are needed. Interpretation of the estimates is therefore often difficult and so additional analysis has been generally necessary to obtain useful values.

In some cases, interactions between variables and/or factors needed to be considered. This also required additional analysis as interpretation of the estimates again can be difficult.

4.2.2 Output from REML

REML (restricted maximum likelihood) is concerned with analysing a generalisation of the linear model equation where several different error terms are present. The method was introduced in 1971 (Patterson and Thompson 1971) but did not become available in general statistical packages until the mid 1980s.

In the statistical analyses of the time series skid resistance data set, there exists an error term for each measurement. However, measurements taken on the same day seem to have a common error (or random effect), possibly due to an operator, equipment or climatic effect. Therefore there is likely to be an error associated with each site, which persists throughout the experiment, and so the generalisation of the linear model equation takes the form:

$$Y_i = \beta_0 + \sum_{j=1}^{m} x_{i,j}\beta_j + \sum_{k=1}^{p}\sum_{l=1}^{q_k} u_{i,k,l}\eta_{k,l} + \varepsilon_i$$

The $\eta_{k,l}$ are the additional random effects and the $u_{i,k,l}$ map them onto the appropriate observations. For a given value of k, the $\eta_{k,l} : l = 1, ..., q_k$ correspond to one set of random effects and has zero mean and the same variance.

The analysis using REML is harder to interpret than the analysis using the ordinary linear model. Wherever possible, an attempt was therefore made to reduce the problem to one in which a linear model applies by averaging results across days or sites. However, in some cases there was no other option than to use the REML analysis. An example is the investigation of the three separate sources of error or variation in the Whangarei data set. This is discussed in greater detail in Section 4.3.7, but the output from the associated Genstat REML analysis is used to illustrate the information provided. The REML derived estimates and their standard errors (s.e.) are:

Effect	**Data after 1 January 1990**	
	Estimate	**s.e.**
Site effect variance	1.42	0.44
Day effect variance	5.28	1.54
Measurement variance	13.87	0.55
Year	–5.98	1.07
Year squared	0.38	0.08
C1	–3.31	0.70
S1	0.14	0.60
Test strip 1	0.00	
Test strip 2	–1.36	
Test strip 3	0.18	
Test strip 4	1.32	
Test strip 5	–1.92	
Test strip 6	0.35	
Test strip 7	–1.79	
..... average s.e. of differences		0.79
Operator DKIT	0.00	
Operator RU	–2.40	
Operator WP	2.25	
..... average s.e. of differences		0.81
Temperature	–0.19	0.06

The first three lines give the estimates of the variances of the three kinds of random effects and standard errors of the estimates. The day and site effect variances are significantly different from zero and large enough to have concern about them.

The following lines are for the estimates of the fixed effects, i.e. β_j. In the above table, estimates for the two factors, test strip and operator, are given. In both cases the effect of the first level of the factor is arbitrarily set to zero and the effects of the other levels of the factor represent differences from the first level. The analysis provides the approximate standard error of the difference between any two levels of a factor.

With reference to the above REML output, it is evident that the three operators are different from each other. The same cannot be said about the test strips. The results of the test strip analysis can be summarised as follows:

Test strip 5	−1.92	▮		
Test strip 7	−1.79	▮		
Test strip 2	−1.36	▮	▮	
Test strip 1	0.00		▮	
Test strip 3	0.18		▮	▮
Test strip 6	0.35			▮
Test strip 4	1.32			▮

If one of the lines connects two of the levels, then those two levels could have the same effect. Hence test strips 5, 7 and 2 could be the same; 2, 1 and 3 could be the same; 1, 3, 6 and 4 could be the same.

4.3 Whangarei Data Set

4.3.1 Trend and Seasonal Analysis

A multiple regression was performed with temperature corrected BPN as the dependent variable. The independent variables were:

- A third degree polynomial of the time in years since the beginning of the experiment;
- Sine and cosine cycles with periods of one year and half a year;
- A site effect (treated as a factor with 42 levels, i.e. 7 strips × 6 locations).

The resulting analysis of variance table is as follows:

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
poly (year, 3)	3	130425.3	43475.09	1210.646	0.00000000
site	41	6706.2	163.57	4.555	0.00000000
C1	1	32806.7	32806.71	913.565	0.00000000
S1	1	331.0	331.04	9.218	0.00242649
C2	1	115.6	115.58	3.219	0.07295431
S2	1	127.5	127.48	3.550	0.05968746
Residuals	2034	73042.2	35.91		

This shows a strong trend over time as expected, a smaller location effect, and cyclic effects. However, the analysis does not correctly take account of the complex error structure in the data and as a result the significance of the variables is exaggerated. It will be shown that the six monthly cyclic terms (C2 and S2) are not significant (refer Section 4.3.4).

An investigation of residuals (i.e. what is not explained by the analysis) identified no high outliers that could seriously upset the analysis, although the scatter was greater at the beginning rather than at the end of the measurement period.

4.3.2 Operator Effect

The measurements were carried out by one of four operators, identified by their initials, as follows: DK, IT, RU and WP. DK carried out only very few measurements so the readings of DK and IT have been combined, since IT's readings seem the closest to those of DK. When operator effect is included, the analysis of variance table becomes:

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
poly (year, 3)	3	130425.3	43475.09	1451.985	0.00000000
site	41	6706.2	163.57	5.463	0.00000000
C1	1	32806.7	32806.71	1095.681	0.00000000
S1	1	331.0	331.04	11.056	0.00089976
C2	1	115.6	115.58	3.860	0.04957995
S2	1	127.5	127.48	4.258	0.03919958
Amalgamated operators	2	12200.4	6100.22	203.736	0.00000000
Residuals	2032	60841.8	29.94		

The operator effects are given in the following table:

	Coefficients	SEs	t Values
DKIT	−1.565932	0.2455928	-6.376129
RU	-3.801723	0.3845177	-9.886992
WP	5.367655	0.2848806	18.841768

The table is adjusted so that the three effects add to zero. The standard errors are likely to be under-estimates so the effects are not as significant as these results suggest. However, they do suggest that there is quite a big difference between operators, with WP tending to get higher readings than the others. But it is also possible that the effect is due to trends in the data rather than a real operator effect, so this should be seen as an indication rather than definite proof.

4.3.3 Two-Way Analysis

In this analysis, the date of the measurement is fitted as a factor with 50 levels and the site as a factor, as before. The resulting analysis of variance table is:

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
date	49	186788.7	3812.014	151.6375	0
site	41	6689.0	163.145	6.4897	0
Residuals	1992	50076.9	25.139		

Both independent variables are highly significant, as expected. However, the important result is that the residual mean square is somewhat less than in the previous analyses. Summarising the residual sums of squares and mean squares for different combinations of independent variables gives:

	Df	Sum of Sq	Mean Sq
trend, site	2034	73042.2	35.91
+ operators	2032	60841.8	29.94
date, site	1992	50076.9	25.14

The last two lines are not completely comparable because on some days more than one operator was taking measurements. However, the conclusion drawn is that there is a day-to-day fluctuation which is common to all sites and which can only partially be explained by operator variation.

The residual distribution was as before but tended to be more concentrated along the zero line. Again, there was more scatter at the beginning of the measuring programme.

4.3.4 Analysis of Daily Averages

This section considers the averages over all sites on each day. In order to reduce the bias from some sites not being present on all sampling days, the following procedure was used to find the average. The analysis of Section 4.3.1 was used to calculate fitted values for each of the measurements including those missing. These fitted values were averaged across sites to obtain an average BPN value for each sampling day.

By considering the averages across sites, the BPN data does not have the complex error structures, and so the significance levels in the analyses are rather more reliable. The resulting distribution of average BPN values are plotted in Figure 22 and yearly cycles are discerned.

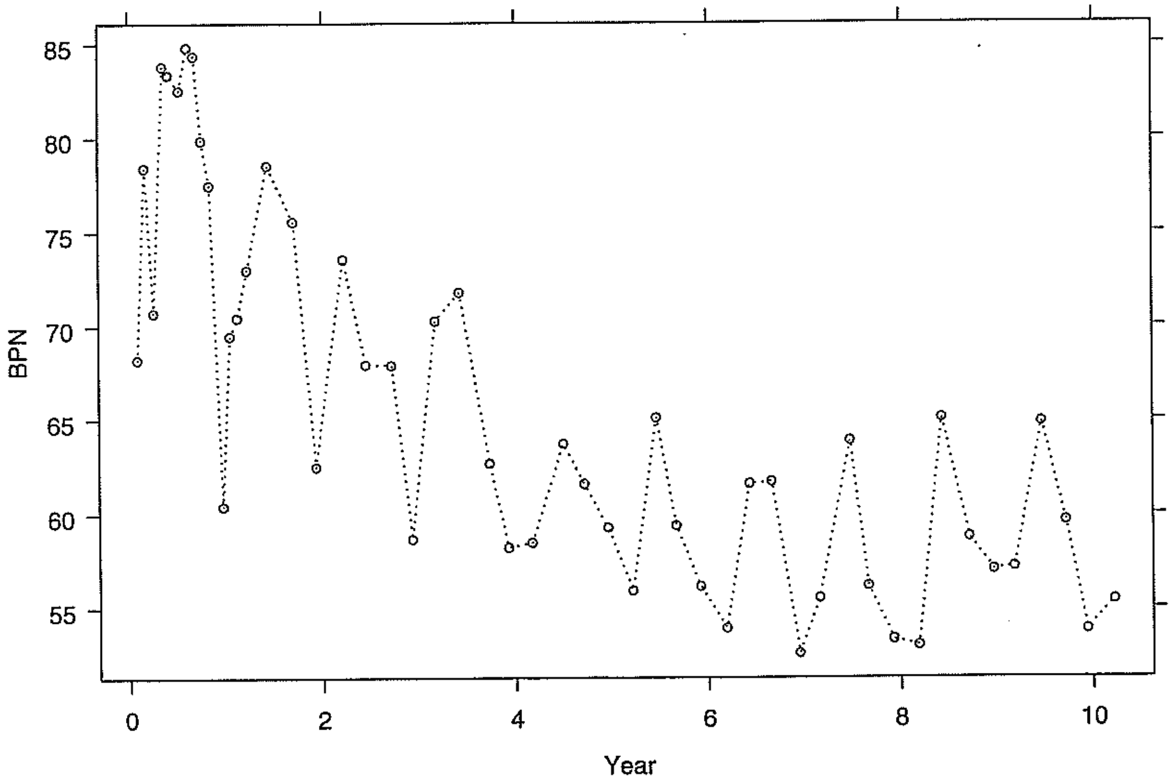
The analysis of variance table that results when fitting the trend and cyclic terms as in Section 4.3.1 is:

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
poly (year, 3)	3	3018.362	1006.121	78.15025	0.0000000
C1	1	778.884	778.884	60.49965	0.0000000
S1	1	3.594	3.594	0.27913	0.6001174
C2	1	4.967	4.967	0.38580	0.5379550
S2	1	2.857	2.857	0.22195	0.6400546
Residuals	41	527.842	12.874		

The six monthly cyclic terms are now not significant, but the trend is (though a second degree polynomial would have been sufficient). Only the cosine term is required for the yearly cycle.

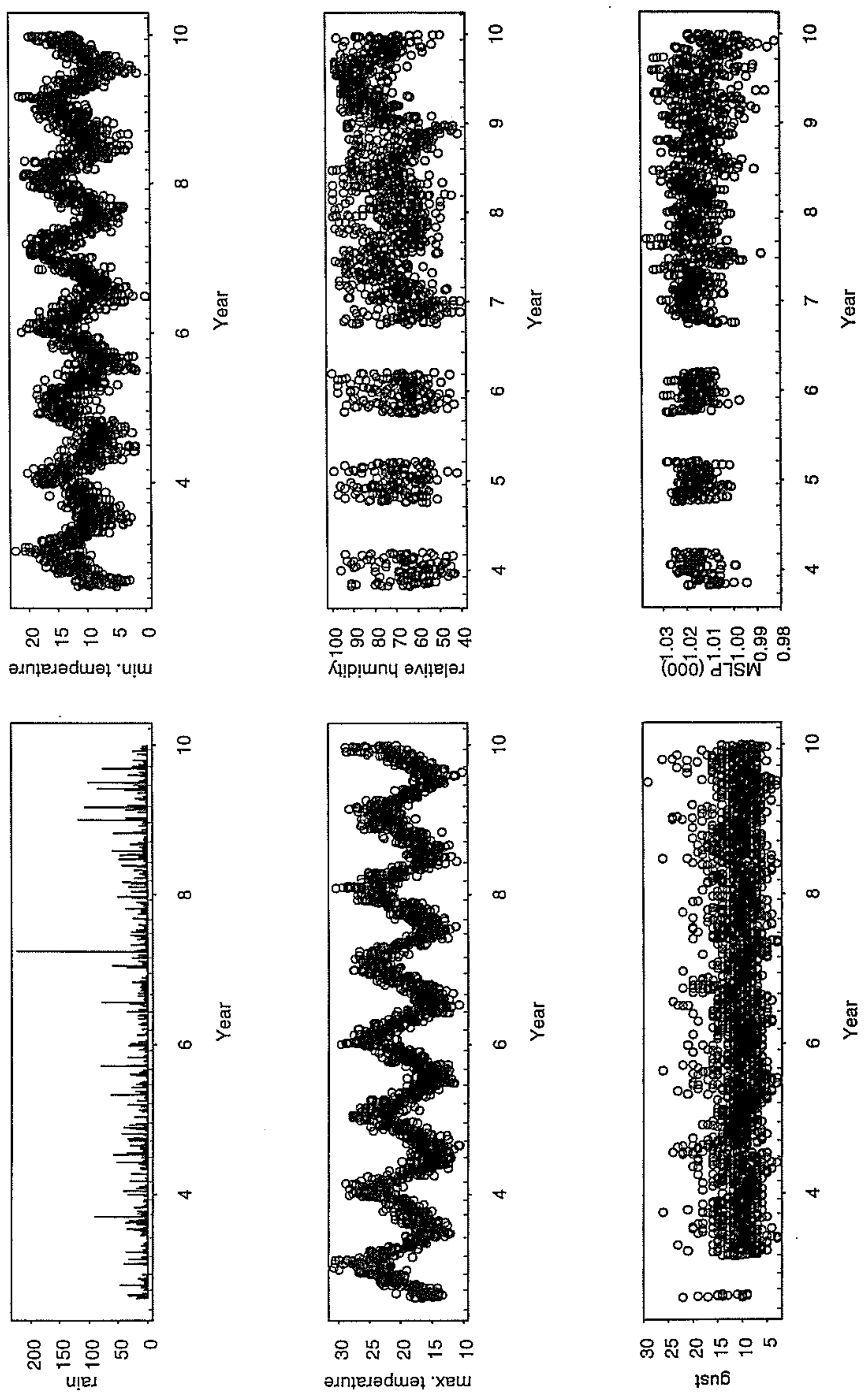
Figure 22. Time history of daily BPN values averaged across all sites.



4.3.5 Meteorological Data

Figure 23 shows graphs of the meteorological data. The tick marks above the x-axis show the times the British Pendulum readings were made. The maximum and minimum air temperatures exhibit a strong yearly cycle. The other series show smaller or no cyclic effects, and are available for only part of the monitoring period.

Figure 23. Summary plots of Whangarei meteorological data.



An investigation was carried out to establish whether the meteorological data can be related to the BPN readings. Initially, a polynomial time trend was fitted to the average BPN data derived in Section 4.3.4. A regression analysis was then applied to see if any of the meteorological variables have any useful predictive power, either by themselves or after fitting a yearly sine/cosine cycle. Both the daily average BPN data and the same data adjusted for the operator effect identified in Section 4.3.2 were considered.

The resulting residual mean squares are as follows:

Average British Pendulum Number				
Meteorological variable	**No. of observations**	**Residual mean squares**		
		Just yearly cycle	**Just met. variable**	**Cycle and met. variable**
Rain	29	6.38	19.80	6.63
Maximum temperature	29	6.38	11.42*	6.65
Average maximum temperature	28	6.64	10.53*	6.92
Minimum temperature	29	6.38	14.05*	6.65
Relative humidity	17	5.73	13.28	6.10
Gust	27	5.98	18.64	6.15
MSLP (barometric pressure)	18	5.73	15.97	5.90
Dirt	29	6.38	19.13	6.59
Wet temperature	49	12.35	18.00*	12.54

Adjusted average British Pendulum Number				
Meteorological variable	**No. of observations**	**Residual mean squares**		
		Just yearly cycle	**Just met. variable**	**Cycle and met. variable**
Rain	29	4.09	18.23	4.25
Maximum temperature	29	4.09	6.18*	3.92
Average maximum temperature	28	4.20	5.67*	4.12
Minimum temperature	29	4.09	11.49*	4.23
Relative humidity	17	4.76	15.02*	4.37
Gust	27	4.22	18.39	4.20
MSLP (barometric pressure)	18	4.76	21.10	5.08
Dirt	29	4.09	17.33	4.16
Wet temperature	49	5.62	8.85*	5.63

The line, average maximum temperature, pertains to maximum temperatures measured over a 5 day period, centred on the day the BPN reading is taken. Dirt is defined in Section 4.3.6. Wet temperature is the temperature of the wet road measurements when the BPN reading is taken. For this analysis, the average of the individual wet temperature measurements for the day have been used. When considering the wet temperature variable, the more variable 1988 and 1989 data is included, resulting in a higher residual mean square. MSLP is the barometric pressure at mean sea level in milli-bars.

Another result of note is that there is a reduction in the residual mean square when the operator effect is adjusted for.

Asterisks indicate the meteorological variable had a statistically significant effect when a sine/ cosine cycle was not fitted. However, none performed as well as a sine/cosine cycle and none were significant when a sine/cosine cycle was included.

4.3.6 Dirt Buildup

During dry periods dirt builds up on the road, reducing skid resistance. It is washed off by rain, causing the skid resistance to be restored. An attempt was made to model this phenomenon by the following equation. Suppose d_i denotes today's dirt level, then tomorrow's dirt level (d_{i+1}) is given by:

$$d_{i+1} = [d_i + \lambda(1 - d_i)] \exp(-\gamma r_{i-1})$$

where λ and γ are constants, and r_i denotes today's rain. For this analysis, values of $\lambda = 0.05$ and $\gamma = 0.1$ have been chosen. With these values the dirt level builds up to half its maximum in about two weeks. About half the dirt level will be washed off with 7 mm of rain. Figure 24 shows the rainfall and the corresponding dirt level given by the equation above.

As noted in Section 4.3.5, no significant relationship between BPN and the dirt level was established for the Whangarei data set.

4.3.7 Genstat/REML Analysis

The analysis of Sections 4.3.1 to 4.3.3 do not handle the error structure of the Whangarei data correctly. Therefore some of the main conclusions were checked using the REML function available in Genstat.

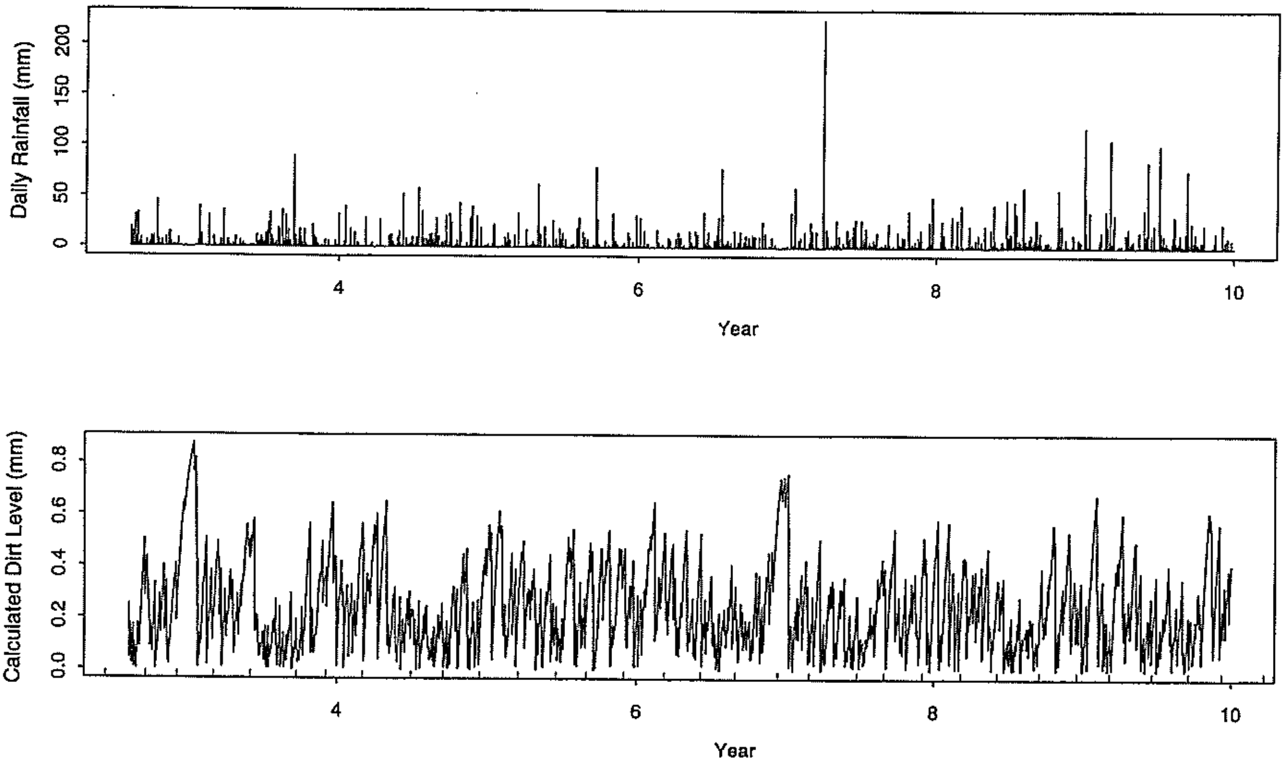
There are three separate sources of error or variation in the Whangarei data:

(a) The error in the individual measurements;

(b) A random effect associated with each site which remains fixed throughout experiment; and

(c) A random effect associated with each sampling day which affects each site equally on a given day.

Figure 24. Modelling of dirt buildup on roads.



For the REML analysis, the following terms were fitted:

- the year,
- the year squared,
- the sine and cosine cycles,
- the road surface type (corresponding to the seven test strips),
- the operator effect,
- the wet road temperature.

The resulting estimates and their corresponding standard error (s.e.) given below correspond to the case when the above terms were fitted to all the data and the case when data before 1990 is excluded. C1 and S1 are the cosine and sine of 2π times the year. All effects, except the sine cycle, are statistically significant, as follows:

Effect	All data		Data after 1 January 1990	
	Estimate	s.e.	Estimate	s.e.
Site effect variance	0.81	0.32	1.42	0.44
Day effect variance	6.05	1.45	5.28	1.54
Measurement variance	25.05	0.79	13.87	0.55
Year	–4.53	0.52	–5.98	1.07
Year squared	0.28	0.05	0.38	0.08
C1	–4.17	0.68	–3.31	0.70
S1	–0.94	0.53	0.14	0.60
Test strip 1	0.00		0.00	
Test strip 2	–0.02		–1.36	
Test strip 3	1.16		0.18	
Test strip 4	2.85		1.32	
Test strip 5	–1.14		–1.92	
Test strip 6	1.27		0.35	
Test strip 7	–1.47		–1.79	
..... average s.e. of differences		0.67		0.79
Operator DKIT	0.00		0.00	
Operatur RU	–2.43		–2.40	
Operator WP	4.73		2.25	
..... average s.e. of differences		0.88		0.81
Temperature	–0.16	0.06	–0.19	0.06

The test strip and operator effects are relative to the first test strip or operator.

The REML analysis is able to detect an effect of road temperature in contrast to the analysis of Section 4.3.5 because measurements made on the same day can be compared. This result suggests that there needs to be an adjustment of the Road Note 27 temperature correction factor.

The last two columns in the above table are probably the most reliable since there seems to be some problem with the early measurements and also possibly the roads were more variable in their behaviour at that time.

Taking the square root of the variance estimate gives the standard deviation. Therefore, the BPN measurements are calculated to have a standard deviation of 3.7. The variation that is common to each day (possibly due to unexplained seasonal effects and calibration effects) is 2.3. In contrast, the site to site variation has a standard deviation of around 1.2. If seasonal, operator and temperature adjustments are left out, these standard deviation values become 3.8, 4.3 and 1.2. As expected, it is the day-to-day variation that undergoes the biggest change.

4.3.8 Concluding Remarks

Effects due to site, season, operator and wet road surface temperature were identified. However, the best seasonal adjustment appears to be a simple cosine curve. The available meteorological data does not perform as well as the simple cosine curve and does not add extra information.

4.4 Three Cities Data

4.4.1 Trend and Seasonal Analysis

Figure 25 shows the resulting time history of BPN values after readings taken on the same day and same test strip are averaged. It also shows the fitted value from a regression analysis that is fitting a polynomial trend, a yearly cycle and city and surface effects. The capital letters denote the city in which the test strip is located, whereas the small letters denote the first letter of the city from where the sealing chip has been sourced.

The analysis of variance table from the regression analysis is as follows:

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
poly (year, 2)	2	1148.384	574.1922	27.65240	0.0000000
C1	1	264.426	264.4261	12.73444	0.0005997
S1	1	0.027	0.0267	0.00128	0.9715040
city	2	921.346	460.6731	22.18545	0.0000000
surface	2	1393.766	696.8830	33.56103	0.0000000
Residuals	83	1723.466	20.7646		

All terms except the sine component of the yearly cycle are statistically significant. However, this analysis does not correctly allow for the error structure and so may be producing false significances.

4.4.2 Genstat/REML Analysis

As in the Whangarei data, there are three sources of error:

(a) the error in the individual measurements;

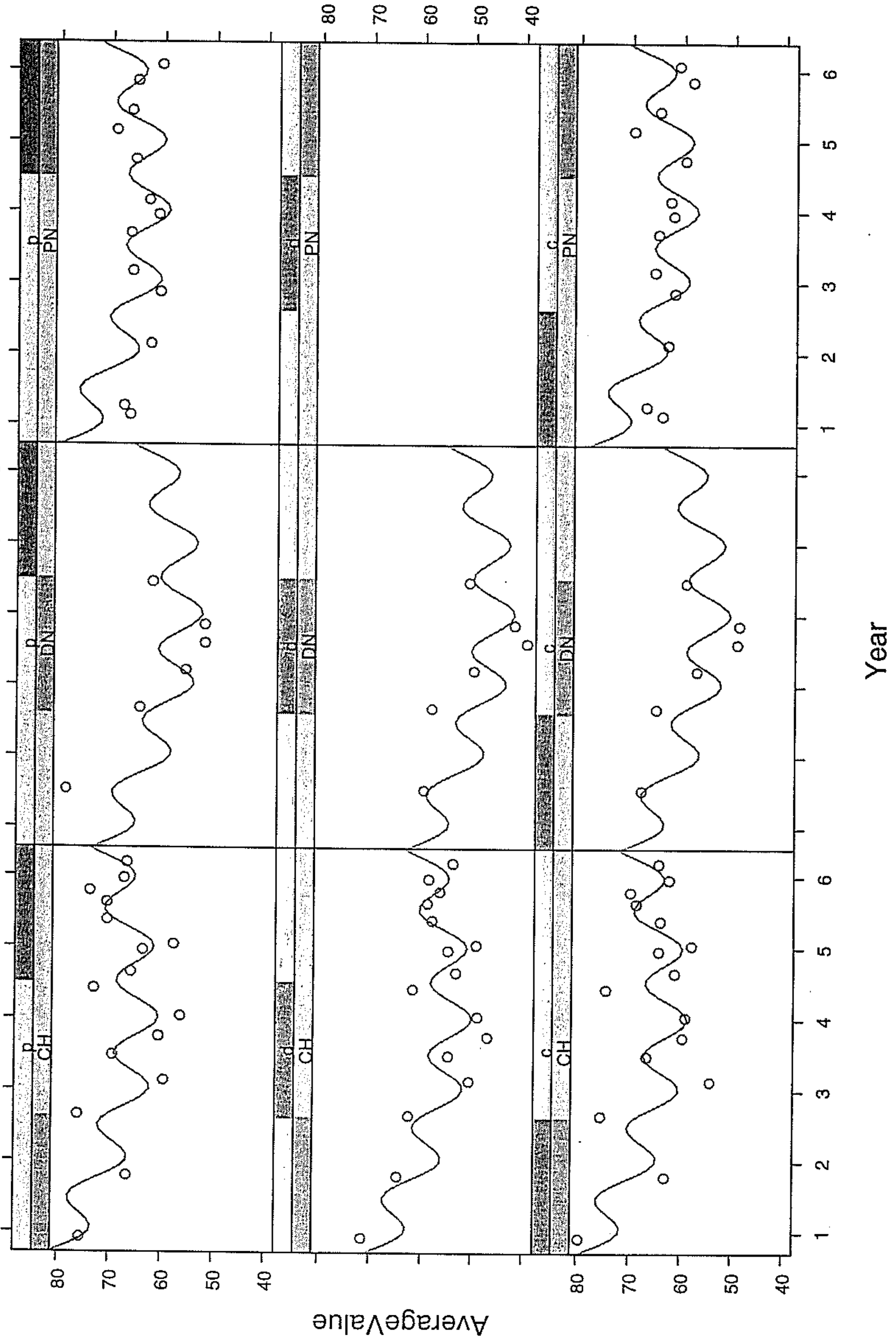
(b) a random effect associated with each site which remains fixed throughout experiment;

(c) a random effect associated with each sampling day which affects each site equally on a given day (the same day in different cities would be considered as different sampling days).

The following terms were fitted:

- the sine and cosine cycles,
- the year,
- the year squared,
- the road surface type,
- a city effect,
- an interaction between the year and year squared on one hand and city on the other.

Figure 25. Time histories of average BPN values plus fitted model for Three Cities data set.



All effects except the sine cycle were shown to be statistically significant.

Interaction between surface type and city, between surface type and cyclic effects, and between surface type and trend were not statistically significant.

The estimates and their standard errors are given below:

Effect	Estimate	s.e.
Site effect variance	13.9	5.3
Sampling day effect variance	12.1	4.3
Measurement variance	19.8	2.0
C1	–4.0	1.1
S1	–0.7	1.0
Surface – c	0.0	
Surface – d	–8.7	
Surface – p	2.0	
..... average s.e. of differences		2.2
City – CH	0.0	
City - DN	–8.7	
City - PN	–0.9	
..... average s.e. of differences		4.3
Year	–13.8	3.5
Year squared	1.7	0.4
City : year - CH	0.0	
City : year - DN	–2.4	
City : year - PN	13.1	
..... average s.e. of differences		9.3
City : year^2 - CH	0.0	
City : year^2 - DN	0.1	
City : year^2 - PN	–1.6	
..... average s.e. of differences		1.5

From the above variance estimates, a standard deviation of 4.4 is calculated for the BPN measurements. The variation that is common to each day (possibly due to unexplained seasonal effects and calibration effects) is 3.5. The site to site variation has a standard deviation of around 3.7. The site to site variation is about three times greater than for the Whangarei data, whereas the other figures are comparable. The cyclic effect is also comparable. Because of the interaction terms, the year decay terms are difficult to interpret and are best examined using the approach detailed in the next section.

4.4.3 Analysis of Overall Daily Averages

The effect of different surface types appears consistent across cities, cycles and time. Therefore the surface type BPN readings were adjusted for the effects found in the REML analysis, and averaged for each sampling date and each city to yield an overall daily average value. The usual regression analysis was then applied to fit year, year squared and city effects, and their interaction and the sine and cosine cycles, giving the following analysis of variance table. This shows all terms to be statistically significant except for the sine cycle.

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
poly (year, 2)	2	309.7480	154.8740	10.60693	0.0005004
city	2	164.6220	82.3110	5.63727	0.0098401
C1	1	199.6542	199.6542	13.67382	0.0011264
S1	1	0.7652	0.7652	0.05241	0.8208692
Poly (year, 2) : city	4	180.2186	45.0547	3.08568	0.0349139
Residuals	24	350.4289	14.6012		

The estimates of the cosine and sine terms are:

	Value	Std Error	t Value	Pr (> I t I)
C1	–3.9137138	1.0827446	–3.61462334	0.00138623
S1	0.7734742	1.0103993	0.76551340	0.45142904

It is difficult to interpret the other estimates in the presence of the interaction so they have not been listed.

The various meteorological variables were included one at a time to investigate whether the fit could be improved. The following table shows the statistical significance of each of the variables and the residual mean square when it is fitted. The two sets of columns are for the analysis with and without the interaction term.

	With interaction		**Without interaction**	
	Significance	**Residual msq**	**Significance**	**Residual msq**
Rain	0.478	14.9	0.558	19.4
Tmax	0.092	14.6	0.124	18.0
Tmin	0.055	12.9	0.123	18.0
RELH	0.003	10.3	0.006	14.8
Gust	0.659	15.1	0.959	19.7
Air temperature	0.894	15.2	0.717	19.3
Wet road temperature	0.335	15.0	0.350	17.7
Dry road temperature	0.412	14.7	0.575	17.9

where Tmax, Tmin = maximum, minimum daily temperature
RELH = relative humidity
msq = mean square

Barometric pressure (variable MSLP) was not included because of numerous missing values. Furthermore, no attempt was made to calculate dirt buildup from the rainfall distribution.

With reference to the above table, relative humidity (RELH) had the most beneficial effect. A significant result was also obtained when all of the following three temperature terms, taken at the time of the BPN measurement, were fitted: air, wet road, and dry road. This combination appeared to be attempting to estimate relative humidity.

The best fit achieved was when both RELH and Tmin (minimum daily temperature) were included. For this case, the sine and cosine terms were not statistically significant and so were omitted. The resulting analysis variance table was:

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
poly (year, 2)	2	309.7480	154.8740	18.58235	0.0000133
city	2	164.6220	82.3110	9.87597	0.0007423
RELH	1	164.6477	164.6477	19.75503	0.0001705
Tmin	1	204.3709	204.3709	24.52116	0.0000470
poly (year, 2) : city	4	162.0211	40.5053	4.85997	0.0051525
Residuals	24	200.0273	8.3345		

All terms are significant. In particular, the city effect cannot be removed. The estimates of the RELH and Tmin effects are:

	Value	Std Error	t Value	Pr (> I t I)
RELH	0.2136494	0.05025007	4.2517238	0.000278
Tmin	–0.4547777	0.09434023	–4.8206125	0.000066

The resulting fit is plotted in Figure 26, where the open circles are the observations and the filled circles are the fitted values.

4.4.4 Concluding Remarks

The best fit to the observed variation in BPN values is when a quadratic trend for each city, a city effect, and an effect for each of relative humidity and minimum daily temperature are included. These last two terms perform better than the cosine curve used in the analysis of the Whangarei data. There is an expectation that these terms are behaving as proxies for a wider range of variables, and so it would be unwise to suppose that they would perform as well in other circumstances. Therefore, on the basis of present findings it would be much safer to use a simple correction using the cosine cycle rather than the correction based on humidity and minimum daily temperature.

4.5 Wellington GripTester Data

4.5.1 Data Processing

4.5.1.1 GripTester data

The measures of skid resistance collected by the GripTester on each run were processed to yield median values. In most cases these were not much different to the corresponding mean values, but provided a degree of protection from any short periods of bad readings during a run.

4.5.1.2 Meteorological data

Rainfall data is required for modelling dirt level, as described in Section 4.3.6. This was complete for the Kelburn Meteorological Centre but incomplete for the weather stations close to the six control sites. Accordingly, a linear regression model for predicting rainfall on a given day based on preceding, actual and following day's rainfall data from Kelburn was used to fill gaps in the Mana, Wallaceville and Kaitoke weather databases. In all cases a square root function was used to transform the data, and regressions with no constant term were used. Summaries of the resulting analyses follows below.

Mana

[1] "Number of missing observations: 28"

Coefficients

	Value	Std Error	t Value	Pr (>|t|)
sqrt (Kelburn)	0.3769	0.0304	12.3812	0.0000
sqrt (Kelburn yesterday)	–0.0044	0.0281	–0.1555	0.8765
sqrt (Kelburn tomorrow)	0.5524	0.0279	19.8162	0.0000

Residual standard error: 1.1065 on 584 degrees of freedom
Multiple r-squared: 0.6588
F statistic: 375.8 on 3 and 584 degrees of freedom, the p value is 0

Wallaceville

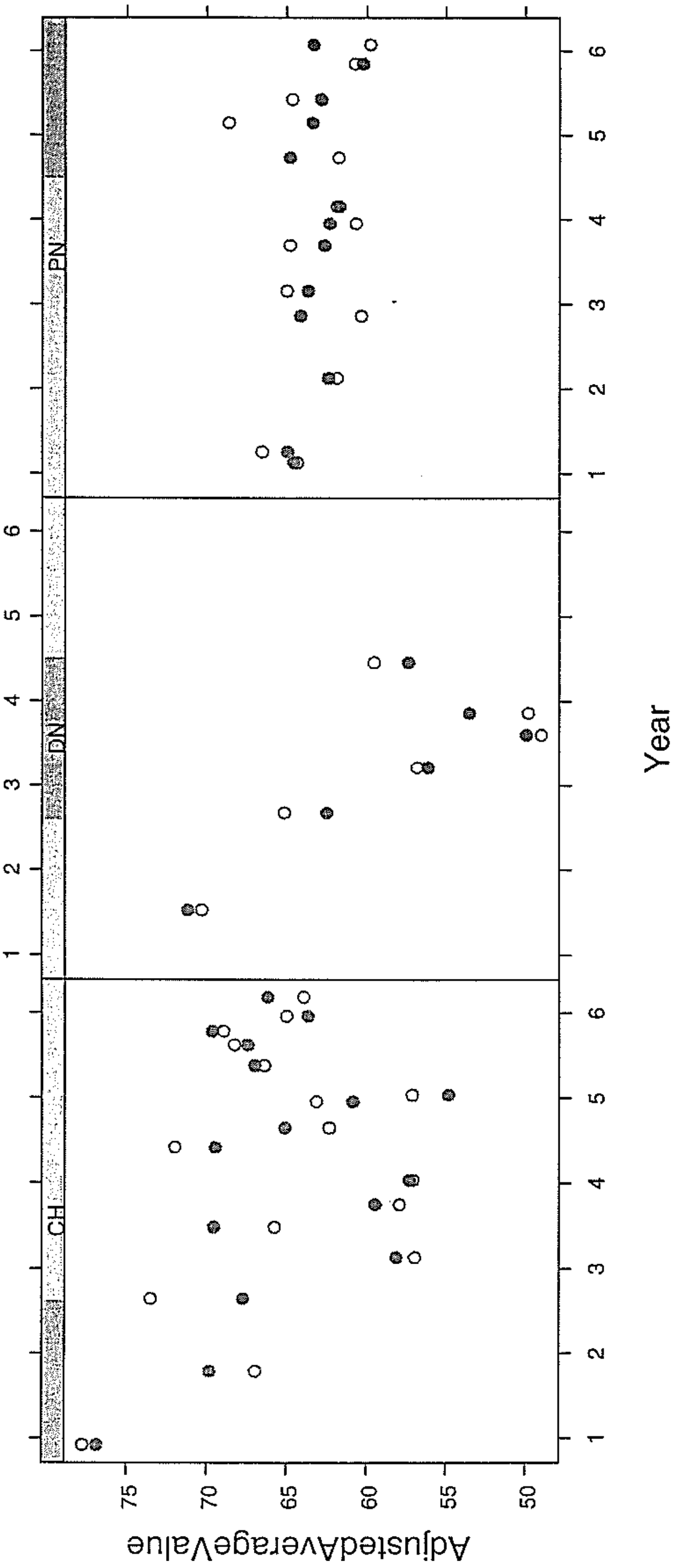
[1] "Number of missing observations: 1"

Coefficients

	Value	Std Error	t Value	Pr (>|t|)
sqrt (Kelburn)	0.8777	0.0243	36.0749	0.0000
sqrt (Kelburn yesterday)	0.0575	0.0222	2.5890	0.0099
sqrt (Kelburn tomorrow)	0.0559	0.0222	2.5207	0.0120

Residual standard error: 0.8915 on 605 degrees of freedom
Multiple r-squared: 0.7968
F statistic: 790.8 on 3 and 605 degrees of freedom, the p value is 0

Figure 26. Three Cities data set - predicted (filled circle) versus actual (open circle) adjusted BPN averages over cities.



Kaitoke

[1] "Number of missing observations: 140"

Coefficients

	Value	Std Error	t Value	Pr (>|t|)
sqrt (Kelburn)	1.0129	0.0430	23.5791	0.0000
sqrt (Kelburn yesterday)	0.1996	0.0392	5.0942	0.0000
sqrt (Kelburn tomorrow)	0.1496	0.0409	3.6609	0.0003

Residual standard error: 1.353 on 422 degrees of freedom
Multiple r-squared: 0.7507
F statistic: 423.6 on 3 and 422 degrees of freedom, the p value is 0

Plots of the calculated buildup of dirt using derived Mana and Wallaceville rainfall data is given in Figure 27.

4.5.2 Analysis of Daily Averages

Previous experience with other statistical analyses of GripTester data suggest that surveys repeated one after the other on the same section agree far more closely than surveys carried out at more separated times. As with other statistical analyses described in this report, spurious results may occur if this operational characteristic of the GripTester is not allowed for. This was achieved by simply averaging the Grip Number readings from the same site on the same day.

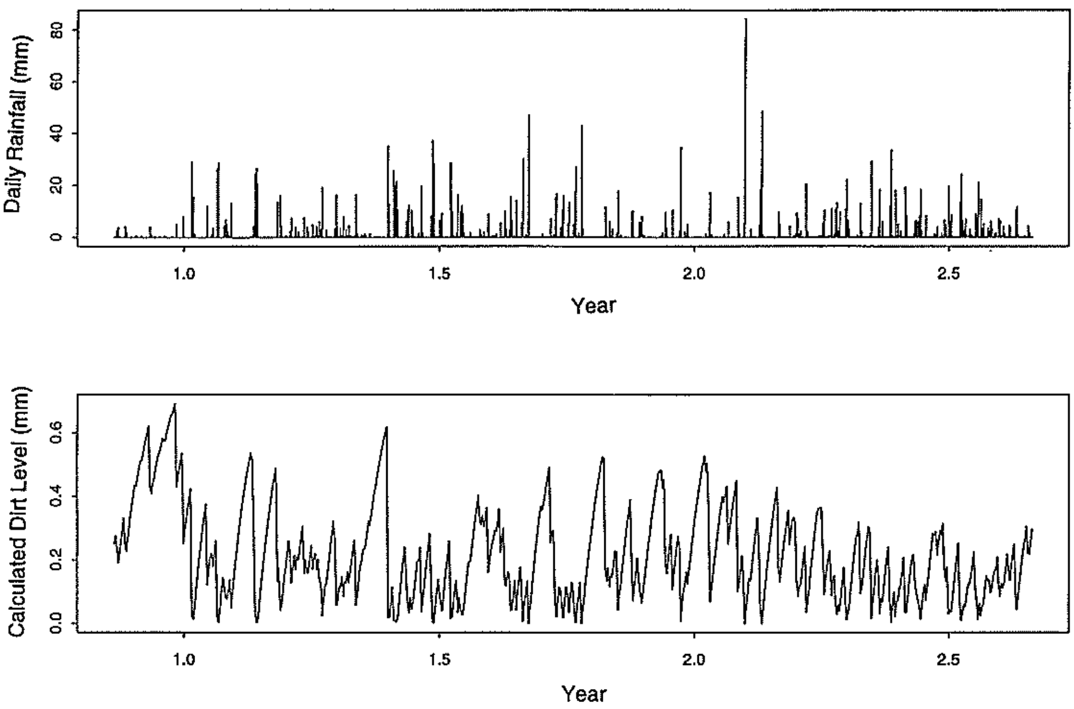
Occasionally, the measuring wheel of the GripTester was changed during the course of a day's survey. In such cases the wheel number first employed on that day is used as the wheel identifier for the purposes of the analysis. For the earlier surveys, the wheel number was not recorded so it is assumed that a single measuring wheel was used, and this has been labelled UNK.

A variety of combinations of various predictor variables were tried. Fourteen of the worst outlying points were deleted from the data and the following predictors selected:

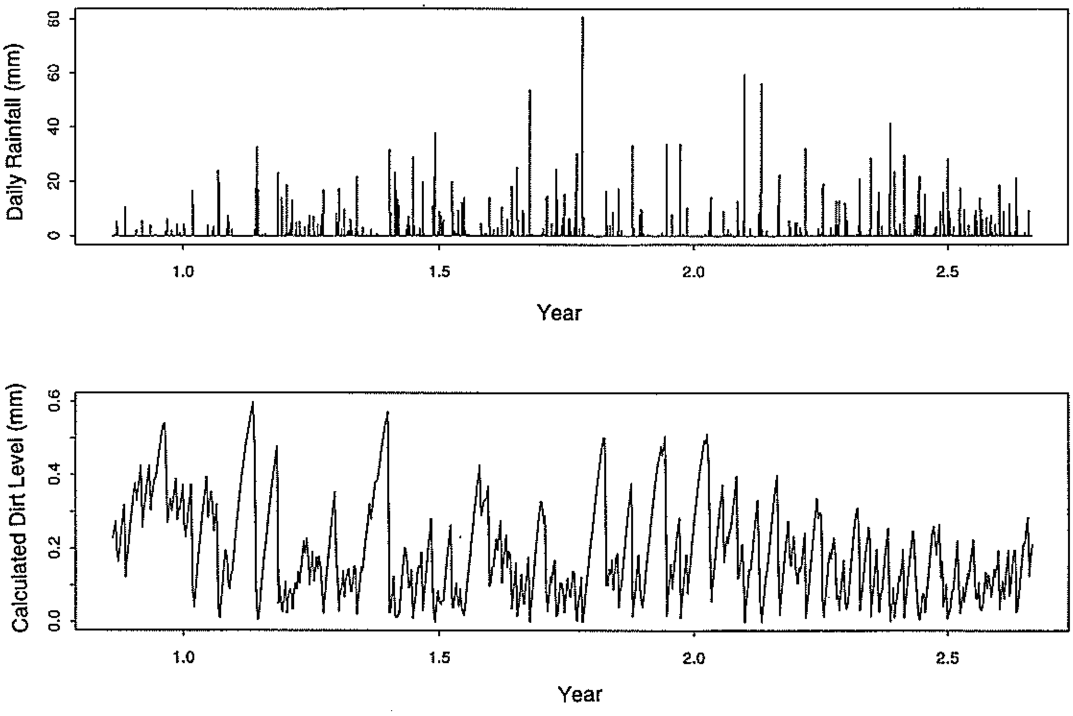
- year and year squared,
- site,
- wheel number (WN),
- average road temperature (avrdtemp),
- dirt level based on Mana rain readings (Dirt.Mana),
- interaction of all of these with site, with the exception of wheel number.

Figure 27. Predicted dirt buildup derived from Mana and Wallaceville weather station rainfall data.

Mana:



Wallaceville:



The resulting variance table is as follows:

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
poly (year, 2)	2	0.0010927	0.00054635	1.4418	0.2382941
site	5	0.3566882	0.07133763	188.2603	0.0000000
WN	4	0.0450293	0.01125733	29.7081	0.0000000
avrdtemp	1	0.0011738	0.00117378	3.0976	0.0795278
Dirt.Mana	1	0.0025381	0.00253809	6.6980	0.0101687
poly (year, 2) : site	10	0.0128057	0.00128057	3.3794	0.0003540
avrdtemp : site	5	0.0115505	0.00231010	6.0964	0.0000226
Dirt.Mana : site	5	0.0048957	0.00097913	2.5839	0.0264402
Residuals	273	0.1034481	0.00037893		

Possibly the interaction with the dirt level could have been omitted.

Figure 28 compares the observed and fitted data, with the filled circles representing the fitted values and the open circles representing the observed values. This figure shows the fitted values tracking the general picture given by the observed values although failing to follow all the values.

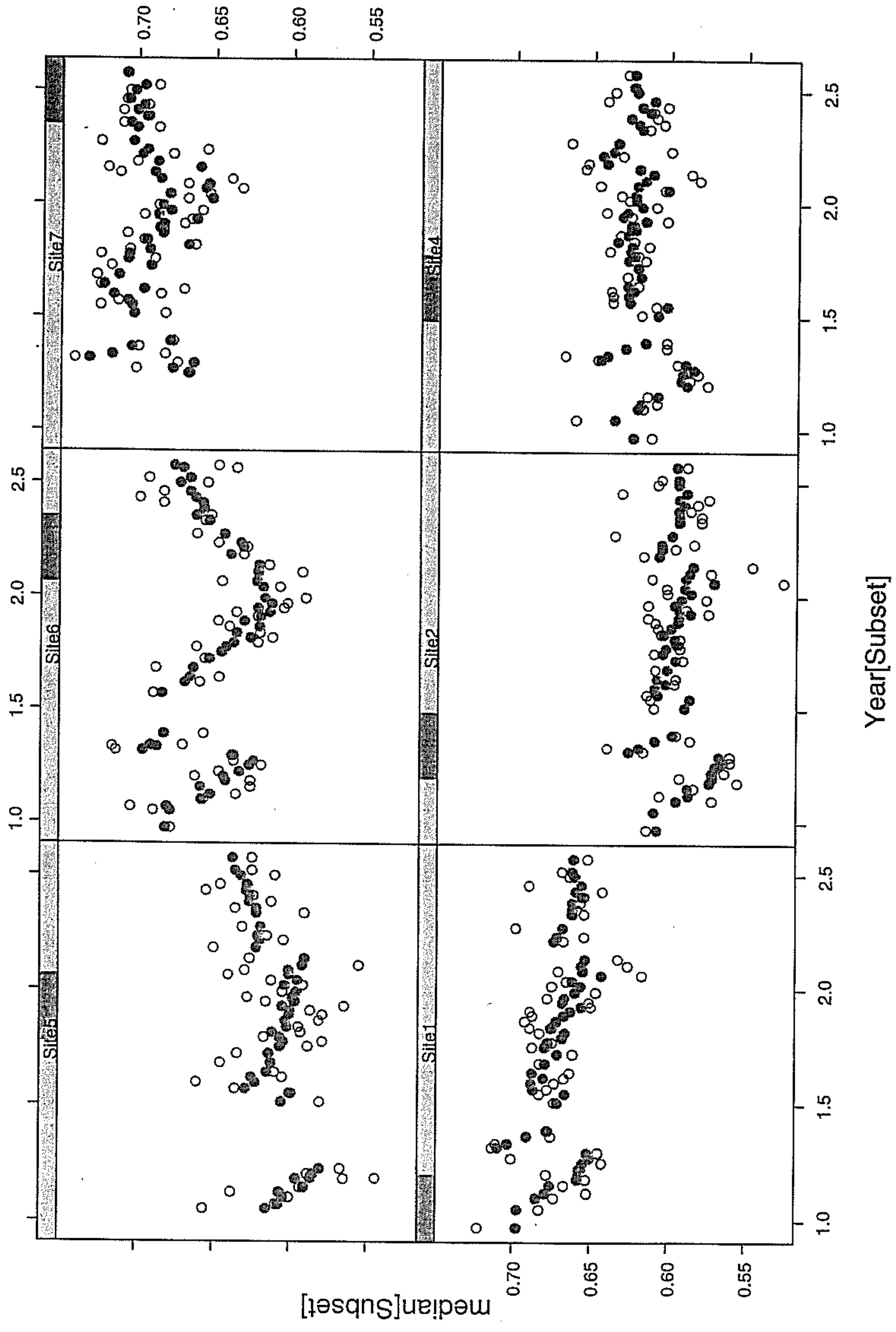
In order to understand how this fit is achieved, and to decide how credible it is, each of the individual terms in the regression equation was graphed. The two important points to arise from this exercise are summarised below.

(1) There is a strong suggestion that as the blank tyre on the GripTester's measuring wheel wears, a lower value of skid resistance is recorded. This is attributed to a change in the hysteresis characteristics of the blank tyre as the raised wearing section reduces and becomes integral with the rest of the tyre. Put in other words, when the measuring tyre is new the roading aggregates indent the tyre rubber. However, when the measuring tyre is near the end of its useful life the roading aggregates indent the stiffer and harder tyre carcass.

(2) The dirt effect was significant for only control site 7. This control site experiences very low traffic volumes (AADT <3000), indicating that skid resistance rejuvenation after rain only occurs for lightly trafficked roads. On heavily trafficked roads, aerodynamic disturbance induced by trucks trends to promote self-cleaning of the road surface. This reasoning is supported by experiences with road delineation, where lightly trafficked roads suffer from an adhesion problem with roadmarking paint (rural roads with traffic volumes of AADT ≤ 100 v/l/d can show a complete loss of paint), whereas this problem has not been encountered on heavily trafficked roads, suggesting a clogging of the road surface texture with fine material (Dravitzki 1992).

The standard deviation of the residuals, i.e. difference between observed and fitted values, is 0.019. Multiplying by 100 to make GripTester skid resistance values comparable to the British Pendulum Number gives the standard deviation as 1.90. This is similar to the standard deviation

Figure 28. Time histories of daily average Grip Number values plus fitted model for Wellington data set.



of day effect with the British Pendulum Tester (standard deviation = 1.45) established for the Whangarei data set.

The analysis was repeated for each control site. Dirt factors based on rainfall data from Mana and Wallaceville weather stations were tried and wheel R4 was combined with wheel UNK as these seemed to have very similar characteristics. The significance probabilities for the control sites are given below. These significant probabilities are calculated as the effects are added one by one.

	Site 1	Site 2	Site 4	Site 5	Site 6	Site 7
poly	**0.027**	0.827	0.229	**0.049**	**0.000**	0.312
WN	**0.002**	**0.000**	**0.001**	**0.007**	**0.000**	**0.048**
Avrdtemp	0.107	**0.016**	**0.000**	0.670	**0.006**	0.069
Mana	0.272	0.344	0.402	0.479	0.619	**0.004**
Wallaceville	0.162	0.758	0.498	0.357	0.332	0.800
Residual s.d.	0.018	0.018	0.017	0.024	0.019	0.021

The last line shows standard deviations of the residuals and suggests that site 5 is a little more variable than the others. The effects significant at the 5% level are shown in bold.

4.5.3 Concluding Remarks

Real progress has been made in explaining part of the pattern of long term GripTester readings. Average road temperature and rainfall distribution on low volume roads appear to be the important factors.

4.6 Comparison with Overseas Derived Predictor Approaches

4.6.1 Sinusoidal Model

The statistical analysis performed on the Whangarei and Three Cities data sets indicated that the best seasonal adjustment could be effected by a simple cosine curve. This is consistent with the findings of Diringer and Baros (1990) who have proposed the following model:

$$SN_{40T} = B1 \sin (B2\ JDAY + B3) \qquad (1)$$

where SN_{40T} = seasonal fluctuation of locked wheel skid number measured at 64 km/h (40 mph) about the terminal value
JDAY = Julian calendar day
B2 = a constant (360/365)
B1 and B3 = estimated regression coefficients

This model was determined from field measurements of seasonal effects of five older, well polished bituminous pavements, each with cumulative traffic in excess of 2 million passes. The five pavements represented three aggregate types, and produced skid resistance measurements ranging from approximately 25 to 40 SN_{40T} units. The amplitude of the seasonal effect (B1) was observed to range from approximately 1.3 to 3.3, depending on the particular pavement. The lateral displacement of the seasonal effect was estimated to be approximately 2° and so the model may be simplified by setting B2 to zero with a negligible loss in precision. This model, in a slightly modified form as detailed below, was applied to the New Zealand data sets in an attempt to establish its suitability for normalising cyclical environmental factors.

4.6.1.1 Form of fitted model

A sinusoidal model of the form given in the following equation was fitted:

$$C1 \cos(2\pi y) + S1 \sin(2\pi y) \qquad (2)$$

where y = date expressed as years, including a fractional part.

y = 0 corresponds to 1 January in the origin year, and it is assumed that there are 365.25 days in a year. Radians was used as the unit of the angle. However, if units of degrees are required, 2π is replaced by 360.

The above equation is equivalent to a model involving a phase angle since

$$B \sin(2\pi y + \theta) = B \sin(\theta) \cos(2\pi y) + B \cos(\theta) \sin(2\pi y) \qquad (3)$$

This is the form of equation (2). However, equation (2) is in a suitable form for fitting using a linear model.

In the preceding analysis, whenever a statistically significant sinusoidal effect is found only the cosine term in equation (2) is significant. This implies that the sinusoidal effect is approximately aligned with the calendar year, with the extremes occurring at the beginning and middle of the year.

An attempt to fit terms of the form given in equation (4) was also tried, but these were shown to be not statistically significant:

$$C_k \cos(2\pi k y) + S_k \sin(2\pi k y) \qquad (4)$$

where k = 2, 3, 4.

The resulting fits are detailed in the following sections.

4.6.1.2 Whangarei data set

The REML analysis in Section 4.3.7 gave an estimate of –3.31 for the value of C1 and 0.14 for the value of S1, with standard errors (s.e.'s) of 0.70 and 0.60 respectively. This analysis, however, was also fitting a wet temperature effect of –0.19 (s.e. = 0.06) and so was adding to the correction already applied. If the correction for the wet temperature effect was omitted, estimates for C1 and S2 become –4.51 (s.e. = 0.59) and 0.08 (s.e. = 0.6) respectively.

A marginally significant result is obtained when testing the hypothesis that values of C1 and S1 vary between the test strips.

4.6.1.3 Three Cities data set

The REML analysis of Section 4.4.2 gave an estimate of –4.0 (s.e. = 1.1) for C1 and –0.7 (s.e. = 1.0) for S1. This is without wet temperature being fitted but with city : year and city : year^2 interactions. If these two interactions are omitted, the estimates for C1 and S1 become –3.9 and –0.2 respectively.

In investigating the influence of aggregate type, city : year and city : year^2 interactions were included. The C1 : surface interaction was found to be significant at the 5% level but not at the 1% level. The resulting values of C1 for the three different aggregates were:

Christchurch greywacke	C1 = –3.87
Dunedin basalt	C1 = –2.42
Palmerston North greywacke	C1 = –5.11

The standard error of differences is 1.03, so there appears to be a difference between the Dunedin and Palmerston North sourced aggregates but one cannot place the Christchurch sourced aggregate. This ordering is at odds to that suggested by the PSV of the aggregate which has the Dunedin sourced aggregate displaying the largest seasonal fluctuation, followed by Palmerston North, and Christchurch the least.

4.6.1.4 Wellington GripTester data set

Employing the same type of analysis as given in Section 4.5, the following estimates of C1 and S1 are obtained when a site effect, a quadratic time effect, and a wheel effect are fitted.

	Value	Std Error	t Value	Pr (> | t |)
C1	0.0023	0.0033	0.72	0.47
S1	–0.0021	0.0035	–0.59	0.55

Neither are shown to be statistically significant. Multiplying by 100 to produce values of skid resistance comparable to those generated by the British Pendulum Tester gives C1 = 0.22 (s.e. = 0.31) and S1 = –0.20 (s.e. = 0.33). The value of C1, representing the magnitude of the seasonal fluctuation, in an order of magnitude less than that found for the Whangarei and Three Cities data.

A statistically significant result is obtained if the value of C1 is derived for each site. The estimates are as follows though not too much credence should be given to the figures as they cover only 18 months of data and may be influenced by changes in wheel characteristics or other trends not included in the model.

Site	C1 (Grip Number)	C1 (BPN equivalent)
1	0.0084	0.8
2	0.0050	0.5
4	0.0101	1.0
5	0.0005	0.0
6	–0.0142	–1.3
7	–0.0016	–0.2

With reference to the last column, the magnitude of the seasonal effect is still quite small when compared to the results for Whangarei and Three Cities, and appears to reflect the factor of 3 difference in temperature sensitivity between the GripTester (when used in tow mode) and British Pendulum Tester.

4.6.2 Rainday Frequency Parameter

It has been suggested that long spells of dry weather result in fine grit accumulating on the road surface and polishing of the road aggregate under traffic. The effect of rain is to flush off the finer grit and to leave the coarser grit which, under the action of traffic, roughens the aggregate, thereby restoring the skid resistance (Rice 1977).

Australian research indicates the period of time the road surface is wet immediately preceding the measurement of skid resistance is more significant than the amount of rain that falls during that period (Dickinson 1989). Therefore a sustained period of light winter rain will provide a greater improvement in skid resistance than a heavy summer shower. Conversely, a long period of dry weather produces a deterioration in skid resistance values.

Dickinson proposed a rainday frequency parameter (RFP), normalised for a 14 day interval, to investigate this effect, defined as:

$$\text{RFP} = \frac{\text{RD} \times 14}{\text{N} \times \text{MMTI}}$$

where N = number of days between the last skid resistance measurement and the current one

RD = number of raindays

MMTI = mean minimum daily air temperature (°C) for the period

A "rainday" is defined as a day with more than 0.1 mm precipitation.

A major problem with RFP in the New Zealand context is that it becomes meaningless if the temperature drops below 0°C. Accordingly, a raindays variable defined as the number of raindays over a specific time interval was investigated along with average temperature over the same interval, and the interaction between both variables. This was achieved by using linear regression to fit these variables to the Whangarei and Wellington GripTester data sets. The Three Cities data set was not utilised as there was too great a time interval between successive skid resistance measurements to allow valid investigation of raindays-temperature interactions.

The time periods examined were 7, 14 and 30 days. In all cases the average is over the preceding days. Where there are missing values, rain is counted as zero and the temperature averaged over days for which data is available.

4.6.2.1 Whangarei data set

The regression analysis included the polynomial time trend, the sine and cosine terms, the raindays variable, the average temperature variable, and the interaction between the raindays and temperature variables.

The following is a typical analysis of variance table that results when considering a 14 day time interval and using maximum temperature and British Pendulum Numbers adjusted for greater effect.

Response: BPN.Adj
Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Poly (year, 2)	2	176.6668	88.3334	19.90865	0.0000116
C1	1	377.4047	377.4047	85.05979	0.0000000
S1	1	3.2449	3.2449	0.73133	0.4016694
Raindays	1	0.3518	0.3518	0.07930	0.7808828
AvTmax	1	3.9113	3.9113	0.88153	0.3579774
Raindays:AvTmax	1	0.2953	0.2953	0.06656	0.7988135
Residuals	22	97.6126	4.4369		

There is no statistically significant effect when the raindays and average maximum temperature variables are added. If the sine and cosine terms are left out, then a statistically significant effect results, as shown in the table below. However, comparing the residuals row of both tables, it can be seen that the fit is not nearly as good as when the sine and cosine terms are included.

Response: BPN.Adj
Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Poly (year, 2)	2	176.6668	88.3334	11.44237	0.0003237
Raindays	1	151.7957	151.7957	19.66304	0.0001751
AvTmax	1	142.4374	142.4374	18.45081	0.0002492
Raindays:AvTmax	1	3.3111	3.3111	0.42891	0.5187515
Residuals	24	185.2763	7.7198		

Similar results to the above was obtained if minimum temperature was utilised instead of maximum temperature, or if the average was taken over 7 or 30 days.

4.6.2.2 Wellington GripTester data set

The best results were obtained for an averaging period of 7 days with data from the Mana weather station. The resulting analysis of variation table is as follows:

Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F value	Pr(F)
poly (year, 2)	2	0.0010927	0.00054635	1.4589	0.2342847
site	5	0.3566882	0.07133763	190.4884	0.0000000
WN	4	0.0450293	0.01125733	30.0597	0.0000000
avrdtemp	1	0.0011738	0.00117378	3.1343	0.0777671
Raindays.Mana	1	0.0025600	0.00255995	6.8357	0.0094264
AvTmax.Mana	1	0.0008500	0.00085003	2.2698	0.1330631
poly (year, 2) : site	10	0.0124294	0.00124294	3.3189	0.0004342
avrdtemp : site	5	0.0131162	0.00262325	7.0047	0.0000035
AvTmax.Mana :	1	0.0029208	0.00292079	7.7992	
raindays.Mana	276	0.1033616	0.00037450		
Residuals					

The fit is comparable to that found in Section 4.5.2.

4.6.3 Concluding Remarks

As with other meteorological based variables, the raindays variable does not perform as well as the simple cosine model, nor does it provide any additional information. However, the lack of success of the raindays variable may be in part due to the fact that rainfall data was not collected at the monitored site but at a meteorological station closest to the site, typically several kilometres away. Localised, site specific climatic effects therefore have not been appropriately accounted for.

With regard to the cosine model, the amplitude of the seasonal effect appears to depend on the aggregate type, climatic region, and skid tester type.

5. CONCLUSIONS AND RECOMMENDATIONS

Within the scope and limitations of field trials undertaken, and the analysis of variance (ANOVA) performed on existing skid resistance databases involving long term GripTester and British Pendulum Tester measurements made at frequent intervals in different regions of New Zealand, the following conclusions and recommendations are warranted.

5.1 Adequacy of Temperature Correction Procedures for the British Pendulum Tester

Rubber resilience increases and hysteresis losses become smaller as temperature rises. These effects combine to reduce the measured value of skid resistance as temperatures increase. This effect was shown to be particularly significant for the British Pendulum Tester operating on both a smooth textured asphaltic concrete and coarse textured chipseal surface during the normal range of temperatures experienced over a summer's day.

A typical sinusoidal relationship associated with seasonal effects was evidenced during daylight hours with the trough occurring between 13:00 and 14:00 hours. The difference between the lowest and highest skid resistance value over a 12 hour period was about 18 BPN units. This is considerably greater than the measurement repeatability of the device estimated to be ±4-8 BPN units. The amplitude of daily fluctuation in skid resistance is comparable to that observed for seasonal fluctuation, suggesting that the underlying cause of long and short term variability in British Pendulum Tester derived skid resistance measurements is, in the main, temperature related.

Application of the temperature correction procedure put forward by the manufacturers of the British Pendulum Tester and presented in Road Note 27 was successful in reducing the amplitude of daily fluctuation by only 2 BPN units. However, it was apparent from measurements of road temperature, air temperature and water temperature made at the time of each skid resistance reading, that a more appropriate correction procedure could be derived. Furthermore, the British Pendulum Tester readings were shown to display a different temperature sensitivity for a coarse textured chipseal surface than for a smooth textured asphaltic concrete surface (–1.41 BPN/°C compared to –0.95 BPN/°C).

5.1.1 Recommendation

If the British Pendulum Tester continues to be used for measuring the skid resistance characteristics of New Zealand road surfaces it is essential that:

(a) Given the range of macrotexture levels on New Zealand roads, a more appropriate temperature correction than presented in Road Note 27 needs to be derived that specifically accounts for texture effects, thereby enabling more reliable skid resistance readings to be made; and

(a) To assist the valid comparison of BPN readings, details of the time of day and temperature (air, dry road surface, wet road surface) when the skid resistance measurement is taken should be recorded until such time a temperature correction procedure, validated for New Zealand road surfaces, becomes available.

5.2 Mechanisms Causing Long and Short Term Variations in Skid Resistance

In modelling long term seasonal fluctuations in skid resistance measurements, the results of the ANOVA analysis indicates that if cosine and sine terms are removed, meteorological records such as temperature, humidity and rainfall become important. However, the resulting model fit is at best comparable to that achieved using a simple cosine cycle correction suggesting factors other than local weather conditions may be having an effect.

Two attempts were made to model short term variations in skid resistance brought about by dry and wet spells. The first involved predicting dirt build up from rainfall records in which the dirt level builds up to half its maximum in about a two week period. The second utilised a rain day variable which corresponded to the number of rain days over a predefined period, a "rain day" being defined as a day with more than 0.1 mm precipitation. Both models produced very similar results and were only partially successful in explaining the observed variations in skid resistance readings.

These results from the statistical analysis suggest that an improved understanding as to how skid resistance of a road surface changes as a consequence of rainfall is first required before progress can be made in deriving a predictor model that adequately accounts for weather factors.

5.2.1 Recommendations

5.2.1.1 Yearly seasonal fluctuation

The most appropriate model for estimating yearly seasonal fluctuation in skid resistance about a terminal value is

$$C1 \cos(2\pi y) + S1 \sin(2\pi y)$$

where y = Julian calendar day / 365.25, and y = 0 corresponds to 1 January.

The constant terms C1 and S1 are a function of the following factors: aggregate type, climatic region, and skid tester. The model may be simplified with a negligible loss in precision if S1 is set to zero. An additional simplifying assumption can be made by holding the amplitude of the seasonal adjustment (C1) at a conservative value, leading to the formulation of the following models:

for the British Pendulum Tester, $BPN = BPN_{terminal} - 5\cos(2\pi/365.25 \times JDay)$
where BPN = British Pendulum Number

for the GripTester, $GN = GN_{terminal} + 0.002\cos(2\pi/365.25 \times JDay)$
where GN = Grip Number when obtained in tow mode

The proposed model for estimating seasonal effects on Grip Number should be treated with caution as it is derived from data covering one climatic region (Wellington) and one aggregate type (greywacke). However, more confidence can be attached to the model pertaining to the British Pendulum Tester because a broad range of climatic conditions and two aggregate types (greywacke and basalt) have been considered.

5.2.1.2 Skid Resistance Measurements Before and After Rainfall

Although the occurrence of rainfall is generally accepted as the reason for short term variations in skid resistance, the mechanism by which the variations are produced is not yet sufficiently well understood to permit reliable modelling. For example, is a cloudburst of, say, an hour's duration during daylight less effective in restoring skid resistance than light rain through the night when traffic is light and the evaporation rate is low. Therefore, to address this knowledge gap, it is recommended that a limited investigation be carried out to determine the skid resistance time histories of a chipseal pavement for different rainfall levels and durations, traffic levels, and the length of the dry spell preceding the rainfall. This will require a rainfall gauge to be located beside the test section, and a skid tester that can make measurements at traffic speeds so traffic flows are not affected. The resulting "before" and "after" rainfall skid resistance measurements will allow the formation of a model that better accounts for short term variations in skid resistance than the dirt-buildup and rain days factors utilised as part of the study and derived on the basis of reviewed overseas literature.

5.2.1.3 Increased Frequency of Readings at Whangarei

The scope of the Whangarei monitoring programme on State Highway 1 between RP 165/6.97 and RP 173/0.0 involving three monthly British Pendulum Tester skid resistance and sand circle texture depth readings should be expanded to include increased frequency of readings, say, every 10 to 14 days, at one of the six test strips. The readings should be supplemented with humidity, air temperature, and dry road surface temperature measurements. A rainfall gauge should also be installed adjacent to this test strip and monitored. This would address the major reservation of the existing analysis that localised, site-specific climatic effects had not been appropriately accounted for as a consequence of employing weather data from meteorological stations that were some distance from the test sites.

The resulting database would be invaluable for validating proposed modelling approaches for accounting for rainfall.

5.3 Relationship Between Amplitude of Seasonal Variation and Aggregate Type

Overseas research suggests that the amplitude of seasonal variations in skid resistance depends on aggregate type. The more polish-susceptible the aggregate, the more pronounced is the seasonal and short term variations in skid resistance. However, analysis of long term data obtained as part of a National Roads Board funded study to investigate the comparative skid resistance performance of Christchurch and Palmerston North sourced greywacke (polished stone value ≈ 55) and Dunedin sourced basalt (polished stone value ≈ 44) gave the opposite result, with the more polish resistant greywacke aggregates displaying larger seasonal fluctuations over a range of traffic levels and climatic regions. This difference in the amplitude of seasonal variation was found to be statistically significant, and merits further investigation as considerable safety benefits may be possible by utilising aggregate types which display relatively small seasonal variation in skid resistance at high risk sites or in regions experiencing climatic extremes.

5.3.1 Recommendation

To resolve the anomaly between overseas and New Zealand research findings, pertaining to the comparative performance of different aggregate types with respect to seasonal and short term variation in skid resistance related to rainfall, a monitoring programme similar to the Three Cities study undertaken by the National Roads Board should be repeated with the following refinements. Firstly, all commonly used aggregate types should be used in the construction of test strips which would be laid adjacent to each other as part of a normal chipsealing operation of a trafficked road. The influence of chip size should be additionally investigated by constructing two groups of test strips: one from coarse textured grade 2 and the other from fine textured grade 4 chip. Secondly, a weather station should be installed adjacent to the test site to obtain local meteorological data, in particular humidity and rainfall. Thirdly, the test strips should be at least 50 m in length to allow monitoring by a vehicle-based skid tester so that the results could be directly related to state highway SCRIM surveys. Each of the test strip groupings, therefore, would have to be preceded by a 400 m length of chipseal surface of the same grade as the grouping to allow for the conditioning of the skid tester's measuring wheel. It is envisaged that one test site, located on a straight section of a state highway would be sufficient and that the monitoring should extend for a minimum period of two years.

The resulting database will identify the need or otherwise to calibrate seasonal adjustment models for aggregate type and size.

5.4 Significance of British Pendulum Tester and GripTester Measurements in Relation to Actual Car Tyre Performance

On the basis of the databases analysed, it appears that the seasonal variations observed in the long term British Pendulum readings are partly temperature related, whereas those for the GripTester are not. It is therefore necessary to establish the significance of this result by determining the degree of correlation of the two skid resistance measures with the straight-line braking performance of a representative passenger car. Depending on the outcome, a seasonal correction factor may not prove necessary.

5.4.1 Recommendation

A series of comparative measurements involving wet and dry GripTester, British Pendulum, and locked wheel braking measurements using an instrumented vehicle should be undertaken first thing in the morning when the road surface temperature is close to its minimum and repeated in mid afternoon when the tempature is at its maximum. The resulting change in braking distance can then be correlated with the observed changes in the Grip Number and British Pendulum Number values. In order to perform the wet measurements, the road surface would need to be artificially wetted.

This comparatively straightforward experimental programme will assist in establishing which device better represents the behaviour of car tyres on wet road surfaces, and provide a better understanding as to how road surface temperature affects the braking performance of vehicles.

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Mr B Saint, Whangarei Laboratory, for making the Whangarei test strip data available in electronic format.

APPENDIX 1

TEMPERATURE EFFECTS DATA

A1 BRITISH PENDULUM TESTER READINGS

Table A1. Asphaltic concrete test site - outdoors.

Date	Time	Temperature (°C)				Skid resistance BPN (uncorrected)
		Dry road surface	Air	Slider	Wet road surface	
3/3/98	8:20	17.5	15.8	15.6	18.0	77
	9:00	19.8	16.8	16.5	19.0	75
	9:37	24.0	17.0	19.6	23.0	71
	10:20	28.0	20.8	22.6	25.0	67
	11:05	32.6	20.2	24.2	26.0	67
	11:50	33.7	23.2	24.8	30.0	65
	12:35	33.7	23.6	23.8	32.5	63
	13:20	35.7	25.2	23.4	33.0	62
	14:05	35.8	22.0	23.0	32.0	62
	14:50	33.0	23.2	21.2	30.0	61
	15:40	32.4	21.0	20.6	29.0	62
	16:15	28.6	20.2	20.4	27.5	60
	17:05	28.8	19.4	18.2	28.5	61
	17:45	25.8	18.8	19.6	27.0	61
	18:25	23.0	18.6	18.2	24.0	63
10/3/98	8:50	24.4	23.0	19.0	23.5	67
	9:40	26.1	21.4	21.2	23.75	67
	10:40	28.6	22.6	23.8	25.5	66

Table A2. Chipseal test site - outdoors.

Date	**Time**	**Temperature (°C)**				**Skid resistance BPN (uncorrected)**
		Dry road surface	**Air**	**Slider**	**Wet road surface**	
3/3/98	8:05	15.6	13.5	14.0	17.0	86
	8:50	16.0	14.0	14.4	16.0	83
	9:30	21.4	17.2	22.2	20.0	80
	10:10	25.2	17.4	20.8	23.0	77
	10:55	29.7	19.6	28.0	25.0	76
	11:40	31.1	20.8	24.4	27.0	70
	12:25	34.0	20.8	25.4	30.0	65
	13:10	37.8	23.2	26.4	30.0	63
	13:55	34.7	22.0	24.0	31.0	65
	14:40	34.1	23.2	23.8	32.0	68
	15:25	34.0	23.0	23.2	31.0	65
	16:10	31.1	20.8	21.2	29.0	68
	16:55	30.1	22.0	19.2	28.0	71
	17:40	28.0	21.2	21.6	25.5	66
	18:15	28.4	17.8	18.2	N/R	71
10/3/98	8:40	22.5	22.8	20.4	23.5	75
	9:25	22.6	21.0	20.6	21.0	71
	10:30	24.6	21.0	22.4	24.0	68

N/R = not recorded

Table A3. Concrete test site - indoors.

Date	**Time**	**Temperature (°C)**				**Skid resistance BPN (uncorrected)**
		Dry road surface	**Air**	**Slider**	**Wet road surface**	
3/3/98	7:50	17.6	13.5	16.3	18.0	26
	8:35	17.2	14.2	14.9	17.0	28
	9:15	17.2	15.1	16.5	18.0	27
	10:00	17.8	15.1	17.8	18.5	25
	10:45	18.2	15.4	19.0	20.0	25
	11:30	18.8	16.5	20.6	19.0	25
	12:15	19.4	18.0	21.2	19.5	27
	13:00	20.6	16.0	22.0	20.0	24
	13:45	19.6	19.8	22.8	21.0	25
	14:30	19.8	18.6	21.6	20.0	25
	15:15	19.4	18.6	21.0	20.0	24
	16:00	19.6	17.8	20.6	18.0	26
	16:45	19.0	19.4	20.0	19.0	24
	17:30	19.1	19.2	19.4	18.5	22
	18:10	18.8	17.8	19.0	18.5	21
10/3/98	8:22	22.0	22.2	22.0	22.0	33
	9:15	20.0	23.2	19.6	21.5	28
	10:10	22.0	23.0	22.4	22.0	30

A2 GRIPTESTER READINGS

Table A4. Asphaltic concrete test site - outdoors.

Date	Time	Temperature (°C)				Skid resistance GN (uncorrected)
		Dry road surface	Air	Measuring wheel	Wet road surface	
3/3/98	9:40	28.0	18.3	26.0	14.8	0.77
	10:20	28.7	18.8	21.6	14.9	0.74
	11:00	36.1	21.2	27.9	16.5	0.72
	11:51	38.0	21.8	25.0	15.9	0.70
	12:40	37.1	22.2	27.7	16.2	0.68
	13:20	39.8	22.4	26.1	16.0	0.67
	14:10	39.5	22.9	28.2	16.7	0.67
	14:55	38.3	21.6	24.4	16.0	0.67
	15:15	39.5	21.0	24.5	15.8	0.68
	16:25	37.9	20.2	23.6	14.9	0.66
	17:03	35.5	19.9	22.7	14.8	0.68
	17:45	34.6	19.8	24.4	16.5	0.68
	18:25	31.8	18.8	23.3	15.7	0.69
10/3/98	8:55	24.8	21.8	23.5	17.8	0.79
	9:40	26.0	22.2	23.7	18.0	0.75
	10:47	30.4	23.8	25.8	19.5	0.73

Table A5.   Chipseal test site - outdoors.

Date	**Time**	**Temperature (°C)**				**Skid resistance GN (uncorrected)**
		Dry road surface	**Air**	**Measuring wheel**	**Wet road surface**	
3/3/98	10:15	27.2	19.7	21.9	15.2	0.73
	10:50	32.2	20.8	24.5	15.8	0.75
	11:42	35.6	21.7	26.4	16.0	0.77
	12:24	38.6	22.5	22.5	16.0	0.72
	13:11	37.0	23.0	24.0	16.0	0.70
	14:00	37.0	22.6	26.4	16.8	0.71
	14:43	38.0	23.2	22.3	16.4	0.69
	15:30	36.5	21.0	22.1	16.2	0.74
	16:10	35.0	22.0	19.2	15.6	0.71
	16:56	36.6	20.5	22.6	16.0	0.72
	17:37	35.5	20.1	21.9	16.6	0.72
	18:17	35.8	19.0	23.9	16.3	0.73
10/3/98	8:46	23.0	21.8	22.0	17.4	0.84
	9:30	23.5	22.2	21.8	18.0	0.79
	10:30	27.5	23.5	22.6	18.8	0.75

Table A6. Concrete test site - indoors.

Date	Time	Temperature (°C)				Skid resistance GN (uncorrected)
		Dry road surface	Air	Measuring wheel	Wet road surface	
3/3/98	10:06	24.3	18.4	24.3	14.3	0.44
	10:45	21.5	19.2	22.3	14.7	0.46
	11:32	24.4	21.1	24.9	15.7	0.46
	12:20	22.6	20.5	22.5	14.9	0.45
	13:03	21.8	21.3	22.9	15.0	0.43
	13:45	21.8	21.4	21.6	16.0	0.44
	14:35	20.4	21.4	20.4	15.4	0.43
	15:15	19.8	21.2	20.3	14.8	0.43
	16:04	19.0	20.2	19.7	14.6	0.43
	16:50	19.0	20.0	19.1	14.6	0.42
	17:31	20.5	19.7	19.8	15.8	0.44
	18:10	22.0	19.0	21.9	15.9	0.44
10/3/98	8:28	22.8	21.7	22.7	17.3	0.52
	9:20	22.8	22.4	23.1	18.1	0.44
	10:25	23.3	23.4	23.6	18.5	0.45

APPENDIX 2

OVERVIEW PLOTS - WHANGAREI DATABASE

Figure A1: Time history of individual site BPN values for test strip 1.
Figure A2: Time history of individual site wet surface temperature values for test strip 1.
Figure A3: Time history of individual site BPN values for test strip 2.
Figure A4: Time history of individual site wet surface temperature values for test strip 2.
Figure A5: Time history of individual site BPN values for test strip 3.
Figure A6: Time history of individual site wet surface temperature values for test strip 3.
Figure A7: Time history of individual site BPN values for test strip 4.
Figure A8: Time history of individual site wet surface temperature values for test strip 4.
Figure A9: Time history of individual site BPN values for test strip 5.
Figure A10: Time history of individual site wet surface temperature values for test strip 5.
Figure A11: Time history of individual site BPN values for test strip 6.
Figure A12: Time history of individual site wet surface temperature values for test strip 6.
Figure A13: Time history of individual site BPN values for test strip 7.
Figure A14: Time history of individual site wet surface temperature values for test strip 7.

Figure A1. Time history of individual site BPN values for test strip 1.

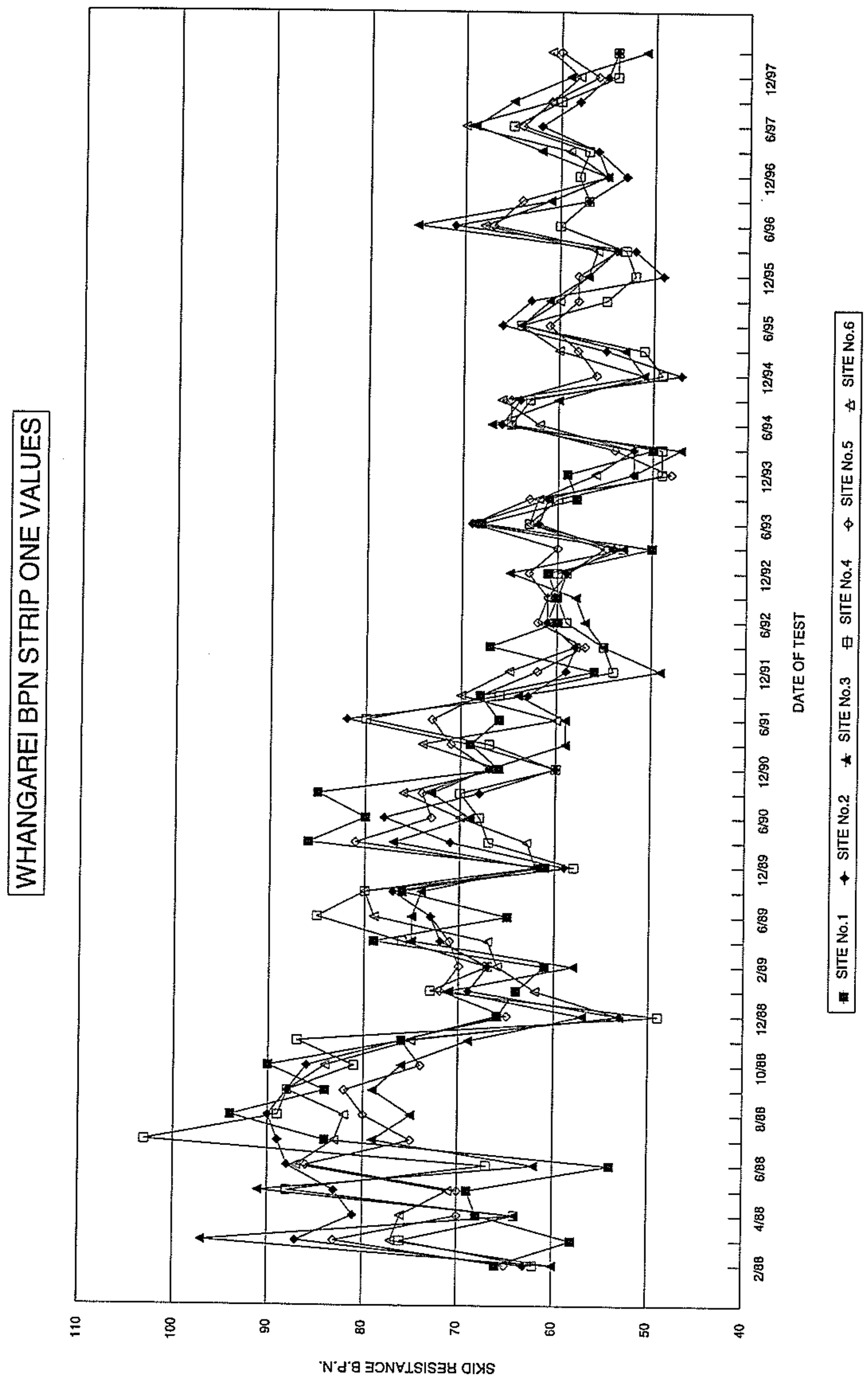

Figure A2. Time history of individual site wet surface temperature values for test strip 1.

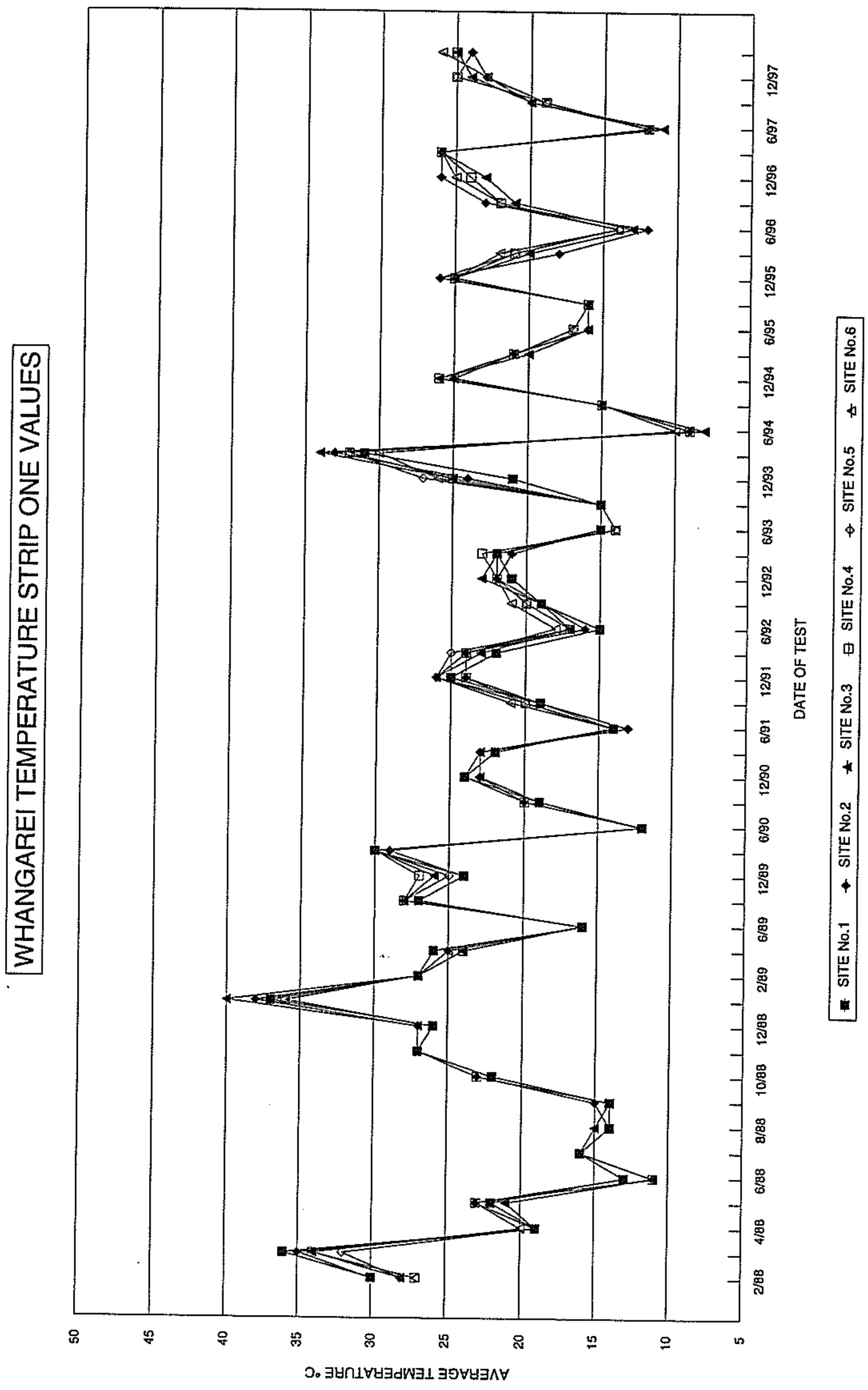

Figure A3. Time history of individual site BPN values for test strip 2.

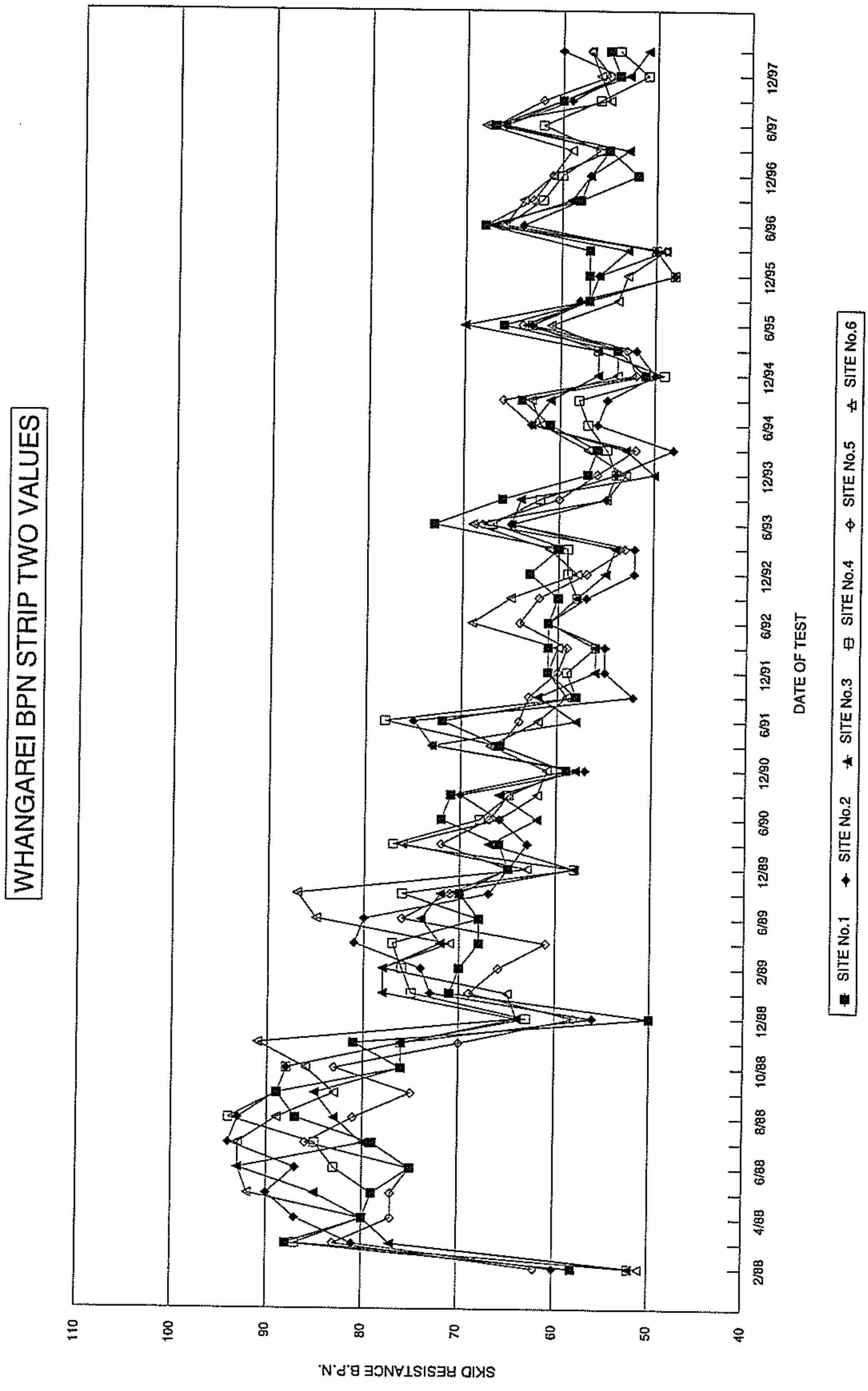

Figure A4. Time history of individual site wet surface temperature values for test strip 2.

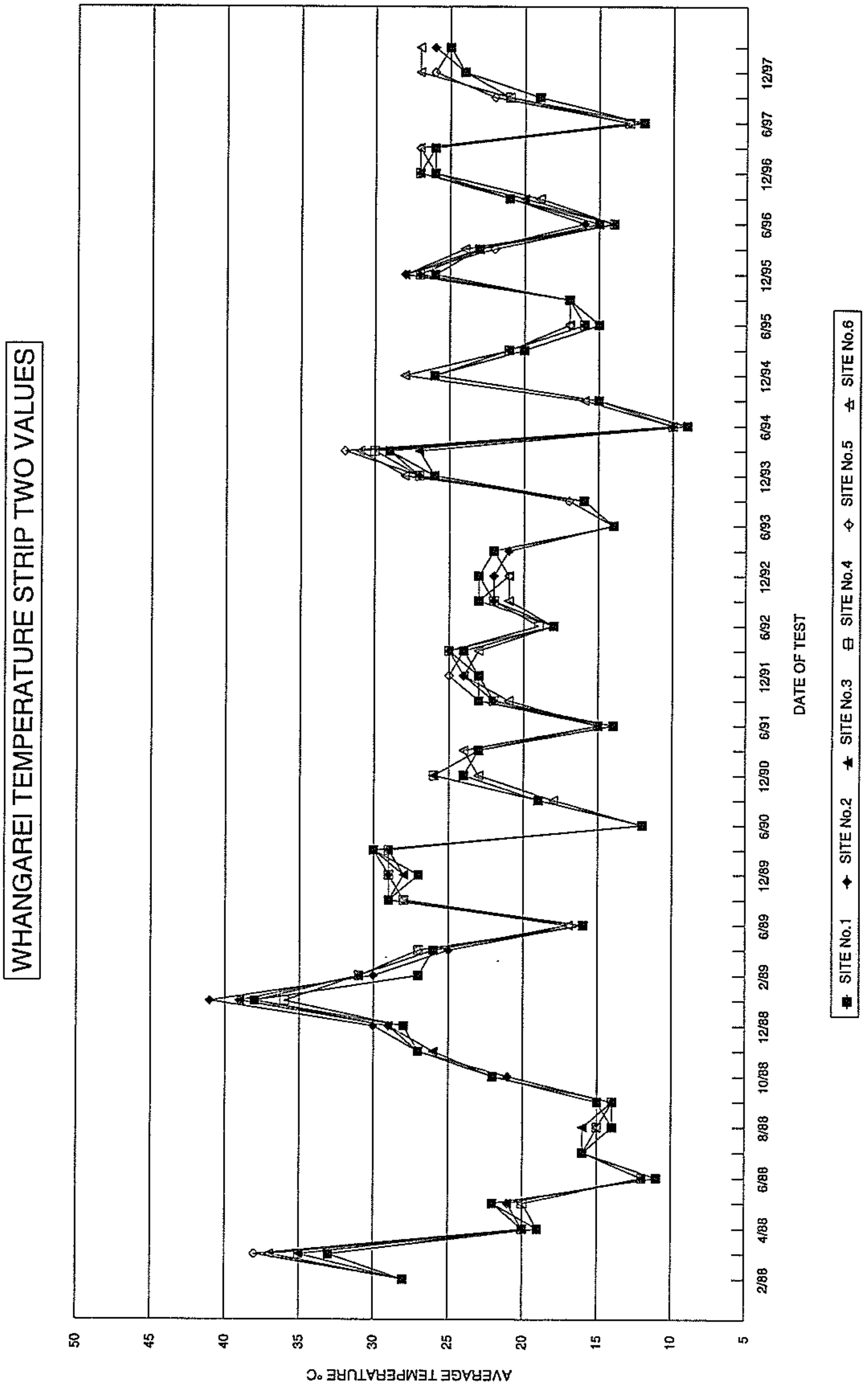

Figure A5. Time history of individual site BPN values for test strip 3.

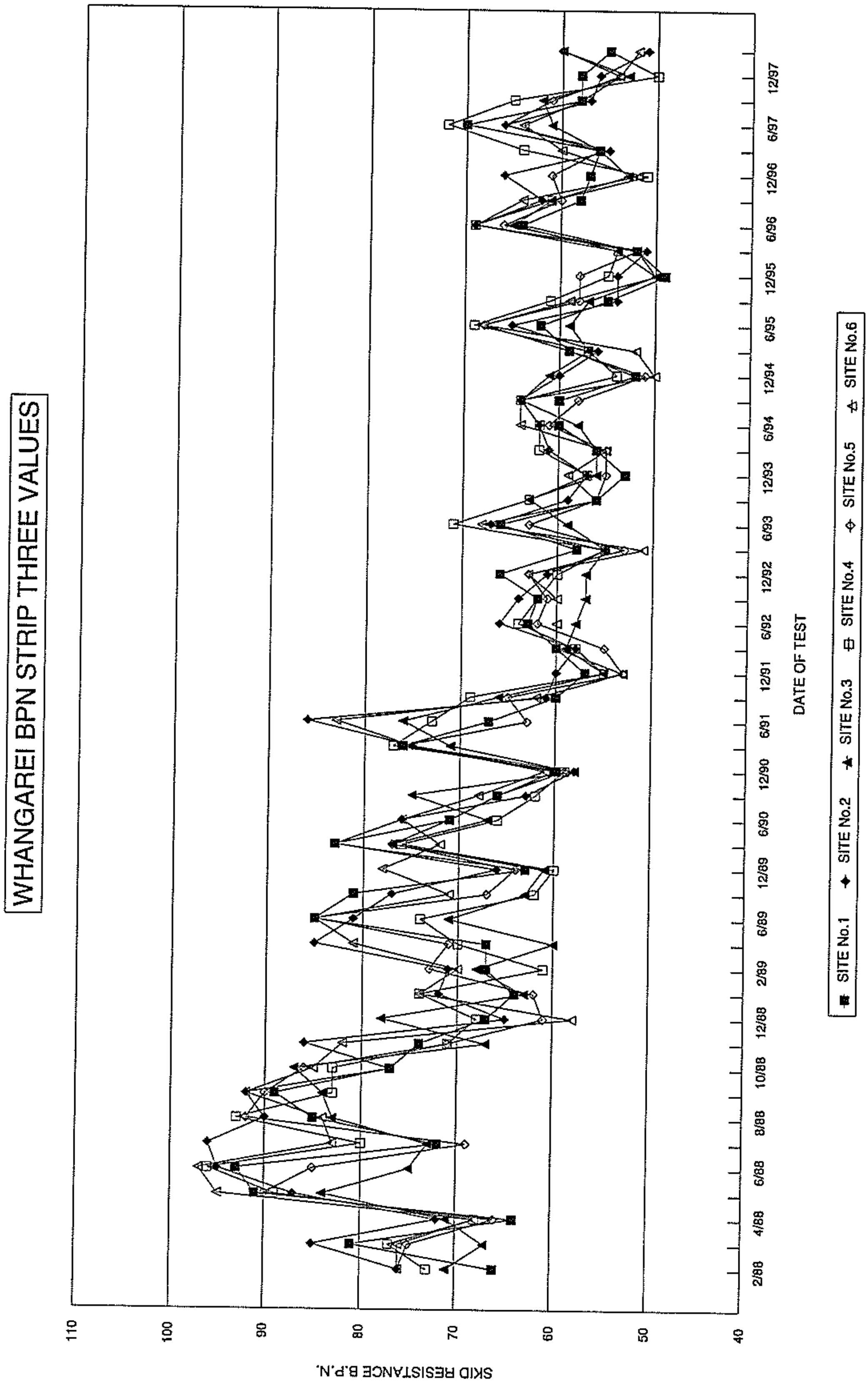

Figure A6. Time history of individual site wet surface temperature values for test strip 3.

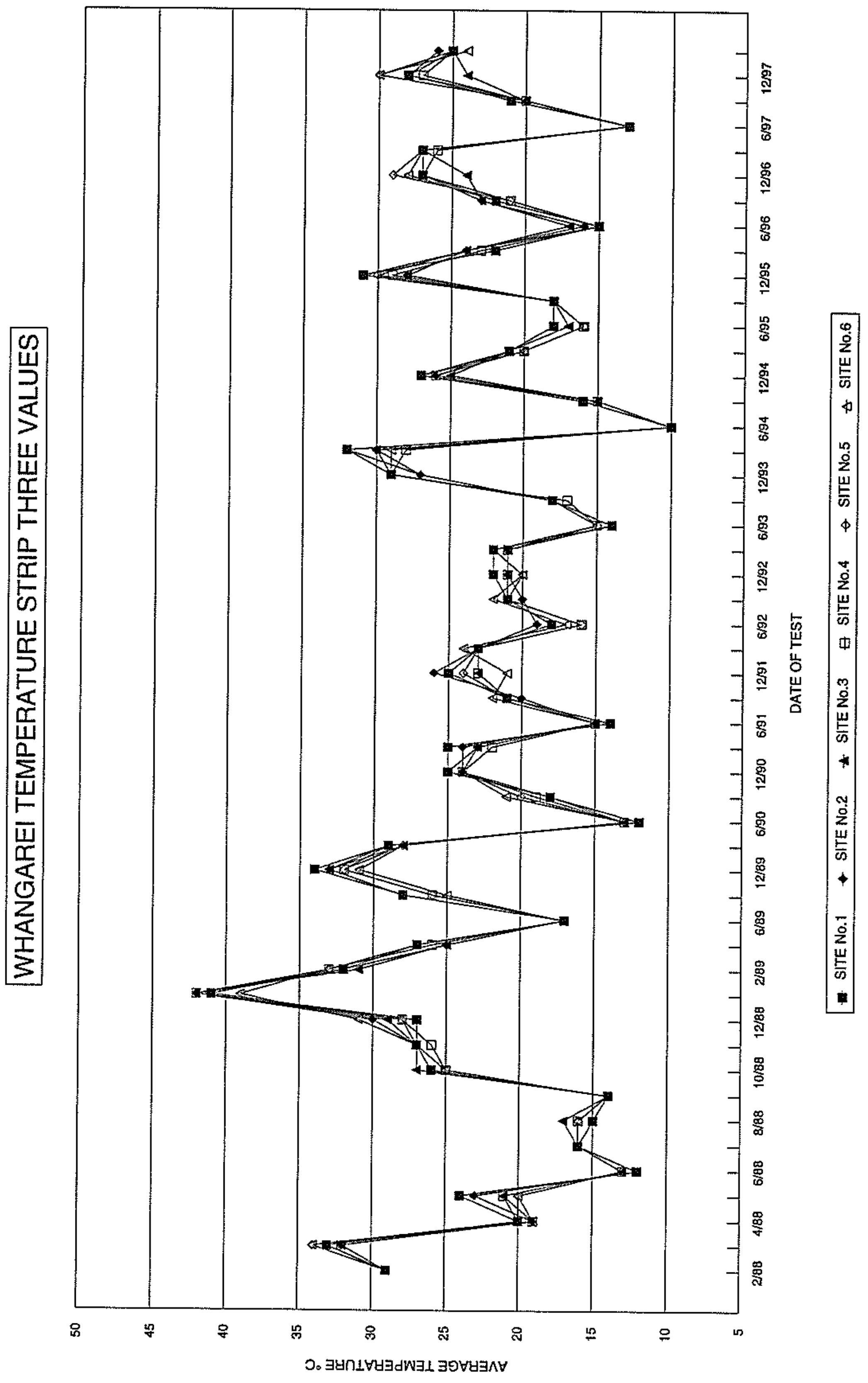

Figure A7. Time history of individual site BPN values for test strip 4.

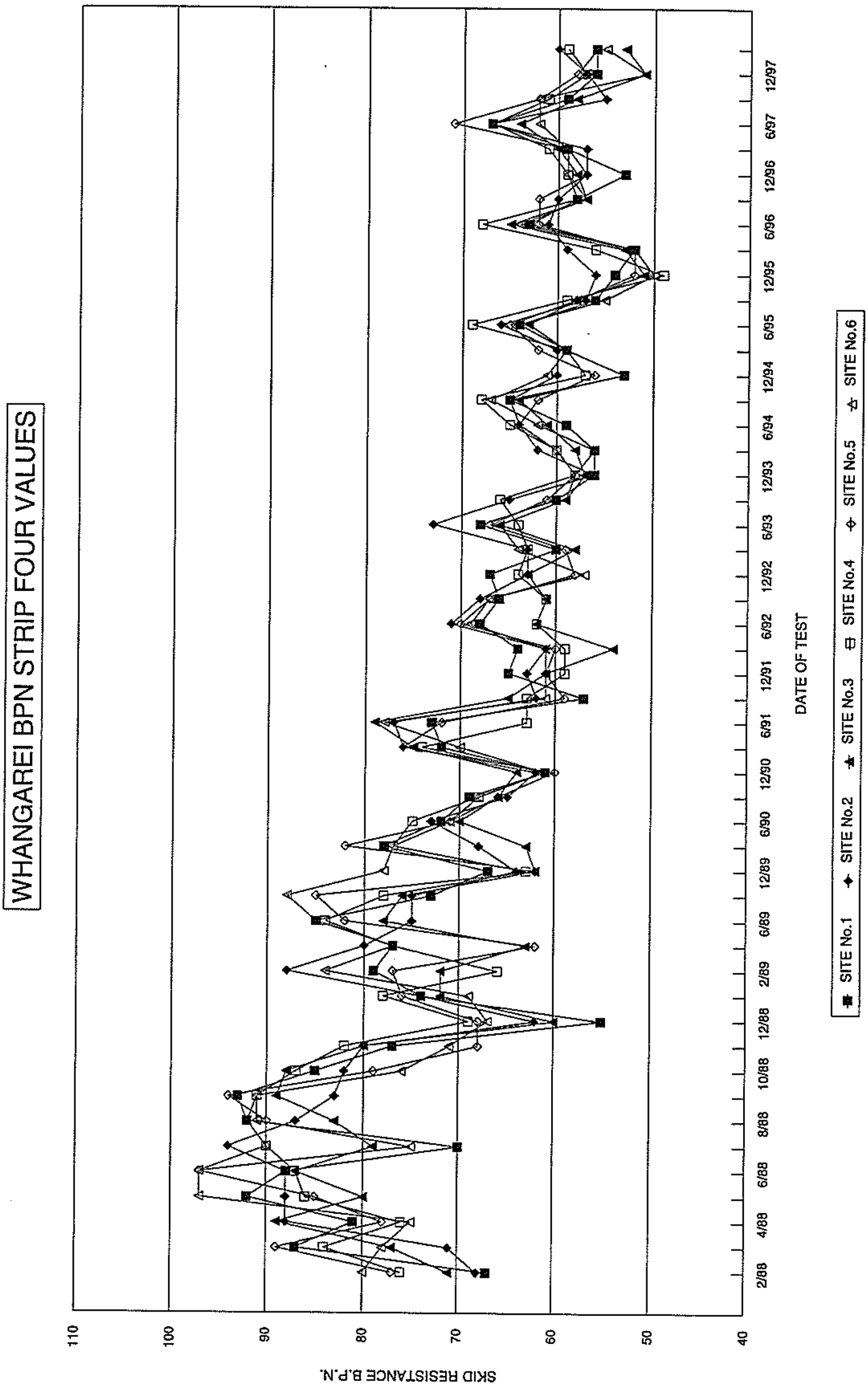

Figure A8. Time history of individual site wet surface temperature values for test strip 4.

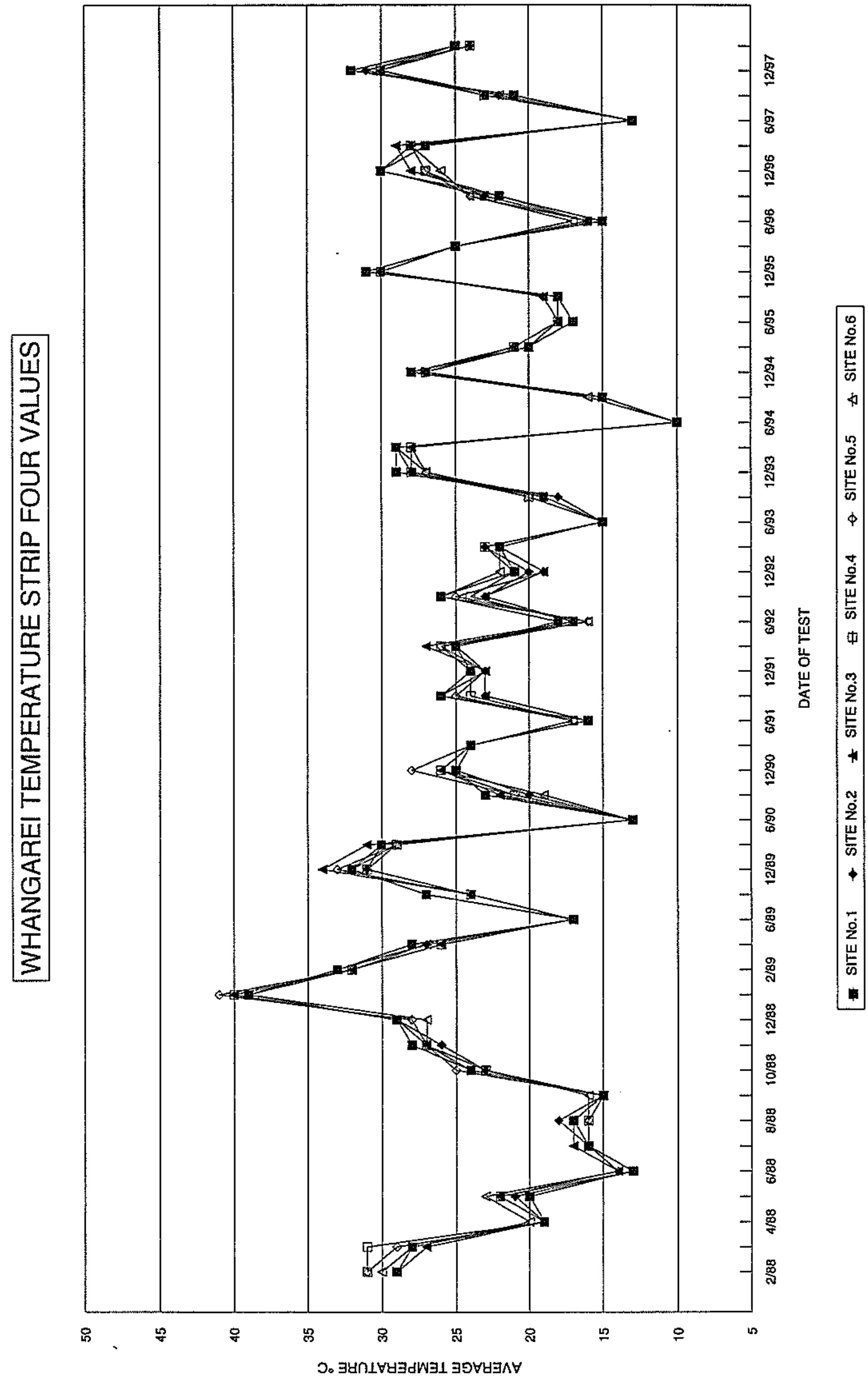

Figure A9. Time history of individual site BPN values for test strip 5.

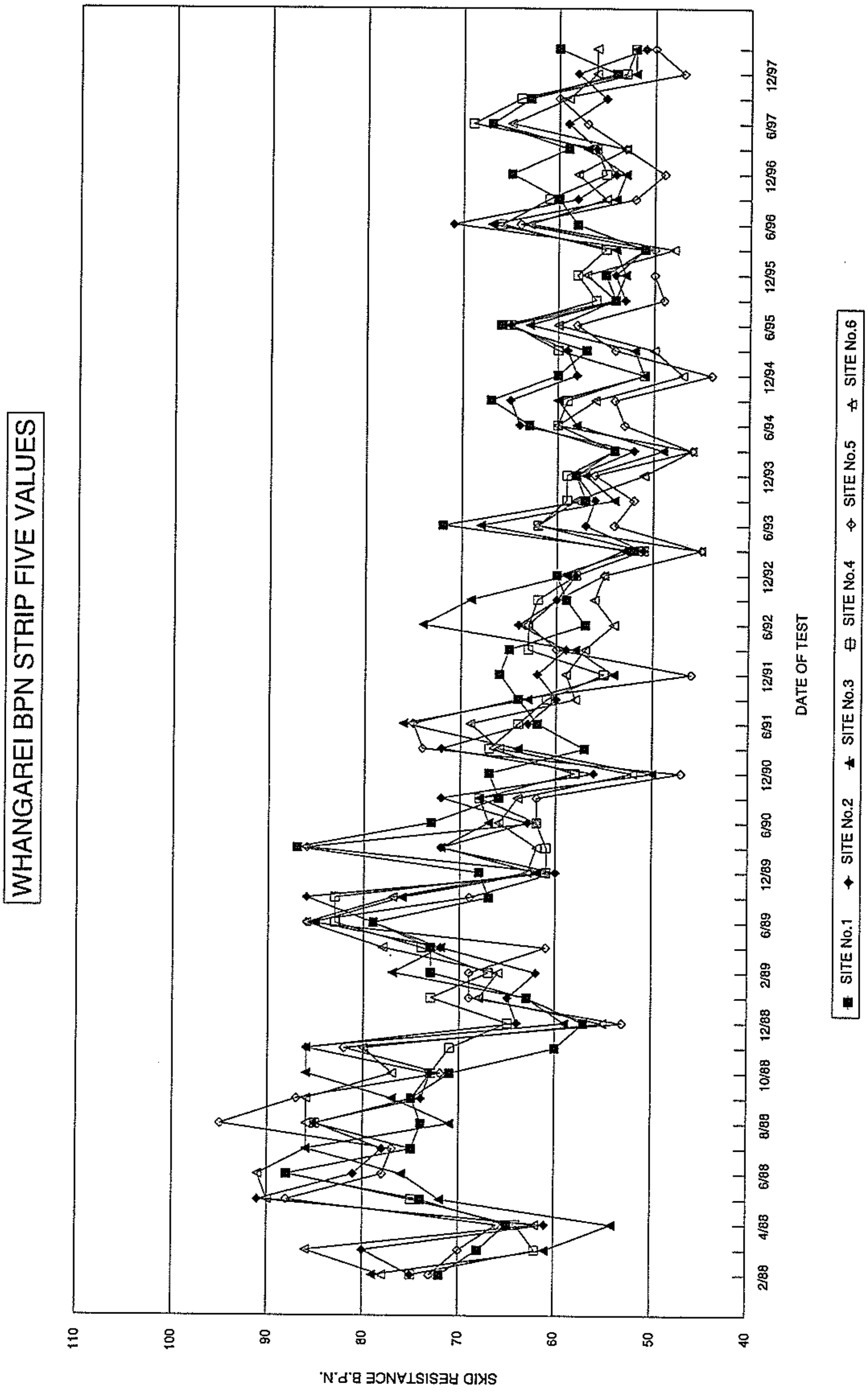

Figure A10. Time history of individual site wet surface temperature values for test strip 5.

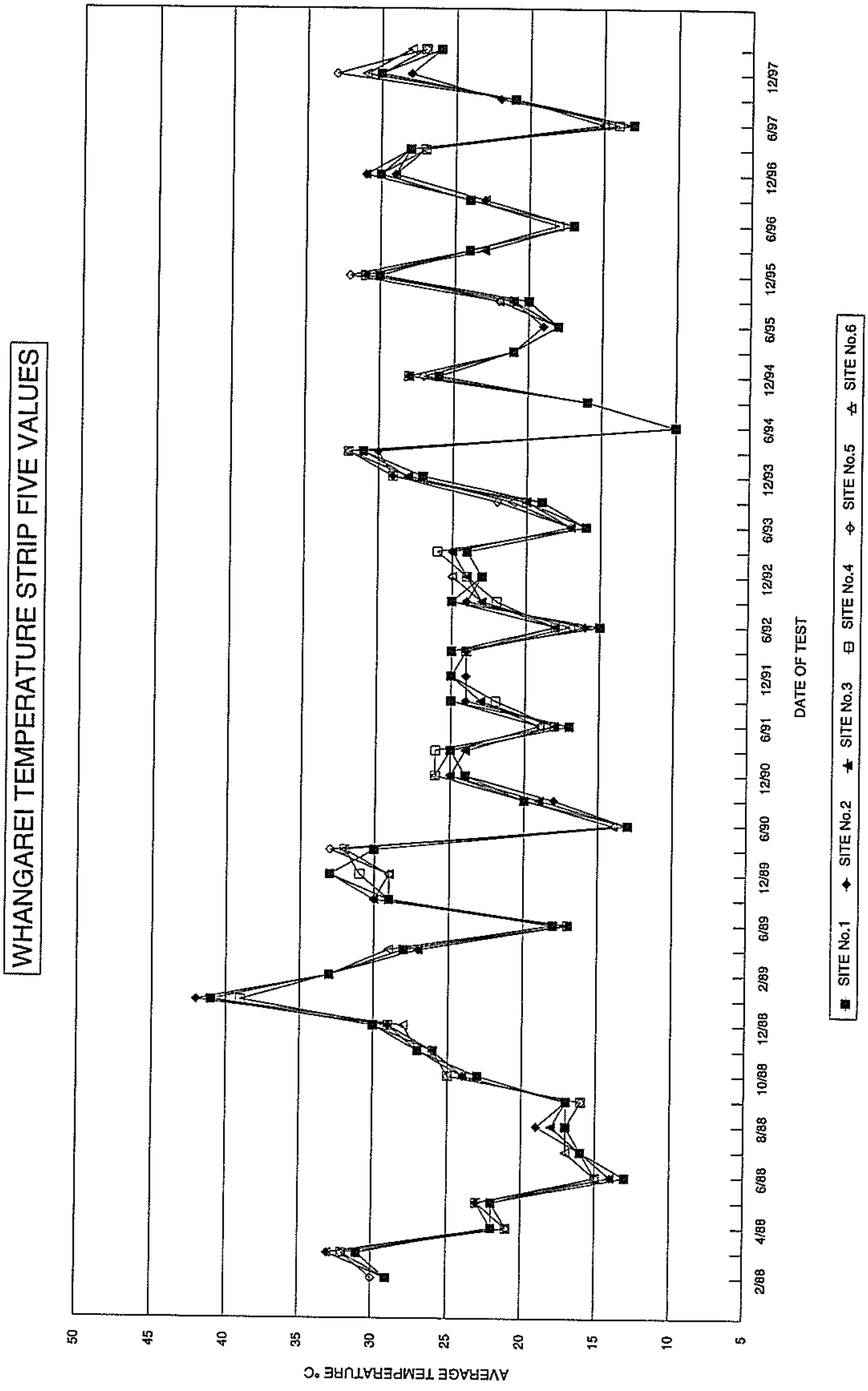

Figure A11. Time history of individual site BPN values for test strip 6.

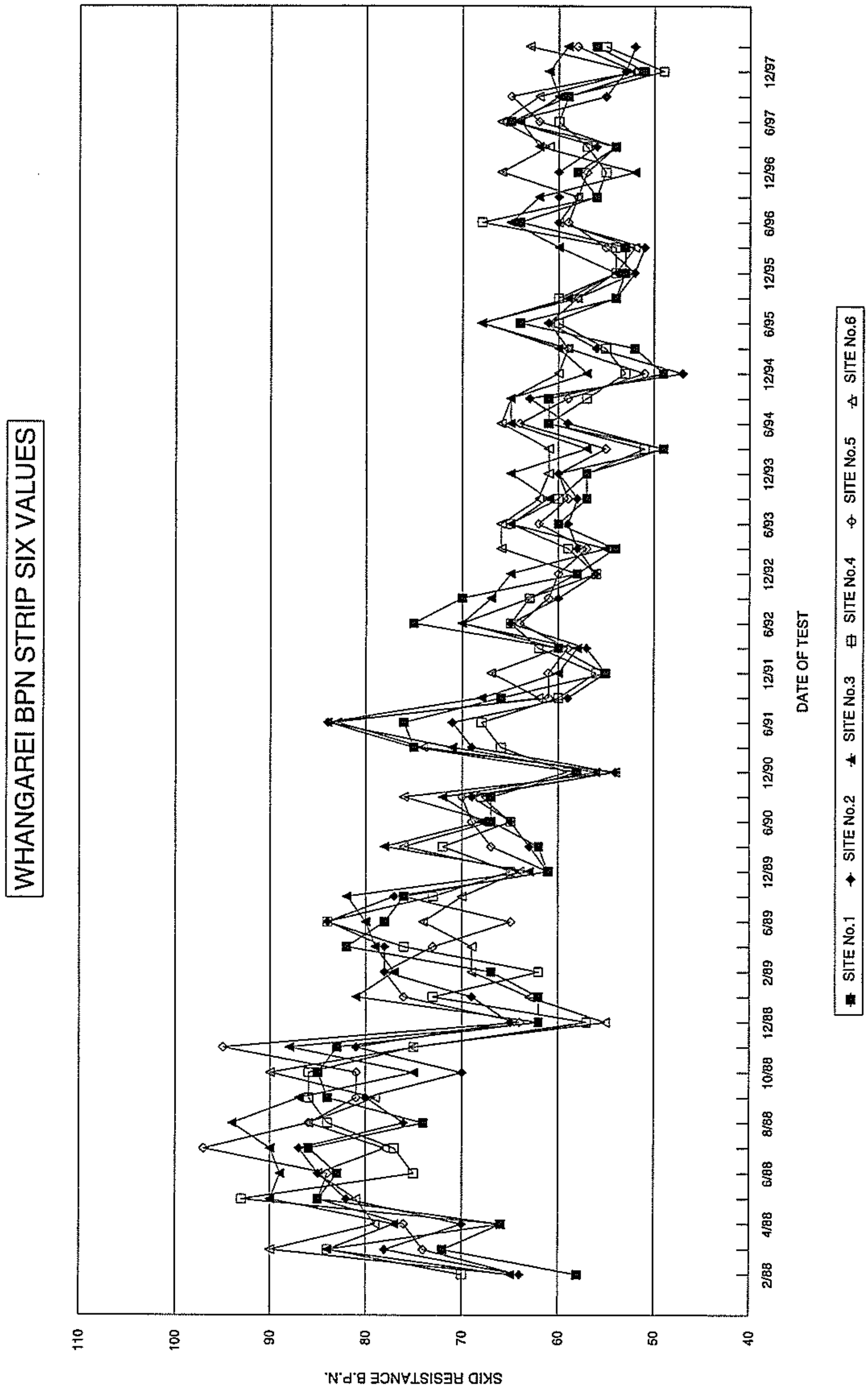

Figure A12. Time history of individual site wet surface temperature values for test strip 6.

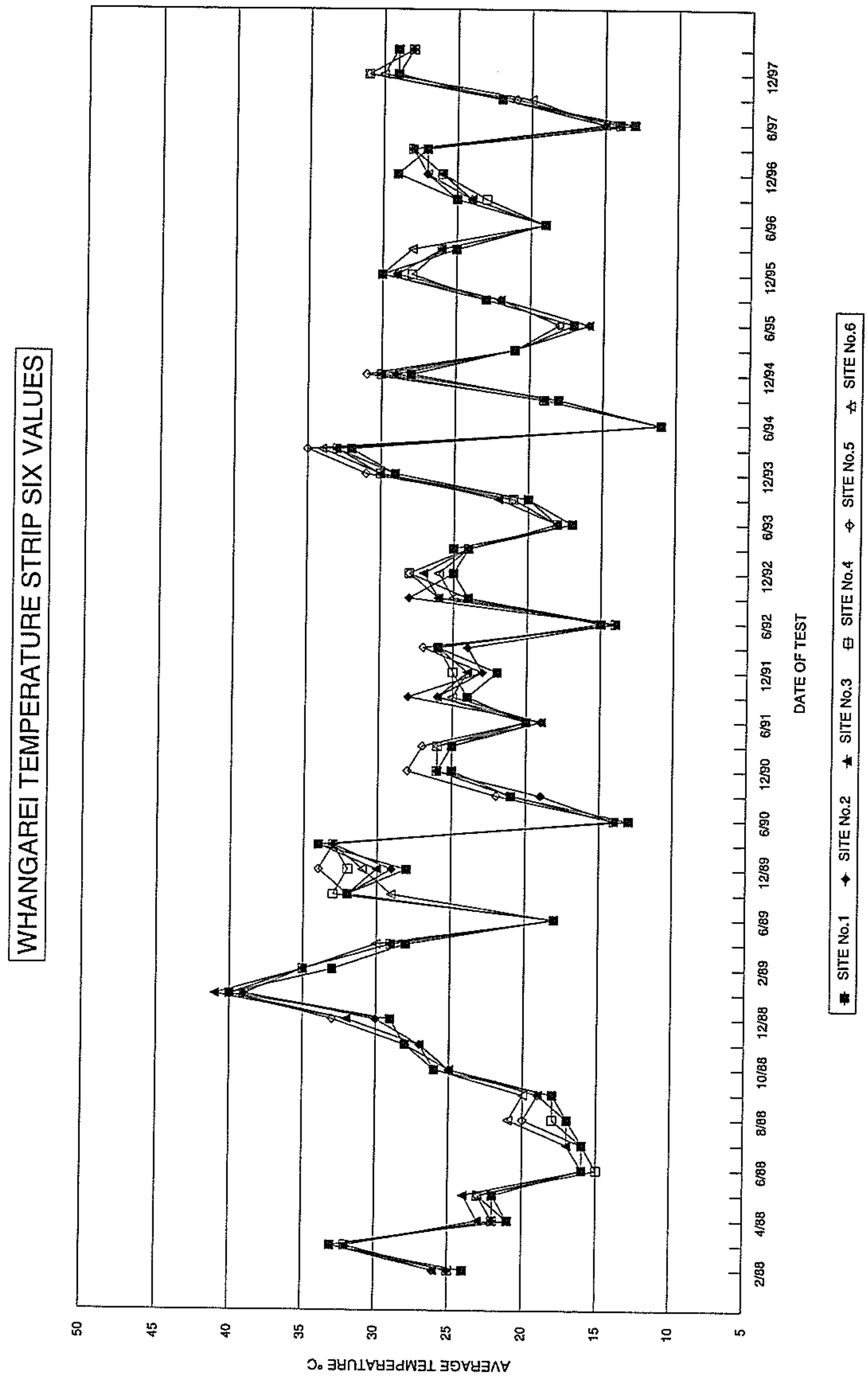

Figure A13. Time history of individual site BPN values for test strip 7.

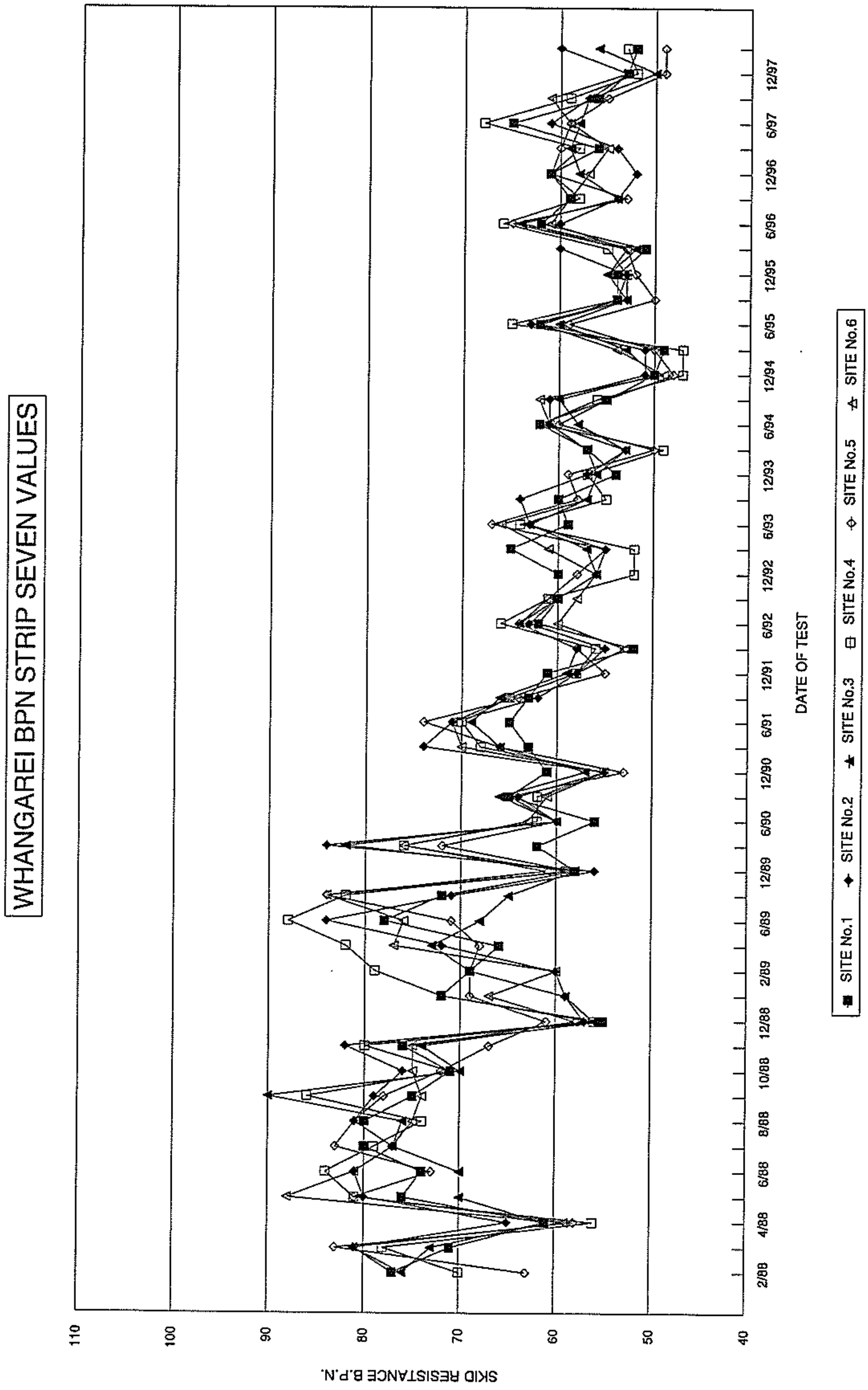

Figure A14. Time history of individual site wet surface temperature values for test strip 7.