Optimising drainage maintenance for pavement performance

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An important note for the reader

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Abbreviations and acronyms

AADT	annual average daily traffic
CAPTIF	Canterbury Accelerated Pavement Testing Indoor Facility
CBR	California bearing ratio
EDA	equivalent design axle
ESA	equivalent standard axle
HCV	heavy commercial vehicle
M	million
MESA	millions of equivalent standard axles
RLT	repeated load triaxial
SWCC	soil water characteristic curves
Transport Agency	NZ Transport Agency

Contents

Executive summary

This project was designed to investigate the importance of drainage maintenance on pavement performance and to recommend a maintenance strategy. With restrained funding for pavement renewals, drainage maintenance is a cost-effective method to ensure optimum pavement performance.

In the 2010/11 financial year the NZ Transport Agency spent 3.7% of its total state highway maintenance budget of $231 million on drainage maintenance and 23.2% on pavement renewals. Better targeting of the drainage maintenance could have a significant effect on reducing the renewal quantity and cost.

Research using the repeated load triaxial testing approach has demonstrated there is an exponential relationship between the degree of saturation and rate of rut development for granular basecourse.

This is reflected in the field where water build up in the pavement as a result of prolonged rainfall can result in rapid pavement failure. It has also shown that a significant loss in life can occur if the wetting and drying of basecourse results in equilibrium water content so that the saturation level is greater than 65% to 70%.

Modelling of the movement of water using a typical cross section of New Zealand thin-surfaced granular pavements endorsed previous New Zealand research that the equilibrium water content in a granular layer is approximately 60%, and in a sandy clay subgrade is greater than 95%. It also confirms the present New Zealand practice of designing pavements with a soaked subgrade.

The modelling showed that once water has infiltrated the basecourse it can take weeks for the water content to return to its equilibrium condition. During this time significant damage can take place and there is a high probability that further rainfall will occur and thus re-saturate the pavement.

A score card was developed to rank the importance of drainage maintenance as a function of:

1 Climate – how much rain falls on the network? Is the area subject to freeze-thaw?

2 Topography – does the water run away quickly and easily? Is the terrain mountainous, rolling or flat?

3 Drainage position – are the drains close to the traffic wheel path? This is a factor of the shoulder width. Are they sealed?

4 Pavement type – will water significantly affect the pavement performance? Bound materials such as asphalt will be less susceptible to poor drainage than granular materials.

5 Traffic level – how much traffic is using the pavement?

6 Surface water flow – will water flow across the surface if the drainage is inadequate? This is both a vehicle safety issue and a pavement issue as tyre pressure can force water through a thin surfacing.

It was concluded that the rating system described in the RAMM manual was suitable for visual rating of drainage and that the surveys undertaken for this project should be based on the score card.

In addition, it was decided that monitoring changes in the rate of rut progression in the left wheel path was a method that could be used to identify areas where subsurface drainage required investigation. A change in rate or difference from one side of the road to the other could signal a drainage problem on the side where the rate of rutting had increased.

It is recommended that:

1 The drainage risk score is included in RAMM.

2 Rating of drainage condition is introduced on higher-risk sections.

3 A strategy of identifying and recording 'hot spots' is implemented.

4 The cost of maintaining the drainage condition to the appropriate level is monitored.

5 Comparison of rut rates on both directions of travel for a pavement is introduced as a standard process to indicate possible subsoil drain blockage.

Abstract

This project was designed to investigate the importance of drainage maintenance for pavement performance and to recommend a maintenance strategy. With restrained funding for pavement renewals drainage maintenance is a cost-effective method to ensure optimum pavement performance.

A combination of repeated load triaxial testing and modelling of water movement has shown that once water has infiltrated the basecourse it can take weeks for the water content to return to its equilibrium condition. During this time significant damage can take place and there is a high probability that further rainfall will occur and thus re-saturate the pavement.

A drainage risk rating score card was developed and it is recommended that this be adopted by road controlling authorities.

1 Introduction

1.1 Background

The purpose of the research undertaken in this project was to enable an estimation of road damage caused by water ingress into the pavement layers (eg when it rains) for a typical thin-surfaced granular pavement The results of the investigation were then used to develop a ranking system that could be used by road asset managers to make decisions on the optimum drainage maintenance needed and/or whether new drains or shoulders were required to improve the level of road drainage.

Pavement drainage can significantly affect pavement performance. There is an old adage that the three most important factors in pavement performance are water, water and water. This research project was designed to obtain a less emotional and more rational approach to determining the optimum maintenance regime that should be used to ensure that significant pavement failure caused by water ingress did not occur.

The problem related to excess water content in pavement layers is that there can be a decrease in strength, degradation of material and loss of bond between layers. Rutting or potholing is the typical mode of pavement failure, which can deteriorate a pavement quickly. Pavement deformation within the wheel tracks (rut) can be primarily caused by factors other than moisture, such as wheel loads, but the rutting accelerates when the pavement is wet. The other mode of failure is fatigue cracking, which allows water ingress and loss of strength.

The research team on this project had already carried out a number of studies to improve the understanding of pavement performance in relationship to water. For example *NZ Transport Agency research report 424*: 'Design moisture conditions for pavement design and material assessment' (Arampamoorthy and Patrick 2010) used a model developed in the US to estimate the equilibrium degree of saturation in subgrade and basecourse material, and applied it to New Zealand data. This research allowed pavement designers to use base materials regarded as 'moisture sensitive' in areas where the risk of moisture ingress was low.

The research recommended that laboratory characterisation of the long-term performance of pavement materials should be performed at 60% saturation for granular bases and at saturated conditions for subgrades. It found that these were the typical equilibrium water contents existing in the New Zealand environment. To keep the 60% condition any water infiltrated through the road surface or shoulder should be able to drain quickly.

Research into the waterproofness of first coat seal (Patrick 2009) showed that water could penetrate through a seal under the pressure exerted by truck tyres. In low traffic situations the water had time to dissipate before pore pressures that could blow a pavement apart were generated. In high traffic situations the water did not have time to flow away and thus the rapid pulsing by heavy vehicles developed excess pore pressure.

That research led to the project described in this report where the waterproofness of different surfacings was investigated at the NZ Transport Agency (Transport Agency) Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF). Opus Research developed a finite element model of water flow through a pavement which was used in the project.

The strength of the pavement can be reduced by moisture in the pavement structure. Arnold et al (2008) assessed the rutting resistance of alternative granular pavement materials using the repeated load triaxial

(RLT) test to simulate the effect of repeated traffic loading. Moisture conditions were set at levels consistent with a 'dry' pavement. However, material performance in this test is known to vary significantly, depending on the moisture conditions, and the standard method used is to test a saturated sample. This conservative approach has resulted in the failure of many materials in the test and is no longer regarded as suitable for use.

Drains are not always totally effective at keeping the water from the pavement layers. There are several reasons for this, including:

- insufficient depth of drain
- flow level above subgrade
- very low flow rates caused by not enough slope, vegetation, silt deposits or a high water table
- water accumulation and stagnation at shoulders
- drainage inlets blocked by debris or elevated
- ineffective subsurface drains or not providing designed filter materials around the drainage coil.

In this research we assumed the drains were well designed and were located in the 'right' position. The research concentrated on the effect blockage of the drains had on water ingress and the subsequent material behaviour.

The models developed in the project were used mainly to identify how long water stayed in a given pavement, and to evaluate the potential effect of the water table, shoulder construction, layering, edge drains and granular basecourse material on the drainage of a flexible pavement system.

In some situations the effectiveness of drainage is not very important to pavement deterioration, such as in low traffic areas. In these circumstances the frequency of drainage maintenance can be reduced and the pavement damage risk is low. Where the traffic volume is high it is expected that poor drainage will lead to rapid pavement deterioration.

Assuming a constrained budget, the research tender document asked to what extent did the level of drainage maintenance impact on pavement performance and was it possible to identify a critical 'tipping point' or minimum level of service related to risk and performance. The document also stated that although the importance of drainage maintenance and the basis of good drainage design were well understood and documented, the optimum frequency and level of maintenance were dependent on a number of factors including pavement type, vegetation, climatic conditions and geometric design.

This project attempted to address these issues by developing a risk profile to use in prioritising maintenance.

1.2 Current expenditure

The Transport Agency in 2010/11 spent just over $437 million on maintaining the state highway network, including bridges, mowing, vegetation control and cycle ways. The most significant area of cost was in the maintenance and renewal of pavements and surfacings which totalled over $231 million. Table.1.1 gives the breakdown of this expenditure, which shows that drainage maintenance and renewal was 6.2% of the total. Pavement maintenance and renewals accounted for over 50% of the total.

Table 1.1 Maintenance expenditure on New Zealand state highways in 2010/11

		2010/11 $	Percent	Percent of grand total
Maintenance and operation	Sealed pavement maintenance	73,122,583	89.5%	31.6%
	Unsealed pavement maintenance	103,279	0.1%	0.0%
	Routine drainage maintenance	8,500,853	10.4%	3.7%
	Total	81,726,715		
Renewal of state highways	Unsealed roads metalling	336,184	0.2%	0.1%
	Sealed roads resurfacing	89,942,902	60.1%	38.9%
	Drainage renewals	5,784,064	3.9%	2.5%
	Pavement rehabilitation	53,577,594	35.8%	23.2%
	Total	149,640,744		
	Grand total	231,367,459		

The distribution of the renewals over the last five years is shown in table 1.2. It gives the percentage of the state highway network classified as mountainous, rolling or flat and also the percentage of the renewals in these classifications. There is some missing data in the RAMM database and these are noted as unclassified.

The table indicates that the distribution of renewals is similar to the distribution of the network and there is no evidence of road pavement requiring more renewals in flat, mountainous or rolling country.

Table 1.2 Distribution of pavement renewals over 2008 to 2012 as a function of topography

	Unclassified	Flat	Mountainous	Rolling
Total network	0.8%	37.5%	15.3%	46.4%
Renewal	5.0%	35.5%	14.3%	45.2%

If drainage quality is a significant factor in pavement renewals, it would seem that flat country where water could pond would have a higher failure rate (more renewals) than in mountainous country where water flow is easier. This premise may not be correct as the water ingress may still occur but by a different path.

The distribution of renewals as a function of traffic volume and the distribution of traffic over the state highway network is shown in table 1.3

Table 1.3 Distribution of pavement renewals as a function of traffic volume

Pavement use	Use 1 (<100vpd)	Use 2 (100–500vpd)	Use 3 (500–2,000 vpd)	Use 4 (2,000-4,000 vpd)	Use 5 (4,000–10,000 vpd)	Use 6 (10,000–20,000 vpd)	Use 7 (>20,000 vpd)
% of network	0.5	5.5	39.6	20.9	21.4	8.7	3.5
% of renewals	1.6	3.8	33.2	22.5	25.5	8.8	4.6

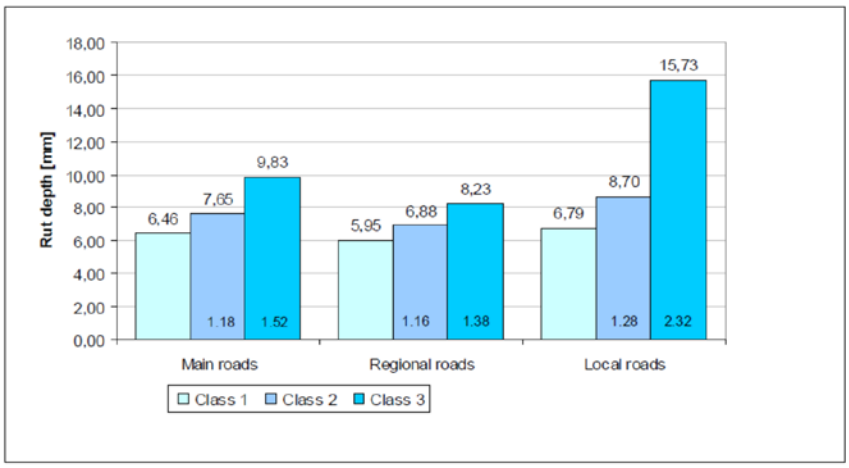
There appears to be no increase in renewal rate with traffic volume as the two distributions are similar.

The average renewal length over the last five years is 242km/year based on the 2010/11 cost of $53,577,594. This is equivalent to $221,400/km.

Drainage maintenance is $8.5 million/year. If drainage quality has a significant effect on pavement performance there is a possibility that improvements in maintenance could decrease the quantity of renewals.

There is very little literature reporting on research into drainage effects on granular pavement performance. One significant study in Finland, however, did obtain interesting data. The project *Developing drainage guidelines for maintenance contracts* (Saarenketo 2007) surveyed the rutting and roughness characteristics of roads with excellent (class 1), average (class 2) and poor (class 3) drainage and found that those with poor drainage had the worst performance. The rutting results are given in figure 1.1.

Figure 1.1 Rut depth average values on each road type and drainage class



Note: The values on top of columns are absolute, in the middle of the bars the values are relative to class 1.

On the main roads, which are similar to New Zealand's thin-surfaced roads, the rut depths were 20% greater on class 2 drainage and 50% greater on class 3 drainage compared with class 1 drainage.

Similar results were found for roughness. The roads in Finland are subject to freeze–thaw and thus drainage is critical to mitigate water ingress.

The Saarenketo (2007) study did, however, demonstrate that poor drainage leads to poor pavement performance and in terms of rutting or roughness this can be up to 50% loss of service.

In New Zealand the methodology for rating drainage is described in the RAMM manual (Transfund NZ 1997). It results in a similar classification as the Finnish research. The rating has to be performed on the total length of pavement. This is in contrast to the visual rating of surfacing and pavement effects which is performed on a 10% sample of the pavement length. The requirement to perform a 100% visual rating and the fact that drainage quality does not usually change significantly from one year to the next has resulted in many networks not having up-to-date drainage ratings.

The current research project suggests that the rating of drainage would be more cost effective and useful to the asset engineer if it was targeted to the areas of highest risk.

1.3 Objectives

The principal objectives of the research were to:

- Determine a typical range of pavement types, cross-sections, materials, drainage locations, water tables and levels of drainage.
- Model the range of pavements using finite element models, developed by Opus based on SeepW software, first for water movement within the pavement caused by a rain event to determine the degree of saturation and its duration, and then to see how light and heavy maintenance would improve the drainage.
- Using rut depth prediction models based on RLT testing, determine the pavement damage caused by different rain events on different pavement and drainage types based on the degree of saturation and the length of time this occurred as calculated by the finite element model.
- Based on the modelling of water movement and predictions of damage due to traffic, assess and develop drainage maintenance standards to define the damage for a range of pavement types, traffic loadings and climate to enable asset managers to determine the optimum drainage standard for their road network.

1.4 Volumetric water content

The water content in soils is usually expressed as either a dimensionless ratio of two masses or two volumes, or is given as a ratio of a mass per unit volume. These dimensionless ratios can be reported either as decimal fractions or percentages, if multiplied by 100. As volumetric moisture contents are unfamiliar to most roading engineers, this section explains how to estimate the commonly used moisture content (mass) and degree of saturation from the volumetric moisture content reported from the modelling. The volumetric moisture content is defined in equation 1.1, which also shows how to determine the moisture content from the volumetric moisture content, the bulk density and the density of water.

$$\theta = \frac{V_w}{V_t} = \frac{M_w/\rho_w}{M_t/\rho_b} = \left(\frac{M_w \rho_b}{M_t \rho_w}\right) = w\left(\frac{\rho_b}{\rho_w}\right) \qquad \text{(Equation 1.1)}$$

Where:

S = volumetric water content

M_w = mass of water

M_t = total mass

ρ_b = bulk density

ρ_w = density of water

w = water content by mass (M_w/M_{dry})

The degree of saturation (% saturation) is defined in Standards NZ (1986) *NZS 4402: 1986 Methods of testing soils for civil engineering purposes – soil tests* and may be calculated using the formula below.

$$\%\ saturation = \frac{dry\ density\ x\ \%\ water}{1 - \dfrac{dry\ density}{solid\ density\ of\ the\ particles}} \qquad \text{(Equation 1.2)}$$

Assuming typical values for solid density, dry density and bulk density for a basecourse aggregate, the moisture content and degree of saturation is shown in table 1.4.

Table 1.4 Moisture content (MC) and degree of saturation (DOS) estimated for a basecourse aggregate from volumetric moisture content

	t/m3	
Bulk density	1.92	
Water density	1	
Solid density	2.50	
Dry density	1.98	
Volumetric	**Mass**	
MC	**MC %**	**DOS %**
0.02	1.04	10
0.04	2.09	20
0.06	3.13	30
0.08	4.18	40
0.1	5.22	50
0.12	6.27	60
0.14	7.31	70
0.16	8.35	80
0.18	9.40	90
0.2	10.44	100

2 Modelling water movement

2.1 Introduction

Water movement in the pavement was modelled using the software programme Seep/W, which facilitates seepage analysis (GEO-SLOPE 2012). The model was used to determine the water content or level of saturation in the pavement layers from a specific rainfall event and pavement cross-section type. The purpose of this modelling work was to determine how the level of saturation changed with time after a rainfall effect and how this was affected by drainage quality. The investigation into the model of water flow considered two levels of saturation: fully saturated and partially saturated material. After a small storm or some other situation the pavement can be in a partly saturated condition and may not necessarily reach a high degree of saturation.

2.2 Model input data

The analysis output depends on the model input data. The key input parameters obtained from several sources are:

- rainfall data
- permeability
- soil water characteristic curve
- cross-section data.

These input parameters are discussed further below.

2.2.1 Rainfall data

The drainage design guide (Transit NZ 1977) uses rainfall data to estimate precipitation for a given duration and the return period for any location in the country. The guide mainly concentrates on the drainage capacity design and therefore the drainage design is based on very high intensity rainfall (five minutes).

The focus of the modelling for this research was the maximum level of infiltration rather than surface flow. Therefore, the rainfall had to be high enough to achieve the maximum level of infiltration. Any higher rainfall would have had little effect on the analysis results once the maximum level of infiltration had been achieved.

Austroads (2013a) noted that road surfaces (network drainage including kerb and channel with inlet pit and pipe systems, and bridge deck) on all roads other than local roads should have a 10-year average recurrent rainfall interval. A 10-year average recurrent interval was also suggested for longitudinal open drainage (table drains, diversion drains, catch drains and bank) for all roads. The average intensity of rainfall was estimated from a 10-year average recurrent period. Thompson (2011) noted the 10-year average recurrent rainfall intensity for one hour was 27mm. This value was used as the model input.

Three layers were considered in the model.

1. Thin impermeable asphalt/chipseal layer
2. Basecourse material
3. Subgrade.

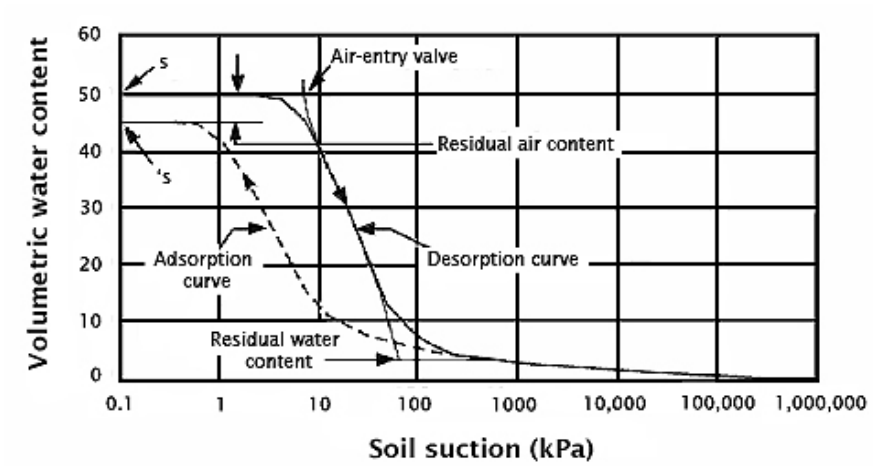
2.2.2 Soil water characteristic curves (SWCC)

The matrix suction characteristics of a soil are used for predicting soil saturation, with the help of SWCC. This curve shows the variation of water storage capacity within the macro- and microspores of a soil with respect to suction (Fredlund et al 1995). A SWCC shows the functional relationship between water content and matrix suction. Water content can be referred to as moisture content or saturation level. Suction is the negative pore pressure related to external air pressure.

In general, soil is a porous media, and the soil's pores are filled with air and water in an unsaturated state. When a soil is fully saturated, all the pores (voids) will be filled with water, leaving no room for any air. The most commonly used terms in this report are water content and saturation level. The water content is the amount of water contained within a soil. The degree of saturation refers to the percentage of voids filled with water. In certain cases, the residual water content is referenced to zero water content. Further terms are explained with the help of a typical curve, as shown in figure 2.1.

As can be seen from figure 2.1 residual water content is where a large amount of energy would be required to remove the water remaining in a soil. Two curves are shown in figure 2.1: desorption and adsorption curves. The desorption curve shows the relationship between soil water content and suction during the *drying* process. The adsorption curve shows the relationship between soil water content and suction during the *wetting* process. The hysteretic nature of the SWCC is well known, but to simplify matters, most applications will assume a non-hysteretic pattern. Beyond the point of residual water content is an area termed the 'high suction range' or 'residual zone' of unsaturation. In this region, the drying and wetting curves are almost identical, although they differ from one another in the lower suction area range. The air entry value is the suction initially needed for air to enter a fully saturated soil.

Figure 2.1 SWCC for a silt soil (taken from Fredlund et al 1994)



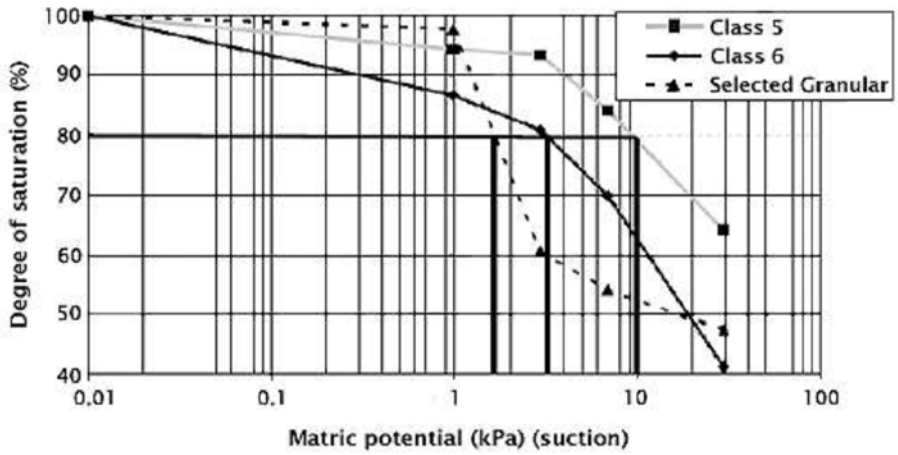
2.3 Basecourse and subgrade material models

The SWCC profile is dependent on water retention capacity and drainage capability. The speed with which a soil drains depends on the distribution of larger-sized voids, which, in turn, are controlled by larger particles (eg those with a diameter of 19mm). In contrast, the length of time water is retained by a soil depends on the smaller voids (controlled by fine particle distribution being the % passing the 75μm sieve). The basecourse model for SWCC should therefore consider total particle grading. Almost no large particles can be found in certain types of soils such as silts and clay, making it unnecessary to consider larger

particles for the relationship between saturation and suction for these soil types.

In figure 2.2 (Roberson 2001), three types of granular material are shown: class 5, class 6 and selected granular materials. The particle distribution of M/4 basecourse material in New Zealand (Transit NZ 2006) is better approximated to class 6 than to class 5 (see table 2.3 in Arampamoorthy and Patrick 2010).

Figure 2.2 SWCC curve for classes 5 and 6 and selected granular material (extracted from Roberson 2001)



Ariza and Birgisson (2002) evaluated the Seep/W software model for saturated and unsaturated flow conditions. They used the soil water characteristic curve and permeability for the class 6 (better approximation to TNZ M/4 basecourse) and a silty clay material for their evaluation. The same data was used in the research for this project, where the subgrade was defined as silty clay.

Permeability of a material is a function of the particle size distribution, fines content and degree of compaction. It is also a function of the degree of saturation. Partly saturated materials have a lower permeability than fully saturated materials.

The input data used for the granular basecourse and subgrade for SWCC and permeability were obtained from Ariza and Birgisson (2002) and are given in tables 2.1, 2.2, 2.3 and 2.4.

Table 2.1 Soil water characteristic curve for basecourse material

Matric suction	Volumetric water content (m^3/m^3)	Degree of saturation (%)
0.01	0.33	100
1	0.099	86
3	0.077	80
7	0.068	74
30	0.04	46

Table 2.2 Soil water characteristic curve for silty clay

Matric suction	Saturation level (%)	Volumetric water content (m3/m3)
0.1	100	0.499
1	100	0.499
10	95	0.457
100	70	0.2167
1000	45	0.073
10000		0.034

Table 2.3 Relationship between permeability and pore water pressure for basecourse material

Matric suction (kPa)	Permeability (m/sec)
0.01	8E-007
23	1E-014

Table 2.4 Relationship between permeability and pore water pressure for subgrade

Matric suction (kPa)	Permeability (m/sec)
0.01	1E-008
23	1E-014

2.3.1 Cross-section data

Three typical cross sections were selected for investigating water movement in the pavement layers. These were flat, cut and fill and a cut section. The design data was initially selected from the Austroads (2003) guide and through discussions with the steering group. The cross-section data used for the model input is given in table 2.5 and the terms illustrated in figure 2.3. The level at the top of the basecourse has been set at 2.00m. Thus the top of the surfacing is at 2.04m.

Figure 2.3 Cross section details

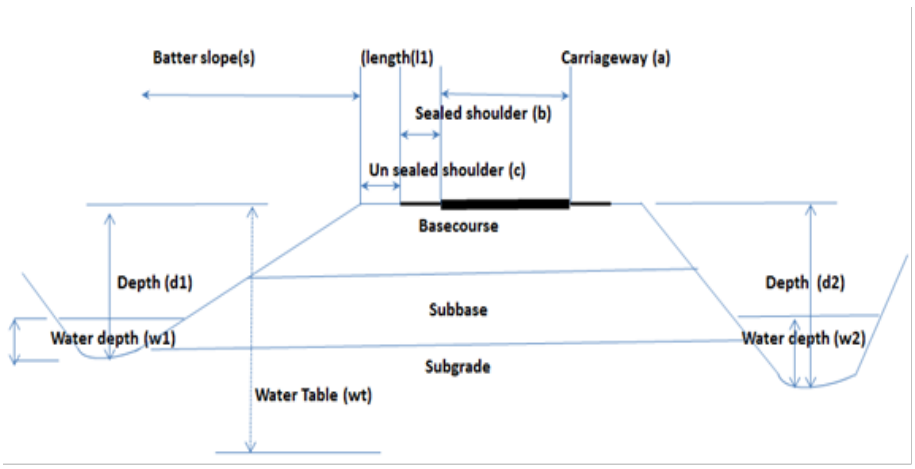


Table 2.5 Input parameters for each typical cross section

Parameters	Cross section		
	Fill	Cut and fill	Cut
Carriageway width in m (a)	7	7	7
Shoulder sealed in m (e)	1	1	1
Shoulder unsealed in m(b)	0.5	0.5	0.5
Channel bed depth in m (d)	0.45	0.45	0.45
Subsoil drain depth in m	0.4	-	-
Water table in m	1, 1.5, 1.9	4.5	3.5
Basecourse thick in m	0.15	0.15	0.15
Seal surface thick in m	0.04	0.04	0.04
Drainage side slope	1:5	1:5	1:5
Drainage bed width	1.4	1.4	1.4

The program uses data on the type of soil and the depth to the water table to determine the initial moisture conditions and saturation level.

2.4 Model results

Details of the modelling outputs are given for the flat section to describe the analysis. The moisture condition 1m from the pavement edge, approximately under the wheel path, was used to compare the different scenarios. Most of the analysis was in the flat terrain to obtain an indication of the effect of changes in the modelling conditions.

Three basic cases were analysed for this pavement cross section. These were:

1 Free flowing drain, ie just after the rain the water in the drain flows away so the drain becomes almost empty. Two water table depths were also modelled in this scenario:

   a initial water table 0.5m

   b initial water table 1.5m.

2 Partial drainage blockage:

   a In case 2 the water in the drain is not flowing very well (ie in most cases the water in the drain is not flowing but seeping)

   b Partial drainage blockage can occur when the road section is located in an area where the water table is closer to the surface (approximately less than or equal to 0.5m below the surface).

3 Completely blocked drain:

   a Case 3 can occur where there is very poor drainage maintenance. The drainage can be blocked by a shoulder slip or can fill with sand in some places or be blocked at a culvert.

2.5 Model output

2.5.1 Case 1: Water in the drain flowing very well

Figure 2.5 shows part of the modelled road cross section in a flat plane, including a portion of the drainage, the side slope of the shoulder, part of the asphalt surface, basecourse layer and subgrade. In this model no infiltration is allowed through the surface. The lower part of the model is also set as an impermeable boundary. The vertical arrows indicate rainfall of 27mm for one-hour duration (as discussed in section 2.2.1).

2.5.1.1 Initial water table 0.5m

In case 1, with good drainage, we assumed the drainage channel was almost empty shortly after one hour of heavy rainfall. In this model the elevation of the drain base is 1.55m, the basecourse and subgrade interface level is 1.85m, the unsealed shoulder surface level is 2m and the asphalt layer thickness is 0.04m. In this part of the analysis two different conditions were considered: initial water table at 0.5m and the initial water table at 1.5m.

Figure 2.5 shows the volumetric water contours at 36 seconds after the start of the hour of rain.

Figure 2.5 Volumetric water content contours at 36 seconds of rain (each colour band is a change in volumetric water content of 0.05 m^3/m^3)

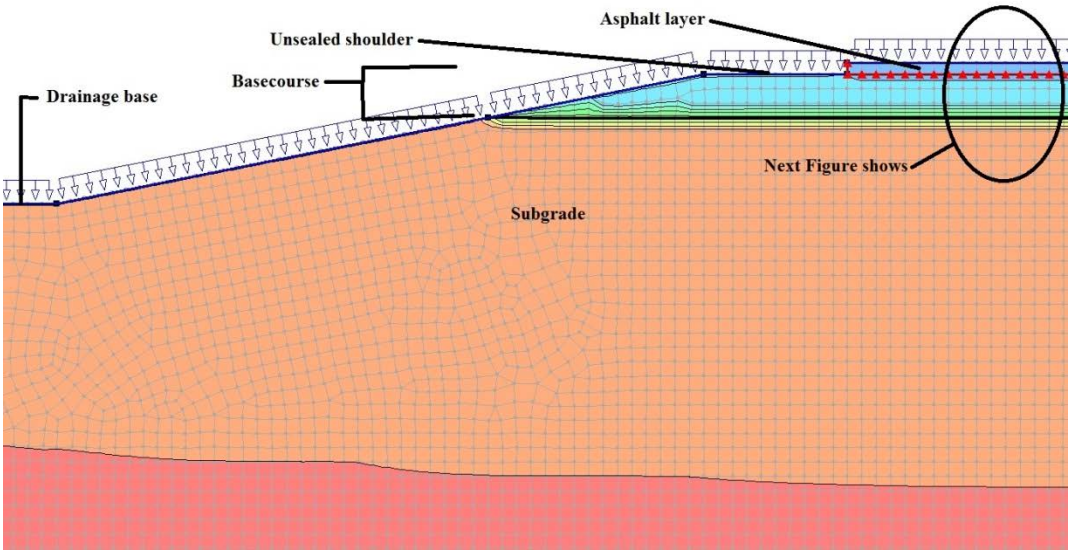


Figure 2.6a Enlarged portion of figure 3.5 at 36 seconds after the start of the rain

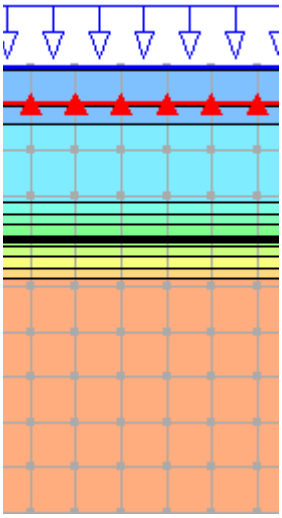


Figure 2.6b Same area as figure 2.5a, after one hour of rain

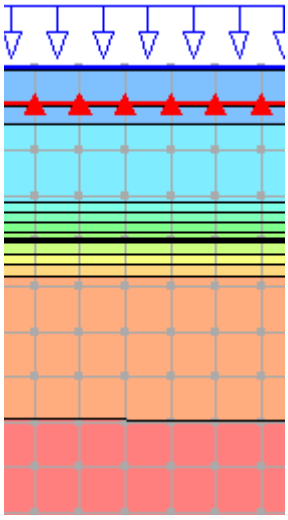
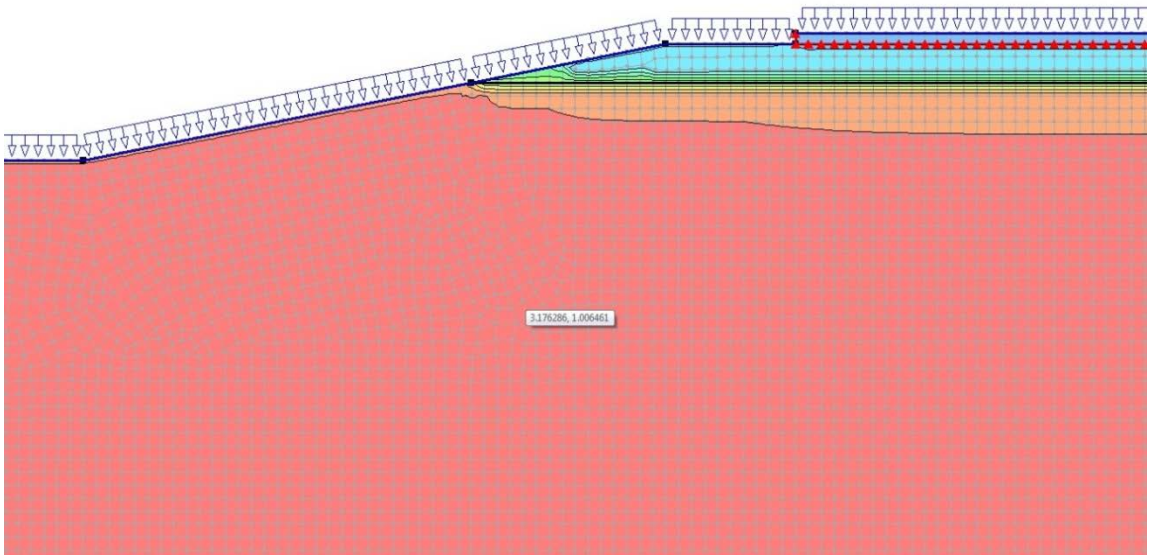


Figure 2.6a is an enlargement of part of figure 2.5 showing the volumetric water content contours at 36 seconds of rain. Figure 2.6b is the same area as figure 2.6a but showing the contours after one hour of rain. Figure 2.6a shows four contour lines in the basecourse but figure 2.6b shows five contour lines. In figure 2.6b the subgrade also shows two contours. As noted above in figure 2.5, the increment of each contour is 0.05m^3/m^3. Still the changes are not big.

Figure 2.7 shows the volumetric water content after one hour of rain.

Figure 2.7 Volumetric water content at one-hour duration

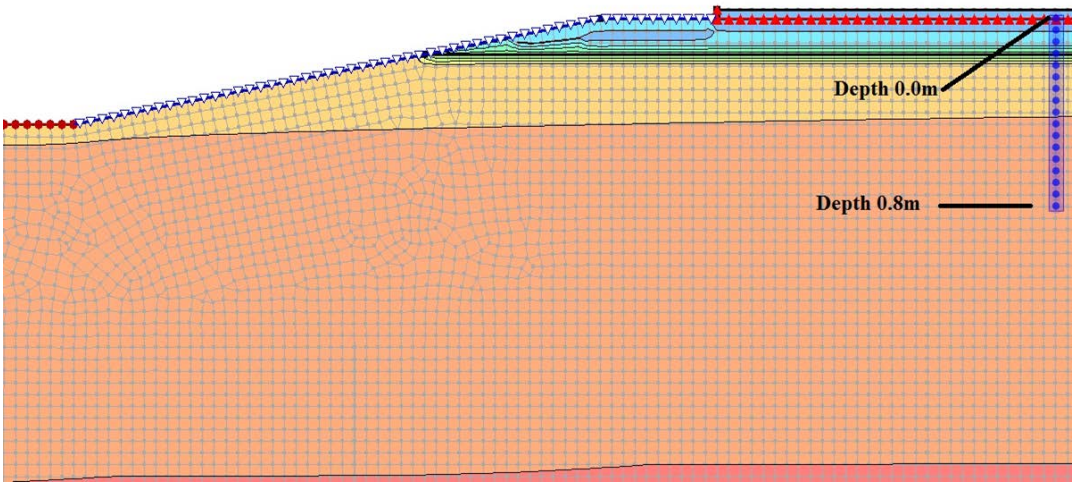


Compared with figure 2.5 there is a higher water content in the subgrade, especially directly under the shoulder, and minimal change in the basecourse.

The model was re-run to simulate rain for one hour and then 30 days of no rain allowing drainage of the water to be determined. Figure 2.8 shows the volumetric water contours at 30 days after the one-hour rain

period which indicates that the moisture content has settled to a very similar level to the original water contents.

Figure 2.8 Volumetric water contours 30 days after one hour of rain



From figures 2.5, 2.7 and 2.8 we can see there are no significant differences in volumetric water contours in the basecourse but there is a small difference in the subgrade.

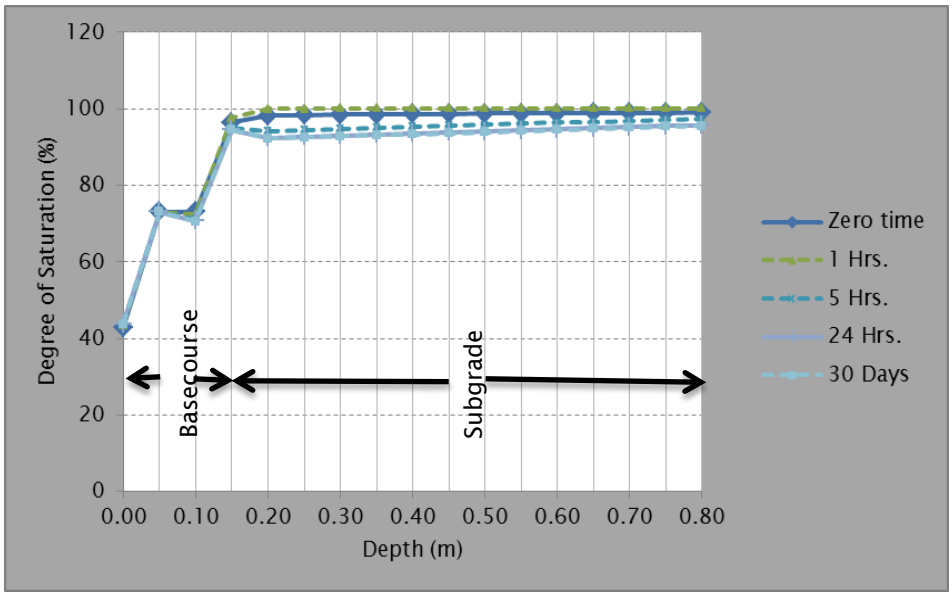
2.5.1.2 Saturation conditions under the wheel track

Figure 2.8 indicates a line of blue dots below the left wheel path of the left lane. The water content at the positions of each of these blue dots has been converted to the percentage of saturation and is plotted in figure 2.9.

Each line in figure 2.9 shows the water content at a different time interval since the start of the one hour of rain, ranging from zero time at the start of the rain to 30 days after the rain stops.

It can be seen that there has been minimal change in the saturation levels which would be expected for this scenario.

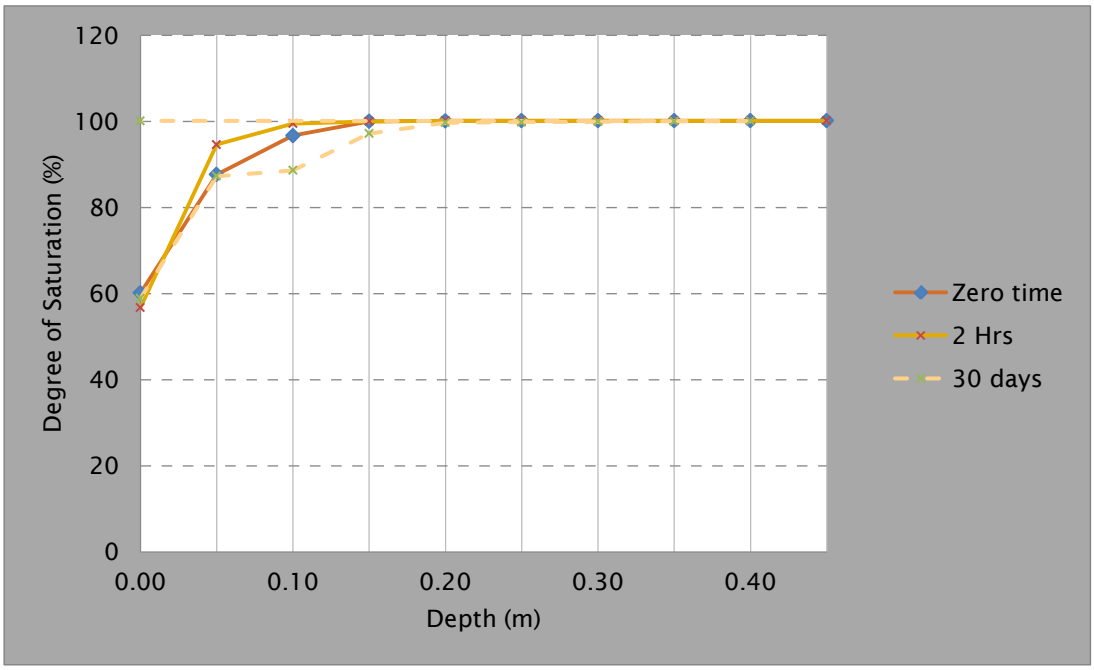
Figure 2.9 Degree of saturation under the wheel track against depth for a flat road with good drainage (initial water table 0.5m)



The initial water table was changed from 0.5m to 1.5m and the water movement determined. The saturation levels for each depth were computed and the results are plotted in figure 2.10.

Again there has been a minimal change and the effect of the water table is not significant. Under these excellent drainage conditions the depth to the water table has not had a significant effect and the degree of saturation of the basecourse has not changed significantly. This result is what would be expected and helps validate the model.

Figure 2.10 Degree of saturation under the wheel track against depth for a flat road with good drainage (initial water table 1.5m)

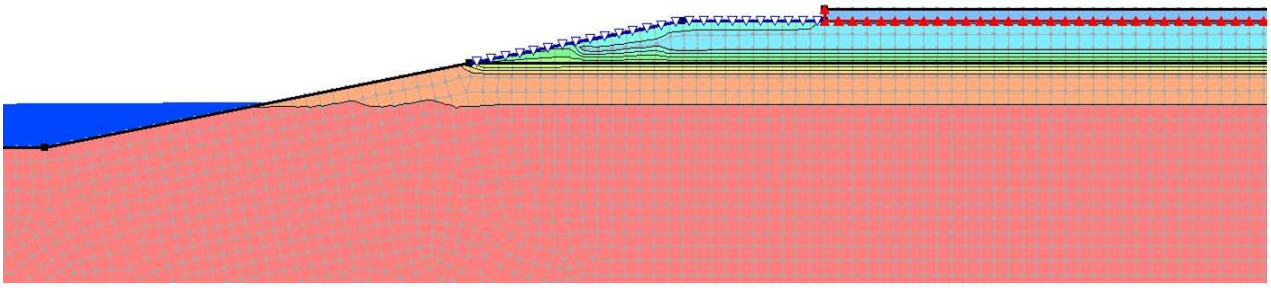


The initial saturation levels computed by the model of 40% to 70% in the basecourse and greater than 90% in the subgrade agree with the results from the moisture condition research (Arampamoorthy and Patrick 2010). The introduction to the 2010 report analyses samples from existing pavements.

2.5.2 Case 2: Partially blocked drain

A common scenario is partially blocked drainage. In this model the depth of the initial water table is 1.7m, ie there is already 0.15m of water in the drain because of the partial blockage. The blocked area is approximately 20% of the water flow area and is assumed to continue for five days. Figure 2.11 shows the volumetric water content contour just after the rain stops and figure 2.12 shows volumetric water content against depth at four seconds, one hour, 1.12 hours and five days after the start of one hour of rain.

Figure 2.11 Volumetric water content contour at one hour, rain just stopped



Note: Dark blue is water blocked drain

Figure 2.12 For a partially blocked drain, saturation levels against depth at zero time, one hour and seven days after the start of one hour of rain

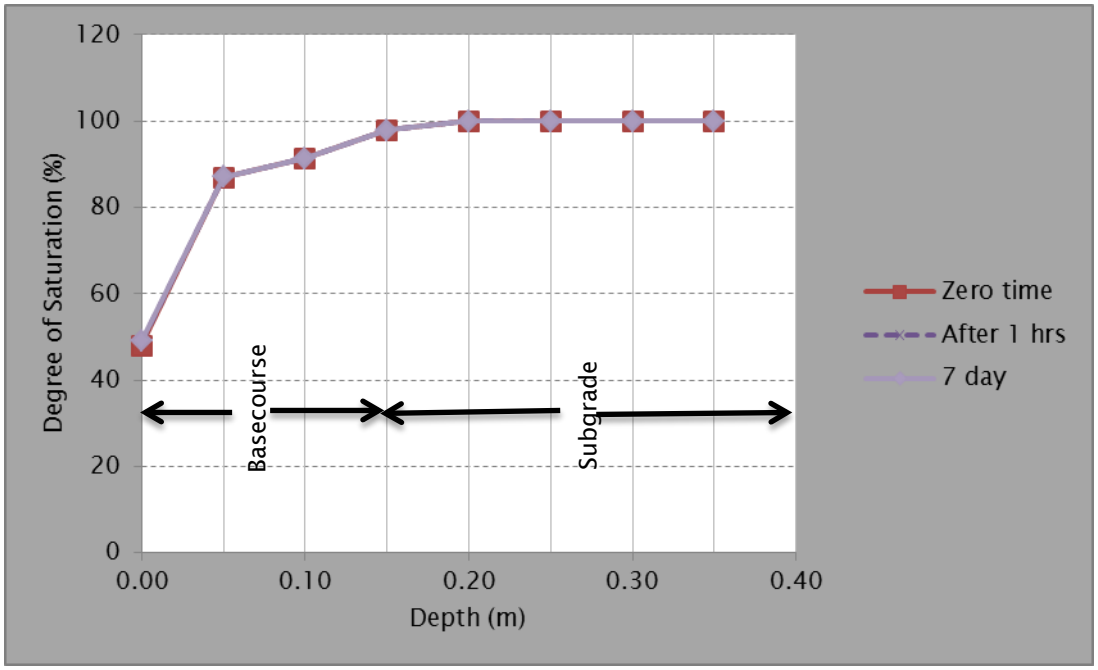


Figure 2.12 shows that the saturation level in the bottom of the basecourse has risen to over 90% when the drain has been blocked with water at zero time. This is the equilibrium water content if the drainage is blocked. This level would lead to rapid shear failure. With the heavy rainfall and subsequent drying there has been no significant change. With the drain 20% blocked with stagnant water, the water does not drain out of the basecourse. In comparison with figure 2.9, the saturation level at a depth of 0.1m has risen from approximately 70% to 90%.

This illustration also shows the importance of the drain having an adequate depth and condition.

2.5.3 Case 3: Blocked drain

In this case, the initial water table is 1.9m, which is just near the basecourse subgrade interface. This situation occurs when there has been a heavy rainfall which lifts the water table from 1.5 to 1.9m, almost at a flooding level. After the last one hour of rainfall the water table starts to drop from 1.9m back to 1.5m. In addition the drainage water level is raised from 1.5m to the unsealed shoulder level (ie 2m) and stays for a certain time (ie two hours and seven days), causing a drainage block. The block was cleared

after this period and the drainage water depth became zero very quickly (in three minutes).

Two other cases were considered with this model:

Case 3a: The modelling starts within one hour of continuous rain and the initial water table depth is 1.9m.

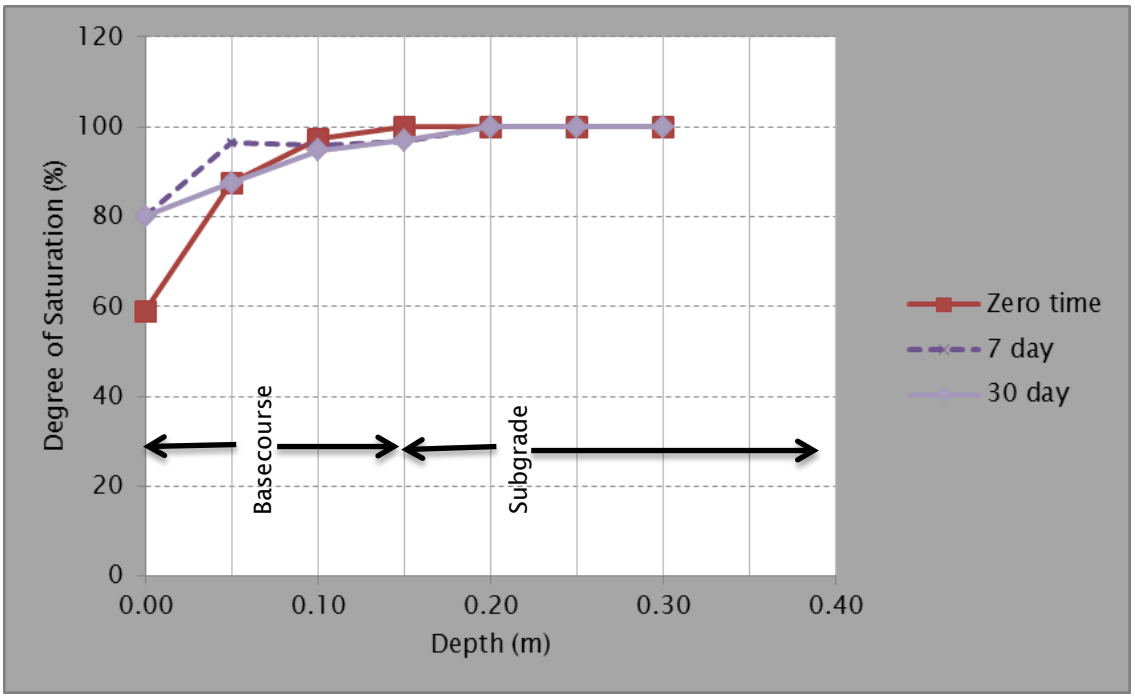
For the first seven days, a drainage blockage was modelled causing the water in the drain to rise up to the shoulder level. At seven days the blockage was cleared and the situation left for 23 days without rain.

Case 3b: The modelling starts within one hour of continuous rain and the initial water table depth is 1.9m.

For the first two hours, a drainage blockage was modelled causing the water in the drain to rise up to the shoulder level. At two hours the blockage was cleared and the situation left for 30 days without rain.

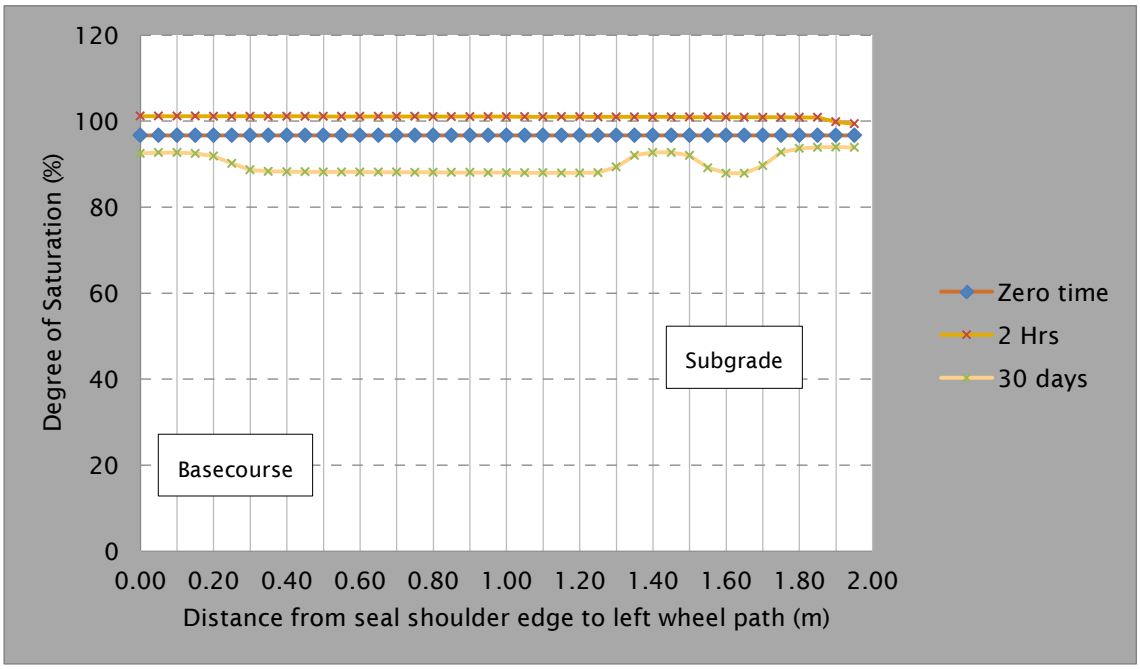
The computation result from case 3a can be seen in figure 2.13 which shows the volumetric water content against depth at zero time, seven days and 30 days after start of the rain. The rainfall continued only for the first hour of modelling and a blockage kept water in the drain until the seventh day.

Figure 2.13 Degree of saturation against depth at zero time, just after 7 days and 30 days after the start of the rain for a 7-day flooded condition



The results from case 3b are plotted in figure 2.14, with one hour of rain and two hours of drainage blockage.

Figure 2.14 Degree of saturation against depth at zero time, just after 7 days and 30 days after the start of rain for a two-hour flooded condition



Results in figure 2.14 show that after flooding the saturation level in the basecourse is over 95% and even after 30 days of drying it is still over 90%.

This demonstrates the significant time it takes for granular basecourse to dry out when it is in a confined situation. If the model had included a significant depth of sub-base then the degree of saturation of the basecourse would have been lower but still relatively high.

Figure 2.15 shows the contours of water content at 58 minutes, which is just before the modelled one hour of continuous rain stops. The blue shaded area represents the water in the drain up to the shoulder level.

Figure 2.15 Water content contours at 58 minutes after rain started

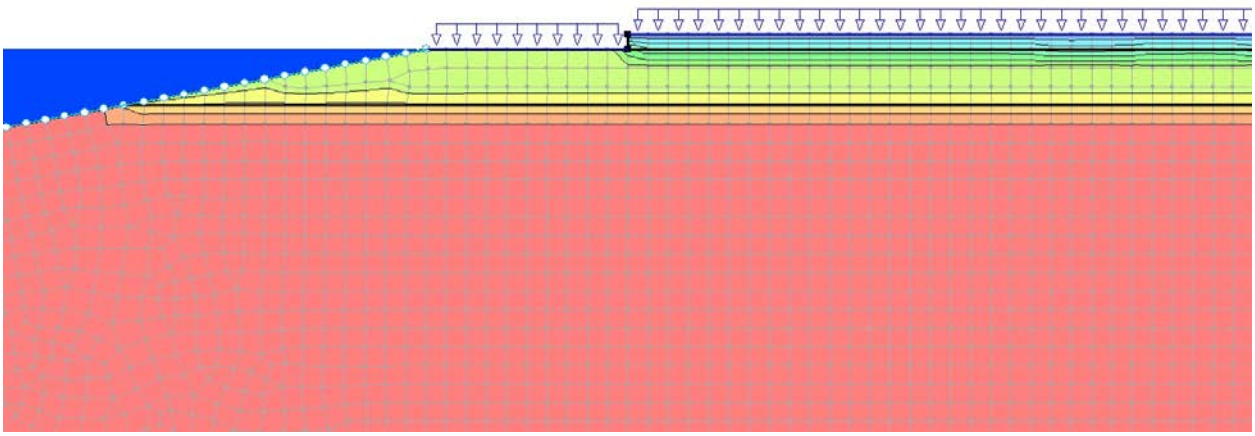


Figure 2.16 shows the contours of water content at two hours, which is just before the drainage blockage is removed.

Figure 2.16 Water content contours at two hours after the start of the initial one hour of rain

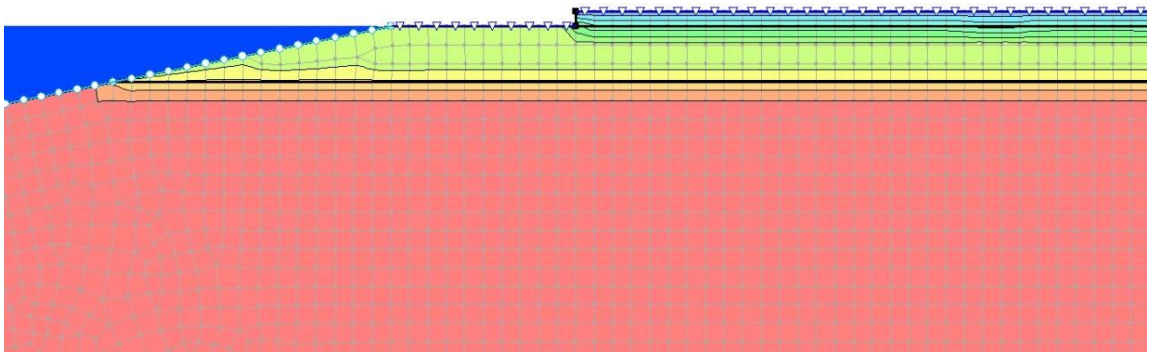


Figure 2.17 shows the water content contours at 2.7 hours, which is 0.7 hours after removal of the drainage blockage. Water has now flowed out of the drain.

Figure 2.17 Water content contours at 2.7 hours

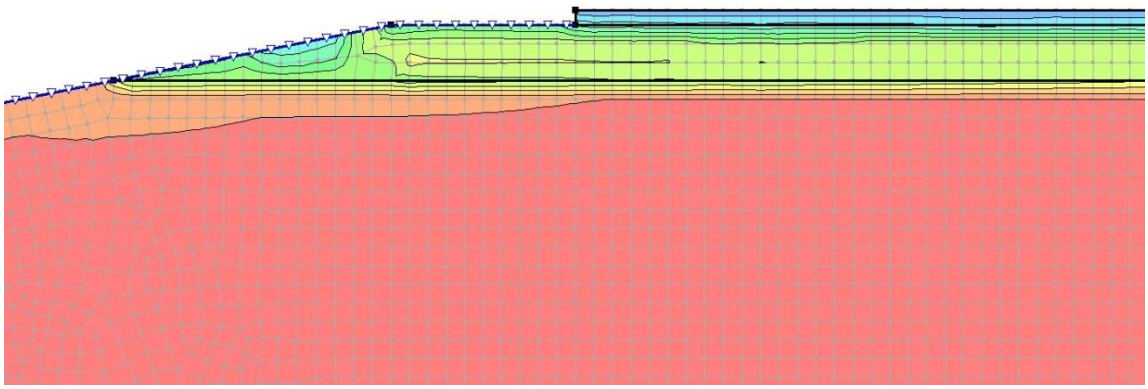
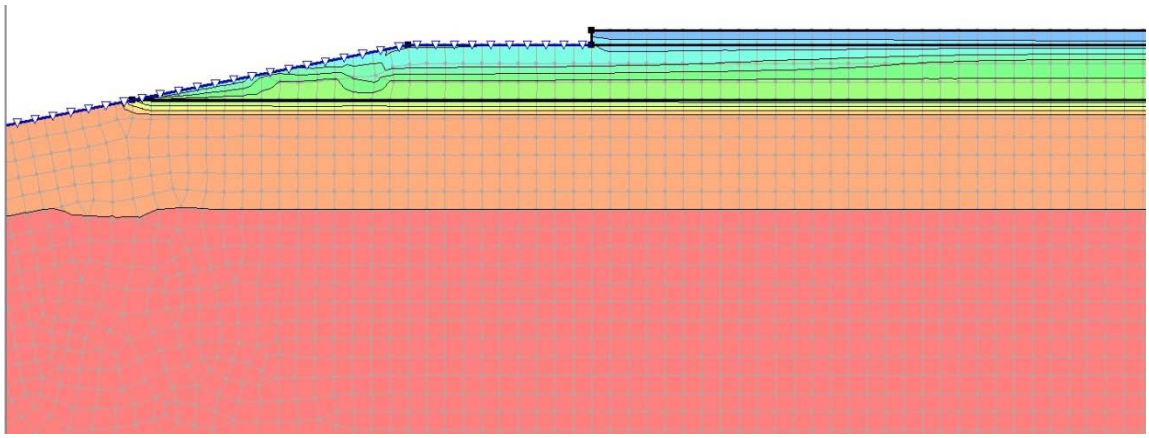


Figure 2.18 Water contours at 30 days after the rain started



2.6 Effect of basecourse thickness, permeability and seal shoulder width

In the following analysis we have considered three modifications to the model used in case 3b (blocked drain).

The modifications in the models are:

1 Basecourse thickness increased to 400mm

2 Permeability of the basecourse increased by a factor of 10 (see the permeability data before multiplied by 10 in table 2.3)

3 Seal shoulder increased to 1.5m.

The model results are given one by one.

1 Increased basecourse thickness to 400mm:

   a The results are plotted in figure 2.19, which shows the degree of saturation against depth below the left wheel path. The results show the basecourse at approximately 90% degree of saturation on the 30th day. There is no significant difference from figure 2.14 especially in the time for drainage to occur.

2 Increased permeability by factor of 10:

   a The model used in case 3b was modified by increasing the permeability by a factor of 10. The results are plotted in figure 2.20, which shows the degree of saturation against depth below the left wheel path. The results show the basecourse has still not drained back to the equilibrium condition after 30 days.

3 Seal shoulder increased up to 1.5m:

   a The model used in case 3b was modified by increasing the seal shoulder to 1.5m. The results are plotted in figures 2.21, 2.22 and 2.23, which show the degree of saturation across the seal shoulder width in the basecourse at three different depths. The data shows there is not a considerable improvement and the moisture condition under the wheel path is still very high after 30 days.

Figure 2.19 Degree of saturation against a 400mm basecourse depth below the left wheel path

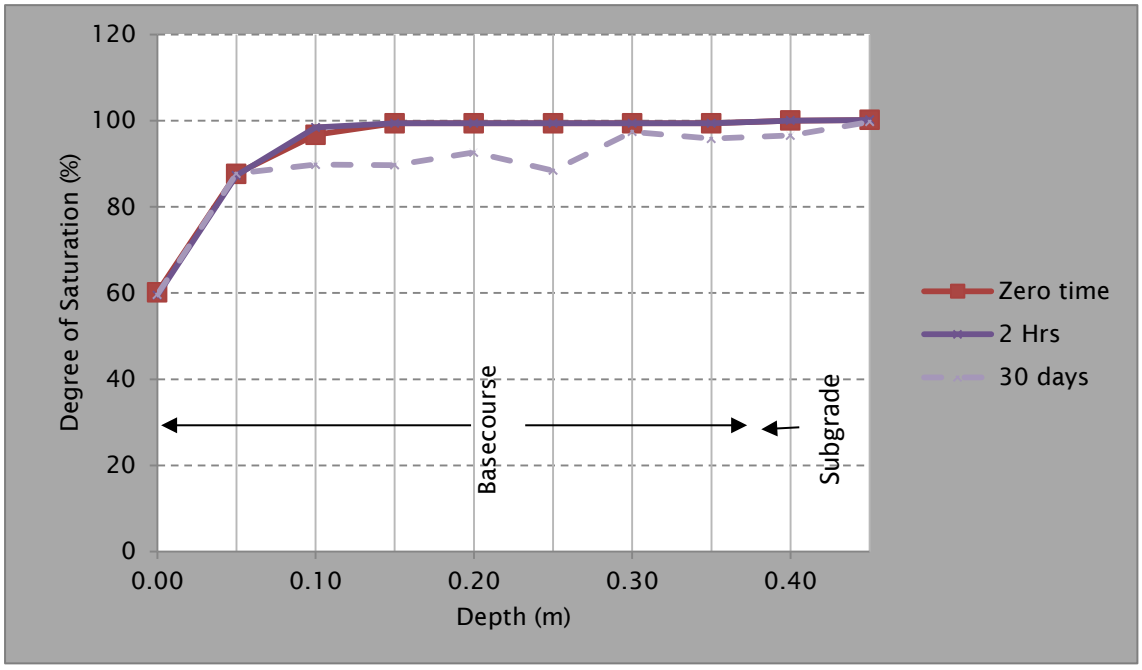


Figure 2.20 Degree of saturation against depth below the left wheel path (permeability increased 10 times)

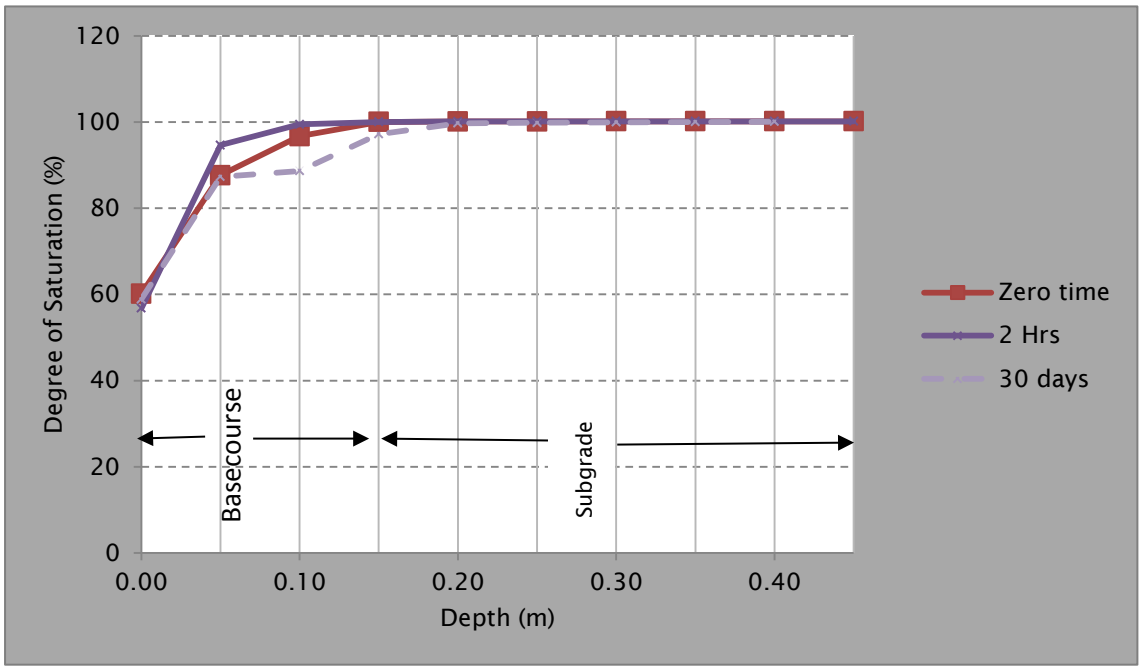


Figure 2.21 Degree of saturation across the seal shoulder interface to the basecourse

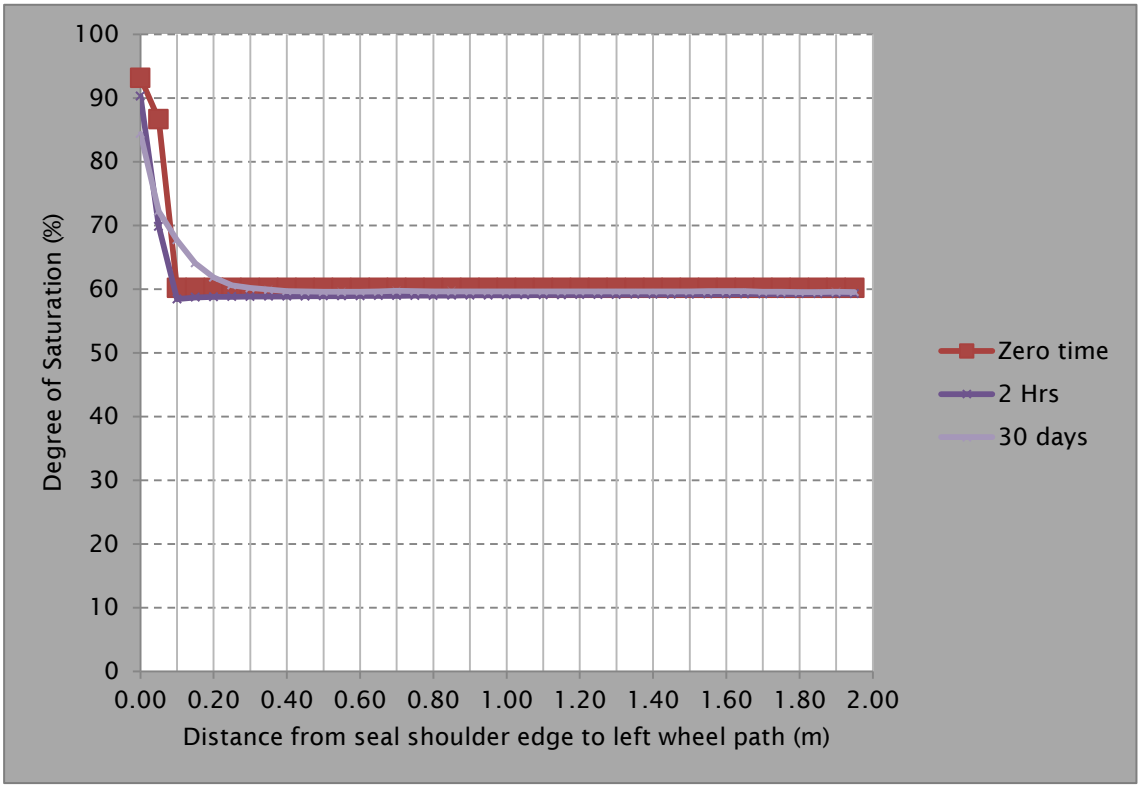


Figure 2.22 Degree of saturation across the seal shoulder at a basecourse depth of 0.05m

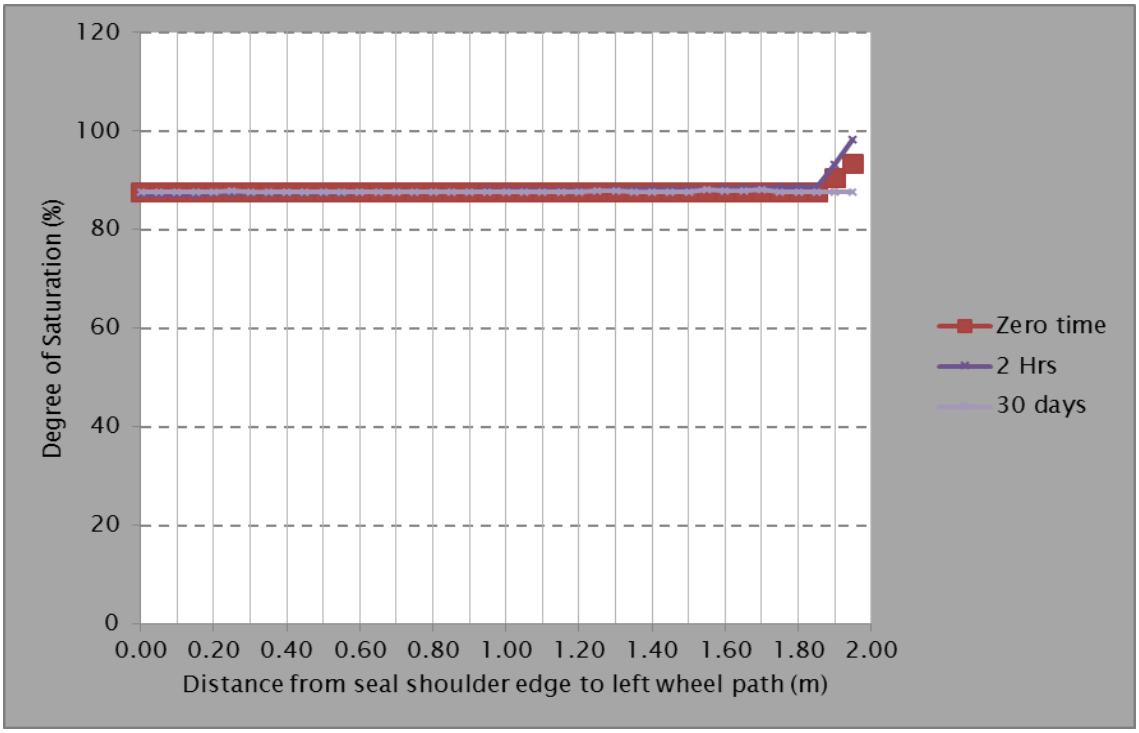
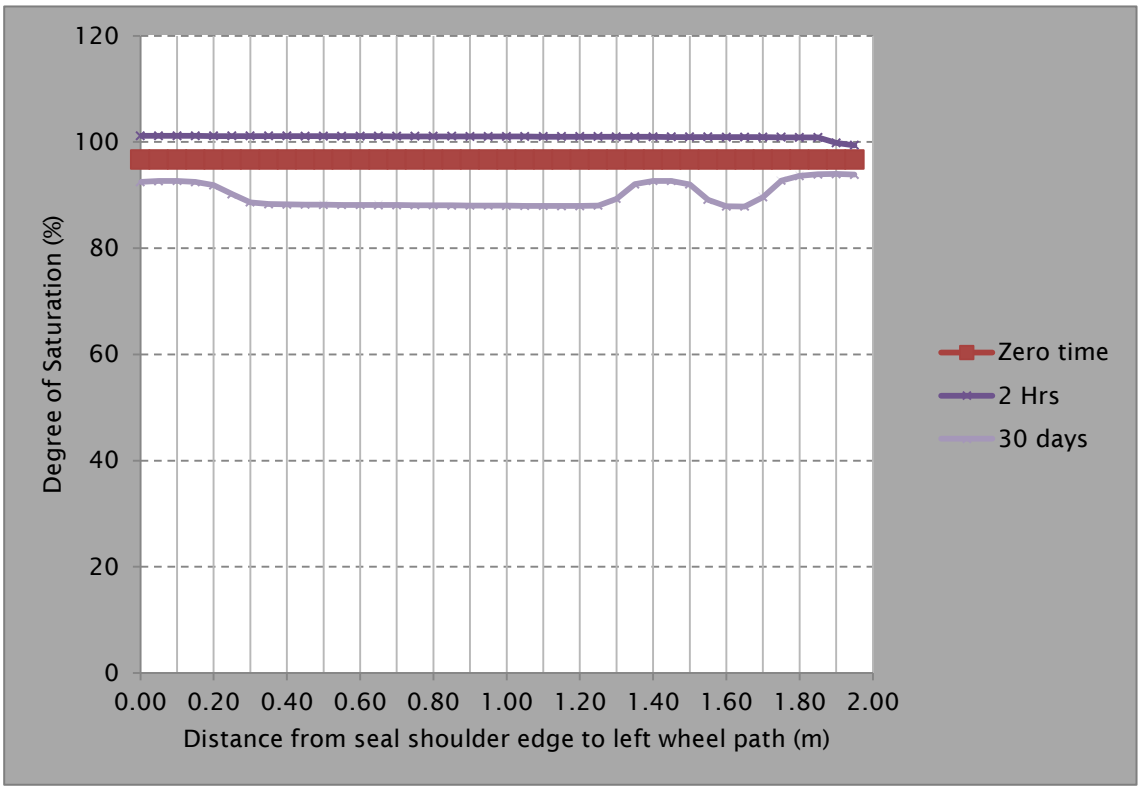


Figure 2.23 Degree of saturation across the seal shoulder at a basecourse depth of 0.1m



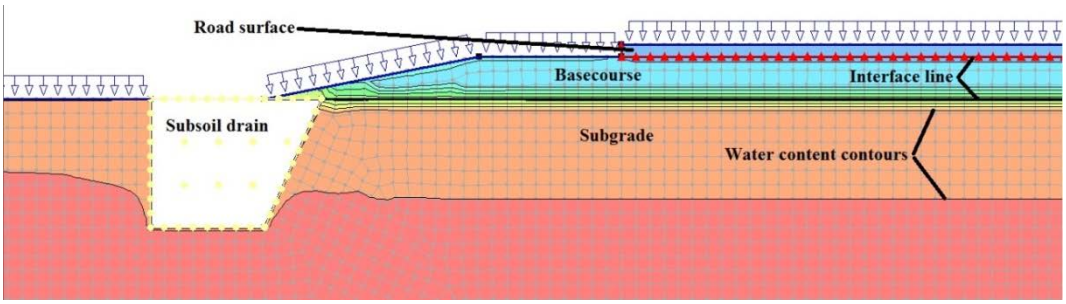
The results indicate there is no significant difference in the saturation conditions with time by increasing basecourse thickness, permeability or seal shoulder width. This shows the flooding condition should be avoided and that the time needed to revert back to a low saturation level is greater than a month. It should be noted that the initial water table is 1.9m, which is close to the basecourse subgrade interface. This situation occurs when heavy rain raises the water table to 1.9m and is near a flooding situation.

2.7 Subsoil drain in flat section

In this section a subsoil drain for a flat road is modelled. Figure 2.24 shows a cross section on one side of the road and the subsoil drain. The other side of the road is modelled the same. The filter material in the subsoil drain is well protected from the top surface. An assumption has been made that no water will flow from the top surface of the subsoil drain. The wetted perimeter of the subsoil drain (shown by the yellow dotted line in figure 2.24) is assumed to be well designed so it would have adequate capacity for expected flows.

Two scenarios were considered for computing the saturation level during one hour of continuous rain then 30 days of no further rain. The first scenario has the subsoil drain in good condition and the second scenario has the drainage in a partially blocked condition.

Figure 2.24 One side of the road cross section including subsoil drain



2.7.1 Subsoil drain in good condition

The computed water content in the pavement layer is plotted in figure 2.25. The figure shows the degree of saturation with depth just below the left lane left wheel path.

Figure 2.25 Saturation levels against depth for zero time, one hour and 30 days of subsoil drain in good condition

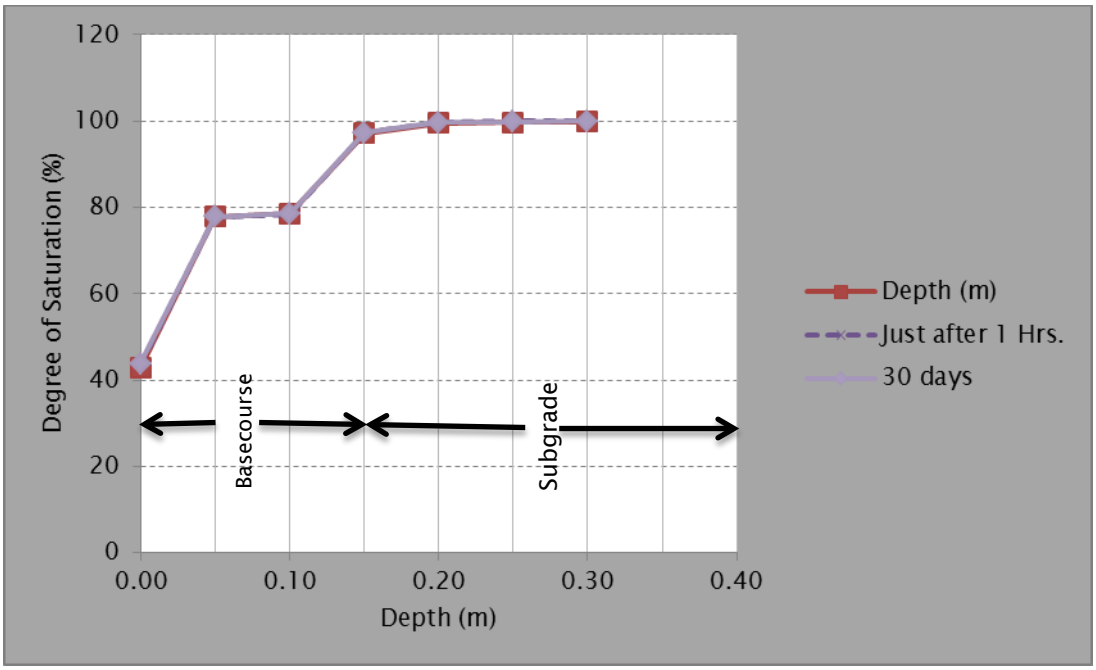
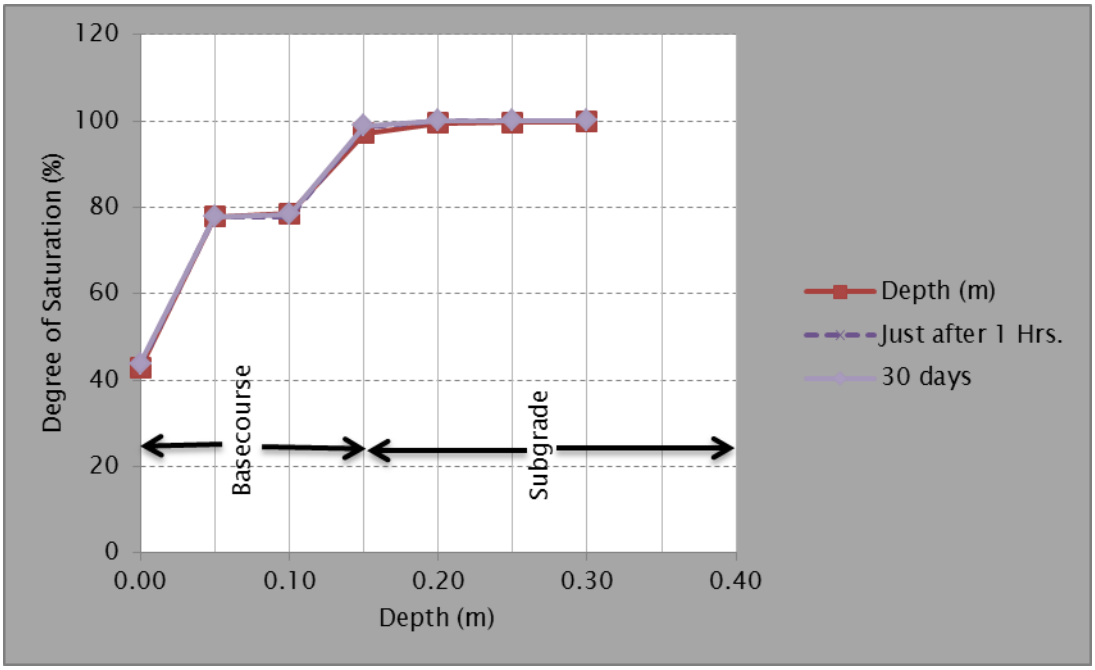


Figure 2.25 shows the saturation level in the basecourse is similar to case 1 (see section 2.5.1) and that it has not changed with the rainfall.

2.7.2 Subsoil drain partially blocked

In the second scenario, the subsoil drain was modelled as partially blocked by a soil with the same characteristics as the subgrade. The computed water content in the pavement layer is plotted in figure 2.26.

Figure 2.26 Degree of saturation against depth under the left lane left wheel path at zero time, just after one hour, 24 hours, five days and 30 days



The subsoil drain is assumed to be well designed and it can be seen that one hour of rain has not been sufficient to result in a partly blocked drain. If the perimeter of the subsoil drain has insufficient capacity this will increase the water content in the pavement for a certain period. This is the reason that the perimeter of the subsoil drain should be well designed.

2.8 Contour cross-section

This section focuses on drainage where the road is not level, for example cross-fall at a curve or where one side of the road is in cut and the other in fill. A typical cross section is shown in figure 2.27. This cross section was modelled after one hour of rain with good drainage and the results are plotted in figure 2.28. Figure 2.28 shows the saturation levels against depth under the left lane left wheel path, which is the 'high' side of the road or the side in fill. Figure 2.29 shows the degree of saturation against depth under the right lane right wheel path, which is the 'low' side of the road or the side in cut. The initial water table for this model is 4.5m below the 'high' unsealed shoulder edge.

Figure 2.27 A typical contour cross-section of cut and fill

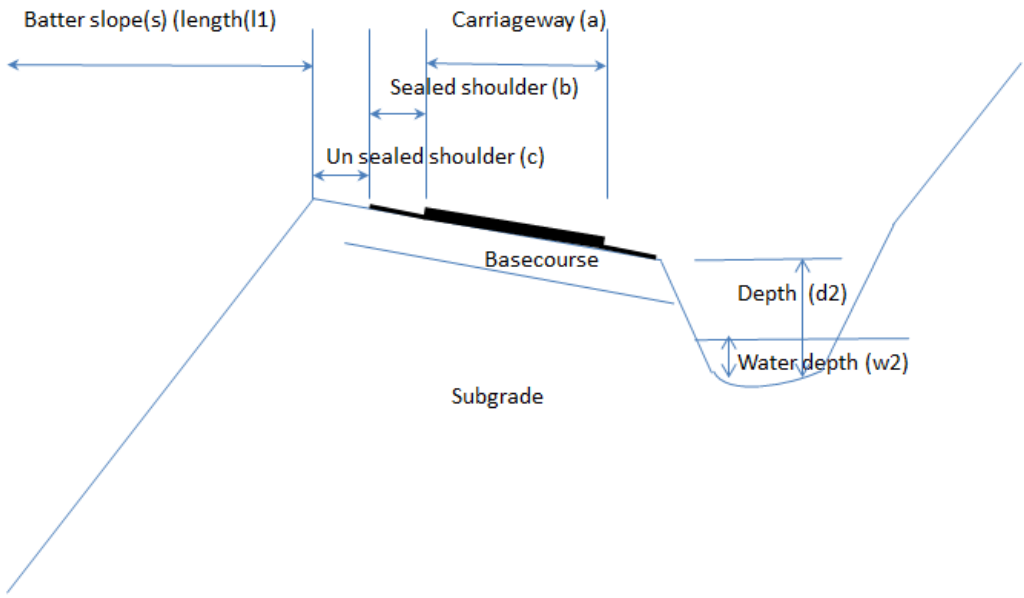


Figure 2.28 Saturation levels against depth under the left lane left wheel path ('high' side of road) with time

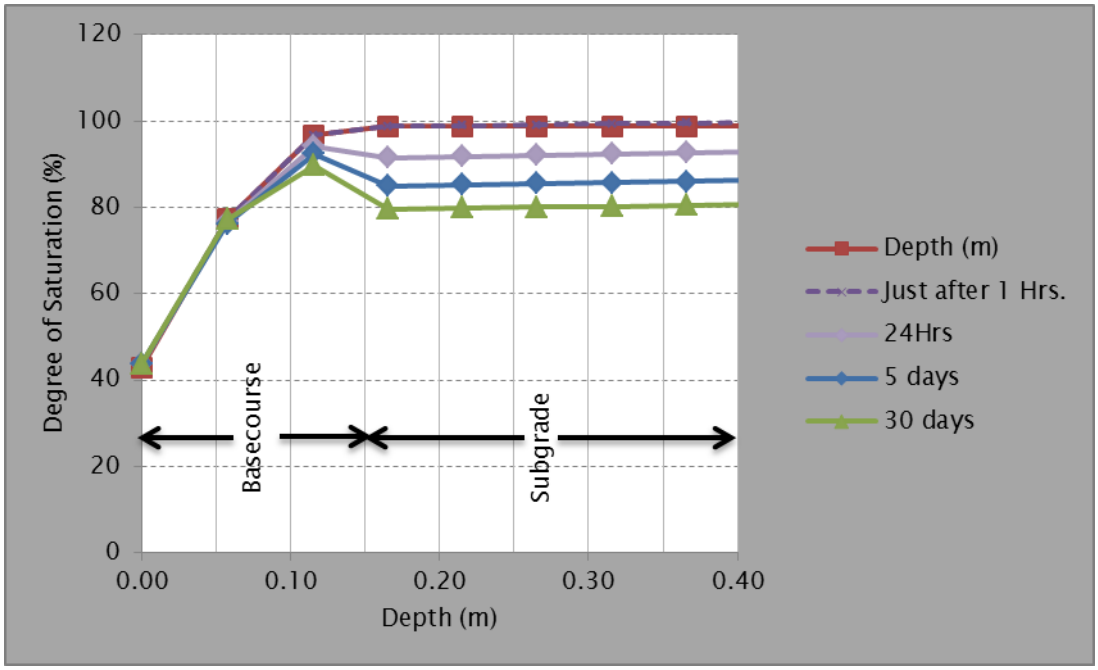
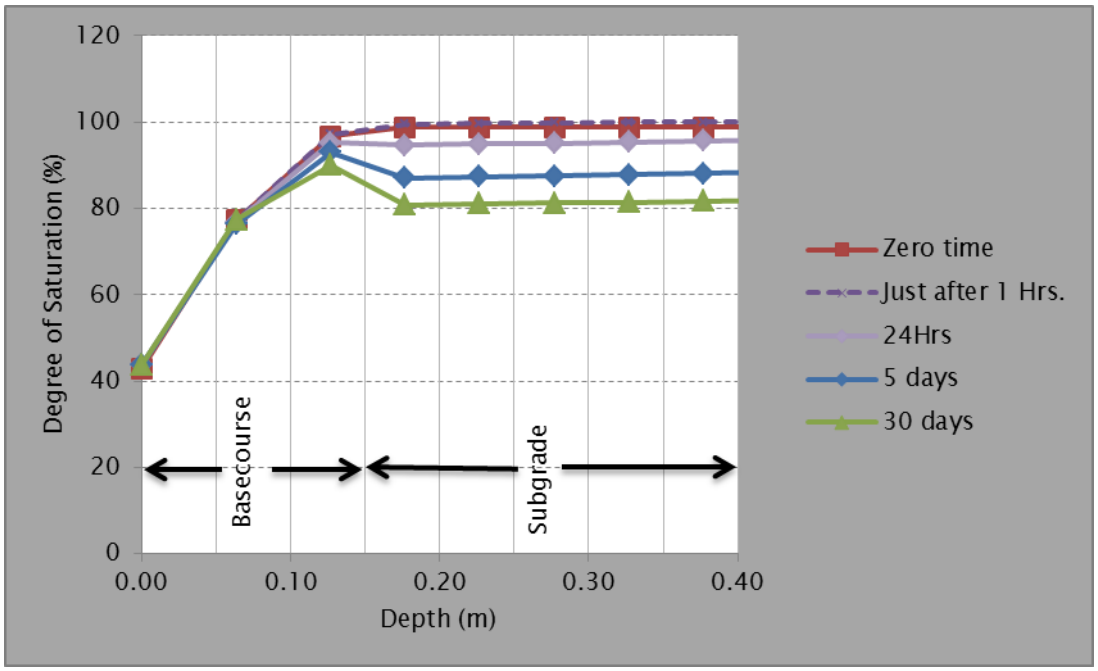


Figure 2.29 Saturation levels against depth under the right lane right wheel path ('low' side of road) with one hour of rainfall



There is no significant difference between figures 2.28 and 2.29. Compared with the flat section of road, this contour section dries more in 30 days. The reason is that the initial water table depth of the contoured section is 4.5m below the surface and the initial water table depths of the flat section are 0.5m or 1.5m. Also the exposed face of the batter promotes water evaporation.

The subsurface longitudinal flow in rolling or hill country roads was not modelled and it was assumed that the side drains were able to effectively remove this longitudinal subsurface flow.

2.8.1 Cut cross-section

A typical cut section is shown in figure 2.30. This cross-section was modelled and the results are plotted in figure 2.31. Figure 5.20 shows the volumetric water content against depth under the left lane left wheel path. The cross section is symmetrical along the centre line so the volumetric water content against depth under the right lane right wheel path is not plotted. The initial water table for this model is 3.5m below the unsealed shoulder edge.

Figure 2.30 A typical cut section

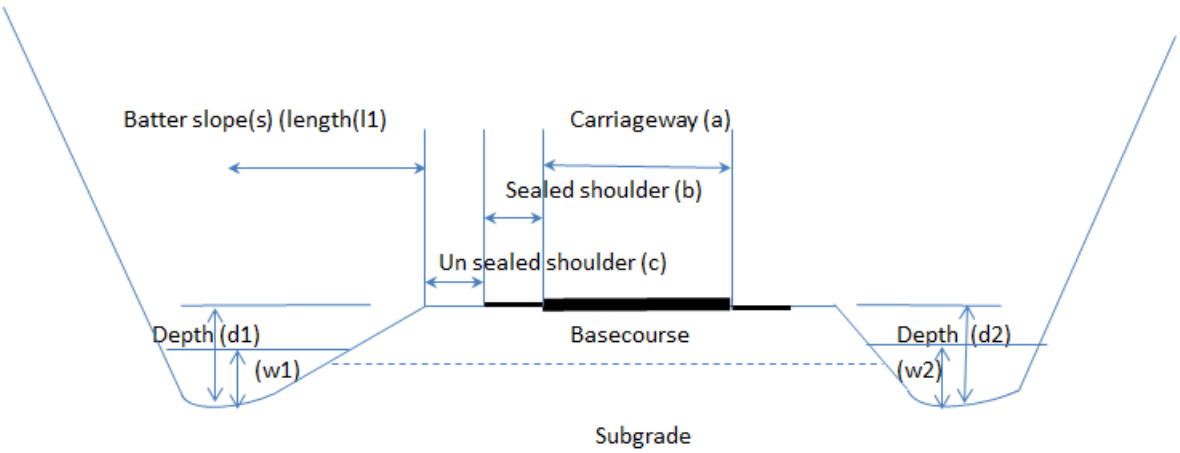


Figure 2.31 Degree of saturation against depth under the left lane left wheel path for the cut section at zero time, just after one hour, 24 hours, five days, 30 days

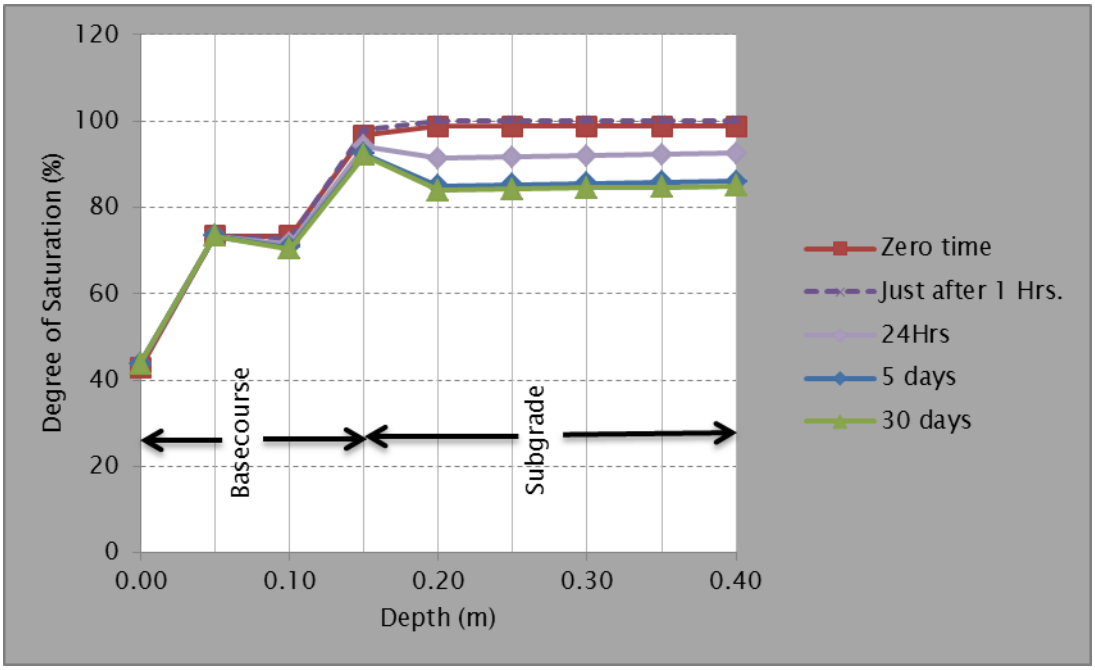


Figure 2.31 shows the saturation level below the left lane left wheel path is constant at 40% for this example. The subgrade at 0.2m depth is drying with time in contrast to the constant degree of saturation found in the flat section. The main reason is that the initial water table depth of the cut section is 3.5m whereas the initial water table depth of the cut and fill section is 4.5m. Another reason is that the fill sections include a large seepage face area that allows more water to seep out.

The subsurface longitudinal flow in rolling or hill country roads was not modelled as it was assumed that the side drains were able to effectively remove this longitudinal subsurface flow.

2.9 Modelling conclusions

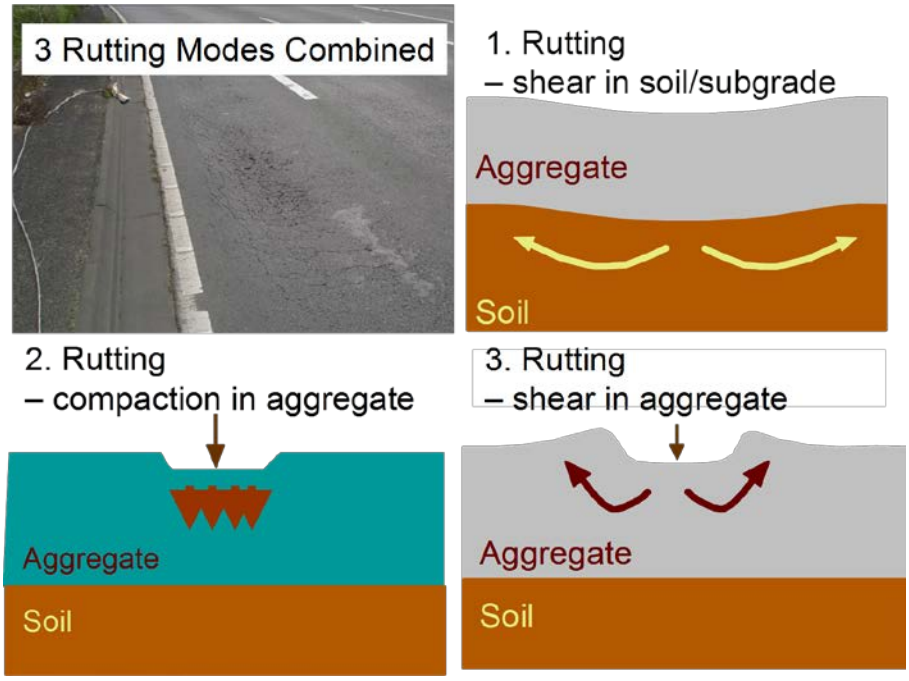
- The analysis of the sections with very clear drainage shows with one hour of rain the water table below 0.5m in depth will not have a significant effect on the saturation levels in the basecourse or subgrade. There was little difference between a water table at 0.5m or 1m. However, when the analysis was performed modelling a cut situation with a water table at 4.5m the equilibrium saturation level in the subgrade was lower than in the shallower water tables.
- Where the drain is partly blocked the saturation level in the bottom of the basecourse can rise to over 80%.
- The outcome from the analysis on a completely blocked drain shows that flooding can raise the saturation level in the basecourse to over 90% throughout its depth and that even after the drain is unblocked very high degrees of saturation still persist after a month.
- The 'drain face' of the basecourse should not be blocked by vegetation or in any other way. Drain face means either side of the sloping face of the exposed basecourse, which is located in the drainage and exposed to allow the water in the basecourse to seep into the drainage.
- If the unsealed shoulder width is less than the distance between the edge of the surface layer and the outer wheel path then the chance of the basecourse below the wheel path becoming wet is almost nil in normal maintenance conditions. Exceptions would be when there is a blocked drain face or if water can infiltrate through a cracked seal surface, which would lead to flooding.
- The outcome from the investigation of the subsoil drain shows that it should be kept clean. If it is partially blocked then the basecourse can become saturated.
- Overall, the analysis results show the equilibrium saturation level in the basecourse layer in the pavement is around 60% saturation. The subgrade saturation level is about 95%.
- It should be noted that the model results are based on a good basecourse material and a silty clay subgrade material. The pavement has a 1m sealed shoulder and a 0.5m unsealed shoulder. We have assumed there is no infiltration through the asphalt layer. If these conditions change the moisture condition can vary.
- We have considered two-dimensional analysis of the transverse direction of the road but not the third dimension, which is water flow along the longitudinal direction of the road. We assumed if the water content in the basecourse is no more than around 60%, water can easily flow in the transverse direction so there is less chance of water flowing in the longitudinal direction if there is no infiltration through the seal surface.

3 Effect of saturation on rutting

3.1 Rutting

Various rut prediction modes for thin unbound granular pavement were analysed as these are the most common in New Zealand. The modes of rutting, developed through shear, as illustrated in figure 3.1 are: 1) subgrade; 2) compaction; and 3) aggregate. Only subgrade rutting is considered in the current Austroads pavement design standards (Austroads 2013a). However, investigations of early pavement failures have found rutting to occur predominantly in the aggregate layers. Rutting of the aggregate layers can be predicted using the RLT test. The rate of rutting increases with increasing moisture content (or increasing level of saturation) for both aggregates and subgrades. In some cases water can weaken the subgrade or aggregate to such an extent that rapid shear failure occurs after the first passage of a heavy axle. The next sections discuss the modes of rut failure and the effect of moisture within various pavement layers.

Figure 3.1 Three modes of rutting in thin-surfaced granular pavements



3.2 Subgrade rutting

The current pavement design procedure determines pavement life from a known subgrade strength/California bearing ratio (CBR) and granular pavement depth as per figure 8.4 from Austroads (2013a). Further, Austroads presumptive values of subgrade CBR show that the CBR can change from 5% for well-drained clay to a value of 2% (see table 3.1). The reduction in life and additional rutting due to a reduction in subgrade CBR of 5% to 3% depends on the pavement depth and traffic. An example is if a road was built/designed for a 25-year life (assumed 25mm failure rut depth) and 25-year design traffic of 10 million ESAs. Then the design rutting rate is 1mm per year for 10 million ESAs over 25 years. If the subgrade CBR is reduced to 2% with the same traffic, Austroads predicts that the life will decrease to four

years and thus the rutting rate will increase to 6mm per year for a 25mm rut depth failure criteria.

The damage caused by a reduction of CBR from 5% to 2% is greater for low traffic roads where the design traffic over 25 years is 1 million ESA. For a CBR of 5% the Austroads design depth is 392mm to achieve a design life of 1 million ESAs.

Using the same assumptions as before, the rutting rate changes from 1mm to 30mm per year for a reduction of subgrade CBR from 5% to 2%.

Table 3.1 Presumptive California bearing ratio values from Austroads (1992)

Subgrade Description		Typical CBR Values (%)	
Material	**USC* Classification**	**Well drained**	**Poorly drained**
Highly plastic clay	CH	5	2 - 3
Silt	ML	5	2 - 3
Silty clay	CL	6 - 7	4 - 5
Sandy clay	SC	6 - 7	4 - 5
Sand	SW, SP	15 - 20	n/a

A research project was carried out in 2001/02 to investigate subgrade soil water conditions of road pavements in New Zealand, in particular the applicability of soaked or unsoaked test specimens, and seasonal influences on subgrade stiffness/CBR (Peploe 2002).

Test sections were established on three roads in the Auckland region. The test sections were subjected to four rounds of field tests over a period of two years to determine subgrade water content and strength/stiffness properties. Standpipes were installed to measure ground-water levels and subgrade samples were taken for laboratory (soaked) CBR tests.

The results showed very few correlations between the various subgrade test parameters measured. No clear relationship was found between rainfall records and subgrade water content or in situ CBR. A reasonable correlation was found between the ground-water level and the rainfall record at one test site, and the in situ CBR and dynamic cone penetrometer-inferred CBR showed reasonable correlation.

The laboratory CBR tests showed that soaked soil conditions would be appropriate for two of the sites but overly conservative for the third site. The observations are considered to be consistent with the topographical features of the various sites.

Typical results are shown in figures 3.2 and 3.3 showing the variation in CBR values over the course of the trial. There appears to be some evidence of the subgrade strength increasing and reducing at different times of the year, but the precision of the test method is not high and this could explain some of the variation.

Figure 3.2 Subgrade CBR changes on Kohimarama Road (Peploe 2002)

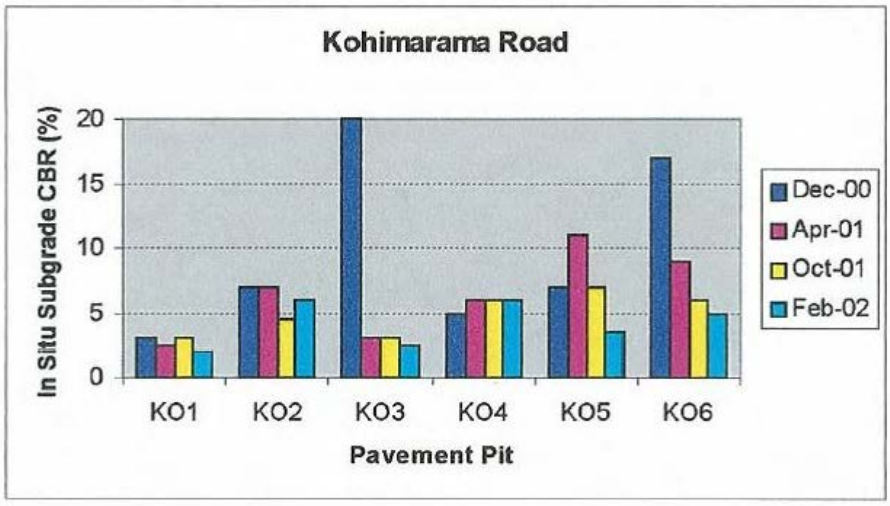
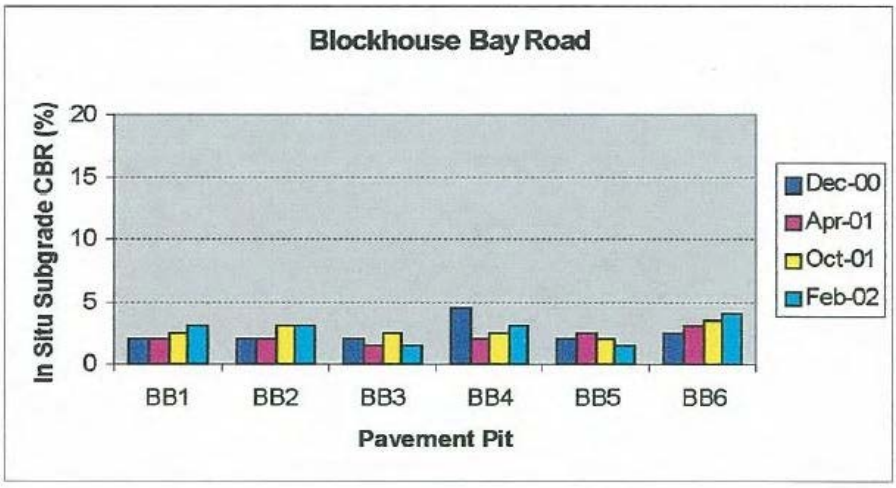


Figure 3.3 Subgrade CBR changes on Blockhouse Bay Road (Peploe 2002)



New pavements designed in New Zealand are based on four-day soaked CBR values which is assumed to be the worst case when the subgrade is wet. Peploe (2002) considered this was appropriate when the water table was within 1m of the pavement. This finding was substantiated in the following research.

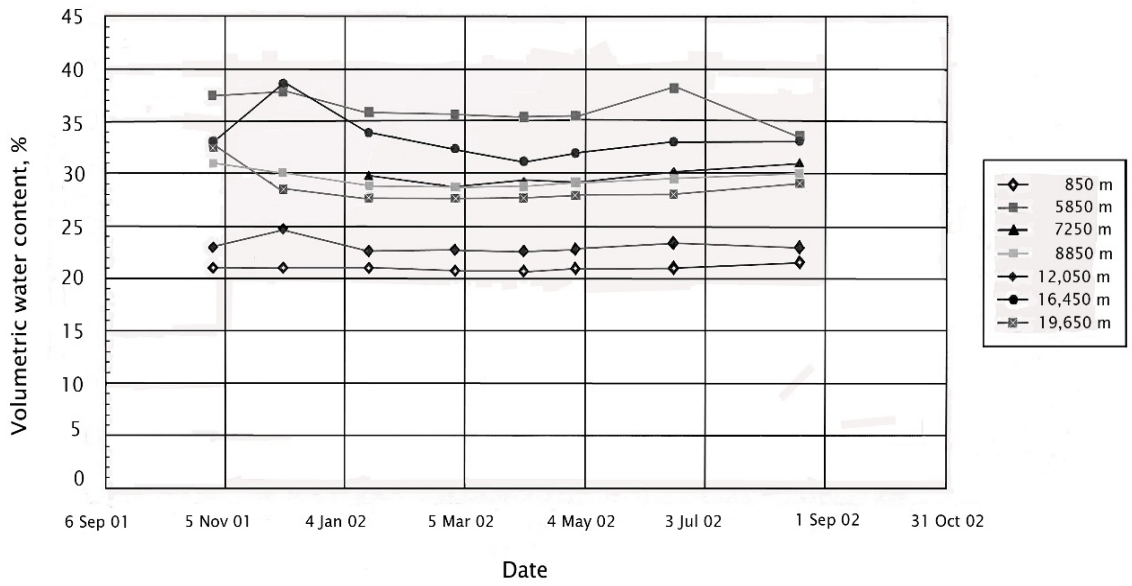
Arampamoorthy and Patrick (2010) used moisture data from the Transport Agency's long-term performance prediction trial sites and compared the degree of saturation estimated in these sites with a US model based on climate and material. The results were consistent with the model and in the New Zealand environment subgrade saturation levels for fine-grained material in the 80% to 95% range were found. In the granular basecourse an equilibrium value of 60% was considered characteristic of an average pavement.

When a pavement is constructed at optimum moisture content it can take a year or more for the material to reach equilibrium with its environment.

Other researchers as discussed in Arampamoorthy and Patrick (2010) have also determined that the moisture content beneath a pavement reaches an equilibrium condition after the pavement is constructed.

Research in New Zealand has confirmed the existence of an equilibrium moisture condition. Figure 3.4, which was taken from Dennison (2002), shows the variation in volumetric moisture content over a one-year period at six sites along a pavement located on flat terrain in the Bay of Plenty. Dennison found no correlation between rainfall and in situ moisture.

Figure 3.4 Equilibrium moisture content over one year in the Bay of Plenty (adapted from Dennison 2002)



Perera et al (2004) note that the equilibrium will not hold where the pavement is subjected to freeze–thaw conditions, or where the water table is within approximately 1m of the surface. They conclude that seasonal effects on moisture content will be insignificant if the point of consideration is 0.9m–1.8m from the edge of the pavement. Infiltration through the road shoulders is influenced considerably by moisture closer to each edge of a pavement. Roberson and Siekmeier (2002) measured the saturation in the pavement base, sub-base and subgrade using the time domain reflectometry method, and found that the moisture content in the outer wheelpath is higher than moisture content at the centreline, with a difference of 10%–15% saturation. Their graph shows that moisture reaches an equilibrium condition in the long term, with minor short-term fluctuations when precipitation occurs. However, this fluctuation is minimal in comparison with rates of precipitation.

Moisture conditions are also dependent on the depth of the water table. Drumm and Meier (2003) consider that moisture conditions in pavement layers will be influenced by the water table if its depth from the surface is less than 6m for clay, 3m for sandy clay or silt, and 1m for sand. Lay (1990) noted the same depths for clay and for sand.

Taking this previous research into account it appears that, in general, subgrades will be towards the high end in saturation but the basecourse significantly lower. When surface drainage is inadequate then the main effect on performance will be in the granular materials. Both subgrades and base layers will be affected by inadequate subsoil that is not performing a cut-off function. The research in this report has concentrated on the basecourse layers but the whole drainage system is critical to the overall performance of the pavement.

3.3 Aggregate rutting

The Austroads pavement design process (Austroads 2013a) does not consider rutting within the aggregate layers (figure 3.1). Over the past five years, many RLT permanent strain tests have been conducted on basecourse aggregates in accordance with the draft T/15 specification (NZ Transport Agency 2011). The test is conducted at optimum moisture content in drained conditions (note the moisture content reduces during the test as water drains for the specimen) and repeated after soaking the compacted aggregate for one hour and then testing undrained (note water trapped in the specimen and typically the moisture content is 2% above optimum and close to saturation). Results of RLT testing are analysed in terms of predicting the number of ESAs to achieve a 10mm rut within the aggregate layer which was identified as a failure criteria in tests at CAPTIF. Typical results found from testing a range of aggregates are detailed in table 3.2.

Table 3.2 Typical results from the Road Science RLT test database

	Traffic loading limit (MESA)		Implications for pavement design and drainage
Aggregate type	**Dry/drained RLT**	**Wet – saturated/ undrained RLT**	
Typical alluvial M4 basecourse aggregates (river gravels)	6 to 10	1 to 3	Due to some rounded stones in the aggregate and worn and smooth surfaces some interlock strength is lost. This means even if the aggregate is kept dry there is a high risk of early rutting failure for design traffic loads over 6 MESA. Small quantities of cement to stabilise the aggregate will only improve the wet performance up to the dry performance level. However, the wet rutting performance is already good (due to clay and silt fines that have been washed away) and the dry performance at best is only 10 MESA, thus low quantities of cement will give limited improvement. These rounded river gravels are free draining and have some rut resistance when wet. Thus there is less risk of rapid early pavement failure should the basecourse become wet.
Typical Auckland M4 basecourse aggregates (crushed rock)	20 to 30	0.01 to 0.5	These crushed rock aggregates have good rut resistance for very high-trafficked roads but poor performance if they get wet; hence all that is needed is small quantities of cement or lime to null the plastic fines to improve the performance when wet. The pavement design can assume unbound granular properties. Good pavement drainage and surface waterproofness is needed at all times otherwise rapid rutting failure could occur, particularly on high-trafficked roads.
Typical sub-base lower quality aggregate	0.1 to 5	0.001	Compared with M4 basecourse aggregates the sub-bases are typically very weak. Although a sub-base gives sufficient strength when dry the higher plastic fines contents in sub-bases cause significant rutting when wet. Therefore, good pavement drainage and surface waterproofness is needed at all times, otherwise rapid rutting failure could occur, particularly on high-trafficked roads.

MESA = millions of equivalent standard axles

RLT = repeated load triaxial (T/15: NZ Transport Agency 2011 draft)

Two aggregates were selected for this study for further RLT permanent strain testing at different levels of saturation, all at undrained conditions. One of the aggregates was a Canterbury river gravel compliant with the TNZ M/4 specification (Transit NZ 2006) while the other was an aggregate dug from a test pit in an old road that is being rehabilitated. The RLT test results are shown in figures 3.5 and 3.6. The analysis of this data in terms of rutting life (which is an output from the T/15 analysis) is given in tables 3.3 and 3.4.

Figure 3.5 Effect of level of saturation on permanent strain in RLT test (Transport Agency T/15) on an old in situ road aggregate

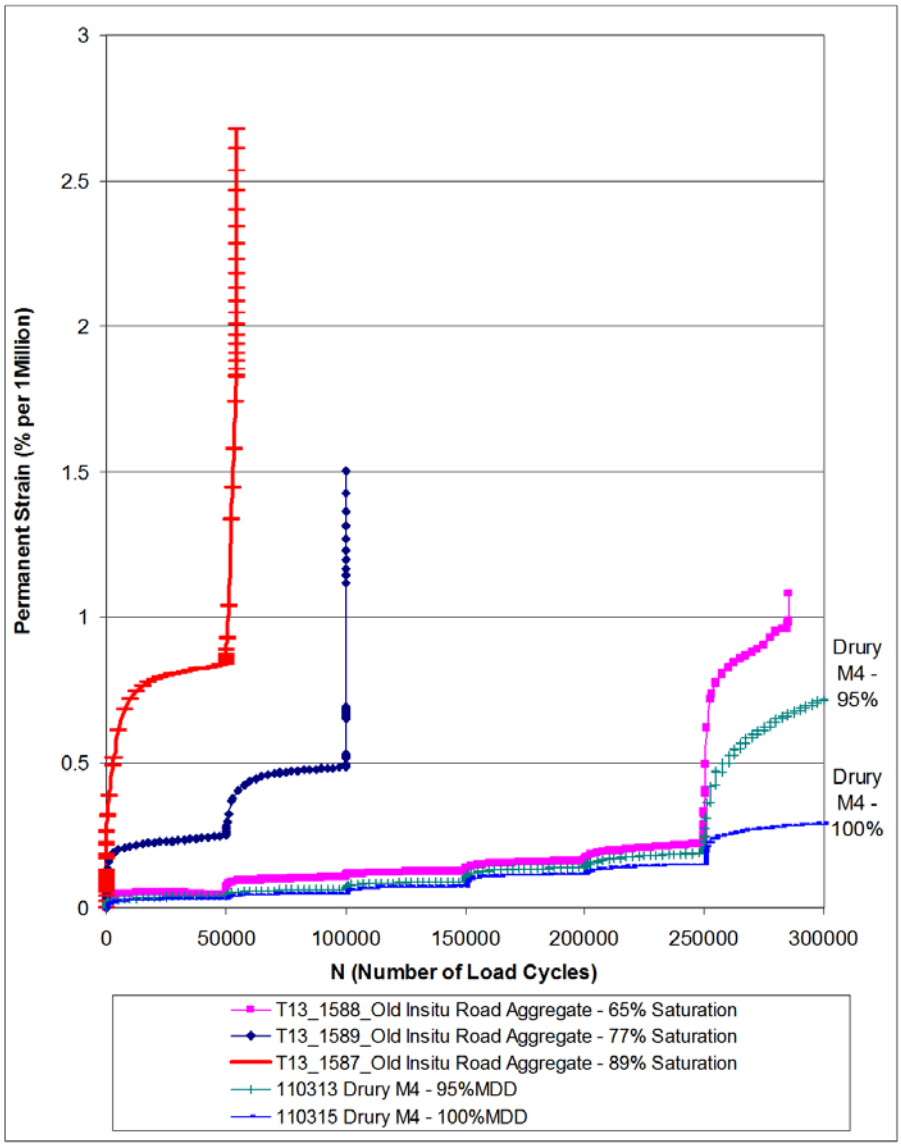


Figure 3.6 Effect of level of saturation on permanent strain in RLT test (Transport Agency T/15) on a Canterbury alluvial aggregate

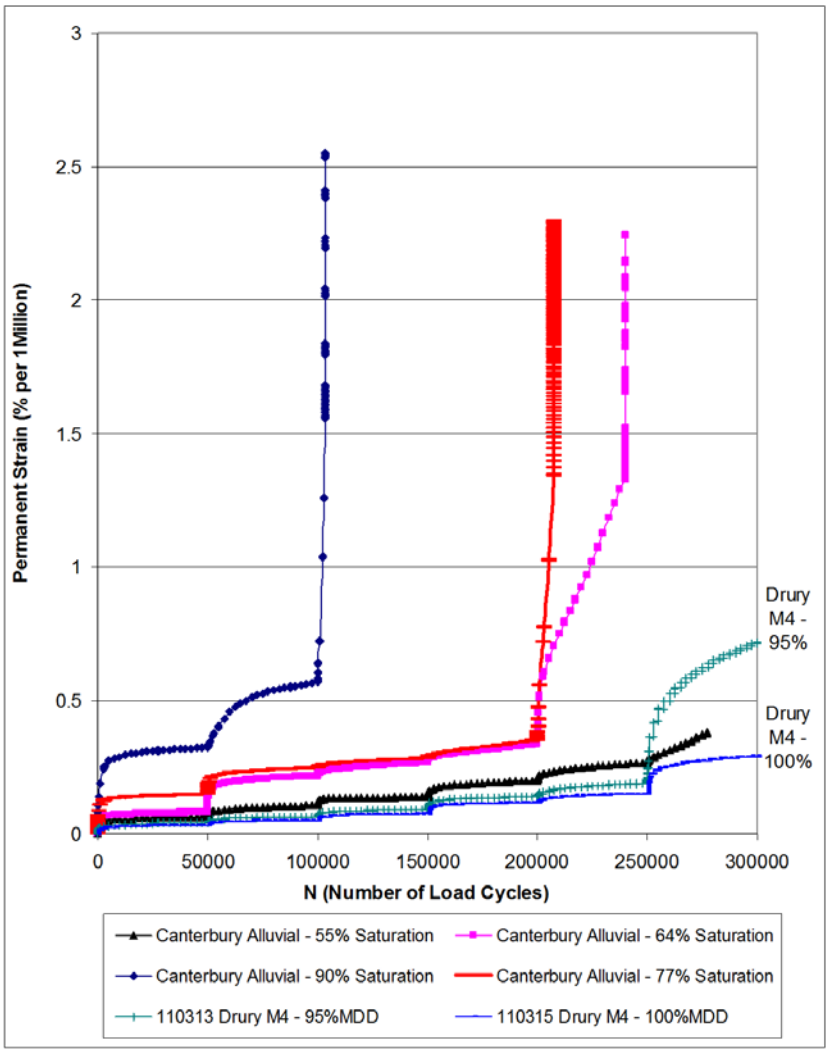


Table 3.3 Summary of the RLT test results in terms of rutting life for old in situ road aggregate

RLT test	Test description	ESA to 10mm rutting
Test 1 (65% saturation)	2% below optimum moisture content	1.2 million
Test 2 (77% saturation)	At optimum moisture content	Too weak
Test 3 (89% saturation)	1% above optimum moisture content	Too weak

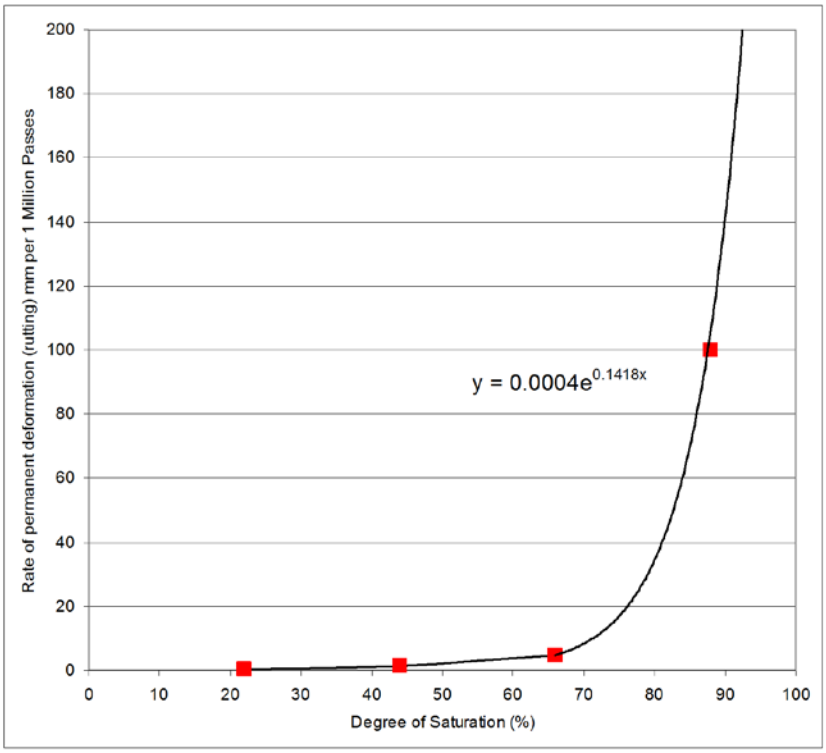
Table 3.4 Summary of the RLT test results in terms of rutting life

RLT test	Test description	ESA to 10mm rutting
Test 1 (55% saturation)	At optimum moisture content	2.4 million
Test 2 (64% saturation)	1% above optimum moisture content	0.1 million
Test 3 (77% saturation)	2% above optimum moisture content	Too weak
Test 4 (90% saturation)	3% above optimum moisture content	Too weak

The effect of saturation on permanent deformation or rutting in the granular layers is an exponential effect. Figure 3.7 shows the rapid decrease in life when saturation increases above 70% that once saturation reaches 85% to 90% the basecourse loses nearly all shear strength and 'collapses'.

The testing has shown that for 'good' performance the saturation level should be maintained below 70% and that the good performance normally obtained on New Zealand basecourses is associated with maintaining low water contents. The results support the earlier research on in situ saturation levels (Arampamoorthy and Patrick 2010) which indicated that basecourses are in an equilibrium moisture regime in a mature pavement where the degree of saturation is approximately 60%.

Figure 3.7 Exponential form of the effect of degree of saturation on the rate of rutting



3.3.1 Effect of traffic volume

The saturation/rut depth relationship given in figure 3.7 can be used to illustrate the speed at which rutting can develop under traffic. The days until a rut depth of 15mm occurs under varying traffic volumes and degree of saturation has been calculated and shown in table 3.5. The conversion of average annual daily traffic (AADT) to equivalent design axles (EDA) is based on 10% heavy commercial vehicles (HCV) and 2.4 EDA/HCV.

Table 3.5 Estimation of days to develop 15mm rut as affected by basecourse saturation level

AADT	50	300	1250	3000	7000	15000
60% saturation	768,000	108,000	27,000	11,000	4,600	2,200
65% saturation	380,000	53,600	13,160	5,431	2,280	1,090
85% saturation	2,2040	3,100	760	315	130	63
90% saturation	1,0940	1540	380	155	66	31
95% saturation	2,070	290	70	30	12	6

The typical traffic level on a New Zealand state highway is 3,000 to 4,000 AADT and table 3.7 suggests the pavement would rut very quickly if the water content remained high. For a typical basecourse the change in water content from 60% saturation to 65%, 85%, 90% and then 95% is 3.9%, 4.2%, to 5.5%, 5.8% and 6.1% respectively. Therefore, only a relatively small change in water content by mass is needed to push the degree of saturation into an unstable situation.

At the lower level of 60% saturation, the days to achieve a 15mm rut is estimated at 11,000 (for 3,000 vpd), which is equivalent to 30 years. It also suggest that if the equilibrium water content results in a saturation level of over 65% there would be a significant loss of life.

The above modelling is not regarded as absolute as the rapid loss of strength with increasing saturation levels could mean that for many granular basecourse materials the above estimates are very conservative. For example the effect of pore pressure build up under rapid loading is not accounted for in the modelling.

However, the analysis supports the view that drainage is not just to protect the pavement in rainfall events but is also required to ensure that it remains in an equilibrium saturation level of about 60%.

New Zealand's temperate climate and position in the ocean means there is normally a consistent rainfall pattern. The 'wetter' months are in the winter. The percentage of days on which more than 1mm of rain fell during the period June to October is given in table 3.6 (taken from NIWA website.[1]

Table 3.6 Percentage of days (June to October) on which more than 1mm of rain fell

Location	% wet days	Location	% wet days	Location	% wet days
Kaitaia	46	Wanganui	37	Mt Cook	47
Whangarei	44	Palmerston Nth	40	Lake Tekapo	24
Auckland	46	Masterton	43	Timaru	19
Tauranga	36	Wellington	40	Milford Sound	53
Hamilton	41	Nelson	29	Queenstown	28
Rotorua	37	Blenheim	26	Alexandra	17
Gisborne	33	Westport	53	Manapouri	39
Taupo	36	Kaikoura	24	Dunedin	31
New Plymouth	43	Hokitika	50	Invercargill	45
Napier	27	Christchurch	25	Chatham Islands	45

It can be seen that in most parts of the country 30%–40% of the days had rain. If we refer back to chapter 2 on the modelling and realise how slowly a saturated basecourse drains, then once a drain is not working efficiently the basecourse is likely to remain highly saturated.

This analysis suggests that inefficient drainage will lead to a basecourse remaining at 90%–95% saturated throughout the winter. The RLT results suggest that even a 'good' basecourse will fail within one month under average loading and two months under light traffic.

It should be stressed that the major effect of poor drainage is associated not so much with the water getting into the pavement but once it has infiltrated it takes a significantly longer time to drain and for the saturation level to drop.

[1] www.niwa.co.nz/education-and-training/schools/resources/climate/wetdays

4 Drainage maintenance strategy

4.1 Introduction

Improper maintenance of the drainage system can lead to blocked drainage and can cause the pavement layers to be submerged with excess water leading to loss of shear strength and rapid pavement failure.

The results of the analysis described in previous chapters support the need for regular maintenance and inspection but as there are limited maintenance funds the effort needs to be directed to the areas with the highest risk:

- Although there may be a case for lower emphasis on drainage maintenance in hill areas with a significant slope, it is not acceptable to have water flow over the road surface causing a safety problem. Thus in a drainage maintenance strategy motorist safety as well as pavement performance needs to be considered.
- The 'drain face' of the basecourse should not be blocked by vegetation or in any other way. Drain face means either side of the sloping face of the exposed basecourse, which allows the water in the basecourse to seep into the drain.
- The subsoil drain should be kept clean and free of blockages so that the drain water can flow well. If the drainage is partially blocked then the basecourse can become saturated.

The proposed maintenance strategy is based on:

1. Identifying areas on the network where inadequate drainage can have a significant effect on the pavement performance or creates a traffic risk
2. Identifying 'blackspots' on the network where specific drainage features, although in an area of low: risk, can result in water flowing across the road, eg blocked sumps
3. Performing an annual rating in areas identified in 1
4. Ensuring regular inspections and maintenance are performed, especially before forecast heavy rain, in areas identified in 1 and 2.

Any occurrence which could block the drainage should be minimised. Examples that could cause blockages and should be part of the 'black spot' strategy include:

- eroded drainage side slope or scour around the structure, which can cause collapsed side slope or structure and block the drain
- sediment deposit and silting
- vegetation and debris blocking the drainage path
- erosion at the shoulder, which can promote ponding
- vegetation growth or fine deposit or any form blocking the slope of the shoulder, which has been exposed to allow seepage.

Erosion and scour, sediment or silt deposit can be critical at high-flow velocity in the drain. This should be minimised. The other possible causes of drainage blockages can be controlled by proper maintenance.

In the 1990s, the RAMM system had provision for visually ranking and recording drainage condition. In contrast to the pavement and surfacing condition rating which is carried out on a 10% sample of the

section, drainage rating covered the total length of the section. The costs associated with this total rating were recognised and there was provision for reduced lengths or even no rating as determined by the client. It appears that drainage rating is now only sporadically performed in some networks. The outcome of the rating also does not appear to be used as an input into forward planning in the network.

The intended output of this current research was the development of a maintenance strategy and guidelines for pavement drainage maintenance. The development of a strategy for renewal which is required if maintenance is not cost effective or the drainage capacity is inadequate for the water flow are beyond the scope of this project.

Although it is recognised that moisture susceptible subgrades exist in New Zealand they will often be controlled by subsurface drainage and the moisture in the granular layers will be controlled by the surface drainage features. However, as shown in the modelling, blocked subsoil drains can result in water entering the granular layers. Therefore a strategy needs to consider both surface and subsurface drainage.

The objective of the drainage features is to minimise the ingress of water to the pavement and therefore to minimise its effect on pavement performance. In summary the proposed strategy asks the following questions:

1 Climate – how much rain falls on the network? Is the area subject to freeze–thaw?

2 Topography – does the water run away quickly and easily? Mountainous, rolling or flat terrain.

3 Drainage position – are the drains close to the traffic wheel path? This is a factor of the shoulder width and if it is sealed.

4 Pavement type – will water affect the pavement performance significantly? Bound materials such as asphalt will be less susceptible to poor drainage than granular materials.

5 Traffic level – how much traffic is using the pavement?

6 Surface water flow – will water flow across the surface if the drainage is inadequate? This is both a vehicle safety issue and a pavement issue as tyre pressure can force water through a thin surfacing.

Based on the responses given to the questions the site can be considered to be at high, medium or low risk of suffering from water-induced damage.

Most of the information required is available in the RAMM database although factors such as water flow across the road will have to be determined by a visual inspection.

4.1.1 Planned maintenance

Based on the risk profile developed from the above questions, areas that are high risk need to be part of a planned maintenance strategy. This could include regular cleaning, vegetation control etc. The intention is to keep these drains free flowing and in the best possible condition.

Subsoil drains will normally be part of a planned maintenance strategy.

A method to rank the sections on a network in terms of risk is given in the following sections.

4.1.2 Proactive maintenance

A systematic approach should also identify ‘hotspots’ in the network where checks of the drainage conditions should be made before forecast heavy rain. This should include keeping grating clear or checking areas where a small slip can partly block drains.

4.1.3 Surface drainage – score card

In order to prioritise and rank the risks of drainage failure on pavement performance a score card has been developed that will give a ranking from 6 to 24 where 24 is very high risk and 6 low risk.

The score card is given in table 4.1 and RAMM has fields for most of the required information.

Table 4.1 Scorecard for ranking drainage maintenance

Surface drainage scorecard					**Score**
Climate	Rainfall	High	Med	Low	
	Temperature	Freeze			
		3	2	1	0
Topography	RAMM classification	Flat	Rolling	Mountainous	
		3	2	1	0
Position	Distance from drain to wheel track	<1m	1–3m	>3m	
		3	2	1	0
Pavement type		Thin surface granular	Thin surfaced bound	Structural asphalt	
		3	2	1	0
Traffic level	RAMM traffic category	6&7	4&5	1,2&3	
		3	2	1	0
Traffic safety/ surface ingress	Flooded drain water path	Across surface		Away from surface	
		6		0	0
Drainage condition		Poor	Satisfactory	Excellent	
		3	2	1	0
				Total	**0**

An explanation of the score card is given below.

4.1.3.1 Climate

How much rain falls on the network? Is the area subject to freeze–thaw? The risk is obviously associated with the quantity of rain. Three zones are proposed based on two-hour two-yearly return period rainfall:

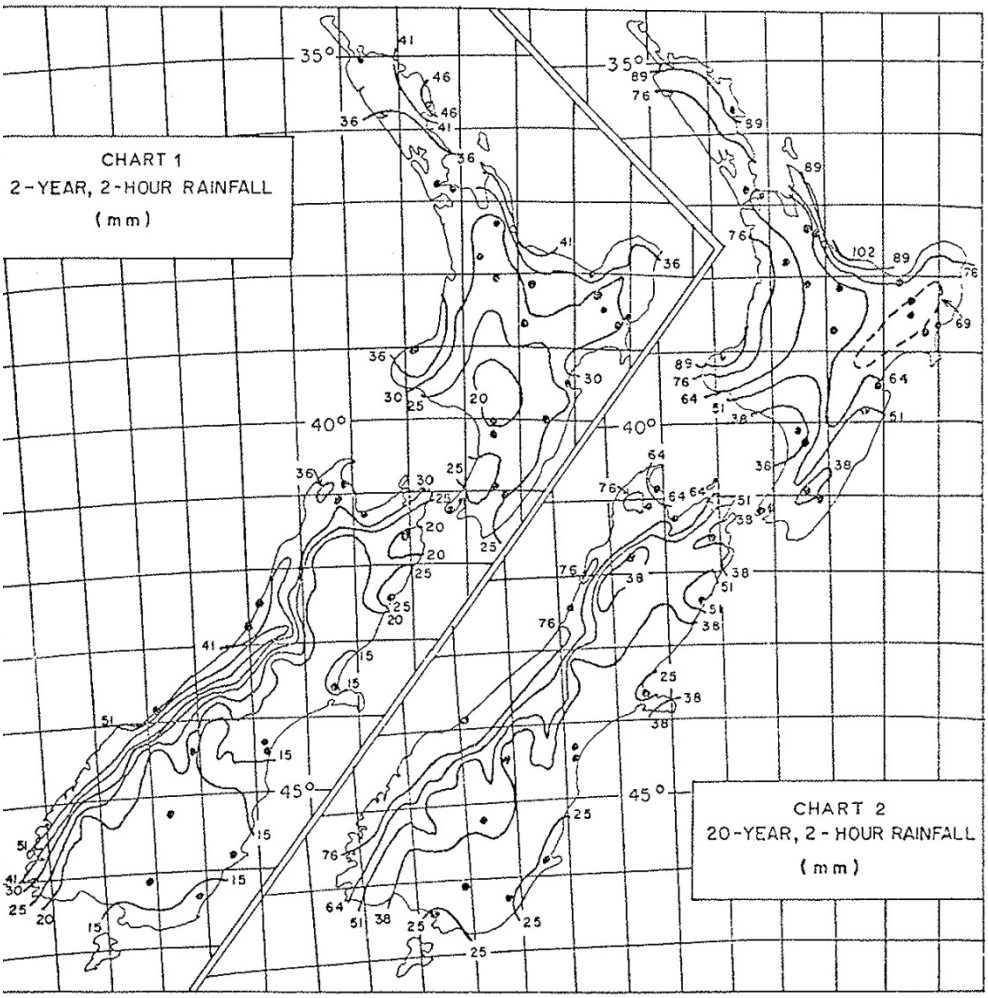
1 High where the rainfall is greater than 35mm

2 Medium where the rainfall is 20-35mm

3 Low where the rainfall is less than 20mm.

Figure 4.1 gives contours of rainfall for New Zealand.

Figure 4.1 Rainfall contours from Transit NZ (1997)



Also associated with climate is the possibility of freeze-thaw, where the pavement is subjected to freezing and the risk of failure is significantly affected by water contained in the unbound material. As illustrated in chapter 2 a basecourse can take weeks to drain and if water infiltrates a pavement in autumn there is a high possibility that it will still be trapped when freezing occurs. The expansion of the water when it freezes will result in it disrupting the structure so that the basecourse will shear when the material thaws.

Therefore areas where freeze-thaw occurs are regarded as high risk.

4.1.3.2 Topography

Does the water run away quickly and easily? RAMM has provision for the section to be classified as mountainous, rolling or flat. Mountainous and rolling country generally allows water to flow quickly and thus the 'standard' of drainage is not as critical as in flat areas where water ponding may be prevalent.

There will obviously be specific sites in mountainous areas where water flow may be impeded and is allowed to flow into the pavement - but the proposed rankings are considered to reflect the relative risks.

4.1.3.3 Drainage position

Are the drains close to the traffic wheel path? This is a factor of the shoulder width and whether it is sealed. Mountainous areas as discussed above will have a ranking of 1 in terms of topography but often there are very narrow or non-existent shoulders. Where the distance from the drain to the traffic wheel

path is low, any water that gets in does not have to move far to affect the pavement strength. In flat terrain there can be wide sealed shoulders that mean any water that may get into the edge of the pavement has a significant distance to travel. The worst case is therefore a flat area where the shoulders are very narrow.

RAMM has provision for information about the shoulder. Specifically it allows input of the 'distance from the LHS of the carriage way to LHS of the surface in metres'.

In the drainage table it has provision for input of 'Distance from seal edge to invert of earth channel' or 'Distance from centre line of carriage way to the edge of the SW channel'.

The surface water channel type, ie kerb and channel, dish channel or SWC s or SWC d.

The last two letters refer to a surface water channel: 's' is less than 400mm deep and 'd' is greater than 400mm deep. It would normally be expected that a shallow drain would attract a higher risk score.

The surfacing type and width is also given.

Therefore from this information the approximate distance from the wheel path to the water channel can be estimated.

4.1.3.4 Pavement type

Will water significantly affect the pavement performance? Bound materials such as asphalt will be less susceptible to poor drainage than granular materials. Thin surfacing with bound material includes material such as foamed bitumen and cement stabilised material where the cement content is greater than approximately 2%. The strength characteristics of these materials are more resistant to water as well as having a lower permeability so that water ingress is slower.

With structural asphalt the assumption is that the asphalt has been well compacted and is thus impermeable. Water ingress is therefore going to be concentrated deep in the pavement and have a minor effect on the overall strength.

4.1.3.5 Traffic level

How many heavy vehicles are using the pavement? Traffic is obviously a very significant variable. As illustrated earlier when the pavement saturation level increases a rapid decrease in strength can occur. RAMM has seven levels of traffic as given below. As the average percentage of HCVs is about 11%, the use classifications given below are regarded as adequate. If the road section had a very high percentage of heavy vehicles then there is always the option of being able to increase the classification risk. For the score card three ranges are proposed: uses 1, 2 and 3 as low risk; uses 4 and 5 as medium risk; and uses 6 and 7 as high risk. In practice, uses 6 and 7 will often have well-designed drainage and bound pavements.

Table 4.2 Risk rating as a function of traffic volume

RAMM use	Traffic AADT	Risk rating
1	<100	Low
2	100–500	
3	500–2,000	
4	2,000–4,000	Medium
5	4,000–10,000	
6	10,000–20,000	High
7	>20,000	

4.1.3.6 Safety considerations

Will water flow across the surface if the drainage is inadequate? Although the risk of water ingress into the sides of the pavement has been the main consideration, the safety risk has to be considered. If a blocked drain results in the water flowing across a pavement then besides the risk to the pavement there is a risk to the motorist of aquaplaning or losing control.

If the water flows away from the surfacing and pavement, there is no risk to the motorist.

Water flowing across the surface can contribute to a different form of pavement distress in that water can be forced through the surfacing under the action of traffic. This will lead to potholes and shallow shear failures.

The combined risk of motorist and water ingress from water flowing across the pavement has resulted in a high ranking for this condition of 6 rather than 3.

The score can vary from a low of 6 to a maximum of 24. Three bands are proposed.

1 6–10 low risk

2 11–14 medium risk

3 >15 high risk.

Because of the higher score (6) associated with water running over the trafficked area, most sites with this condition will be classified in the medium- or high-risk category.

All high-risk sites should have well-maintained drainage and the methodology to rate drainage condition is given below.

The risk score given in the previous section is then matched against the drainage condition.

4.1.3.7 Drainage quality

Are the drains functioning correctly?

As part of the RAMM rating system there is a manual that describes the procedures to be used for the visual condition rating of surface drainage (Transfund 1997). The manual gives photos of typical inadequate drainage and a system of determining a ranking of 1 to 3, where 1 is good drainage and 3 is poor. The manual's drainage inspection methodology is reproduced in appendix A.

Explanation of the severity indicator from the manual is reproduced in figure 4.2.

Figure 4.2 ESWC condition severity indicator

ESWC Condition Severity Indicator

This rating assigns a number on a scale of 1 to 3 to indicate the general severity of faults on the ESWCs.

1 Indicates low severity of faults as typified by ESWCs that comply with the conditions in the flow chart above.
I.e. 80% of the ESWCs in the treatment length show no faults and faulty areas are less than 10m long

Or

- Subsoil drainage is present
- The ground is free draining
- The client has specified that ESWCs are not required for this TL.

2 Indicates that the ESWC faults exceed the levels above. (Longer than 10m in length and Over 20% of the total length of channel is faulty. But there are no obvious water related faults on the carriageway or evidence of flooding or ponding on the carriageway, or shoulder

3 Indicates that the ESWC faults exceed the levels of level 1 and the following conditions also exist

- Boggy or rough water damaged shoulder
- Evidence of water ponding on the shoulder or carriageway
- Water related faults on the carriageway adjacent to areas of faulty ESWC

The methodology proposed in this research will identify those sections of the network that require regular rating (from the scorecard) and use the RAMM rating system to classify the condition. It is recommended that the 'or' clauses for condition 1 are not used and thus a rating of 1 is only given to sections where the faults are of low severity.

Obviously those sections classified by the rating as 3 and in an area with a high score will require maintenance.

Subsoil drains

In contrast to surface drainage where the condition can be visually assessed subsoil drains require special video equipment to obtain a realistic view of the drain. Even this does not give an indication of the condition of the filter material and geosynthetic material that encase the pipe. If the flow into the pipe is inadequate then water will build up and flood the granular layers.

The importance of subsoil drains, especially in the cut side of a pavement, was highlighted by Saarenketo (2007) who found the rate of rut progression on low-volume Nordic roads was significantly greater on the 'cut' lanes where drainage was inadequate.

The only practical way to assess subsoil drains is to determine that water is flowing through them after rain.

An indirect method is to compare the rut rate on the outside wheel paths of a pavement in both directions. When there is a significant difference especially where the section is in a cut then the subsoils should be inspected closely and if necessary cleaned.

Sites where subsoil drain performance is critical should be placed on the 'hot spot' list compiled for surface drainage.

5 Conclusions and recommendations

5.1 Conclusions

This project was designed to investigate the importance of drainage maintenance on pavement performance and to recommend a maintenance strategy. With restrained funding for pavement renewals drainage maintenance is a cost-effective method to ensure optimum pavement performance.

In the 2010/11 financial year the Transport Agency spent 3.7% of its total state highway maintenance budget of $231M on drainage maintenance and 23.2% on pavement renewals. Better targeting of the drainage maintenance could have a significant effect on reducing the renewal quantity and cost.

This research used the RLT approach to demonstrate there is an exponential relationship between the granular basecourse degree of saturation and rate of rut development.

It has demonstrated that if rainfall events result in water build up in the pavement then rapid failure can occur. It has also shown that a significant loss in life (permanent deformation) can occur if the wetting and drying of the basecourse results in an equilibrium water content so that the saturation level is greater than 65% to 70%.

Modelling of the water movement using typical cross section of New Zealand thin-surfaced granular pavements has confirmed previous New Zealand research that the equilibrium water content in a granular layer is approximately 60% and in a sandy clay subgrade is greater than 95%. This high subgrade saturation level confirms the present New Zealand practice of assuming a soaked subgrade when designing pavements.

The modelling showed that once water has infiltrated the basecourse it can take weeks for the water content to return to its equilibrium condition. During this time significant damage can take place and there is a high probability that further rainfall will occur and thus re-saturate the pavement.

A score card was developed to rank the importance of drainage maintenance as a function of:

1 Climate – how much rain falls on the network? Is the area subject to freeze–thaw?

2 Topography – does the water run away quickly and easily? Mountainous, rolling or flat terrain?

3 Drainage position – are the drains close to the traffic wheel path? This is a factor of the shoulder width and whether it is sealed.

4 Pavement type – will water significantly affect the pavement performance? Bound materials such as asphalt will be less susceptible to poor drainage than granular materials.

5 Traffic level – how much traffic is using the pavement?

6 Surface water flow – will water flow across the surface if the drainage is inadequate? This is both a vehicle safety issue and a pavement issue as tyre pressure can force water through a thin surfacing.

The research concluded that the rating system described in the RAMM manual is suitable for visual rating of drainage and that these surveys should be targeted based on the score card.

The research also concluded that monitoring changes in the rate of rut progression in the left hand wheel path is a method that could be used to identify areas where subsurface drainage requires investigation. A change in rate or difference from one direction to the other could signal a drainage problem.

5.2 Recommendations

It is recommended that:

- the drainage risk score be included in the RAMM manual
- rating of drainage condition be introduced on higher-risk sections
- the strategy of identifying and recording 'hot spots' be implemented
- the cost of maintaining the drainage condition to the appropriate level be monitored
- the comparison of rut rates on both sides of a pavement be introduced as a standard process to indicate possible subsoil drain failure.

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Appendix A: Extract from the RAMM rating manual

2 Faults Recorded

2.1 Surface water channels (SWCs)

Surface water channels (SWCs) can be either earth channels or surfaced channels.

Types of surfaced channels are:

- Kerb and channel
- Concrete dished channel
- Mountable kerb and channel
- Concrete nib kerb (if it is acting as a drainage path)
- Sealed channel
- Asphaltic concrete channel
- Half pipe channels.
- Any other constructed channel which has been surfaced

If both earth and surfaced channels are present in a road section then both are rated.

If two sets of SWCs are present parallel to the road, the SWC closest to the carriageway should be rated.

Each side of the carriageway is recorded separately on the rating form.

Shoulders are defined as the unsealed area between the edge of seal and the surface water channel. The shoulders are rated at the same time as the surface water channels.

2.1.1 Surfaced Channels

NOTE: The surfaced channels are to be rated for *the whole treatment length*, **not** just the inspection length. Left and right sides are recorded separately

This rating records the length of channel, which is defective in some respect and therefore not effective in gathering and transporting water from the pavement to the catchpit/sump.

LHS Surfaced Surface Water Channel (SWC) – Broken	The length of surfaced SWC in the rating length that is ineffective because it is broken. An entry is required.
LHS Surfaced SWC with High Lip of Channel	The length of surfaced SWC in for the rating length that is ineffective because it has a high channel lip. An entry is required.
LHS Surfaced SWC with Broken Surface at Channel Lip	The length of surfaced SWC in for the rating length that is ineffective because there is a break in the carriageway surfacing along the pavement/channel boundary.
Surfaced SWC with Blocked Channel	The length of surfaced SWC in the rating length that is ineffective because the channel is blocked. An entry is required.
Surfaced SWC with Grade of Channel Incorrect	The length of surfaced SWC in metres for the rating length that is ineffective because the grade of the channel is uphill to the catchpit. An entry is required.

2.1.2 Earth Surface water Channels

Earth SWC – Blocked	The length of earth SWC in metres for the rating length which is blocked by vegetation and/or soil such that water ponds and the SWC is not able to effectively channel water away from the pavement to a cut-out or culvert. An entry is required.
Earth SWC – Inadequate	The length of earth SWC in metres for the rating length that is below the standard set by the road controlling authority. This could also be a length where an SWC is required but does not exist. An entry is required.
Ineffective Shoulder	The length of shoulder in metres for the rating length that will not allow the free flow of water from the road surface to the SWC. An entry is required.
Channel Condition Indicator	Scale of 1 – 3 specifying the general condition of the Water Channel in regard to its effectiveness. (1 = Good , 2 = Average, 3 = Poor)

PART TWO – RATING GUIDE

1 General

The purpose of this part of the manual is to provide a reference to determine the type and quantity of defect. A number of examples of each distress type are shown with an explanation of the type of defect and any information or techniques that may be helpful in determining the type of distress fault.

2 Surface Water Channels And Shoulders

Surface water channels and shoulders are rated for the whole length of the rating section, not just the inspection length.

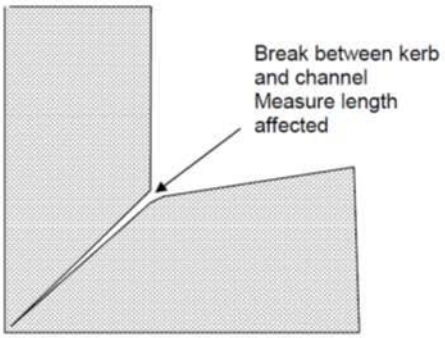
2.1 Surfaced Channels

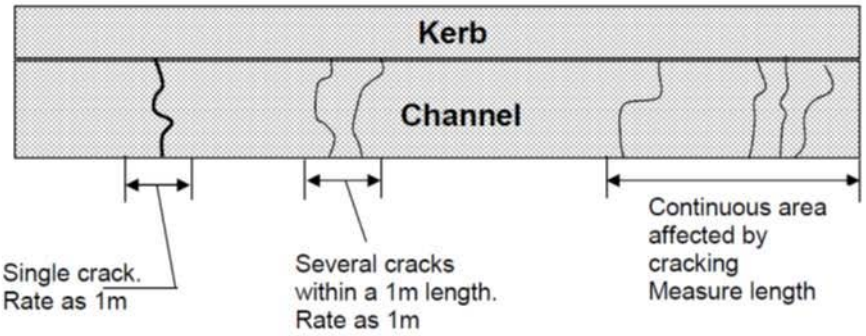
The types of channel which are rated for surfaced channels are as follows:

- Kerb and channel
- Concrete dished channel
- Mountable kerb and channel
- Concrete nib kerb (if it is acting as a drainage path)
- Sealed channel
- Asphaltic concrete channel
- Half pipe channels.

2.1.1 Broken

A broken channel is any channel, which is badly cracked or broken which will allow a light flow of water to readily leak through to the sub-base material. Inadequate joints between kerbing blocks and separation between the back of the kerb and the channel are included as cracking.





The photos below show broken channel, inadequate kerb block joints and separation between channel and back of kerb

(i) Example of a badly broken kerb and channel that is readily leaking water through to the sub-base of the carriageway.

(ii) A broken section of channel adjoining a vehicle crossing.

(iii) Separation between the channel and the kerb upstand is to be rated as broken.

(iv) A single crack >10mm wide at the surface is rated as 1m of broken channel.

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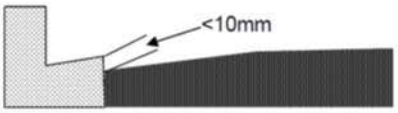
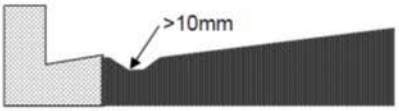
2.1.2 High Lip of Channel

If the lip of channel is 10mm, (the height of a Bic pen), or more higher than the carriageway surface then the length of kerb affected is recorded. Where there is also broken carriageway surface, this height will have to be estimated from a straight edge placed on the carriageway surface and extended to the channel edge.



Where the carriageway surface is shaped so that it is more than 10mm below the channel lip at a short distance from the line of the channel, then this should also be rated as high lip.



(i) The photo above shows the lip of channel above the carriageway. A pen such as the one in the photo is an easy way of measuring height differences.

(ii) Another good example of a kerb where the lip is higher than the carriageway surface.

2.1.4 Blocked Channel

A channel is blocked when weed growth, firm settled debris, or other obstructions fill 75% of the channel width or cause water to flow onto the carriageway to get past.

(i) Kerb and channel blocked by debris and weed growth.

(ii) Kerb and channel blocked by badly maintained plate crossing. In this case the length of the crossing would be recorded as blocked

2.2 Earth Surface Water Channels

Earth surface water channels (ESWCs) and shoulders are rated for the whole length not just the inspection length.

2.2.1 Blocked

Vegetation, slips, soil, aggregate or general debris may block the ESWC. The channel is blocked if water ponds or it cannot effectively transport water from the pavement to cutoffs/culverts, or if it is blocked to such an extent that it causes the water to flow along the carriageway surface.

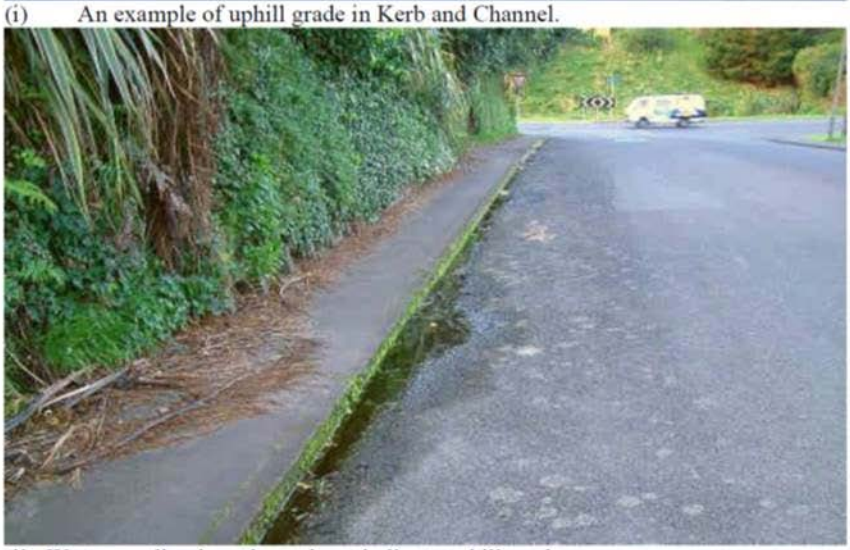
(i) ESWC blocked by a solid mass of vegetation.

2.1.5 Grade of Channel Incorrect

This rating is for recording the length of channel that is ineffective because the grade is uphill to the catchpit/sump or it has sagged causing water to pond onto the carriageway surface.

A level and string line may be used to check the grade of the channel if a grade problem is suspected.

(i) An example of uphill grade in Kerb and Channel.



(ii) Water ponding in a channel can indicate uphill grade

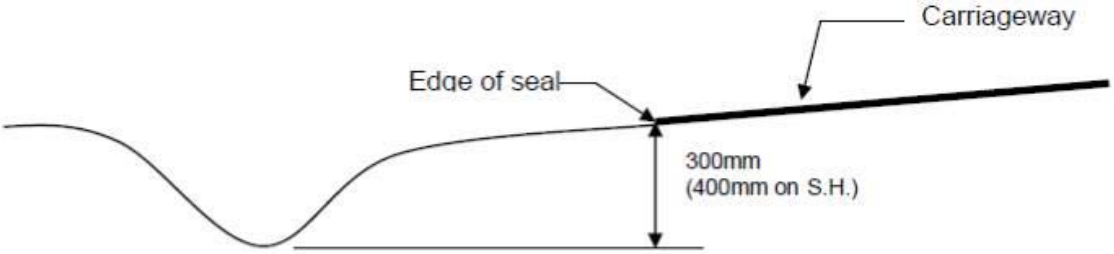
(ii) ESWC blocked by weed growth.

(iii) ESWC, culvert that has been blocked. The inlet for the culvert can just be seen. The length of the culvert is recorded as blocked

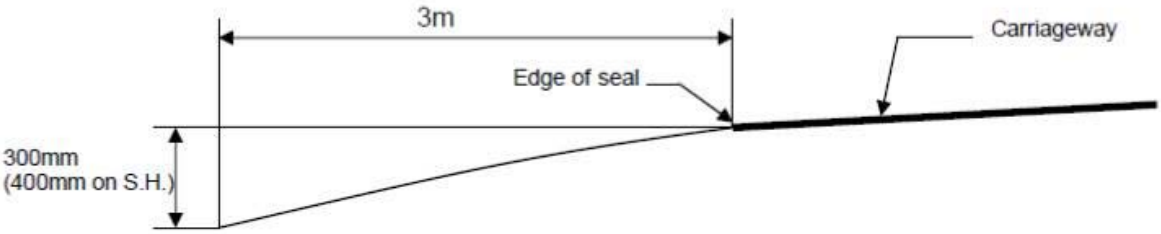
ESWC Blocked by a slip

2.2.2 Inadequate

This rating is for recording the length of ESWC where the depth of the adjoining pavement surface to the invert is less than 300mm (400mm for state highways).



Where there is no defined ESWC but the ground falls away from the carriageway, the depth is assessed at a point 3m from the edge of seal.



In some areas the minimum standard for channels may vary due to local conditions. Consultants should check with the client to establish any local variations.

(i) The photo above shows an inadequate ESWC.

(ii) Inadequate ESWC because of the depth of the channel. the weed growth in this photo would slow water down but would not cause it to pond

(iv) The photo above is a case where a SWC does not exist. It is rated as inadequate if there is not 300mm of fall 3m out from the edge of the carriageway

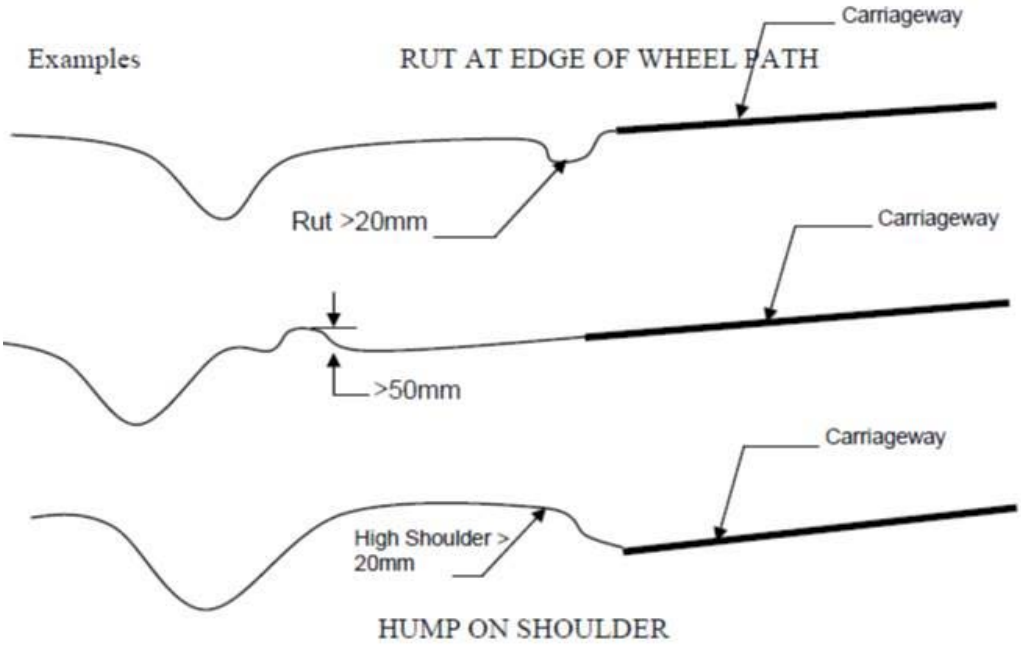
2.2.3 Ineffective Shoulder

This rating is for the length of shoulder where any obstruction, 20 mm or more within 1m of the carriageway prevents water flowing freely away from the carriageway surface.
OR: Any obstruction (e.g. windrow) that would cause ponding of water to a depth of >50 mm:

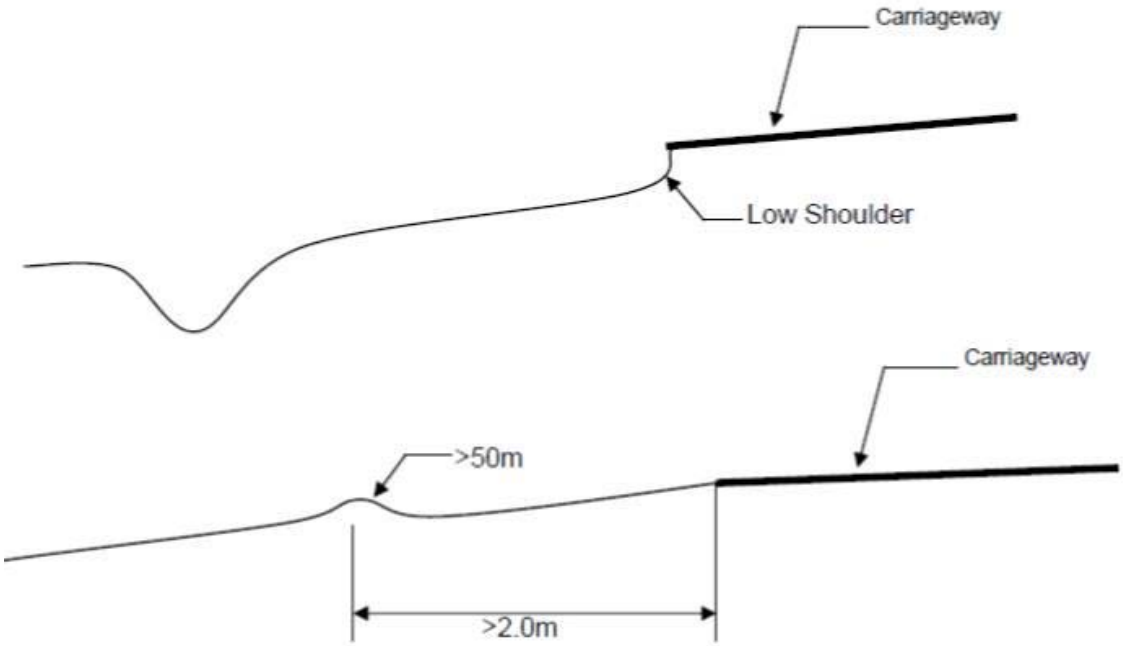
- Between the carriageway and the surface water channel
- Within 2 m of the carriageway surface where there is no formed surface water channel and the ground falls away from the carriageway

Typically high shoulders with edge rutting would be rated as ineffective shoulders. Low shoulders that do not impact the flow of water should not be rated.

Examples



LOW SHOULDER (SHOULD NOT BE RATED AS INADEQUATE)



(ii) Another common problem is when the shoulders have been metalled too high and so cause water to flow along the carriageway. If the grass on the shoulder is not mown or cleared a problem can arise with the collection of material so that the shoulder builds up above the carriageway level.

Ineffective Shoulder. In this case the shoulder is higher than the carriageway

Shoulder is ineffective due to the wheel rut along the edge of the carriageway

Ineffective shoulder due to deep tyre tracks.

Ineffective shoulder due to the high area between the carriageway and the ESWC

2.3 Alternative Drainage Rating

Several problems have been highlighted concerning the existing method of rating ESWC's. These are:

- disproportionate amount of time rating ESWC's compared to carriageway faults
- variations in local requirements
- importance of the results to the treatment selection process

In order to accommodate these issues, the following alternative methods are available at the discretion of the client.

2.4 Combined Rating

To better balance the effort in rating ESWC drainage with the use of data in the Treatment Selection process, the three defect types (ineffective shoulder, blocked SWC, and inadequate SWC) may be amalgamated into a single rating as inadequate drainage.

Double counting of the defect quantities is to be avoided where more than one defect occurs at the same location.
Recording of the length of inadequate drainage is by length in metres and is to be entered in the inadequate SWC field.
The option of recording as three separate defects is still available.

2.5 SELECTIVE RATING

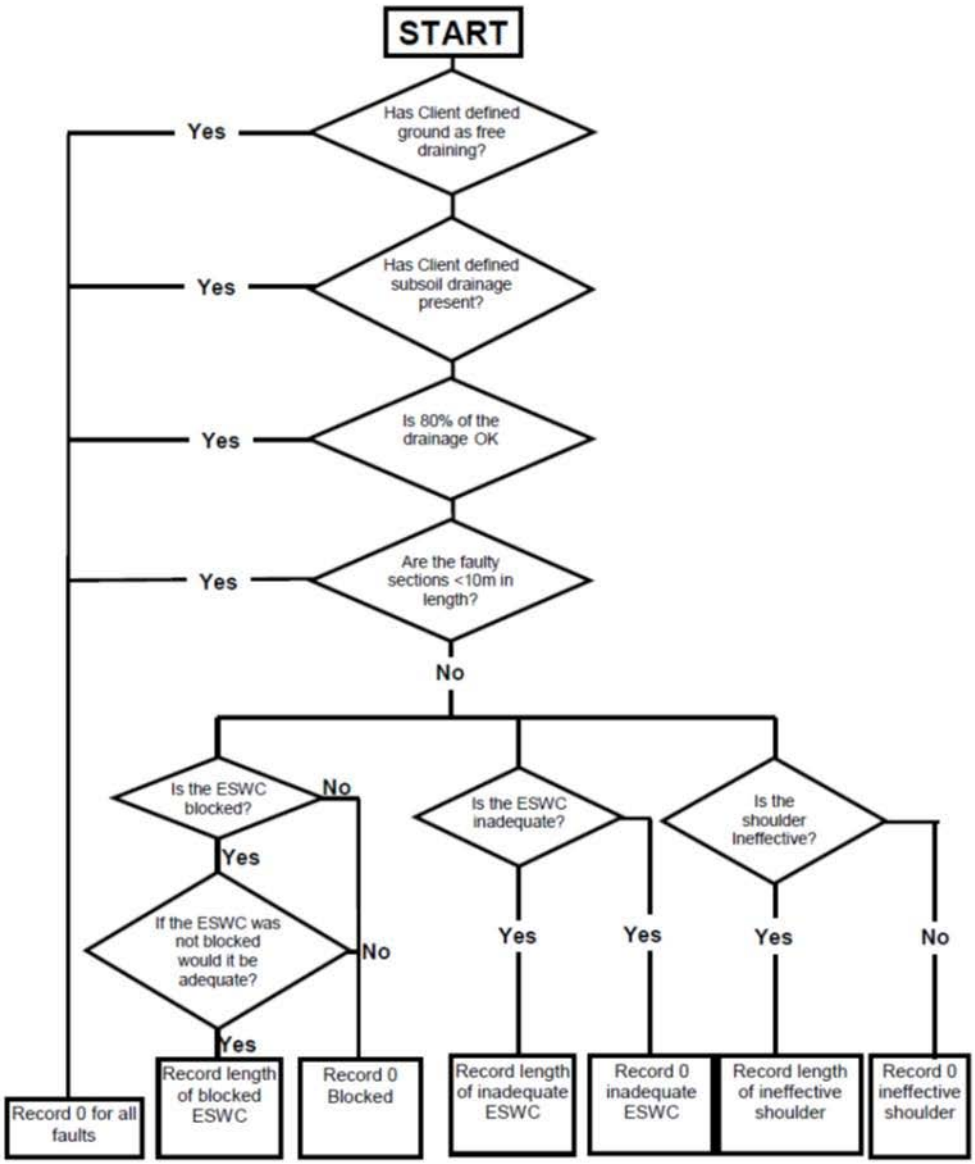
The client has the option of designating certain areas that should not be rated due to one of the following.

- Ground is free draining
- Sub-soil drainage is present
- An embankment situation
- Superelevation on curves

The rating forms for the inspection sections which fall in should be marked accordingly. For each form marked as above the raters should enter zero in the ESWC columns.
The rater makes an initial assessment as to whether greater than 20% of the treatment length ESWC is inadequate due to ineffective shoulder or inadequate channel. If less than 20% of the section fails then zero is entered in the *inadequate* column. If greater than 20% fails as above, but the failed areas are less than 10m in length, then zero is entered as inadequate
If greater than 20% of the length fails, and this is made up of areas greater than 10m in length then the length failed is recorded.

The flow chart overleaf illustrates the logic flow for this method.

2.6 ESWC RATING FLOW DIAGRAM



This process may be modified at the client's discretion

ESWC Condition Severity Indicator

This rating assigns a number on a scale of 1 to 3 to indicate the general severity of faults on the ESWCs.

1 Indicates low severity of faults as typified by ESWCs that comply with the conditions in the flow chart above.
I.e. 80% of the ESWCs in the treatment length show no faults and faulty areas are less than 10m long

Or

- Subsoil drainage is present
- The ground is free draining
- The client has specified that ESWCs are not required for this TL.

2 Indicates that the ESWC faults exceed the levels above. (Longer than 10m in length and Over 20% of the total length of channel is faulty. But there are no obvious water related faults on the carriageway or evidence of flooding or ponding on the carriageway, or shoulder

3 Indicates that the ESWC faults exceed the levels of level 1 and the following conditions also exist

- Boggy or rough water damaged shoulder
- Evidence of water ponding on the shoulder or carriageway
- Water related faults on the carriageway adjacent to areas of faulty ESWC