University of Southern Queensland
Faculty of Engineering and Surveying

Traffic Induced Moisture Entry Into Road Pavements

A dissertation submitted by

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ABSTRACT

Most Australian roads have experienced potholes and other types of pavement failures. An excessive amount of moisture in road pavements is often a major contributing factor to these pavement failures. Queensland has a very large road network connecting rural with urban and dense populations with sparse populations.

This project seeks to investigate the penetration of water into road pavements due to the compounding nature of traffic. This project will determine if moisture enters the pavement through the compounding nature of traffic and quantify the extent of the problem.

In Australia sprayed seal surfacing are used on most rural, arterial and rural local roads. Tyre pressures, traffic volumes, speed, loads and the amount of heavy vehicles have increased dramatically over time. This has led to an increase in pavement failures particularly in the wheel paths. An obvious cause of these failures is excessive amounts of moisture in these failure zones.

Data provided by Queensland Department of Transport and Main Roads – Toowoomba and samples that were collected were analysed. As a result of this analysis it was found that there was more moisture in the wheel paths compared to between the wheel paths. Although the majority of locations had higher moisture content in the outer wheel path than the inner wheel path, infiltration through the shoulder was an unlikely cause due to the moisture content in the inner wheel path shoulder being less than that of the outer wheel path in some cases. It is also evident that the more re-seals there were, the less moisture content there was within the pavement.

The results of the permeameter tests revealed that spray seals are classed as ‘permeable’ under atmospheric pressure. Under pressure at the same locations the classification increases to ‘moderately free draining’. This indicates that under more realistic traffic conditions, moisture does penetrate spray seals.

The results of this study show that moisture does penetrate the pavement due to the compounding nature of traffic.

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CERTIFICATION

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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ACRONYMS

AADT	Average Annual Daily Traffic
Austroads	Australian Roads and research Board
BWP	Between the Wheel Path
DG	Dense Graded
DGA	Dense Graded Asphalt
GBD	Gatton Bypass Duplication
IWP	Inner Wheel Path
M/C	Moisture Content
OG	Open Graded
OGA	Open Graded Asphalt
OWP	Outer Wheel Path
QDTMR	Queensland Department of Transport and Main Roads
SM	Stone Mastic

Chapter 1 INTRODUCTION

1.1 Background

Most Australian roads have experienced potholes and other types of pavement failures. An excessive amount of moisture in road pavements is often a major contributing factor to these pavement failures.

Queensland has a very large road network connecting rural with urban and dense populations with sparse populations. All of these interconnecting areas rely on roadways for travel, communication, freight etc.

QDTMR is responsible for the state-controlled road network which consists of more than 34 000km of the state’s 177 000km road network. This may only be 20% of the Queensland road network; but this component of the network carries more than 80% of its traffic (Guide to Queensland Roads, 2009). Freight movement is largely responsible for heavy vehicles on road networks. Due to the amount of heavy vehicles using these roads, there is a crucial need to provide durable and reliable surfacing techniques to prevent damage to the road pavement.

For roads with lower volumes and in particular rural roads, sprayed sealing is usually adopted as the primary surfacing technique. Roads in the Darling Downs region are primarily spray sealed roads.

The study ‘Permeability’s of Chipseals in New Zealand’ has concluded that water penetration in road pavements is one of the issues causing road defects. Infiltration of water into the pavement through the traffic movement may act as an accelerator when it comes to pavement defects. The weight load and tyre patterns of heavy vehicles combined with wet weather may contribute to pavement flaws.

1.2 Significance

This study focuses on the water penetration through pavement surfaces due to the forces of traffic. It is a commonly recognised problem and has been emphasised through the report titled 'Permeabilities of Chipseals in New Zealand' which says: '*The actual amount of water absorbed will depend on the rainfall and on the amount of heavy traffic'* (Ball& Towler, 2001). This penetration may be through either asphalt, or sprayed surfaces. The extent of this problem has yet to be proven in the Toowoomba region.

Water penetration into road pavements is an ongoing problem throughout the world. Water has been known to penetrate the pavements through water tables, infiltration into shoulders, from lower soil layers, seepage from higher ground, and infiltration through the pavement surface. The control of this moisture is essential to ensure that road pavements are durable and have predictable performance throughout the life of the road.

A study made from New Zealand state highway system found that the two major types of surface distress that lead to the decision to reseal are alligator cracking of the seal and flushing on chipseal roads. It has been found that chipseals are more permeable than first thought (Towler & Ball, 2001).
From the Transfund research reports No. 122 (Ball & Patrick, 1998) and 156 (Ball, Logan & Patrick, 1999) it is evident that there are at least two main causes of flushing:

> **Trafficking**. This is immediately apparent because flushing commonly appears first in the wheeltracks. A subsequent investigation of the relative effects of traffic levels, seal type, seal binder rheological properties and the pavement construction beneath the top seal was reported in Transfund Research Report No. 122
> An investigation of the effects of water in the flushing processes in chipseals was reported in Transfund Research Report No. 156.

> Moisture rising through the pavement beneath the seal. This results in miniature 'volcanoes' appearing where bubbles of binder form above the water vapour and then collapse as the vapour breaks through and escapes. This phenomenon can appear in seals that have significant texture depth (i.e. it is not directly associated with loss of texture depth from trafficking), with the binder rising to the surface in small pockets which eventually coalesce to cause flushing. This type of flushing can be found anywhere on a road surface, although it is often more prominent where the pavement is trafficked.

It is evident that water does penetrate seals through tyre pressure as stated below by the Transfund Report - Permeabilities of Chipseals in New Zealand.

> The predominant pavement type used in New Zealand State Highways is an unbound granular sub-base and basecourse, with a chipseal wearing course. These pavements are very susceptible to the presence of moisture, which may induce both cracking and flushing of the surface under traffic and climatological stresses. It has been believed in the past that chipseals were impermeable provided there were at least 1.5L/m^2 of bitumen. However, recent tests have suggested that water may gain access to the pavement undersurface by being forced through from the top of the chipseal by tyre pressure …Core samples were taken from a selection of seals and the water permeability of these seals measured under pressure. The results support the proposition that water access occurs through the upper seal surface and it may be a possible factor in causing chipseal distress. (Towler & Ball 2001 p. 1).

Therefore it is possible that seals are not entirely permeable in the Toowoomba area, and further investigation should be undertaken to see if the same phenomenon occurs.

A report by titled '*Effects of Crack Width and Permeability on Moisture-Induced Damage of Pavements'* (Chen et al, 2004) based in Taiwan revealed that moisture does penetrate Stone mastic asphalt, dense graded asphalt and porous asphalt, and the relationship between permeability and air voids is exponential. Therefore as asphalt content is increased, and the air void content is reduced, the asphalt becomes more impermeable. From this report, both dense and stone mastic asphalt are shown to be impervious when air void content is below 7%.

The testing report titled ‘Investigation of the Observed Distress on the Stone Mastic Asphalt Surfacing’ on the Bruce Highway (North Coast Hinterland District) has revealed that asphalt permeability is minimal when under heavy trafficked conditions. Under the correct mix composition and compaction, the SM14 layer, DG14 layer and the DG20 layer were almost ‘impermeable’.

> For site 1, only one of the eight test locations (ie about 12% were found to be “permeable” with the remainder being classified as almost “impermeable”. (Ramanujam et al, 2002)

The accelerated deterioration of pavements due to moisture has led QDTMR and other road contractors to look for more economical solutions to these problems.

After a comprehensive literature review sourced both from Australia and overseas, studies show that there is ample data supporting the notion that water penetrates into road pavements. Research reports from the Transfund Research Centre have proven very helpful in establishing the effects of traffic induced moisture into road pavements. Hong Kong’s ‘Analysis of Pavement Residue Properties Under Moisture Induced Attack at Tuen Mun Highway, Hong Kong’ (Hung, Wong & Tang, 2003), ‘Effects of Crack Width and Permeability on Moisture-Induced Damage of Pavements’ (Chen, Lin & Young, 2004), and ‘Forensic Investigations of Roadway Pavement Failures’ (Chen & Scullion, 2008) have proven to be very useful in gathering data for this report.

Despite all of the information that has been gathered, there is very little that has been compiled from Australia, therefore this project aims to provide data to confirm that traffic plays a large part in moisture entry into road pavements within the Australian environment.

1.3 Aims and Objectives

This study will analyse data collected world-wide and compare the results with those acquired from this project. Key aspects such as AADT, percent commercials, location, climatic conditions and type of seal will be examined.
This project aims to investigate the penetration of water into road pavements due to the compounding nature of traffic specifically in the Toowoomba/Darling Downs region. It will focus on commercial vehicles and the types of tyres that are used as well as the loads associated.

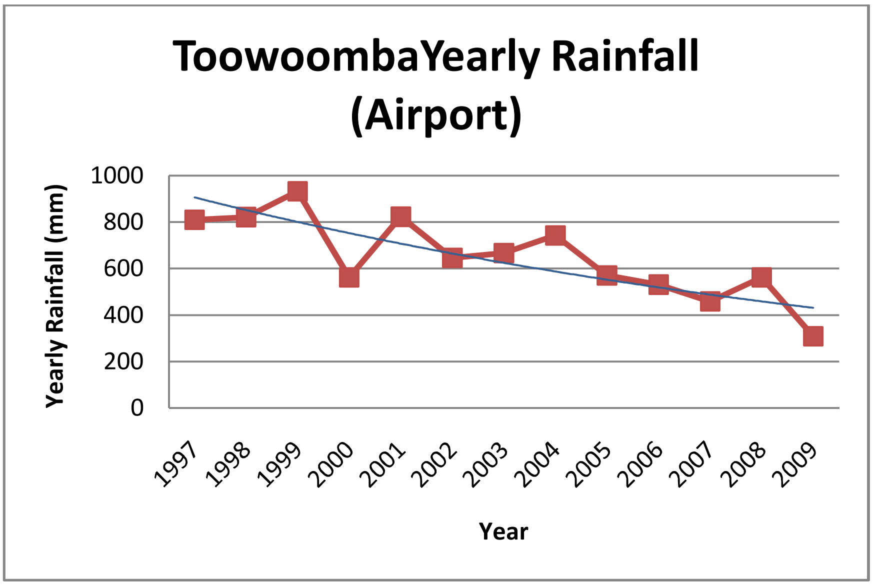
From the literature review and some testing data it is aimed that water penetration into spray seals will be the main focus for this report. The objective of this study is to determine if there is significantly more pavement moisture located in the wheel path of roadways in comparison to non-trafficked areas within the road. From this, a further analysis of AADT and the percentage of heavy vehicles using the road, will determine the extent to which heavy vehicles contribute to the moisture penetration. At the conclusion of this study it is anticipated that through various data collection methods it will be clear that the M/C in the wheel paths will be higher than between the wheel paths.

1.4 Location

Toowoomba Queensland is located approximately 90 minutes west of Brisbane. Toowoomba experiences a cooler climate with much less humidity than coastal areas in Queensland. The climate pattern is described as having wet summers and dry winters. The average summer temperatures range from 16-27 degrees Celsius and the winter temperatures range from 5-18 degrees Celsius.

Toowoomba's recent rainfall has decreased over the past 13 years as shown in Figure 1.4.1. The average yearly rainfall at the Toowoomba Airport over the past 13 years is 648.5mm and over the past 136 years the average is 944mm (Bureau of Meteorology, 2009). This is significantly higher than the past 5 years where it has dropped from 741mm to approximately 300mm. This trend shows that yearly rainfall continuously decreases with time.

Due to minimal recent rainfall, testing data may not be as accurate as it would be during a wetter period and alternative data sources such as permeameter tests, probe data and existing data will also be analysed.



(1) Figure 1.4.1 – Toowoomba yearly rainfall

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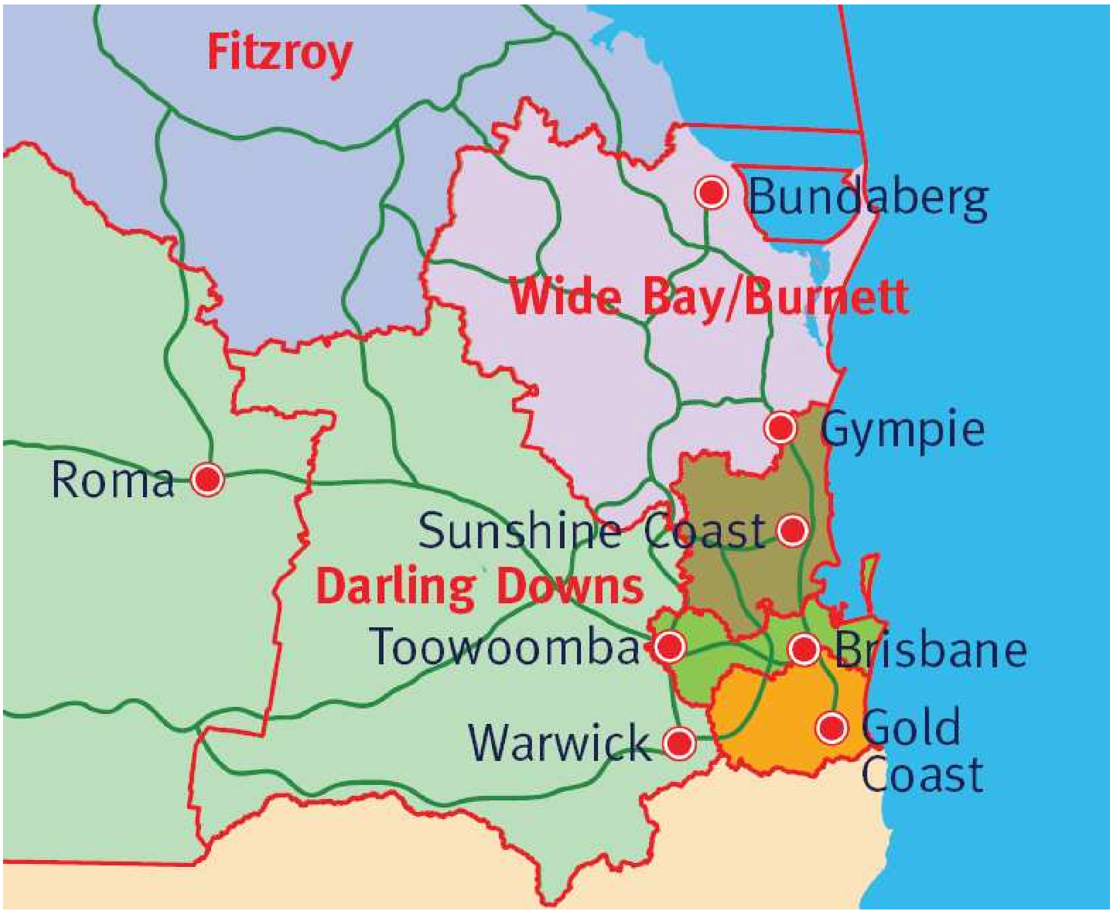
This study will test relatively high commercially trafficked roads, and compare these to low commercially trafficked roads. This will provide a comparison of the different AADT's and therefore assist in finding the root cause of moisture entry into road pavements. Testing will be located throughout the Toowoomba area with test samples gathered from various roads and chainages. The samples at each location will be taken from the wheel paths, and in between the wheel paths respectively to compare M/C between a trafficked area and a non-trafficked area. Moisture data previously acquired by QDTMR will also be analysed.

The Darling Downs Regions and the Toowoomba District office location is shown below in Figure 1.4.2.



(2) Figure 1.4.2 – Darling Downs Regional boundary for QDTMR

Chapter 2 LITERATURE REVIEW

2.1 History of Roads

The first indications of manufactured roads are the stoned paved streets in Ur - Iraq (4000$_{\text{B.C.}}$), corduroy roads used in swamps in Glastonbury – England (4000$_{\text{B.C.}}$) and brick paving in India ((3000$_{\text{B.C.}}$). By around 2000$_{\text{B.C.}}$ metal tools were available which meant that villages could shape stones for paving roads, streets and paths. The first stone road was formed around this time by the Minoans. This road ran for 50km and included 200mm thick pavement made from sandstone pieces which was bound together by clay-gypsum mortar (Lay 1992).

From this, other countries began their road construction with the first recorded Asian road builders in 1100$_{\text{B.C.}}$ constructing a mountain road for King Tiglath-pileser using bronze pick axes (Lay 1992).

European roads involved the Glastonbury corduroy road through swampy plains linking settlements with an island in the swamp. This road was 2km in length using longitudinal logs and planks to form a path.

Roman roads were the pinnacle in ancient road construction with the exception of the Chinese. The Roman’s achieved well structured roads, bridges and tunnels. This advanced road network was inspired by the incentive of military, economic and administrative advantages. To produce a stronger road, the Romans used lime cement (300$_{\text{B.C.}}$) and pozzolan cement (200$_{\text{B.C.}}$) for their mortar. From this the Romans then added aggregate to the mortar to form a strong concrete. This engineering marvel was then forgotten for over a millennium after the fall of the Roman Empire (500$_{\text{A.D.}}$).

Roman roads construction process began with a statumen course of up to 500mm placed on the natural formation. From this, 50mm flat stones were then placed on top of the statumen course followed by a cement-stabilized course of 250mm thick which composed of smaller stones. An additional mortar layer or nucleus course up to 250mm thick is added which consisted of even smaller broken down stones well compacted into position. If the traffic was expected to be heavy, there would be a wearing course called the sumna crusta or pavimentum of large 600mm by 250mm thick carefully fitted hexagonal flagstones. The pavement is constructed so it has a cross fall and a longitudinal drainage. These roads have been criticised that they often look like walls, however they were skilled enough to create such a durable road, aesthetics was not their priority. (Lay 1992).

The road builders of the late 1800s depended solely on stone, gravel and sand for construction. Water would be used as a binder to give some unity to the road surface. Modern tarred roads were the result of the work of two Scottish engineers, Thomas Telford and John Loudon McAdam. Telford designed the system of raising the foundation of the road in the center to act as a drain for water. Thomas Telford (born 1757) improved the method of building roads with broken stones by analysing stone thickness, road traffic, road alignment and gradient slopes. Eventually his design became widely used for many roads. John Loudon McAdam (born 1756) designed roads using broken stones laid in symmetrical, tight patterns and covered with small stones to create a hard surface. McAdam's design, called "macadam roads," provided the greatest advancement in road construction during his time in the late 1700 and early 1800’s. (Hindle B, 1990)

During the mid 1800’s it became apparent that an efficient road system in Australia was needed to transport agricultural produce, ore from mines, and residents and labourers around the rapidly expanding colony. In spite of this need, rough unmade roads, a lack of bridges, floods and rain, made travel a hazardous undertaking in Adelaide until the first constructed roads in 1837. Today our life style remains dependent upon a suitable road network. (Early Roads, 2003)

Colonel William Light surveyed Adelaide’s first roads in 1837, but it was mostly left to the colonists to initiate early roadworks. The first bridge, built by Alfred Hardy over the River Torrens near the present Morphett Street Bridge in 1839, was funded by public donations. The South Australian Company paid for the construction of the first major roadwork in the colony – an extension of the existing roadway near the port to the Company's new wharf further north.

At the time of original surveys most roads were placed on a regular pattern following the land surveys without thought for the terrain. Bullock and horse drawn drays often faced steep inclines making travel a difficult and dangerous undertaking.
Since these pioneers in transport engineering, engineers have sought to develop improvements and advancements in road construction and surfacing techniques.
This project will seek to continue these advancements through improved road and seal construction.

2.2 Surfacing Treatments

There are many road surfacing treatments used all over the world. There are 3 major surfacing treatments used in Australia, and the Toowoomba regions in which this study will focus on. These surfacing treatments are:

- Spray Seal/ Chip Seal – Sprayed bituminous seal widely used due to ease of construction and cost. See section 2.2.1.
- Dense Graded Asphalt (DGA) – Low air voids, generally used in low traffic areas, or heavy vehicle turning areas. See section 2.2.2.
- Open Graded Asphalt (OGA) – High air voids allowing water to flow through the layer to prevent vehicle spray in wet weather. See section 2.2.3.

2.2.1 Sprayed Seals/Chip Seals

Chip sealing is one of the oldest bituminous surfacing methods and most successful of road surfacing due to its ease of placement, and high performance. In many countries it is used for high volume roads. A chip seal is an application of binder in the form of emulsion or hot spray and an application of aggregate. The aggregate is the running surface of the road which means shape, grading, stone embedment, amount of binder, application conditions and stone cleanliness are critical.

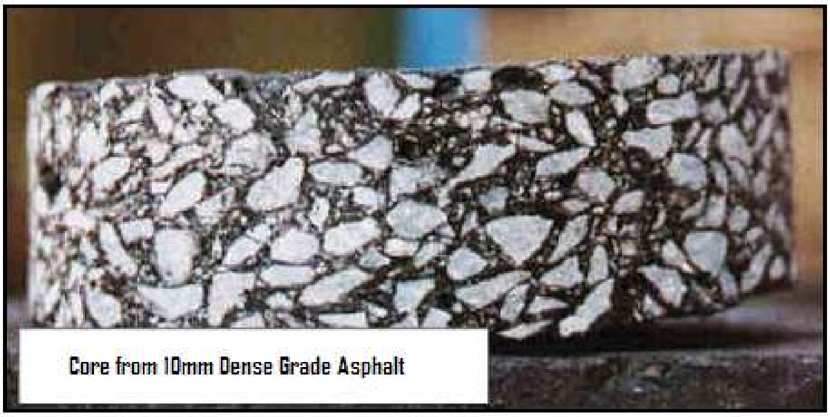
Chip seals are used for restoring skid resistance, protecting a surface from ageing, restoring a running surface, eliminating dust, and sealing gravel pavements (re-seals). Different stone sizes are used for different surface textures and different traffic situations. The aggregate size is usually sand, 7mm, 10mm, 14mm, 20mm or 25mm. (Austroads,2004)

(3) Figure 2.5.1 – Typical 10mm chip seal surface

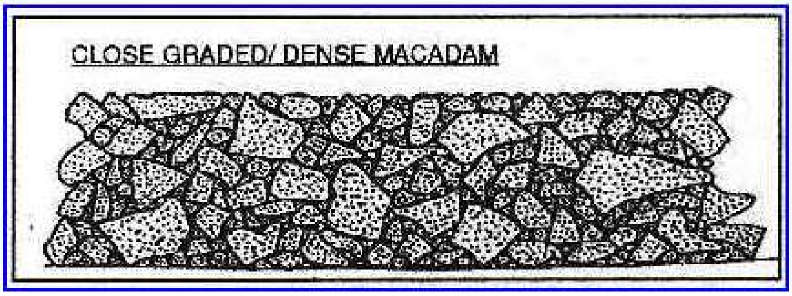
2.2.2 Dense Graded Asphalt

The most common type of asphalt is dense graded asphalt (DGA) which is a mixture of continuously graded aggregates, sands, filler and bitumen which is mixed and placed while hot. When compacted it has relatively low air voids and has a tight surface of close texture. The workability of DGA is dependent on its temperature and therefore it is recommended that the layer be placed while hot.
By varying the aggregate combination to provide a range of different air voids, and using different grades of binder, asphalt properties can be adapted to suit applications from low-traffic areas to highways and heavy duty areas. (Austroads 2003)

A core of 10mm dense graded asphalt (Figure 2.4.1) is shown below as well as a cross section (Figure 2.4.2).



(4) Figure 2.4.1 – Core sample of dense graded asphalt



(5) Figure 2.4.2 – Cross section of dense graded asphalt

Common modes of distress for asphalt layers are:

- Permanent deformation under heavy traffic due to insufficient stability
- Cracking due to fatigue
- Ravelling due to oxidation and hardening of the binder

The report, 'Effects of Crack Width and Permeability on Moisture-Induced Damage of Pavements' (Chen et al, 2004) states that there is evidence that water penetrates the DGA layer when there is greater than 7% air voids. 'The intrusion of water can be greatly reduced when the asphalt mixture is properly compacted to an air void level of 7% or less.

Permeability's of Chipseals in New Zealand, states that the thinner layers of DGA are clearly permeable, but layers that are 20-30mm did stop water. Therefore to some extent water must penetrate the DGA to a certain depth.

2.2.3 Open Graded Asphalt

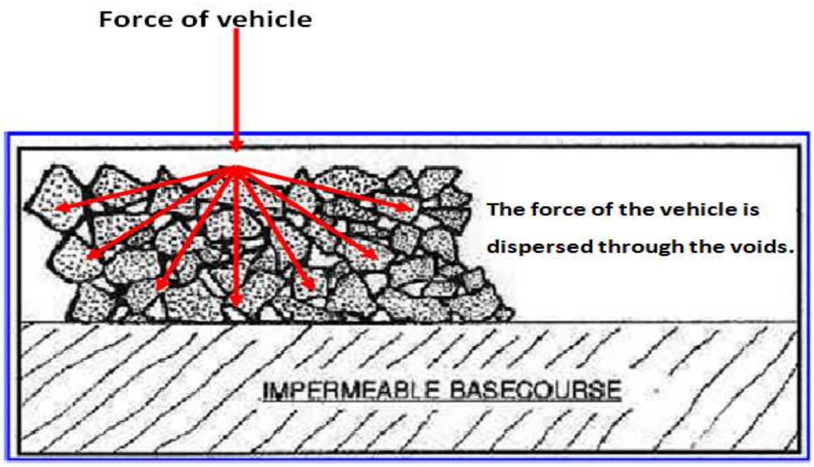
Open graded asphalt is used as a wearing course to provide increased safety in wet weather. The porous nature of the open graded asphalt (OGA) allows water to flow through the asphalt reducing the surface water and therefore increases skid resistance, reduces spray and reduces noise during rain. Open graded asphalt is an asphalt mix with little to no fines, and therefore has large air voids (18%-25% voids) to allow surface water to drain away. The size of the aggregate within the open graded mix is usually 10mm or 14mm. (Austroads, 2003)

If there is no waterproofing layer placed underneath the OGA then there is a high possibility that water will enter the underlying layers or pavement. In most cases a water-proofing seal or a uniform heavy tack coat is placed prior to the OGA surfacing to prevent this water penetration.

It is also important to provide an outlet for the water that enters the OGA seal. If there is no outlet, dust and debris may build up and reduce the desired performance of the OGA.

(6) Figure 2.3.1 – Core sample of open graded asphalt

As seen above, there are approximately 20% air voids allowing the force of the water to disperse through the layers and reach the impermeable seal at the bottom of the OGA.



(7) Figure 2.3.2 – Cross section of open graded asphalt

Due to the large number of air voids in OGA there is no direct pressure from the water being forced into the pavement by the truck tyre as stated previously. Therefore by the time the water reaches the impermeable chipseal layer, the force is relatively low and therefore forced water penetration is unlikely.

For there to be any water force to be applied to the layer, there first needs to be a layer of water to be pushed down. As the OGA is porous, the water filters through and does not rest on top of the road surface. Instead it filters to the impermeable layer and flows to the kerb or water outlet away from the traffic lanes. This then provides minimal surface water leaving no forced moisture into the pavement. There is too much water movement within the OGA for the water to be trapped and be forced into the pavement. (Nichols, 1998)

It can be assumed that this type of pavement has little to no contribution to traffic induced moisture.

2.3 Construction Techniques

2.3.1 Surface Preparation

Before any bituminous surfacing is applied, there first needs to be surface preparation. The shape, compaction, M/C, sweeping and watering of the surface are necessary procedures that need to be checked before the surfacing is placed.

The granular pavement must provide a smooth ride, as a seal will not correct existing irregularities. To achieve this, the surface should be constantly checked using a straight edge to measure the variations in surface levels. The surface should be free from bumps, hollows, and sudden changes of grade.

Compaction of the pavement should take place from the bottom up. Compaction should be pneumatic tyred, multi-wheeled, steel wheeled and rolled.
Moisture content of granular pavements affect both the strength and bearing capacity of the pavement as well as the effectiveness of priming and primer-sealing materials.

The prepared surface should be swept with a rotary broom to remove surface dust and to provide a surface that is free of foreign material, with the larger sized stones at the surface of the pavement exposed but not loose or dislodged (Figure 2.3.1.1).

If the pavement surface is too dry, the bitumen will not coat the surface evenly. A light coat of water from a water truck will wet the road surface allowing the bitumen to bond to the road surface properly. (Nichols, 1998)

(8) Figure 2.3.1.1 – Sweeping the surface in preparation for spraying bitumen

2.3.2   Sprayed Seal / Chip Seal

First the application of bitumen is applied after the surface has been moistened. Before spraying the bitumen, the pavement temperature will be checked to determine the appropriate concentration of cutter oil. The bitumen will then be applied at a specific spray rate depending on the location, traffic and weather conditions of the road. It is a general process for the use of protective paper at the start and end of the spray run for protection of adjacent structures, drains etc.

After the bitumen has been applied, the aggregate is then placed as soon as possible (Figure 2.2.3.1). If the aggregate is placed too late, it will not bond to the bitumen properly. The aggregate is applied at a specified spread rate depending on its size.

Rolling is to commence as soon as possible after the aggregate spreading, paying special attention to the number of roller passes. Rolling is to continue until the aggregate has properly bonded. The traffic is then allowed to drive over the new surface at low speeds until the loose stones have been removed by sweeping the road surface. (Austroads 2004)

(9) Figure 2.3.2.1 – Aggregate spreading onto sprayed bitumen

2.3.3 Dense Graded Asphalt and Open Graded Asphalt

The asphalt mix usually consists of a mixture of continuously graded aggregates, sands, filler and bitumen which is mixed and placed hot. Open graded asphalt is manufactured with a large proportion of course aggregate and only a small amount of fine aggregate resulting in a high void content.

After the surface preparation a thin layer of bitumen (tack coat) is applied to promote bonding. The asphalt is then heated and laid over the road surface at a specified depth. The asphalt can be laid over a sprayed seal to prevent water penetration into the pavement layers. After the application of the asphalt layer, it is then compacted using a vibrating roller until optimum compaction is achieved. (Nichols, 1998)

2.4 Surfacing Failures

Deficiencies in road seal surfaces can occur as a result of pavement support deterioration of base material. Pavement deficiencies can include:

- Cracking
- Deformation
- Rutting
- Corrugation
- Shoving
- Depressions
- Potholes

2.4.1 Slippage Cracking

Slippage cracks are a result of tearing of asphalt surfacing arising from poor bonding with the pavement. This poor bond is because of moisture in the underlying layer. Where there is a lack of bonding, slippage cracks will occur in areas where vehicles frequently brake or accelerate. Adjacent areas of the pavement are also easily stressed and material breaks loose. This leads to potholes. (Ayers, 2008)

2.4.2 Rutting

Rutting is the vertical deformation in the wheel path caused by moisture and traffic loading. It occurs due to deformation in the pavement layers. Excess moisture weakens the particle bonds and deforms the material, therefore creating a rut.

2.4.3 Depressions

There are some areas within the pavement which are lower than surrounding surfaces. Depressions generally occur as a result of settlement or volume change in the subgrade or subbase material because of:

- Service trenches
- Soft or poorly compacted areas
- Embankment material
- Change of M/C due to water penetration or drying out of the soils

2.4.4 Potholes

Potholes are local failures of the wearing surface caused by the action of traffic and weather. The development of potholes often coincides with rain. Possible causes include:

- Loss of surface materials by aggregate stripping or ravelling
- Moisture entry through the seal
- Disintegration of the seal due to large loads

Minimising water will help minimise potholing. (Ayers, 2008)

There are many other pavement deficiencies; however the above are the ones that relate to moisture entry into the pavement layers. ‘Permeability’s of Chipseals in New Zealand’ bases the study on chipsealed roads. With 66 percent of Australia’s sealed network being chipsealed, it is an area in which needs focus (Austroads 2000). As chipseals have the thinnest layer before reaching the pavement surface, there is more risk that water may penetrate into the pavement through the seal.

If bleeding in the wheel path occurs, it can be predicted that there will be deformation in that particular area in the future. This is because there is little aggregate binding to the bitumen creating less air voids between the vehicles wheel and the seal surface. Therefore there is a higher chance of water being pushed into the pavement through the seal.

As the following quote indicates, it has been proven in Hong Kong that there is less possibility of water penetration if there is more than one layer of chipseal on the road. This suggested that water does penetrate the seal surface due to aggregate properties, mix design, construction procedures, environmental conditions and traffic.

(Hung et al, 2003 p. 32) says:

> Moisture induced damage is found to be a cause of pavement defects and the moisture attack is more prominent on the pavement along the climbing hillside direction owing to the higher chance of rainwater accumulation. Resurfacing is an effective maintenance strategy to prevent further moisture attack and maintain the structural integrity of the pavement. It appears that there is a direct relationship between the number of resurfacing and the resistance to moisture induced damages. The more the number of resurfacing, the better is the resistance to moisture induced damages.

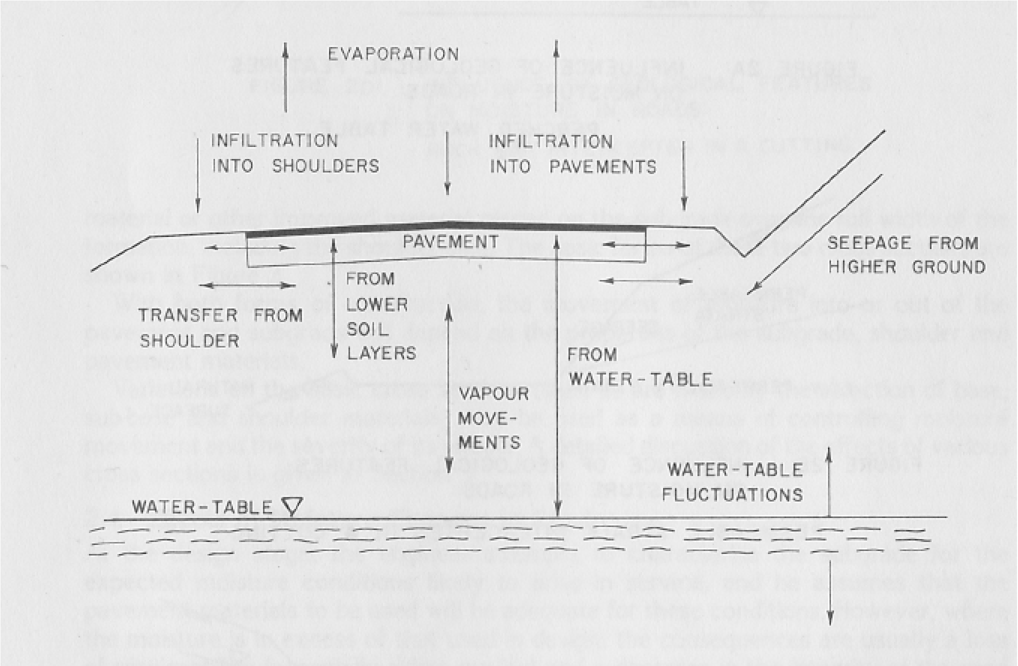
2.5 Causes of Defects

2.5.1 Water/Moisture Penetration

Water/moisture can infiltrate the pavement in many ways which will eventually influence the road structure. The amount of moisture in any road usually results from one or more of the following:

- Water on verges, shoulders and pavements. Permeable seals and surface cracking will assist in water infiltration.
- Water flowing or standing in table drains, catch drains, median areas, traffic islands, or adjacent to the road.
- Leakage of water supply and drainage lines.
- Passage of water through construction joints in pavements, and back and front of kerb and channel, between old and new pavements and behind bridge abutments.
- Movement of subsurface water from aquifers.
- Water from rainfall or excessive watering during formation and pavement construction, and roadside watering or irrigation.
- Longitudinal seepage within pavements and subgrades, particularly in cuttings and sag vertical curves.
- Fluctuation of water tables levels.

Most of the above points can be controlled by installing table drains, catch drains, kerb and channel, bituminous surfacing, road geometry, shoulders, embankments, barriers, subsoil drains, rubble drains and stabilising the pavement layers. A diagram of the infiltration techniques is located below in Figure 2.1.1.



(10) Figure 2.1.1 – Means of moisture movement on road pavements (Ayers 2005, p.5.3)

If water does happen to penetrate the pavement, the consequences are usually a loss of serviceability and a decrease in the integrity of the road with an increase in maintenance. Various forms of pavement damage including rutting, cracking, potholes are likely to occur after long periods of rain on sections of road which do not drain well.

For this study, we will focus on the infiltration through bituminous surfacing. Both asphalt and bituminous seal are intended to be impermeable. However they are often quite permeable and may develop cracks which will allow water to penetrate the lower parts of the pavement. Water often enters the pavement through these defects. The compounding nature of traffic continues to make the situation worse. Once a crack is formed and water has access, the nature of the traffic moves the water in and out of the cracks which eventually disrupts the small fines bound into the pavement therefore losing the bonding and more and more fines are removed until a pothole is formed.

It is evident that the compounding nature of traffic and in particular heavy vehicles has a significant effect on moisture entry into the road pavements. It is also evident from the report ‘Permeabilities of Chipseals in New Zealand’ (Ball, Towler, 2001), and Analysis of Pavement Residue Properties Under Moisture Induced Attack at Tuen Mun Highway, Hong Kong’ (Hung et al, 2003) that seals are permeable even under static pressures – ‘Moisture induced damage is found to be a cause of pavement defects’ (Hung, Wong & Tang, 2003). This report revealed that water does penetrate the chipsealed layers at lower pressures than that of a typical truck as stated below:

> *The water permeability of seals was measured under pressure using an apparatus designed and constructed for the Transfund New Zealand Research Report No.156 (“Flushing processes in chipseals: effects of water”). The apparatus was designed and constructed to apply a head of water to the surface of seal samples. The head can be pulsed regularly at pressures typical of those caused by truck tyres on wet roads, and the rate of ingress of water measured. Experience showed that samples were permeable even under static pressures, and the work described here was carried out under these conditions…*
>
> *…The proposed method of checking this possibility was to apply pulsed water pressure at a realistic level (around 500kPa, typical of truck tyre pressures) to the surface of lightly bleeding seals retrieved from the field, and to measure the degree to which water penetrated the surface. Subsequently it was found that samples were generally permeable even under static pressures of much lower magnitude, and flow rates at high pressures were too high to accurately measure with the apparatus available. Consequently the work to be described here was carried out at static water pressures up to 300kPa.*
>
> *(Towler & Ball 2001, p. 2)*

These reports suggest that water permeability into road seals may be more extensive than first thought. These facts may be widespread and have the same effects in Australia. Through a series of tests in the Darling Downs Region, this may be confirmed.

2.5.2 Heavy Vehicles

Vehicle loads are transmitted through the suspension to the tyres and on to the road surface and into the pavement. These loads are then distributed from the pavement layers to the subgrade soil. The heavier the vehicle, the more force it will impact into the road pavements. This study therefore bases its research on the effects of heavy vehicles on road pavements.

From the research report ‘Effects of Heavy Vehicle Characteristics on Pavement Response and Performance’ (Gillespie 1992 p. 52) said: ’The maximum axle load is the strongest determinant of fatigue damage on both rigid and flexible pavements.’ Therefore the vehicles with the heaviest axle loads are classed as major contributors to the damage of Australian roads. The durability of roads is dependent on the type of truck, weight, speed, local geology, and climate. On an average road it can be said that it takes approximately 10 000 cars to produce the same amount of pavement damage as one single axle truck loaded to about standard maximum allowable axle-load. This is proven using the Fourth Power Law (Ron Ayers 2008 p. 5.7). This gives reason as to why roads are designed for the amount of commercial and heavy vehicles that utilise them.

Water has a higher probability of entering the pavement layers if there is a combination of 3 factors:

1. Wet weather
2. Tyre/tread that is not designed to release water
3. The force that is applied by the vehicle onto the pavement surface

If the above 3 points are combined, then there is a higher probability that water will enter the pavement through the seal. For example if it is raining to an extent where the road surface has a reasonable layer of water covering it and a fully loaded heavy vehicle travels over it with tyres that are designed to wear slowly rather than disperse water, then water will be forced through the seal and into the pavement. The types of truck tyres and the forces applied to the pavement are explored in sections 2.5.2.1 and 2.5.2.2.

2.5.2.1 Tyres/Tread

There are many different types of tread for all types of vehicles. After a brief analysis comparing the tread on trucks tyres and car tyres, it can be assumed that truck tyres do not disperse water as well as car tyres due to different tread configurations, as shown below.

Tyre A **Tyre B**

(11) Figure 2.2.1.1 - Typical truck tyres – (www.goodyear.com.au)

Tyre A – Haul Tyre (trailer tyre) Details

- Strong, solid shoulder ribs
- Reduces cupping and irregular shoulder wear
- Penetration protectors
- Resists stone retention for increased casing re-treadability
- Optimised mould shape and construction
- Reduces running temperature for durability

Tyre B – Haul Tyre (trailer tyre) Details

- Rugged casing construction
- Reduces casing fatigue with heavy loads at highway speeds
- 5-rib tread design with heavy shoulders
- Resists uneven tread wear
- High rubber-to-void ratio
- Provides extended kilometres

The patterns of both tyres are designed for low platform trailer use. They have a high volume of rubber to be worn and solid shoulders to resist uneven wear. They are premium trailer tyres with a pattern designed to realise high mileage and to minimise irregular wear. They are tyres primarily designed for wear and durability, not water displacement.

As you can see, the solid shoulders of the tread have no grooves to allow water to be displaced. When the truck comes in contact with a wet surface, the water becomes trapped within the tread and is pushed down into the pavement by the force exerted from the load of the truck.

A typical passenger car tyre differs from a truck tyre dramatically. This is to provide refined performance and handling, an aspect which a trailer tyre does not need. Below are typical passenger tyres:

Tyre A Tyre B

(12) Figure 2.2.1.1 - Typical truck tyres – (www.goodyear.com.au)

Tyre A - Passenger Vehicle - Details

- Active Corner grip Technology
- Superior driving performance on straight roads and on cornering. Impressive wet handling and reduced risk of aquaplaning.
- Racing compound Technology
- Excellent grip performance in wet and dry conditions.
- Asymmetric tread design
- Delivers superior control and comfort for a quiet and secure ride.

Tyre B - Passenger Vehicle - Details

- Silica based tread compound
- Superior braking, cornering and handling in wet and dry conditions. Also reduces rolling resistance, which can enhance fuel economy.
- Low noise generation pattern
- Promotes a quieter and smoother ride
- Circumferential grooves
- Disperses water to reduce the risk of losing control in wet conditions.

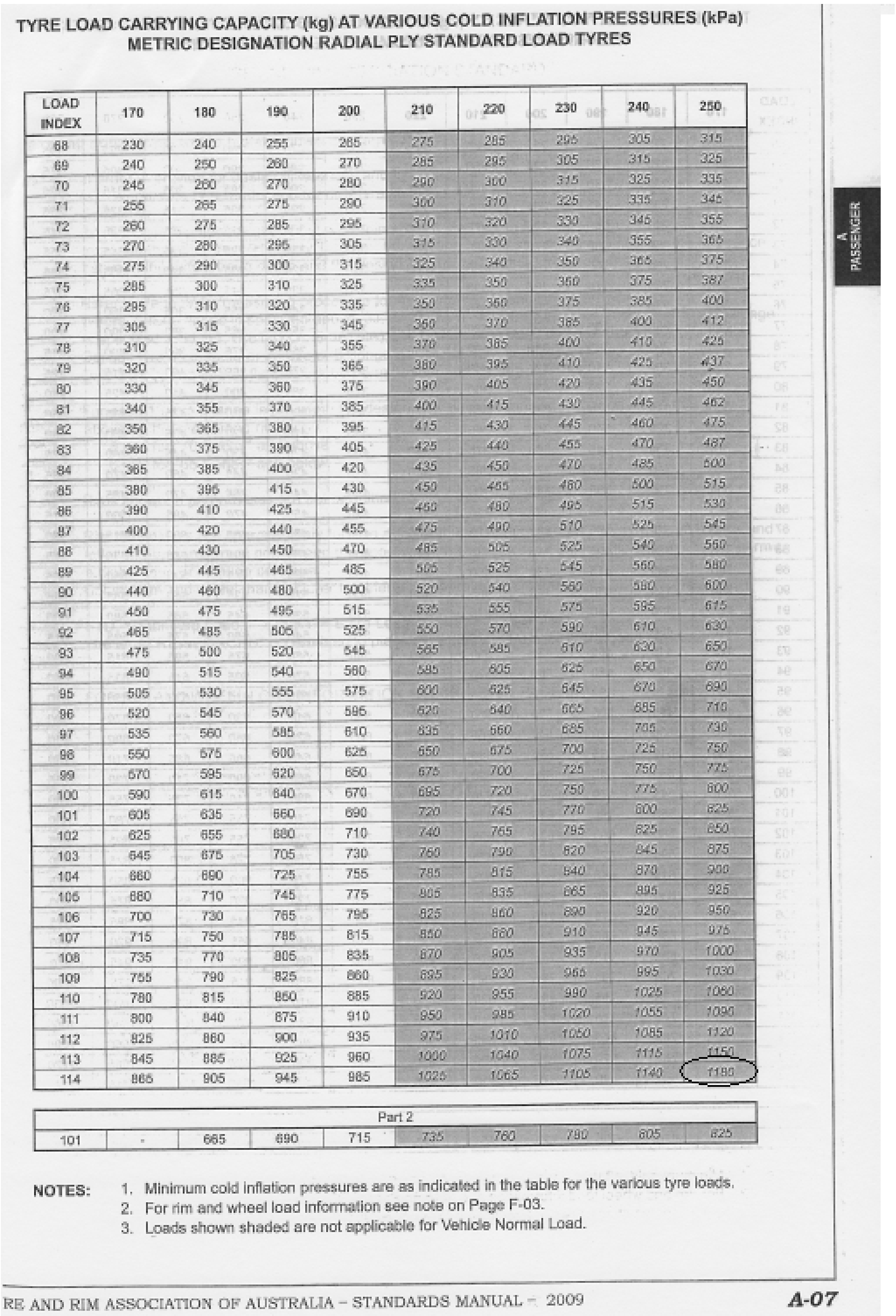
These tyres are all rounder tyres which provide well-balanced handling and low tyre noise. This translates into a safe, smooth and comfortable ride. These tyres are designed to give outstanding control of the car, without compromising on performance. They allow the vehicle to achieve high speed cornering and grip. These tyres provide high performance for the driver and vehicle, therefore allowing the movement of water throughout the tread of the tyre to allow better grip to the surface of the road.

In conclusion, the truck tyres are much more likely to retain water within the tread, and therefore it is another reason to focus research and testing on heavy vehicles.

2.5.2.2 Forces Applied

For all pavements, performance is usually influenced by heavy traffic. Road designers only take into account heavy vehicles for the pavement design, however smaller vehicles are considered for the road capacity. The maximum truck capacity is 68.5 tonnes for a B-Double on a Queensland highway. Assuming there are approximately 34 tyres on the truck and the weight is evenly distributed, there will be about 2 tonnes of force applied to each tyre. This force will then be absorbed by the seal, base, subbase and subgrade.

Compare this to a passenger car of about 1 tonne and 4 tyres. This will have a force of only 0.25 tonnes applied to the pavement layers. Below is a table extracted from the Tyre and Rim Association of Australia showing the different tyre loads at different inflation pressures. As outlined below, the maximum force on one tyre is 1.180 tonnes for a passenger vehicle (please note that this is the absolute maximum load and pressure for a passenger vehicle tyre).



TYRE LOAD CARRYING CAPACITY (kg) AT VARIOUS COLD INFLATION PRESSURES (kPa)
METRIC DESIGNATION RADIAL PLY STANDARD LOAD TYRES

LOAD INDEX	170	180	190	200	210	220	230	240	250
68	230	240	255	265	275	285	295	305	315
69	240	250	260	270	285	295	305	315	325
70	245	260	270	280	290	300	315	325	335
71	255	265	275	290	300	310	325	335	345
72	260	275	285	295	310	320	330	345	355
73	270	280	295	305	315	330	340	355	365
74	275	290	300	315	325	340	350	365	375
75	285	300	310	325	335	350	360	375	387
76	295	310	320	335	350	360	375	385	400
77	305	315	330	345	360	370	385	400	412
78	310	325	340	355	370	385	400	410	425
79	320	335	350	365	380	395	410	425	437
80	330	345	360	375	390	405	420	435	450
81	340	355	370	385	400	415	430	445	462
82	350	365	380	395	415	430	445	460	475
83	360	375	390	405	425	440	455	470	487
84	365	385	400	420	435	450	470	485	500
85	380	395	415	430	450	465	480	500	515
86	390	410	425	445	460	480	495	515	530
87	400	420	440	455	475	490	510	525	545
88	410	430	450	470	485	505	525	540	560
89	425	445	465	485	505	525	545	560	580
90	440	460	480	500	520	540	560	580	600
91	450	475	495	515	535	555	575	595	615
92	465	485	505	525	550	570	590	610	630
93	475	500	520	545	565	585	610	630	650
94	490	515	540	560	585	605	625	650	670
95	505	530	555	575	600	625	645	670	690
96	520	545	570	595	620	640	665	685	710
97	535	560	585	610	635	660	685	705	730
98	550	575	600	625	650	675	700	725	750
99	570	595	620	650	675	700	725	750	775
100	590	615	640	670	695	720	750	775	800
101	605	635	660	690	720	745	770	800	825
102	625	655	680	710	740	765	795	825	850
103	645	675	705	730	760	790	820	845	875
104	660	690	725	755	785	815	840	870	900
105	680	710	745	775	805	835	865	895	925
106	700	730	765	795	825	860	890	920	950
107	715	750	785	815	850	880	910	945	975
108	735	770	805	835	870	905	935	970	1000
109	755	790	825	860	895	930	965	995	1030
110	780	815	850	885	920	955	990	1025	1060
111	800	840	875	910	950	985	1020	1055	1090
112	825	860	900	935	975	1010	1050	1085	1120
113	845	885	925	960	1000	1040	1075	1115	1150
114	865	905	945	985	1025	1065	1105	1140	1180

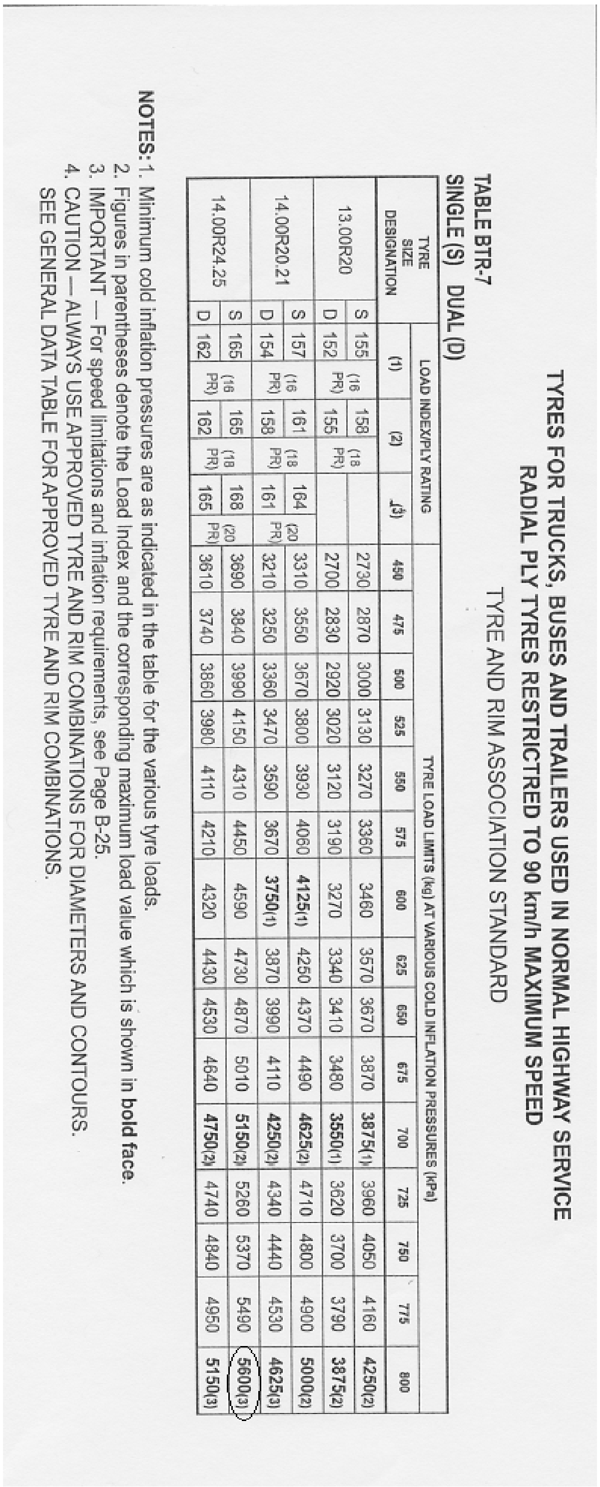
Part 2									
101	-	665	690	715	735	760	780	805	825

NOTES:
1. Minimum cold inflation pressures are as indicated in the table for the various tyre loads.
2. For rim and wheel load information see note on Page F-03.
3. Loads shown shaded are not applicable for Vehicle Normal Load.

RE AND RIM ASSOCIATION OF AUSTRALIA – STANDARDS MANUAL – 2009 **A-07**

(1) Table 2.2.2.1 – Tyre Load Carrying Capacity for Passenger Vehicles (Tyre and Rim Association of Australia Standards Manual)

Heavy vehicle tyres are designed to withstand much more pressure and therefore more force. As shown below the most force a single truck tyre can withstand is 5.6 tonnes. This is approximately five times more than the passenger vehicles.



TYRES FOR TRUCKS, BUSES AND TRAILERS USED IN NORMAL HIGHWAY SERVICE
RADIAL PLY TYRES RESTRICTRED TO 90 km/h MAXIMUM SPEED
TYRE AND RIM ASSOCIATION STANDARD

TABLE BTR-7
SINGLE (S) DUAL (D)

TYRE SIZE DESIGNATION		LOAD INDEX/PLY RATING						TYRE LOAD LIMITS (kg) AT VARIOUS COLD INFLATION PRESSURES (kPa)														
		(1)		(2)		(3)		450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
13.00R20	S	155	(16 PR)	158	(18 PR)			2730	2870	3000	3130	3270	3360	3460	3570	3670	3870	**3875(1)**	3960	4050	4160	**4250(2)**
	D	152		155				2700	2830	2920	3020	3120	3190	3270	3340	3410	3480	**3550(1)**	3620	3700	3790	**3875(2)**
14.00R20.21	S	157	(16 PR)	161	(18 PR)	164	(20 PR)	3310	3550	3670	3800	3930	4060	**4125(1)**	4250	4370	4490	**4625(2)**	4710	4800	4900	**5000(2)**
	D	154		158		161		3210	3250	3360	3470	3590	3670	**3750(1)**	3870	3990	4110	**4250(2)**	4340	4440	4530	**4625(3)**
14.00R24.25	S	165	(16 PR)	165	(18 PR)	168	(20 PR)	3690	3840	3990	4150	4310	4450	4590	4730	4870	5010	**5150(2)**	5260	5370	5490	**5600(3)**
	D	162		162		165		3610	3740	3860	3980	4110	4210	4320	4430	4530	4640	**4750(2)**	4740	4840	4950	**5150(3)**

NOTES: 1. Minimum cold inflation pressures are as indicated in the table for the various tyre loads.
2. Figures in parentheses denote the Load Index and the corresponding maximum load value which is shown in **bold face**.
3. IMPORTANT — For speed limitations and inflation requirements, see Page B-25.
4. CAUTION — ALWAYS USE APPROVED TYRE AND RIM COMBINATIONS FOR DIAMETERS AND CONTOURS.
SEE GENERAL DATA TABLE FOR APPROVED TYRE AND RIM COMBINATIONS.

(2) Table 2.2.2.2 - Tyre Load Carrying Capacity trucks buses and trailers (Tyre and Rim Association of Australia Standards Manual)

From Table 2.2.2.1 and Table 2.2.2.2 we can safely say that the impact of truck tyres influences the pavement performance much more than the passenger car tyres. Therefore this project will use the data acquired for heavy vehicles only.

2.5.3 AADT – Percent Commercial Vehicles

As heavy vehicles are the major cause of road deformation, this study will be based on testing the local roads in the Darling Downs region which have high percentages of heavy vehicles. By comparing the data with that of low percentages of heavy vehicles it can be concluded that heavy vehicles are the cause of water penetration into road pavements.

Further analysis will determine which roads to test. The 2007 Traffic Analysis and Reporting System describe all of the AADT in the Darling Downs Area. This will be used to assist in finding optimum sample locations within the Toowoomba area.

2.6 Conclusion

This literature review has revealed that there is information available about ‘Traffic Induced Moisture Into Road Pavements’, however little information exists in Australia. From the Transfund New Zealand Reports it is safe to conclude that water does penetrate chipseals at a higher rate than expected.

The report from (Chen et al 2004) does suggest that asphalt is permeable, however when there is less than 7% air voids, it was regarded as impervious.
From research into the three major types of pavement surfacing, OGA, DGA and chipseals, it can be expected that chipseals will have the most moisture entry into the pavement due to the thin layer it provides. OGA disperses the force of water throughout the voids therefore providing minimal water force into the pavement. From various reports, it can be said that water does penetrate DGA through very thin layers and at different compaction levels, however through thicker compacted layers it was deemed impermeable. Further research and testing will be required to confirm the results of the literature review.

This report has revealed that water plays a major part in the sustainability of road pavements, and there are a number of ways in which water penetrates the pavements. Through previous studies, water does penetrate chipseals; however DGA and OGA are relatively impermeable but costly. The review has also revealed that heavy vehicles are major contributors to pavement stress, and attention needs to be focused upon roads which carry many heavy vehicles.

Tyres are a contributing factor when it comes to water penetration into pavements. Tyres that are designed for wear and not to disperse water are more likely to have a larger effect on the pavement. It was concluded that these types of tyres are used on trucks, particularly on the haul trailers.

In conclusion, this report needs to focus on heavy vehicle routes, chipseal surfaces, and wet areas.

Chapter 3 METHODOLOGY

3.1 Introduction

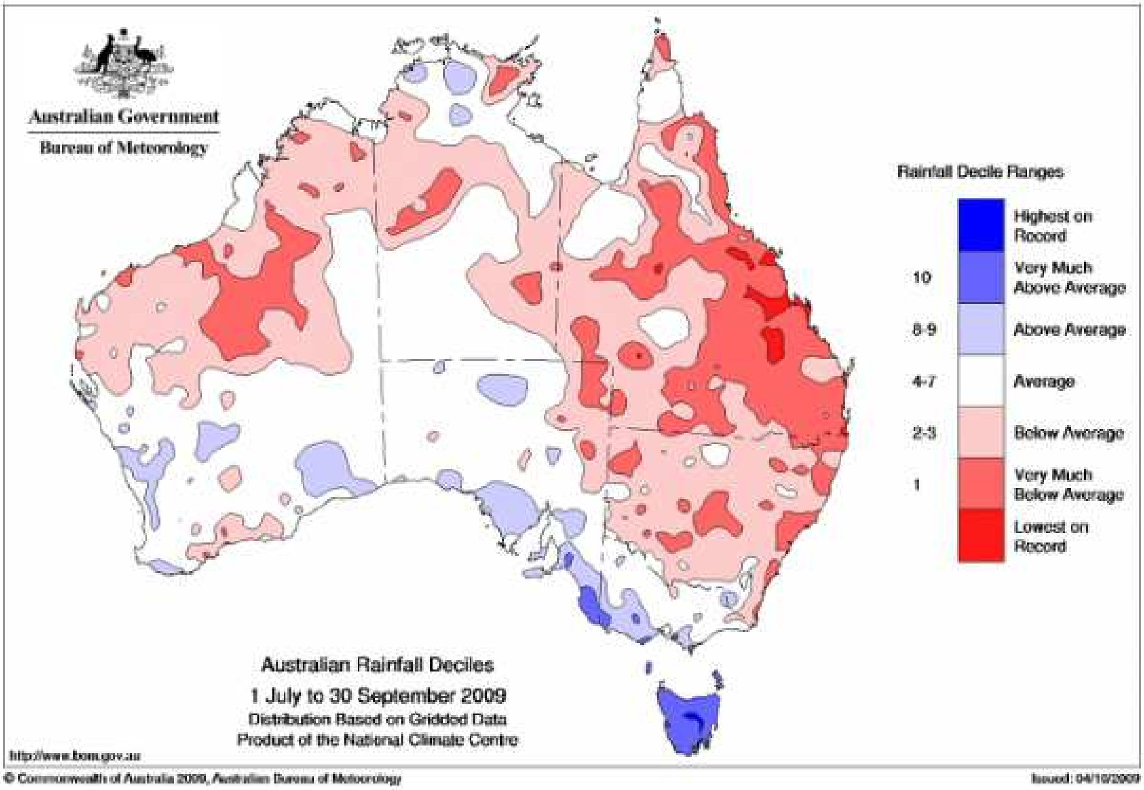
Observations of roads show that moisture induced damages such as shoving and rutting occurs in the outer wheel path of the lane. This is the usual location for severe bitumen flushing or bleeding. From the literature review, it was proven by Towler & Ball (2001) that the two major types of surface distress are alligator cracking and flushing of the seal. From visual inspections, it is clear that these types of distress are located primarily in the wheel paths and in particular the OWP's. This type of distress may be due to traffic when combined with moisture. Therefore testing will focus on M/C's in the wheel paths.

As the area in the OWP's and the area between the wheel paths theoretically provide the greatest contrast on moisture levels, it is logical to take samples and find data in these areas. For this study previous moisture data and probe data were gathered from the QDTMR database and critically analysed. On site testing involved sample collection and permeability tests to determine if road surfaces are impermeable or permeable.

On a newly constructed road surface the M/C should be uniform across the pavement layers. As the pavement becomes trafficked, the wheel paths receive most of the wear and use, particularly in the OWP. During rain periods the wearing surface of the road combined with the compounding nature of traffic provides ample opportunity for traffic to induce moisture into the pavement. It is an indication of traffic induced moisture if there is more moisture in the wheel paths compared to BWP's.

It is not unreasonable to assume that two roads with the same surface characteristics and similar AADT will have similar moisture penetration through the seal. If the only variable is the variation in M/C across the traffic lane, it should be possible to compare the data obtained in various locations to gain some quantitative results across the pavement.

The recent climate in Toowoomba can be described as windy and dry. The winter period is known to be the ‘dry season’ which will not assist in providing accurate data in the sampling process as shown in Figure 3.1.1 below. The rainfall in the Toowoomba area is described to be ‘very much below average’ which may not assist in the sample analysis. High trafficked roads with flushed seals are more desirable to test as there would be a greater chance of it containing a higher moisture variation within the pavement across the lane width. An alternative to testing the M/C is to trial the permeability of the road surface by using a permeameter. This is essentially placing a constant head of water on the road and monitoring the decrease in water level over time (see section 3.5). A further alternative is to analyse past data that QDTMR has acquired over many years of testing. This data includes pavement investigations and the GBD Probe data.



(13) Figure 3.1.1 – 3 month rainfall history (July-October) (Bureau of Meteorology, 2009)

The results of this investigation and information gathered from other sources during the literature review were combined to draw conclusions relating to the penetration of moisture into the road pavements due to the effects of traffic.

3.2 Existing Data

Prior to the commencement of this project, QDTMR had completed many soil tests within roadways. The previous data is stored in archives at QDTMR soil testing laboratories. Permission to access the archives and use the data was verbally acquired from Murray Peackock (QDTMR District Director) and written approval was then specified by Allan Doulin (Core Tech Services Coordinator) shown in Appendix B3. It was requested that job numbers and company names be left out of this report due to confidentiality requirements.

QDTMR archives contained an abundance of road testing information however it was difficult to find data that would specifically support traffic induced moisture into road pavements. A comparison of M/C in trafficked areas compared to non-trafficked areas would have been ideal data for this project; however this data proved to be difficult to acquire.

After a thorough search through QDTMR archives, a total of 4 testing locations were found for which previous testing assisted the research of this project. These roads are:

- Drayton Connection Road
- Gatton Bypass Duplication
- Toowoomba Cecil Plains Road
- Warrego Highway / Bowenville Road

The data analysis for the roads above is provided below in ‘Chapter 4 – Results and Discussion’.

3.3 On Site Soil Sampling

During August and September of 2009, soil samples were taken in the wheel paths and BWP at various locations around the Darling Downs for comparison. Site details such as location, rainfall history and AADT were noted prior to taking the samples at each location. Location selection was limited due to funding restraints therefore co-operation with QDTMR and 'RoadTek – Asset Services South' was needed throughout the testing process.
Throughout the testing process there were numerous problems to overcome and demands that needed to be met, and there will be discussed further in the below sections.

3.3.1 Site Selection

It was originally anticipated that testing locations would be selected by analysing rainfall data, AADT data and seal type. Locations were to be selected based on highest percentage of 'heavy vehicle' roads, high rainfall areas and the seal that was desired (bitumen spray-seal or asphalt). QDTMR was unable to grant funding for this project due to the poor current economic conditions. Therefore testing locations were limited to low density roads.

The site selection process adopted was to simply liaise with RoadTek – Asset Services South engineers to find out when a traffic lane would be closed during other works (bridge maintenance) in order for testing to be completed at minimal cost. This occurred at four separate locations listed below:

- Murgon / Byee Road
- Hampton / Esk Road
- Gatton / Clifton Road
- Chinchilla / Tara Road

The above roads were tested in liaison with Geoffery Kineavy (RoadTek Asset Services South – Structures Project Manager) and Belinda Krause (QDTMR - Soil Labs). It was ensured that at each site the correct safety procedures were undertaken in accordance with QDTMR. Safe working distances from traffic, the use of traffic control, the use of correct PPE, and constant supervision were all utilised during the sample collection process on site.

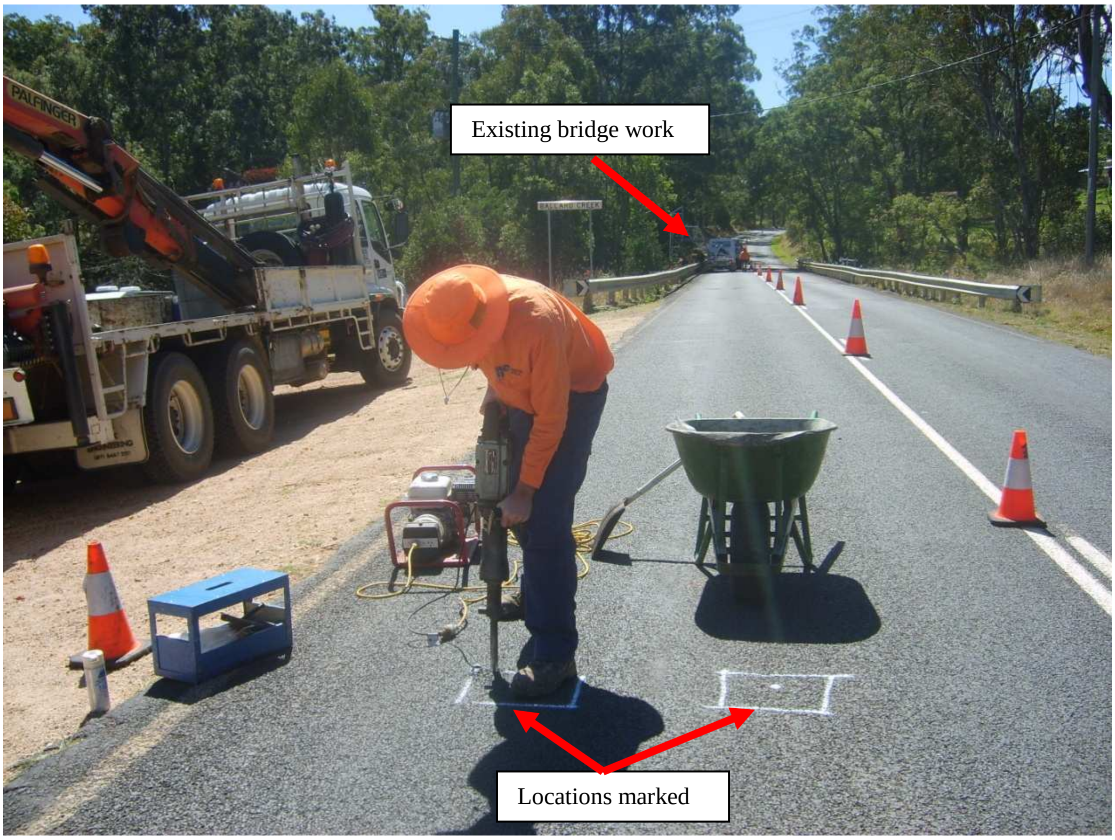
3.3.2 Sample Collection

After liaising with RoadTek Engineers and selecting the location, the site was then set up for work (bridge maintenance as shown in Figure 3.3.3.1). Equipment required to complete the sample collection was attained prior to arriving on site.

The equipment involved included:

- Marking paint to mark out testing locations of wheel paths etc.
- Measuring tape to measure depth of seal, and distance from shoulder and control line.
- Generator for powering the jack-hammer.
- ear-plugs.
- Jack-hammer allows penetration through the seal and loosening of the base-course.
- Wheel barrow to transport the cold mix and excess gravel etc.
- Cold Mix to fill the sample holes.
- Shovel
- Crow-bar to compact the cold mix and to loosen the base-course.
- Air tight sample bags to keep the soil sample in exactly the same condition as found.
- Hard bristle broom to sweep the road clean.
- Sample spoon to collect the loose base material and place it into the sample bag.

This equipment enabled easier sample collection whilst under supervision and safety of traffic control.



(14) Figure 3.3.3.1 – Collecting samples at Ballard Creek Bridge

After the site was established the samples were taken as shown steps shown below (Section 3.3.3):

3.3.3 Method

Step 1:

The site was firstly established to be safe, and locations were then marked out for sample selection. Locations were selected on the wheel path and BWP.

Step 2:

Equipment was transported to the sample site.

Step 3:

The seal was removed, and the base-course was loosened using a jackhammer.

Step 4:

The loose material was then gathered and placed in an air tight sample bag (ensuring the bag was correctly labelled with the location number, seal type, seal thickness, distance from the shoulder and distance from the control line).

Step 5:

All loose material was removed from the sample hole. Using the wheelbarrow and shovel, the cold mix was then placed into the sample hole and compacted with the crow bar, making sure the cold mix was heaped above the hole to account for further compaction by traffic.

(15) Figure 3.3.4.2 – After samples have been taken

Step 6:

The site was then swept to ensure it was clear of loose stones. Proceeded to next test location.

3.3.4 Lab Testing

QDTMR laboratory permitted use of their equipment to test the moisture content of the samples. The samples were taken into the laboratory and placed into specimen containers as shown in Figure 3.3.4.1 below.

(16) 3.3.4.1 – Samples placed in specimen containers

Details of the specimens were recorded in QDTMR standard ‘Worksheet for Moisture Content’. These details include:

- Job Number
- Date
- Operator
- Specimen Number
- Mass of Container
- Mass of Container and Wet Soil
- Mass of Container and Dry Soil
- Check Mass

These worksheets are located in Appendix D.

After the wet specimen was placed in the specimen container, it was then weighed to find the mass of the wet soil as shown in Figure 3.3.4.2. The specimen was then placed in a drying oven at 100°C (Figure 3.3.4.3) for a period of approximately 24 hours.

(17) Figure 3.3.4.2 – Weighing the specimens

(18) Figure 3.3.4.3 – Specimens placed in oven

After 24 hours, the specimen is then weighed again and the M/C is calculated by using the following equation:

$$Moisture\ content = w(\%) = \frac{W_w}{W_s} * 100$$

Where, W_s = weight of the soil solids
W_w = weight of the water

For a more direct approach, the weight details were entered into a spreadsheet and the M/C was automatically calculated. An alternative method would have been to enter the details into ‘DataPro Laboratory Test Data Processing System – Version 4.1’, which would then provide a printout of the M/C’s etc as shown in Appendix D. After the M/C’s have been calculated, the samples were placed back into the oven for another hour and are re-weighed. If the weight is the same, then the soil is classed as ‘dry’ and the calculated M/C’s are assumed to be correct.

3.4 Time Domain Reflectometry (TDR) - Probes

During 2003, Time Domain Reflectometry (TDR) Monitoring units were installed on the GBD during construction. These units use high frequency electromagnetic pulses to calculate the relative permittivity of the material in the location where the probes are installed. Initial recording of the data was frequent until disestablishment of the trained staff. From there, recordings were six monthly.
For the purpose of this project, only the moisture data was acquired for further analysis. (O'May 2007)

The GBD probe data was provided by David O'May (QDTMR – Engineer). There were seven locations throughout the GBD where the probes were installed. The number of probes at each site varied (Table 3.4.1), being dependant on the type of cross section at each location. Site data including the chainage, verge information, number of probes, date of installation and cross section type is shown in Table 3.4.1. Five (5) sites were located in fill cross sections, while two of the sites were located in cut/fill areas (O'May 2007).

Site	**Chainage (m)**	**Verge**	**Cross Section Type**	**Probes Installed**	**Date of Installation**
A	56 090	--	Fill	9	07/06/03
B	56 570	2	Fill	13	23/04/03
C	58 320	2	Cut/Fill	13	24/04/03
D	63 430	2	Low Fill	13	15/08/03
E	66 268	--	Cut	12	25/08/03
F	72 670	1 - Top	Fill	13	25/08/03
G	74 820	2	High Fill	13	20/06/03

(3) Table 3.4.1 – Probe location details (O'May, 2007, p. 80)

3.4.1 Probe Installation Procedures

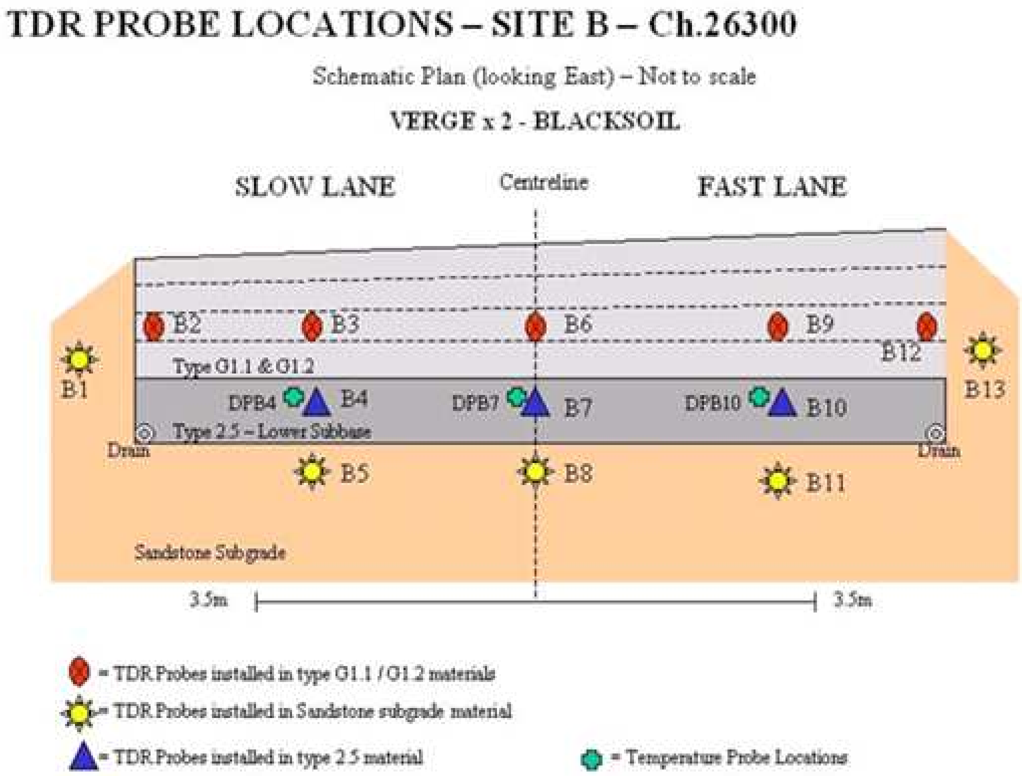
Installations were carried out after pavement construction was complete and prior to sealing. Installation procedures for the probes involved:

- Prior to installation the chainage was clearly marked and identified by a chainage marker.
- A backhoe then proceeded to excavate a trench across the road at a width of 0.3m.
- The depths of the probes were then marked throughout the layers of the pavement.
- To ensure correct readings the probes were placed where there was a good contact area along the wall of the trench.
- The probes were then secured into the pavement with tension bolts on the probes.
- The probes were installed and M/C samples taken next to each probe.
- The cabling for the probes was then installed through a rigid conduit. It was ensured that the conduit was sealed correctly to reduce false readings of the probes.
- The trench was then backfilled using a small compaction hammer around the proximity of the probes to ensure no damage was made.
- The pavement was then sealed, and the probes calibrated to ensure accurate recordings.

(O’May 2007)

3.4.2 Probe Locations within the Pavement

Probes were installed in the OWP of the fast and slow lanes and the control line. At each of these locations there was a probe installed in each of the base, lower subbase and subgrade layers as shown below in Figure 3.4.1.1 (O'May 2007).



(19) Figure 3.4.1.1 – Probe locations at Site B (O'May, 2007, Appendix B)

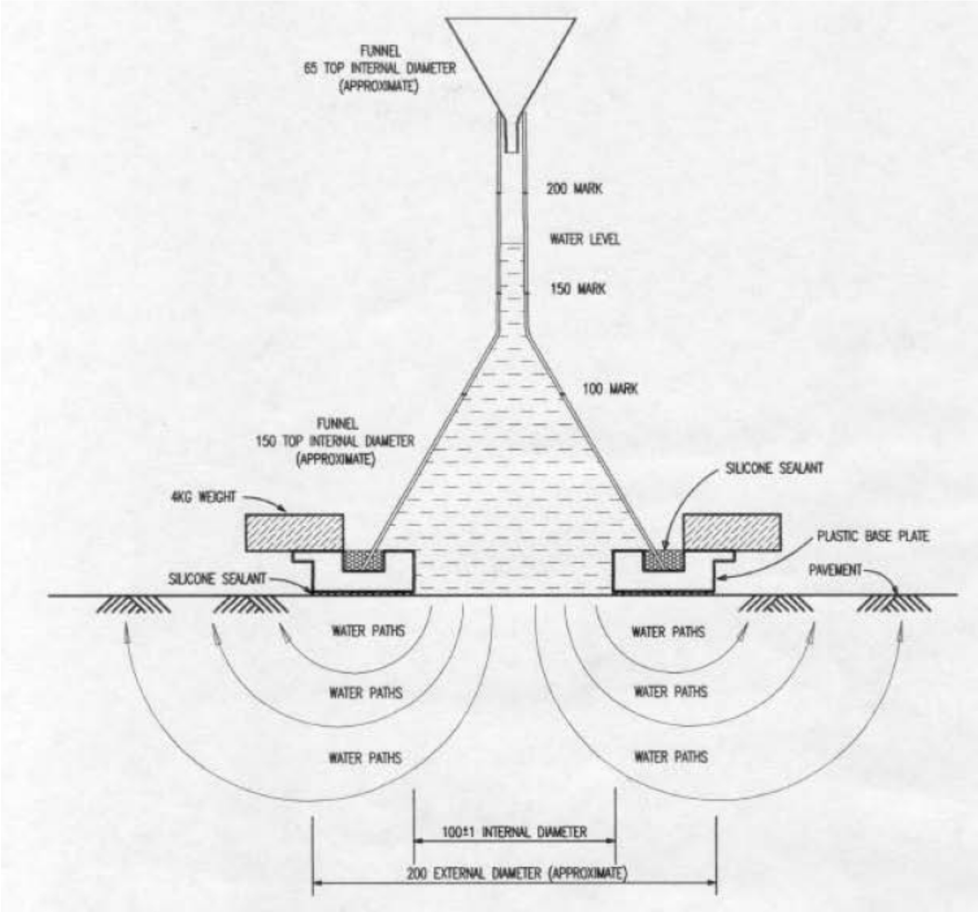
As seen above, there are probes located throughout the pavement. Probes B2, B3, B6, B9 and B12 were analysed for this study. Other probe sites have a slightly different probe configuration which can be viewed in Appendix E. The reason for selecting these probes is because they will be affected by traffic induced moisture to a greater extent than the other probes.

3.5 Permeameter Testing

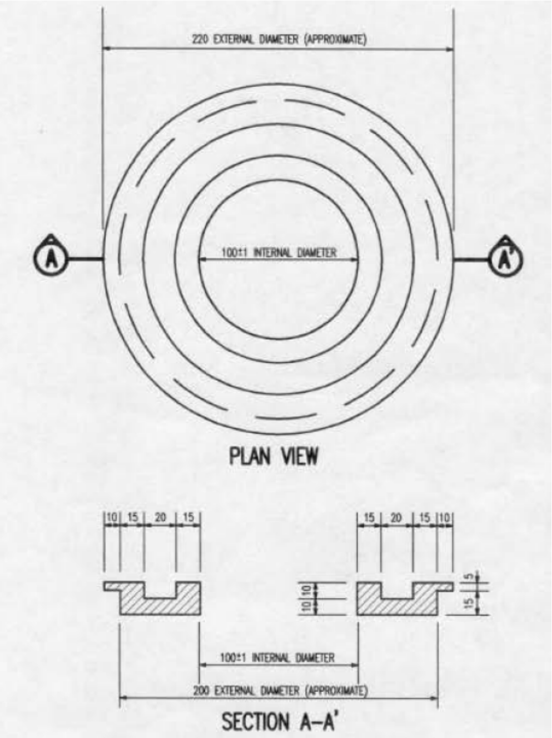
Permeameter testing determines the permeability of pavement materials using the Even-flow Field Permeameter. The permeameter is to be applied to bituminous and granular materials (bitumen spray seals, asphalt, and well compacted gravel). The testing involves water under constant gravity head, and testing water under constant pressure. The pressurised environment adopted the original test procedure by placing an air tight lid and using a compressor to pressurize the inside atmosphere.

3.5.1 Apparatus

Two types of apparatus were used to complete this testing. The first type consists of an inverted clear plastic conical funnel attached to a rigid plastic base as shown in Figure 3.5.1.1 and Figure 3.5.1.2.

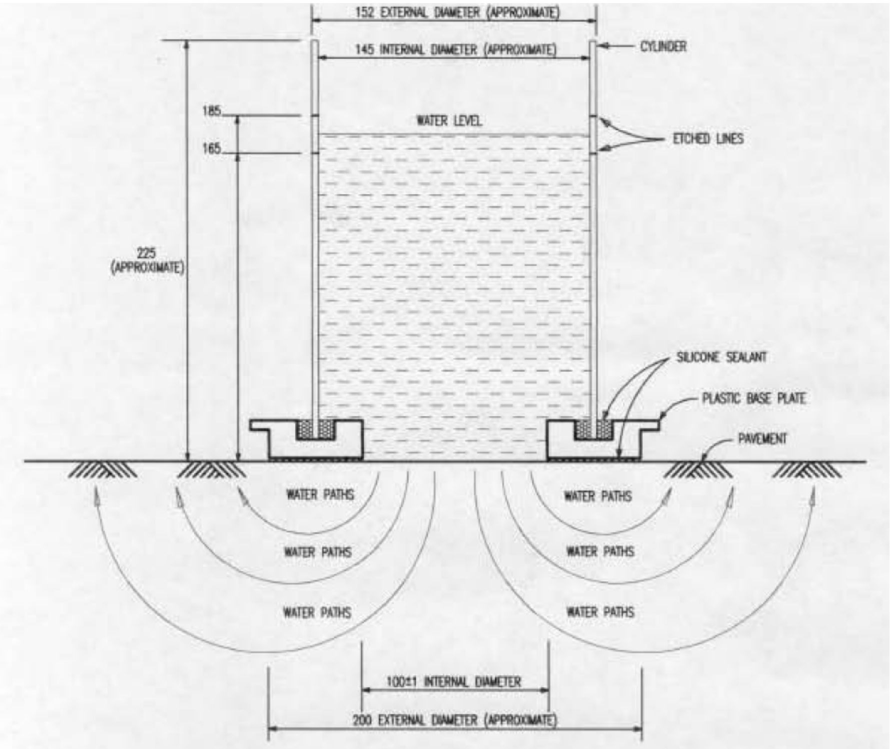


(20) Figure 3.5.1.1 – Even-flow Field Permeameter – Cross Section (QDTMR 2002, p69)

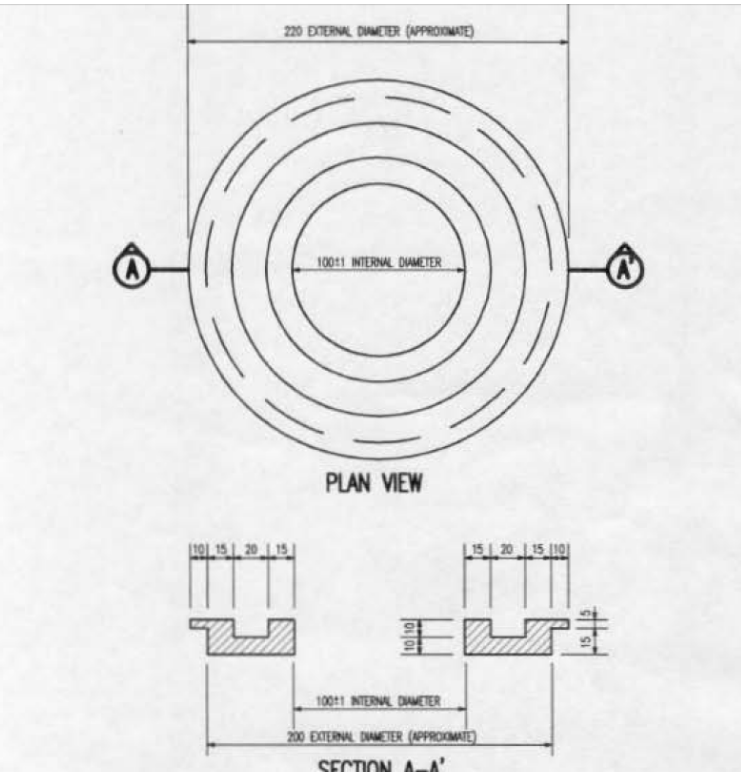


(21) Figure 3.5.1.2 – Even-flow Field Permeameter - Plan view (QDTMR 2002, p70)

The second type consists of a cylinder of clear rigid plastic attached to a rigid plastic base as shown in Figure 3.5.1.3 and Figure 3.5.1.4.



(22) Figure 3.5.1.3 – Rapid-flow Field Permeameter – Side View (QDTMR 2002, p75)



(23) Figure 3.5.1.4 – Rapid-flow Field Permeameter – Side View (QDTMR 2002, p76)

3.5.2 Testing Procedure

There were a total of four different types of tests:

- The even-flow field permeameter under atmospheric pressure.
- The even-flow permeameter under 30kPa pressure.
- The rapid-flow permeameter under atmospheric.
- The rapid-flow permeameter under 30kPa pressure.

These four tests were completed on an aged chipseal surface over period of two days. The location is a residential cul-de-sac with low traffic flow. The calm aspects of the cul-de-sac allowed the testing to be completed safely over a period of two full days. This also allowed ample room for the testing to be completed without disturbing any of the residents.

The testing procedure included the following equipment:

- Broom and air compressor to clean the surface of loose materials.
- Marking crayon to aid application of the silicon sealant to the pavement.
- Permeameter.
- Water container to fill the permeameters.
- Silicone sealant and silicone gun.
- Spatula to aid the application of the silicone.
- Assorted implements to clean the road surface after the testing is complete.
- Air compressor to pressurise the permeameter.
- Custom made lid to seal onto the permeameter and to connect to the compressor.
- Timer / Stopwatch.
- Recording sheet.

3.5.3 Non-Pressurised Method

Step 1:
Any loose material was removed from the road pavement.

Step 2:
The template was then placed onto the pavement and the crayon was used to mark out the position for the test apparatus

Step 3:
The permeameter was attached to the pavement by applying silicone to the pavement, and the permeameter was then pressed firmly onto the silicone.

Step 4:
The circular weight was then positioned onto the permeameter, and the silicone was left to cure.

Step 5:

Water was poured into the permeameter to the level of 150 - 200mm and checked for leaks.

Step 6:

A lid was then placed to prevent evaporation and timing began. The water level was measured after a significant drop.

Step 7:

The permeameter was removed along with any excess silicone from the pavement.

(24) Figure 3.5.3.1 – Even-flow Permeameter

(25) Figure 3.5.3.2 – Rapid-flow permeameter

3.5.4 Pressurised Method

Step 1:

Any loose material was removed from the road pavement.

Step 2:

The template was then placed onto the pavement and the crayon was used to mark out the position for the test apparatus

Step 3:

The permeameter was attached to the pavement by applying silicone to the pavement, and the permeameter was then pressed firmly onto the silicone.

Step 4:

The circular weight was then positioned onto the permeameter, and the silicone was left to cure.

Step 5:

Water was poured into the permeameter to the level of 150 - 200mm and checked for leaks.

Step 6:

The custom made lid was then attached to the apparatus using silicone, and left to dry.

Step 7:

Weights were placed onto the lid to counteract upward forces and the compressor hose was also attached (Figure 3.5.4.1).

Step 8:

The compressor was turned on and allowed to slowly release pressure until 30kPa. At this point it was kept constant.

Step 9:

Timing then began, and the water level was measured after a significant drop.

Step 10:

Once data collection was complete, both the permeameter and any excess silicone were removed from the pavement.

(26) Figure 3.5.4.1 – Permeameter under pressure

(27) Figure 3.5.4.2 – Pressurised testing in process

3.5.5 – Calculations

First find the volume of the displaced water using equation (1):

$$V = \pi * r^2 * h \qquad (1)$$

Calculate the permeability using equation (2):

$$k = \frac{25.5 * V}{t} \qquad (2)$$

Where,

k = permeability (µ m/s)
V = Volume water (mL)
T = average time (sec)
r = Radius (mm)
h = Height difference of water (mm)

Finally check the category and description with corresponding ‘k-values’ in Table 3.5.5.1.

Compare results with the permeability categories in Table 3.5.5.1 below.

Permeability (µ m/s)	**Category**	**Description**
0.01 – 0.1	A1	Very low permeability
0.1 – 1	A2	Low permeability
1 – 10	B	Moderately permeable
10 – 100	C	Permeable
100 – 1000	D	Moderately free draining
1000 - 10000	E	Free draining

(4) Table 3.5.5.1 – Permeability Category and Description (QDTMR 2002, p74)

Chapter 4 - RESULTS & DISCUSSION

Four (4) types of testing were selected to prove that traffic induces moisture into road pavements in the Toowoomba Region. These four methods are tested in various locations primarily in low volume roads. There are a total of eight locations of M/C sampling, seven locations along the GBD (probes), and two locations for the permeability testing.

4.1 Existing Data

Data acquired from QDTMR – Toowoomba District includes:

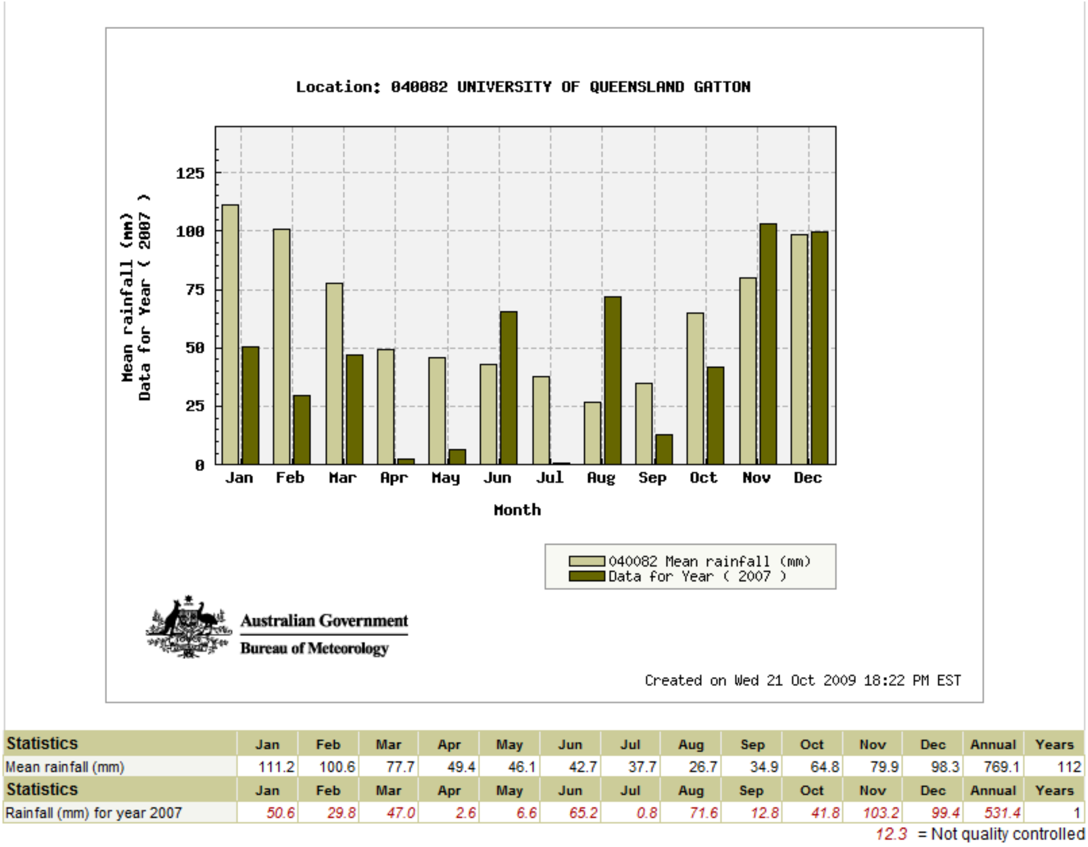
- Gatton Bypass Duplication
- Bowenville / Dalby Road
- Drayton Connection Road
- Toowoomba / Cecil Plains Road

This data was acquired with the permission from QDTMR. A copy of this approval is in Appendix B3.

4.1.1 Gatton Bypass Duplication

These samples were taken on the 25th July 2007 on the eastbound lanes. A series of locations across the lanes were taken at various chainages as depicted in Table 4.1.1.1. The AADT on the GBD is 12 958 vehicles including a heavy vehicle percentage of 15.65% which totals approximately 1014 heavy vehicles per day (The Department of Main Roads, 2007).

Rainfall in 2007 was significantly below average during the time of the sample collection (25/07/07). June's rainfall was 1.5 times the average rainfall (Figure 4.1.1.1) which may have had an effect on the results shown in Table 4.1.1.1.



Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean rainfall (mm)	111.2	100.6	77.7	49.4	46.1	42.7	37.7	26.7	34.9	64.8	79.9	98.3	769.1	112
Statistics	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**	**Years**
Rainfall (mm) for year 2007	*50.6*	*29.8*	*47.0*	*2.6*	*6.6*	*65.2*	*0.8*	*71.6*	*12.8*	*41.8*	*103.2*	*99.4*	*531.4*	1

12.3 = Not quality controlled

(28) Figure 4.1.1.1 – Rainfall Data for Gatton in 2007 (BOM, 2009)

The soil samples were taken directly after the rain event in June. The combination of a recent rain event, high AADT, high percentage of heavy vehicles, and spray seals is ideal in analysing traffic induced moisture into the road pavement.

Table 4.1.1.1 shows M/C's in the slow lane and the fast lane at various chainages. This shows a comparison of M/C's in the IWP, OWP and the shoulder. By looking at the first three chainages it can be seen that the OWP has higher M/C than the shoulder. This indicates that something other than infiltration through the shoulder is assisting in the higher pavement moisture content.

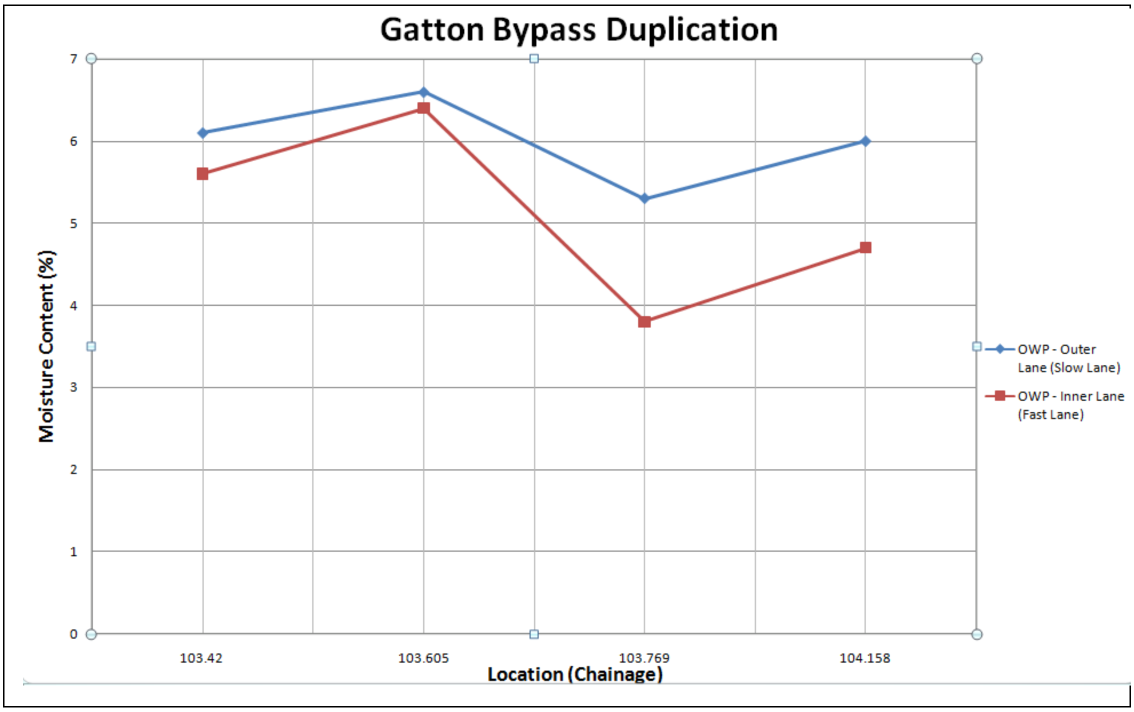
Figure 4.1.1.2 has combined the M/C's of OWPs in each lane with the chainages to show that the OWP in the slow lane has higher moisture content than that of the fast lane. This could show that there may be more traffic in the slow lane assisting in moisture penetration during the rain period. With no knowledge of AADT for each lane, this cannot be proven.

Gatton Bypass Duplication (Eastbound)

Location	Base					Heavy Vehicle AADT	
Chainage	Unknown	IWP	OWP	BWP	Shoulder		Notes
63.47		4.5	4.9		4.3	15.65% or 1014	Outer Lane - slow lane
63.67		3.7	4.4		4.3	15.65% or 1014	Outer Lane - slow lane
67.94			4.6		4.2	15.65% or 1014	Outer Lane - slow lane
67.75				3.6	3.6	15.65% or 1014	Outer Lane - slow lane
67.31	4.3					15.65% or 1014	Outer Lane - slow lane
103.42		5.5	6.1			15.65% or 1014	Outer Lane - slow lane
103.42		4.9	5.6			15.65% or 1014	Inner Lane - Overtaking lane
103.577	5.5					15.65% or 1014	Outer Lane - slow lane
103.605		6.1	6.6			15.65% or 1014	Outer Lane - slow lane
103.605		6.2	6.4			15.65% or 1014	Inner Lane - Overtaking lane
103.611	6.2					15.65% or 1014	Outer Lane - slow lane
103.611	6.1					15.65% or 1014	Inner Lane - Overtaking lane
103.769		3.8	5.3			15.65% or 1014	Outer Lane - slow lane
103.769		4.2	3.8			15.65% or 1014	Inner Lane - Overtaking lane
104.045	4.9					15.65% or 1014	Good Condition
104.15	6					15.65% or 1014	Failure
104.158		5.2	6			15.65% or 1014	Outer Lane - slow lane
104.158		5.4	4.7			15.65% or 1014	Inner Lane - Overtaking lane
104.16	5.4					15.65% or 1014	Failure

(5) Table 4.1.1.1 – Gatton Bypass Duplication Moisture Contents

Table 4.1.1.1 also shows the M/C in the OWP is consistently higher than the IWP (Figure 4.1.1.2). This suggests either infiltration through the shoulder (this is not the case at chainages 63.47, 63.67 and 67.94) or that traffic induces moisture into the pavement during wet periods. The cross-fall of the road distributes the load of the vehicle (particularly heavy vehicles) to the OWP in which the elevation slope is running (in most cases the OWP). This assists in pushing water into the pavement.

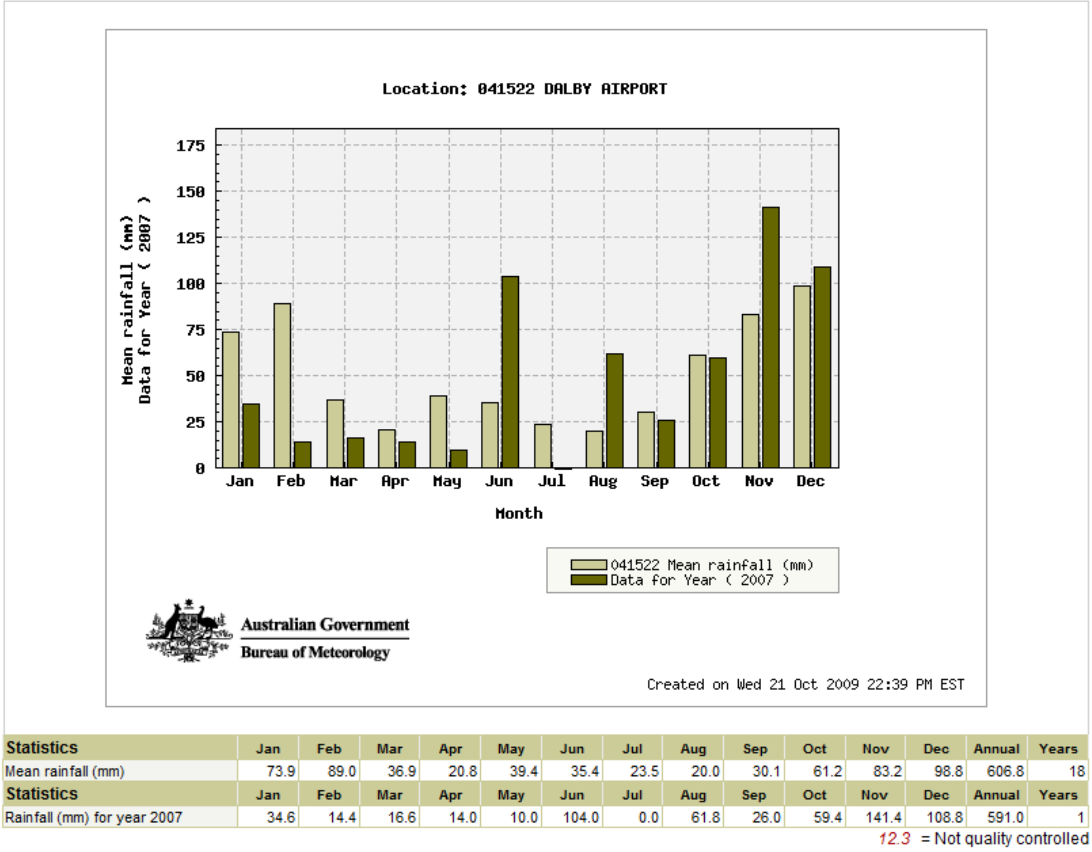


(29) Figure 4.1.1.2 – Gatton Bypass Duplication

4.1.2 Bowenville / Dalby Road

Bowenville / Dalby samples were taken on the 10th January 2008 on the Warrego Highway at approximately chainage 72.64km. The AADT on the Bowenville / Dalby Road (between 26.83km and 80.82km) carried 4433 vehicles per day with 21.75% heavy vehicles in 2007. Therefore the heavy vehicles that used the road daily totalled 482 in each direction (The Department of Main Roads, 2007).

Rainfall in January 2008 was significantly below average, however there was a major rain period in November and December of 2007. These rain periods were far above average which may also have an effect on the M/C results shown in Figure 4.1.2.1.

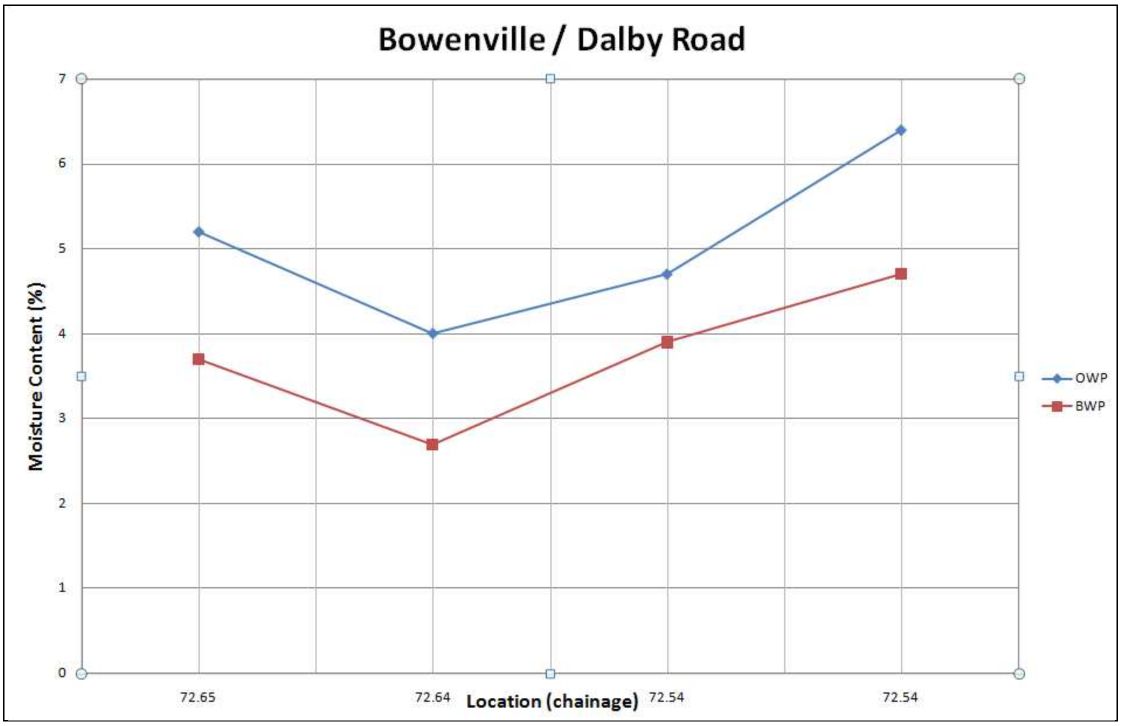


Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean rainfall (mm)	73.9	89.0	36.9	20.8	39.4	35.4	23.5	20.0	30.1	61.2	83.2	98.8	606.8	18
Statistics	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**	**Years**
Rainfall (mm) for year 2007	34.6	14.4	16.6	14.0	10.0	104.0	0.0	61.8	26.0	59.4	141.4	108.8	591.0	1

12.3 = Not quality controlled

(30) Figure 4.1.2.1 - Rainfall Data for Dalby in 2007. (BOM, 2009)

Figure 4.1.2.2 clearly shows that the M/C in the OWP is significantly higher than BWP. Between the four locations there is approximately 1% difference in M/C’s. There is a good chance that the difference in M/C’s is due to the long rain event that occurred in November and December prior to the samples being taken. As the shoulders at this location are not completely sealed, there is a chance that this moisture difference could be due to infiltration through the shoulder. As this is a highly trafficked road with a large number of heavy vehicles, traffic may have assisted in the high moisture readings.

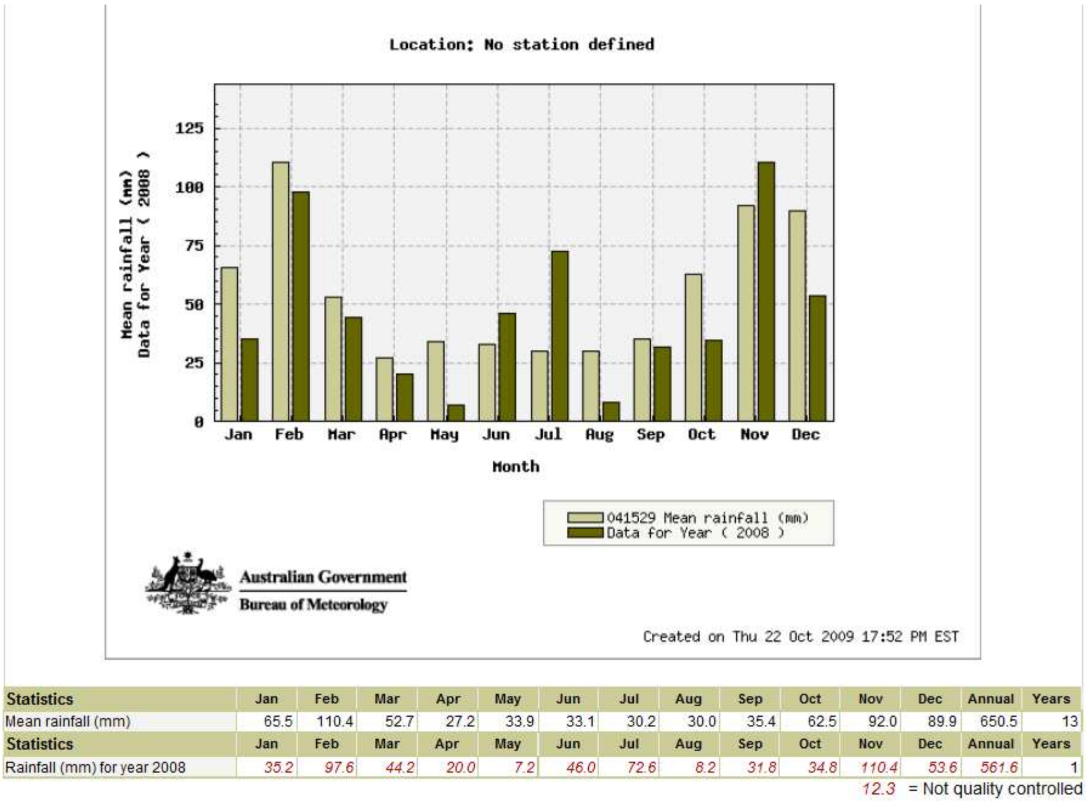


(31) Figure 4.1.2.2 – Bowenville / Dalby Road (Warrego Highway)

4.1.3   Drayton Connection Road

These samples were taken on the 18th December 2008 on the Drayton Connection Road at approximate chainages of 1.5km to 3.68km. The AADT on the Drayton Connection Road carried 3745 vehicles per day with 12.31% heavy vehicles in 2007. Therefore the heavy vehicles that used the road daily totalled 231 in each direction (The Department of Main Roads, 2007).

As can be seen in Figure 4.1.3.1, the rainfall for the November/December period is close to average. Therefore under these conditions, the M/C's should be as expected for an average year of rainfall. Moisture penetration should be evident in the wheel paths due to the rainfall of November and December totalling over 160mm.

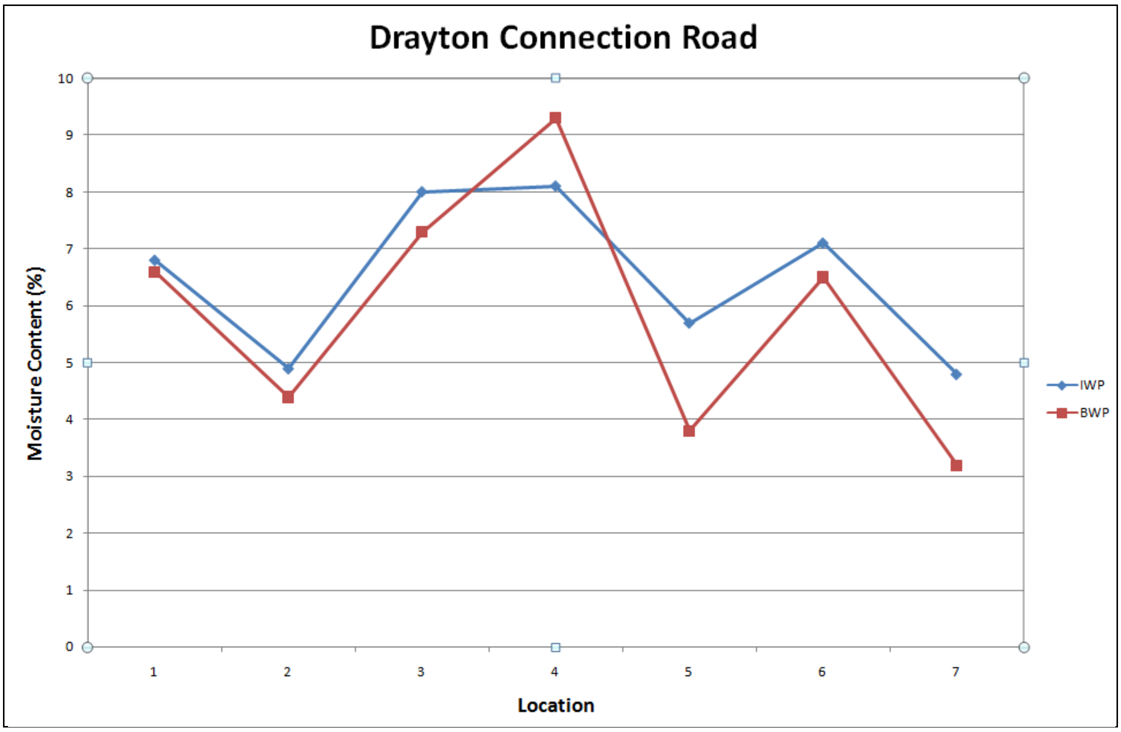


Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean rainfall (mm)	65.5	110.4	52.7	27.2	33.9	33.1	30.2	30.0	35.4	62.5	92.0	89.9	650.5	13
Statistics	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**	**Years**
Rainfall (mm) for year 2008	*35.2*	*97.6*	*44.2*	*20.0*	*7.2*	*46.0*	*72.6*	*8.2*	*31.8*	*34.8*	*110.4*	*53.6*	*561.6*	1

12.3 = Not quality controlled

(32) Figure 4.1.3.1 - Rainfall Data for Toowoomba in 2008. (BOM, 2009)

Figure 4.1.3.2 shows that the M/C in the IWP is higher than BWP. Although the BWP plot does overlap the IWP plot, the average of the IWP is 6.49% compared to 5.87% for BWP. This shows a significant difference in M/C’s between the two locations. As the IWP is near the middle of the road, there is a good chance that the difference in M/C’s is due to the long rain even that occurred in November and December prior to the samples being taken as shown in Figure 4.1.3.1. Infiltration through the shoulder can be exempt as BWP would have higher M/C if that was the case. Evidence suggests as this is a highly trafficked road with a large amount of heavy vehicles that traffic did assist in the high moisture readings.

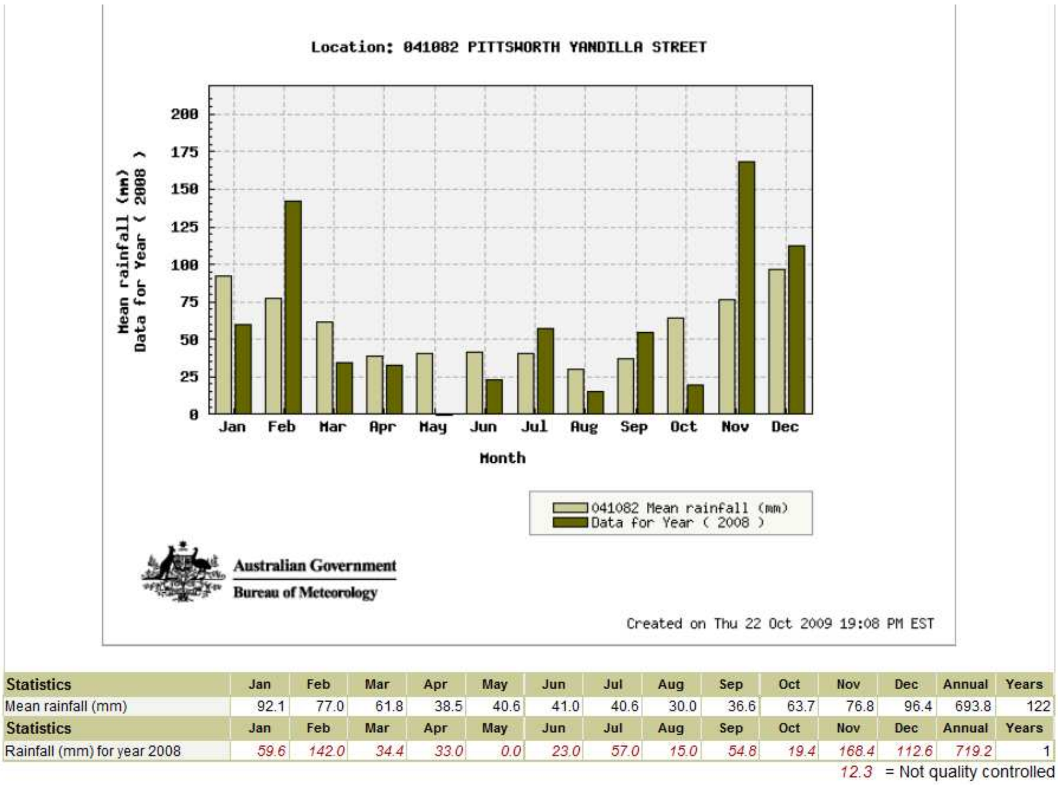


(33) Figure 4.1.3.2 – Drayton Connection Road

4.1.4 Toowoomba / Cecil Plains Road

The Toowoomba / Cecil Plains Road samples were taken on the 4th March 2008 at various locations between chainage 28.3km and 50.6km. The AADT for Toowoomba / Cecil Plains Road has a total of 1624 vehicles per day with 13.09% heavy vehicles. With 106 heavy vehicles using each lane per day, it is feasible that moisture can be pushed into the road base by the movement of traffic.

The rainfall data in Figure 4.1.4.1 shows that February's rainfall for 2008 is approximately double the average with 142mm of rain compared to 77mm. Due to this excessive amount of rainfall, there is a higher chance that M/C's may vary and show that traffic contributes to moisture penetration into road pavements.



Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean rainfall (mm)	92.1	77.0	61.8	38.5	40.6	41.0	40.6	30.0	36.6	63.7	76.8	96.4	693.8	122
Statistics	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**	**Years**
Rainfall (mm) for year 2008	*59.6*	*142.0*	*34.4*	*33.0*	*0.0*	*23.0*	*57.0*	*15.0*	*54.8*	*19.4*	*168.4*	*112.6*	*719.2*	1

12.3 = Not quality controlled

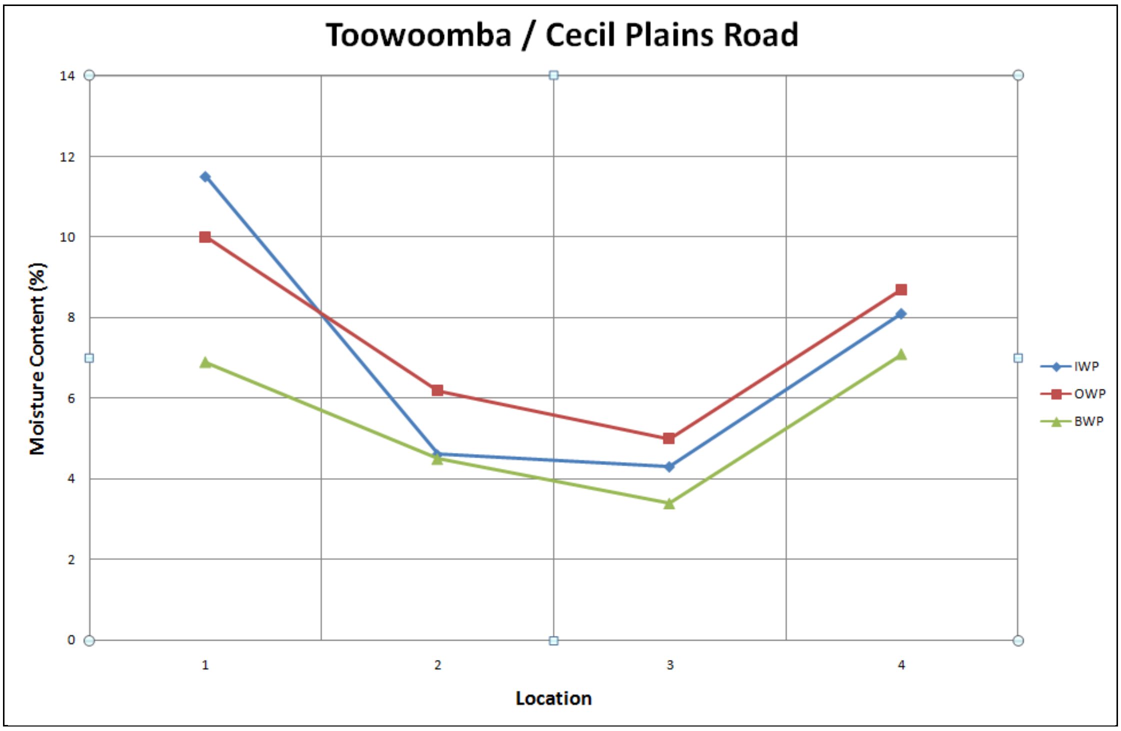
(34) Figure 4.1.4.1 - Rainfall Data for Pitsworth in 2008. (BOM, 2009)

From Table 4.1.4.1 and Figure 4.1.4.2 it can be seen that BWP is consistently lower than the OWP and IWP. The IWP has less moisture than the OWP which could be due to infiltration from the shoulder or the cross-fall of the road. As can be seen on many roads, flushing generally occurs on the OWP, and this may be the case for moisture penetration. The flushing on the OWP is generally caused by the cross-fall of the road which distributes the weight of the vehicle towards the direction the cross-fall is sloping.

In this case it is clear that there is more moisture located in each of the wheel paths particularly in the OWP when compared to BWP.

Chainage (m)	29.18	30.2	42.33	50.6
IWP M/C (%)	11.5	4.6	4.3	8.1
OWP M/C (%)	10	6.2	5	8.7
BWP M/C (%)	6.9	4.5	3.4	7.1

(6) Table 4.1.4.1 – Moisture contents at various locations



(35) Figure 4.1.4.2 – Toowoomba / Cecil Plains Road

4.1.5 Conclusion

In conclusion it is clear that there is high moisture content in the wheel paths compared to between the wheel paths. It is common in all of the test locations that a significant rain event occurred prior to the sample collection. The rain events combined with reasonable AADT and percent heavy vehicles plays a significant part in the moisture penetration into the road pavement.

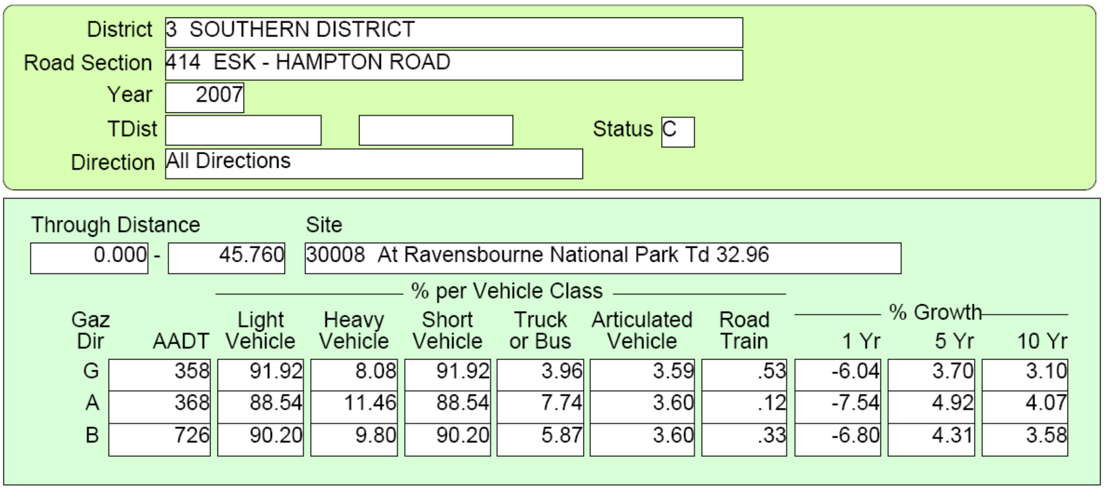
From the GBD data (Table 4.1.1.1), it has been proven in this case that infiltration through the shoulder does not occur as the OWP has higher M/C than that of the shoulder.
See Appendix C for M/C tables for each location.

4.2 Field Testing Data

4.2.1 Esk / Hampton Road

Esk / Hampton Road is a narrow two lane road located on the Northern edge of Toowoomba. Samples were taken on the 10th September 2009. Both of the approaches to the Ballard Creek Bridge are of similar construction and appearance. The approaches to the bridge have recently been widened therefore two gravel types have been used.

The AADT states that there are a total of 726 vehicles that use the road (combination of both directions) and an average of 9.8% heavy vehicles (Figure 4.2.1.1). This means that approximately 35.6 heavy vehicles use each lane per day.



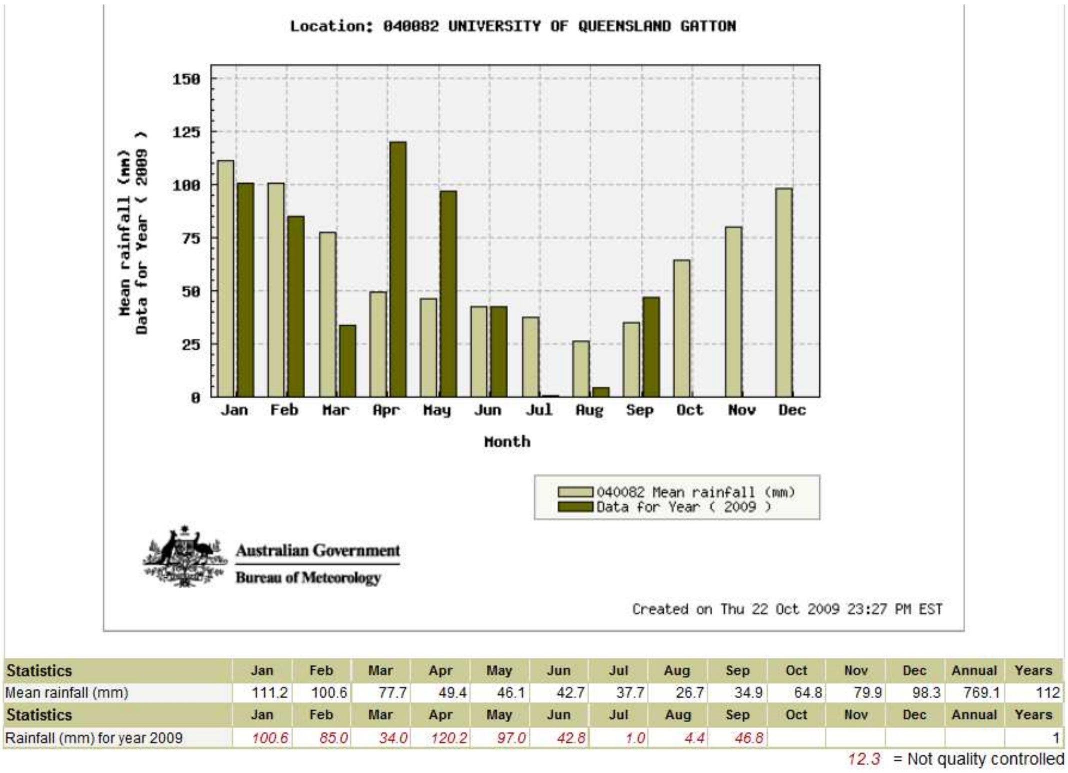
District	3 SOUTHERN DISTRICT
Road Section	414 ESK - HAMPTON ROAD
Year	2007
TDist	
Status	C
Direction	All Directions

Through Distance	0.000 - 45.760
Site	30008 At Ravensbourne National Park Td 32.96

		% per Vehicle Class						% Growth		
Gaz Dir	AADT	Light Vehicle	Heavy Vehicle	Short Vehicle	Truck or Bus	Articulated Vehicle	Road Train	1 Yr	5 Yr	10 Yr
G	358	91.92	8.08	91.92	3.96	3.59	.53	-6.04	3.70	3.10
A	368	88.54	11.46	88.54	7.74	3.60	.12	-7.54	4.92	4.07
B	726	90.20	9.80	90.20	5.87	3.60	.33	-6.80	4.31	3.58

(36) Figure 4.2.1.1 - AADT for Esk / Hampton Road (QDTMR, 2007, p57)

The samples were taken on the 10th September 2009. According to the Bureau of Meteorology, the closest location for weather recordings for the Esk / Hampton Roads is Gatton (Figure 4.2.1.2). This indicates that there has been a ‘very much below average’ rainfall in this area during the start of September and August 2009.



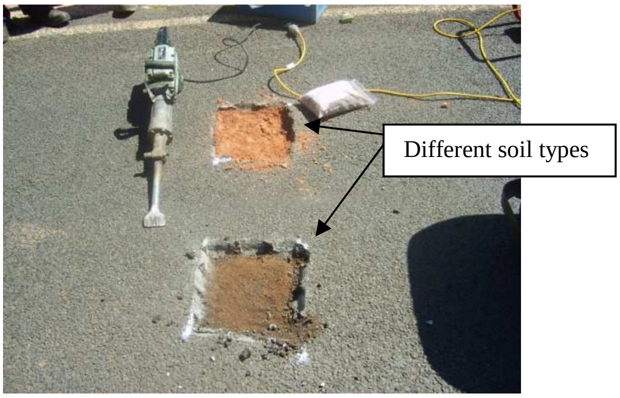
Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean rainfall (mm)	111.2	100.6	77.7	49.4	46.1	42.7	37.7	26.7	34.9	64.8	79.9	98.3	769.1	112
Statistics	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**	**Years**
Rainfall (mm) for year 2009	*100.6*	*85.0*	*34.0*	*120.2*	*97.0*	*42.8*	*1.0*	*4.4*	*46.8*					1

12.3 = Not quality controlled

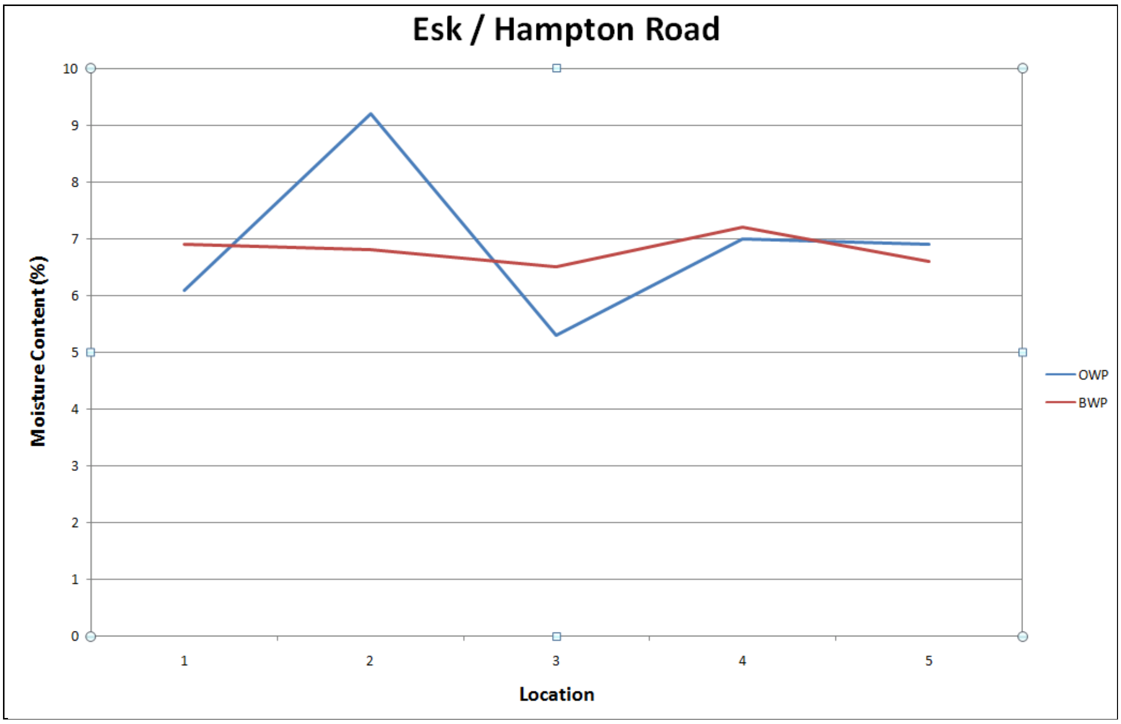
(37) Figure 4.2.1.2 - Rainfall Data for Gatton in 2009 (BOM, 2009)

As can be seen in Figure 4.2.1.4, the moisture variation on the Esk / Hampton Road is not significant. The reasons for this may be because,

1. It is a low volume road with few heavy vehicles.
2. The recent rainfall is very minimal.
3. The road has once been widened and there is two types of soil. The OWP soil is different to the BWP soil (see Figure 4.2.1.3).



(38) Figure 4.2.1.3 – Sampling at Esk / Hampton Road

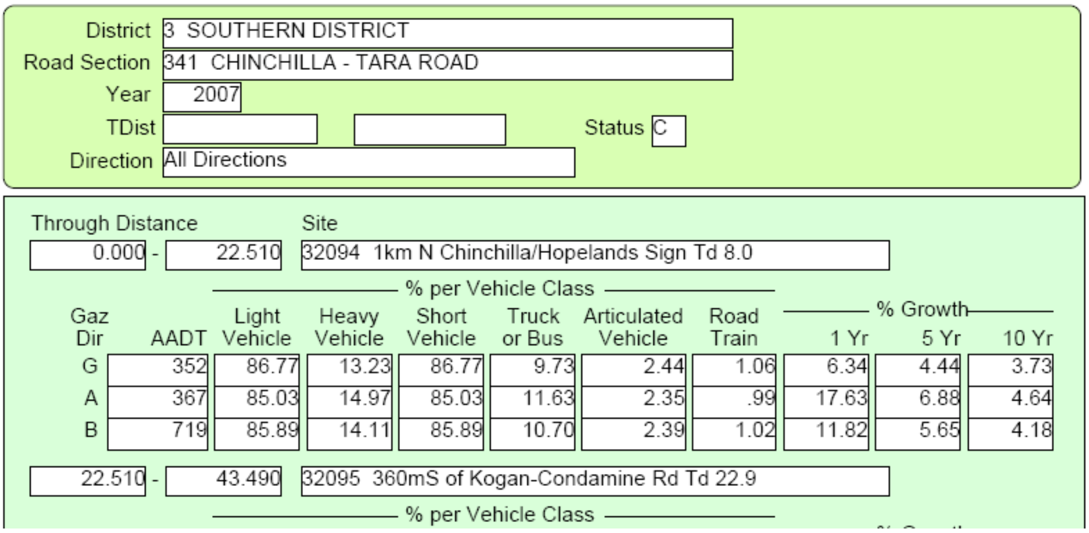


(39) Figure 4.2.1.4 – Esk / Hampton Road

As can be seen in Figure 4.2.1.4 above, the M/C results are inconclusive and therefore do not support the theory that traffic induces moisture into the road pavement. If there had been a recent rain event the data may have provided more positive results, however a low volume road with different soil types indicates that the moisture variation is not as predicted.

4.2.2 Chinchilla / Tara Road

Chinchilla / Tara Road is a narrow two lane spray sealed road with non-sealed shoulders. Samples were taken on the 20th of August 2009 at various locations along the Chinchilla / Tara Road. The road has a total of 719 vehicles per day with 14.11% heavy vehicles. This totals 51 heavy vehicles in each lane per day.



District: 3 SOUTHERN DISTRICT
Road Section: 341 CHINCHILLA - TARA ROAD
Year: 2007
TDist:
Status: C
Direction: All Directions

Through Distance: 0.000 - 22.510
Site: 32094 1km N Chinchilla/Hopelands Sign Td 8.0

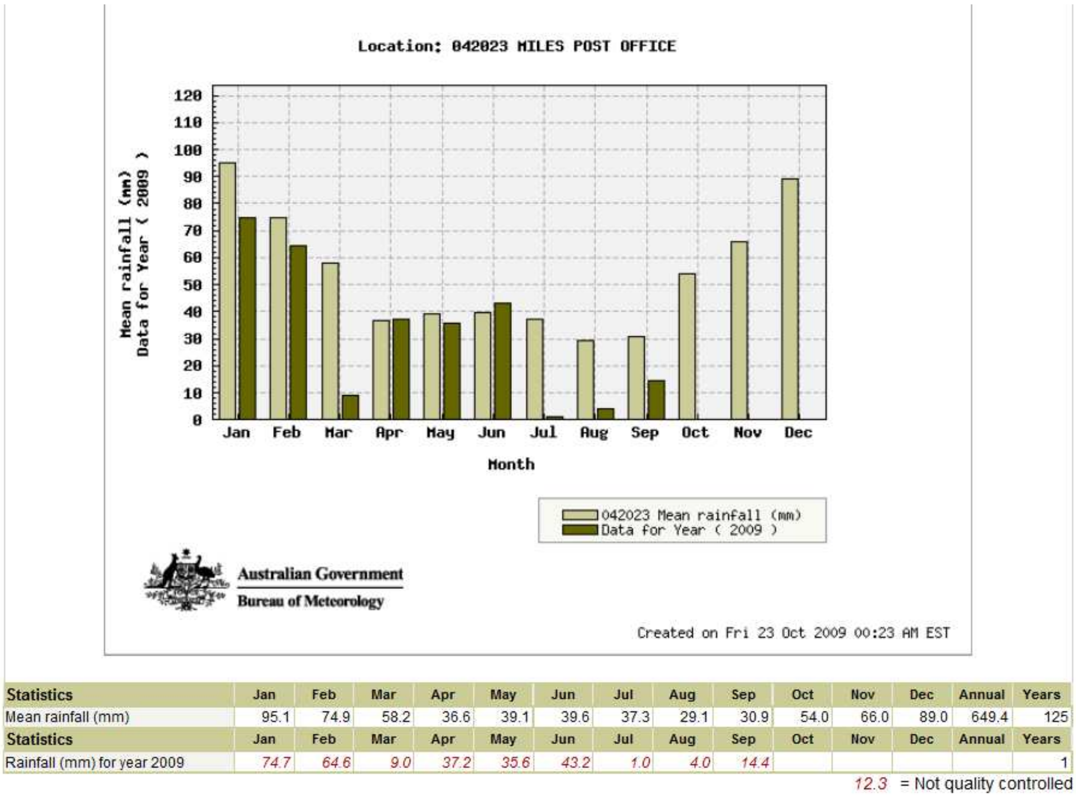
		% per Vehicle Class						% Growth		
Gaz Dir	AADT	Light Vehicle	Heavy Vehicle	Short Vehicle	Truck or Bus	Articulated Vehicle	Road Train	1 Yr	5 Yr	10 Yr
G	352	86.77	13.23	86.77	9.73	2.44	1.06	6.34	4.44	3.73
A	367	85.03	14.97	85.03	11.63	2.35	.99	17.63	6.88	4.64
B	719	85.89	14.11	85.89	10.70	2.39	1.02	11.82	5.65	4.18

22.510 - 43.490
32095 360mS of Kogan-Condamine Rd Td 22.9

% per Vehicle Class

(40) Figure 4.2.2.1 - AADT for Chinchilla / Tara Road (QDTMR, 2007, p46)

The rainfall data in Figure 4.2.2.2 shows that rainfall in 2008 for July/August is significantly lower than average with 5mm of rain compared to 66.4mm. Minimal rainfall explains the low M/C's at each location.

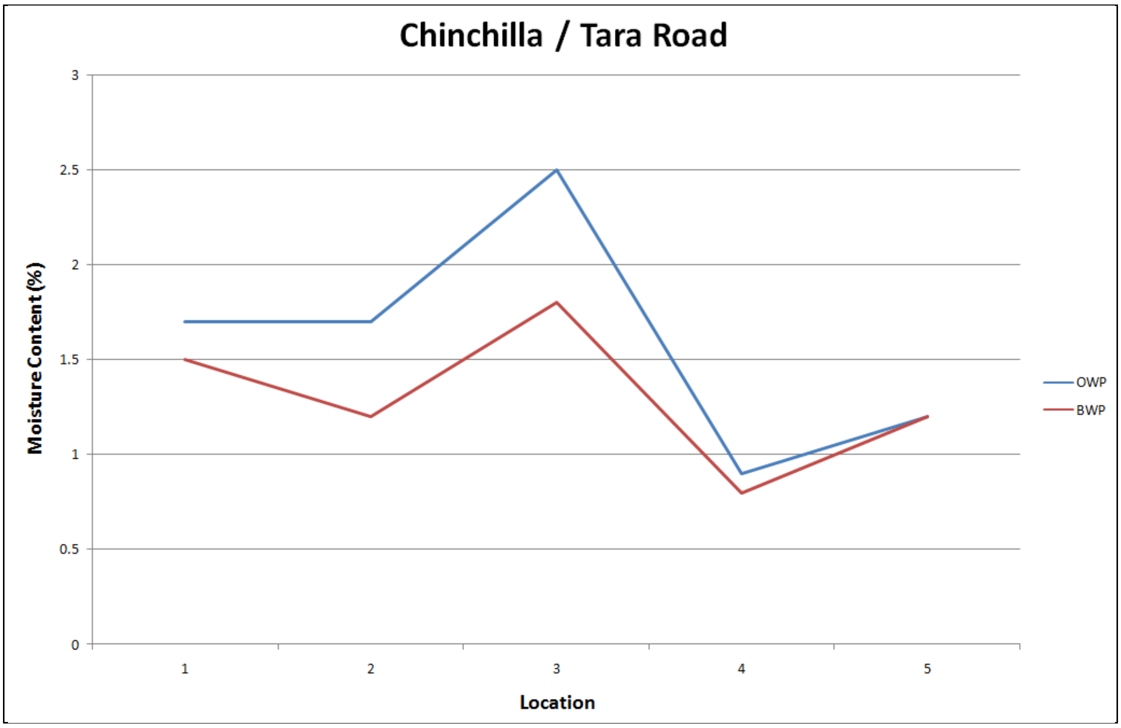


Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean rainfall (mm)	95.1	74.9	58.2	36.6	39.1	39.6	37.3	29.1	30.9	54.0	66.0	89.0	649.4	125
Statistics	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**	**Years**
Rainfall (mm) for year 2009	*74.7*	*64.6*	*9.0*	*37.2*	*35.6*	*43.2*	*1.0*	*4.0*	*14.4*					1

12.3 = Not quality controlled

(41) Figure 4.2.2.2 - Rainfall Data for Miles in 2009 (BOM, 2009)

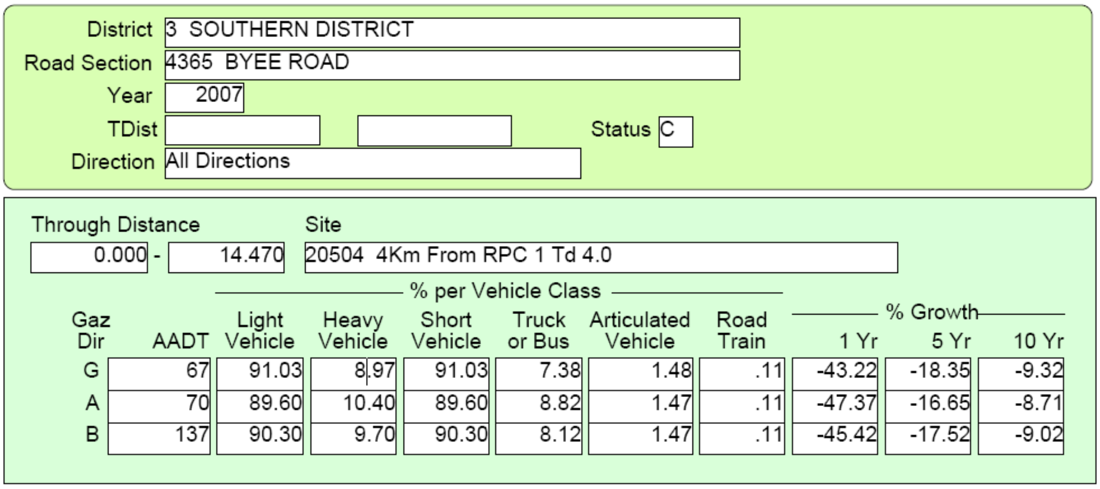
Figure 4.2.2.3 shows that the M/C is very low with an OWP average of 1.6% and an IWP average of 1.3%. The recent dry weather may be a reason for the low M/C data. It is clear that the OWP has higher M/C than the IWP. As the shoulders are not sealed infiltration may have occurred during the last rain event, however traffic may have contributed to this moisture difference as well.



(42) Figure 4.2.2.3 – Chinchilla / Tara Road

4.2.3 Byee Road

Byee Road is a narrow road primarily accessed by local residents and farmers. Samples were taken on the 1st of October 2009. The soil type is primarily black soil with a recent upgrade to the Barambah Creek Bridge approximately 2 years ago. The traffic analysis and Reporting System – AADT Segments Report details the AADT of Byee Road as shown in Figure 4.2.3.1 below. This figure states that there are a total of 137 vehicles that use the road (a combination of both directions) and an average of 9.7% heavy vehicles. This means that approximately 6.65 heavy vehicles use each lane per day. This is a very minimal number of heavy vehicles and the variation of moisture may not differ across the trafficked lane.



District 3 SOUTHERN DISTRICT
Road Section 4365 BYEE ROAD
Year 2007
TDist
Status C
Direction All Directions

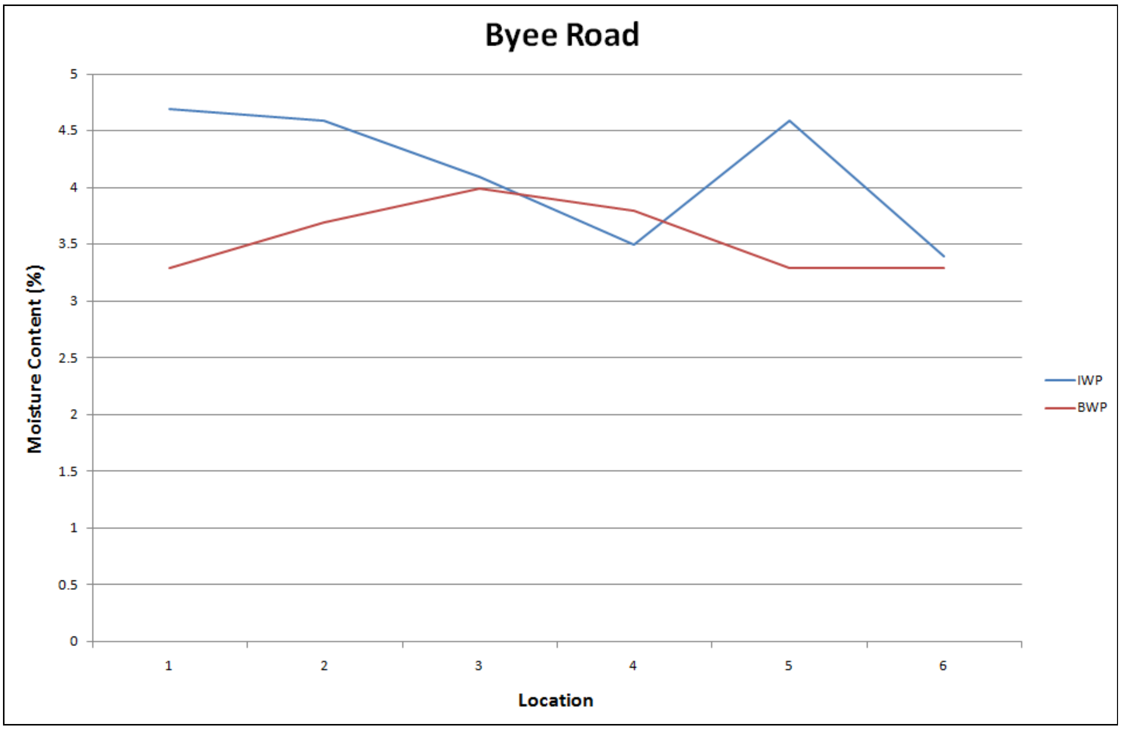
Through Distance 0.000 - 14.470
Site 20504 4Km From RPC 1 Td 4.0

		% per Vehicle Class						% Growth		
Gaz Dir	AADT	Light Vehicle	Heavy Vehicle	Short Vehicle	Truck or Bus	Articulated Vehicle	Road Train	1 Yr	5 Yr	10 Yr
G	67	91.03	8.97	91.03	7.38	1.48	.11	-43.22	-18.35	-9.32
A	70	89.60	10.40	89.60	8.82	1.47	.11	-47.37	-16.65	-8.71
B	137	90.30	9.70	90.30	8.12	1.47	.11	-45.42	-17.52	-9.02

(43) Figure 4.2.3.1 – AADT for Byee Road (QDTMR, 2007, p84)

The Australian Bureau of Meteorology states that the average annual rainfall from l905 to 2001 is 776.2mm. Over the past 8 years, rainfall has decreased significantly in the Toowoomba region. It can be assumed that from Figure 3.1.1 and the recent drought that rainfall from the July, August and September is very minimal ranging between 5-10mm per month.

The test results in Figure 4.2.3.2 show that the IWP has higher M/C than BWP. There is an overlap in some areas showing that the recent dry weather may have an effect on the moisture conditions within the pavement. Overall it is clear that the IWP has higher M/C than BWP. The average IPW compared to the average BWP is IWP=4.15% and BWP=3.6%.

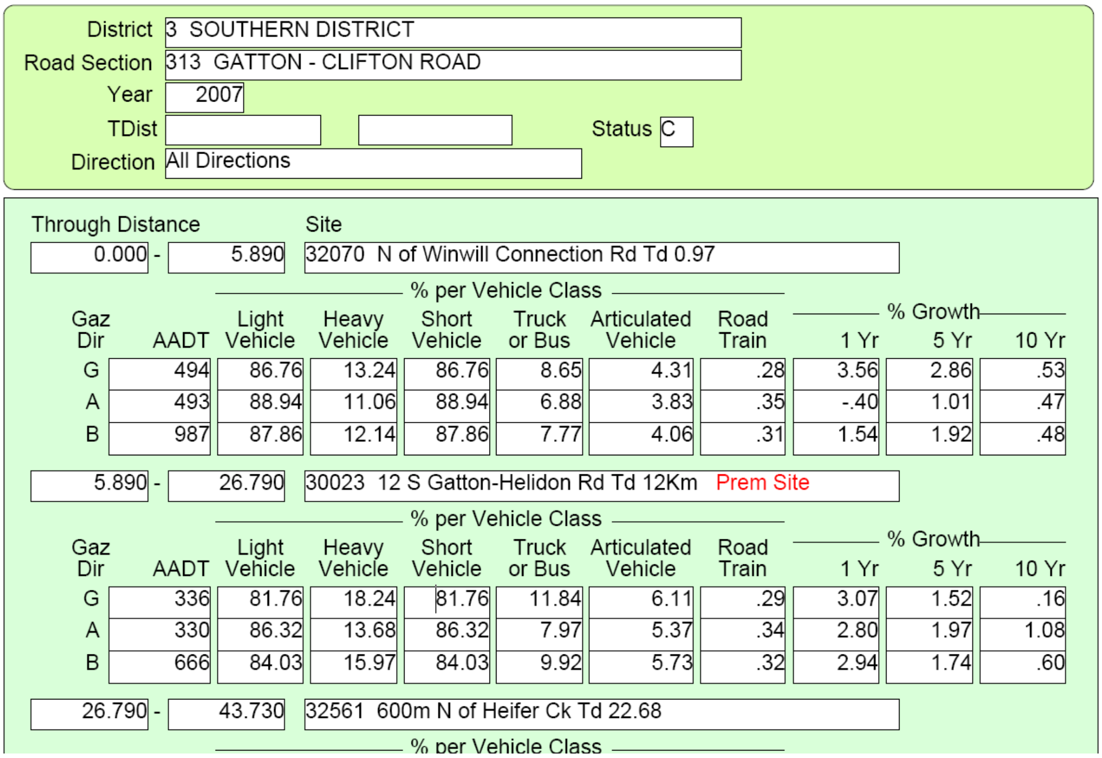


(44) Figure 4.2.3.2 – Byee Road

4.1.4 Gatton / Clifton Road

Gatton / Clifton Road is a narrow road with various upgrades and widening completed over the past years. Samples were taken on the 10 September 2009. By visual inspection at Heifer Creek Bridge, the Northern approach is a new road, whilst the Southern approach is much older. This may show a comparison between seal thicknesses under the same conditions, possibly concluding that M/C decreases with a greater number of seals.

The AADT in Figure 4.1.1.1 states that there are a total of 666 vehicles that use the road (combination of both directions) and an average of 15.97% heavy vehicles. This means that approximately 53 heavy vehicles use each lane per day.



District 3 SOUTHERN DISTRICT
Road Section 313 GATTON - CLIFTON ROAD
Year 2007
TDist
Status C
Direction All Directions

Through Distance 0.000 - 5.890
Site 32070 N of Winwill Connection Rd Td 0.97

Gaz Dir	AADT	Light Vehicle	Heavy Vehicle	Short Vehicle	Truck or Bus	Articulated Vehicle	Road Train	% Growth 1 Yr	5 Yr	10 Yr
G	494	86.76	13.24	86.76	8.65	4.31	.28	3.56	2.86	.53
A	493	88.94	11.06	88.94	6.88	3.83	.35	-.40	1.01	.47
B	987	87.86	12.14	87.86	7.77	4.06	.31	1.54	1.92	.48

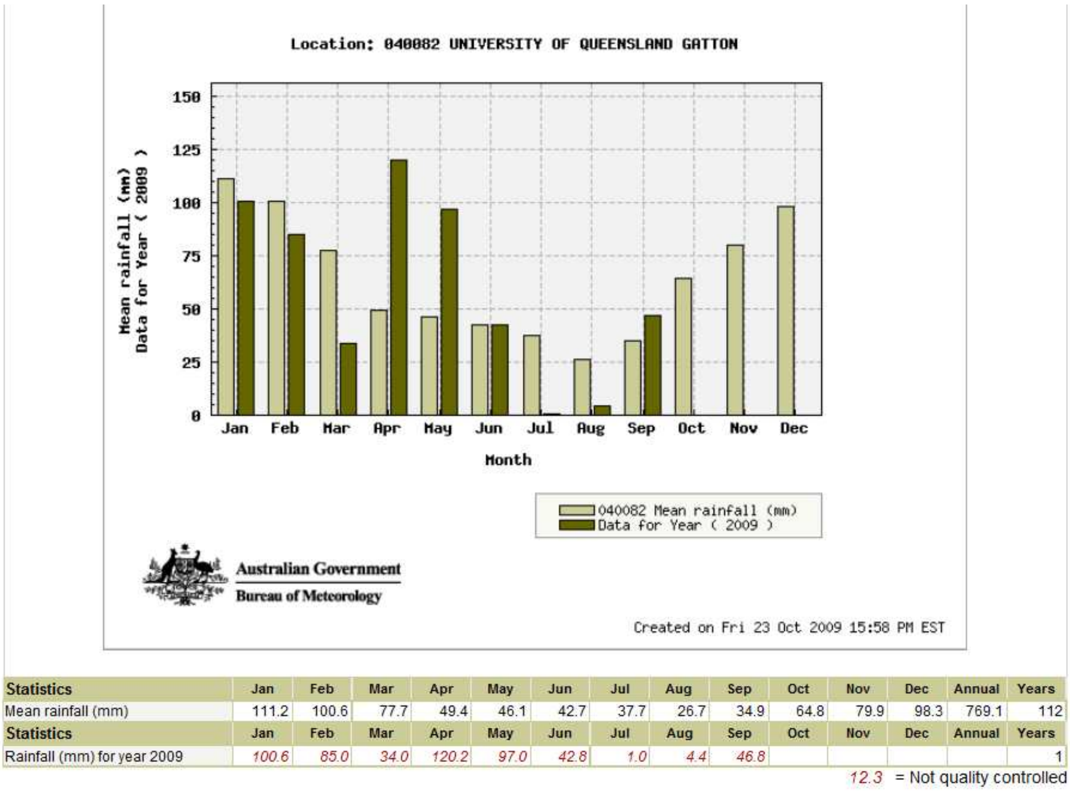
5.890 - 26.790 30023 12 S Gatton-Helidon Rd Td 12Km Prem Site

Gaz Dir	AADT	Light Vehicle	Heavy Vehicle	Short Vehicle	Truck or Bus	Articulated Vehicle	Road Train	% Growth 1 Yr	5 Yr	10 Yr
G	336	81.76	18.24	81.76	11.84	6.11	.29	3.07	1.52	.16
A	330	86.32	13.68	86.32	7.97	5.37	.34	2.80	1.97	1.08
B	666	84.03	15.97	84.03	9.92	5.73	.32	2.94	1.74	.60

26.790 - 43.730 32561 600m N of Heifer Ck Td 22.68

(45) Figure 4.1.4.1 - AADT for Gatton / Clifton Road (QDTMR, 2007, p20)

Recent rainfall in the Gatton region is dramatically below the annual average. The Gatton / Clifton Road samples were taken on 10th September 2009. As shown below in Figure 4.1.4.2, rainfall prior to this date is extremely low with only 5.4mm of rain in the previous 2 months. April and May shows a large fluctuation in rainfall when compared to the average. This type of rain period may show a slight difference in M/C.



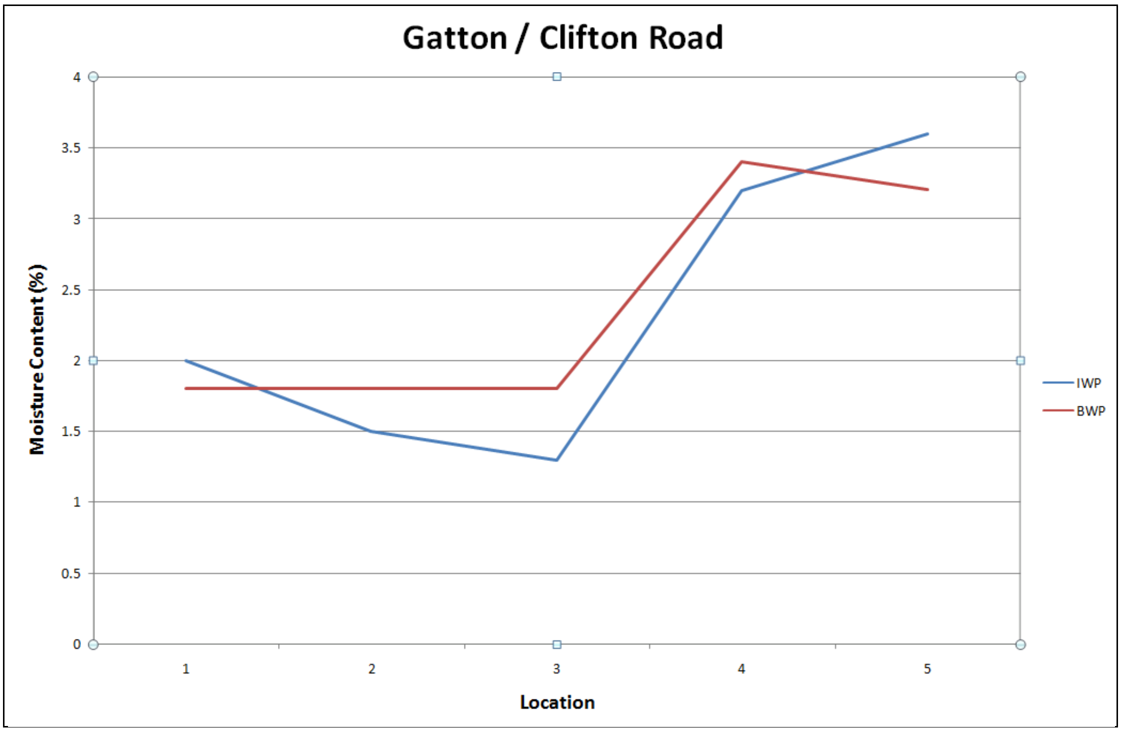
Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean rainfall (mm)	111.2	100.6	77.7	49.4	46.1	42.7	37.7	26.7	34.9	64.8	79.9	98.3	769.1	112
Statistics	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**	**Years**
Rainfall (mm) for year 2009	*100.6*	*85.0*	*34.0*	*120.2*	*97.0*	*42.8*	*1.0*	*4.4*	*46.8*					1

12.3 = Not quality controlled

(46) Figure 4.1.4.2 – 2009 Rainfall data for Gatton (BOM, 2009)

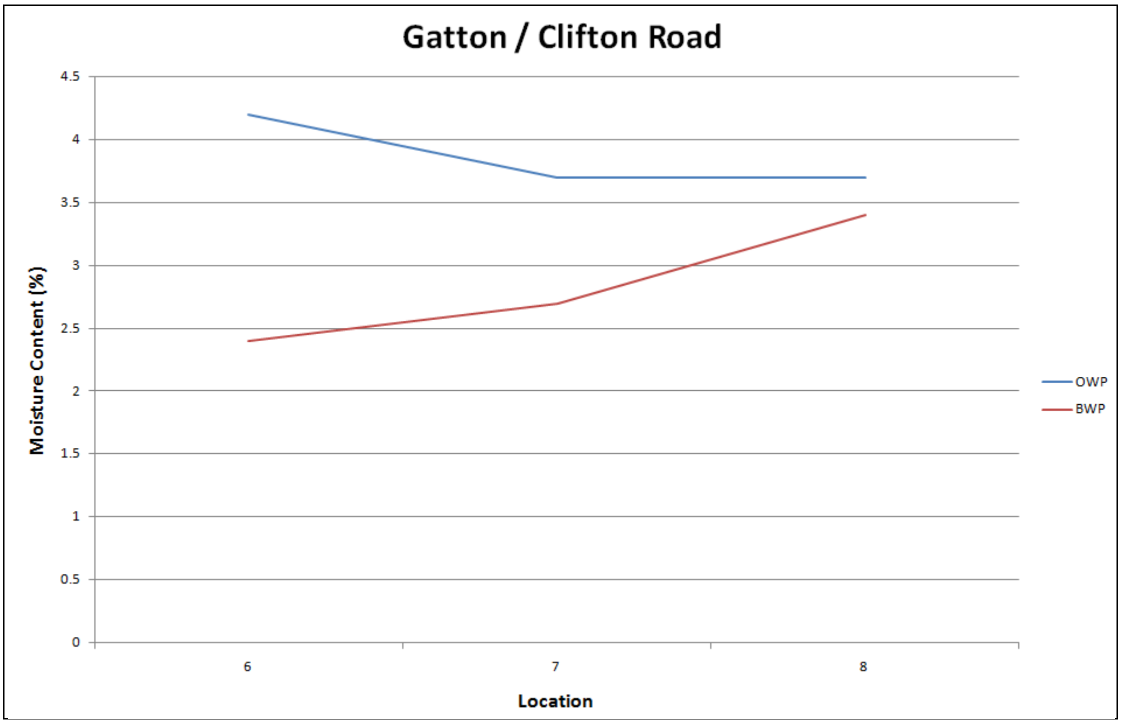
Samples at locations one, two and three were taken at the southern approach of the bridge (numerous reseals) whilst locations four, five and six were taken at the northern approach (new section). The seal thicknesses on the southern approach of the bridge averaged between 80mm and 140mm while the northern samples were only 10-25mm thick.

Samples were taken at the OWP, IWP and BWP as shown in Figures 4.1.4.3 and 4.1.4.4. Figure 4.1.4.3 shows a comparison between IWP and BWP at various locations. It can clearly be seen that location four, is significantly higher than locations one, two and three. This indicates the change in road type from old to new gives a direct comparison between seal thicknesses and M/C's. The soil types do differ between these locations which may also have an effect on the M/C. For locations one, two and three the M/C in the IWP is lower than BWP indicating that the dry weather and thickness of the seal have a direct relationship with M/C.



(47) Figure 4.1.4.3 – Gatton / Clifton Road

Figure 4.1.4.4 shows a comparison between the OWP and BWP. There is a significant difference in M/C's between the two locations. It is clear that the moisture in the OWP is much higher than BWP. The M/C's are much higher than locations one, two and three showing this may suggest that the thickness of the seal and soil type does have an impact on M/C results.



(48) Figure 4.1.4.4 – Gatton / Clifton Road

4.1.5 Conclusion

In conclusion, there is higher moisture content in the wheel paths as opposed to BWP. The moisture difference in the inner and outer wheel paths compared to ‘between the wheel paths’ is much closer than the ‘Existing Data’ analysis. The reason for this is a combination of low AADT, low heavy vehicles and minimal recent rainfall.

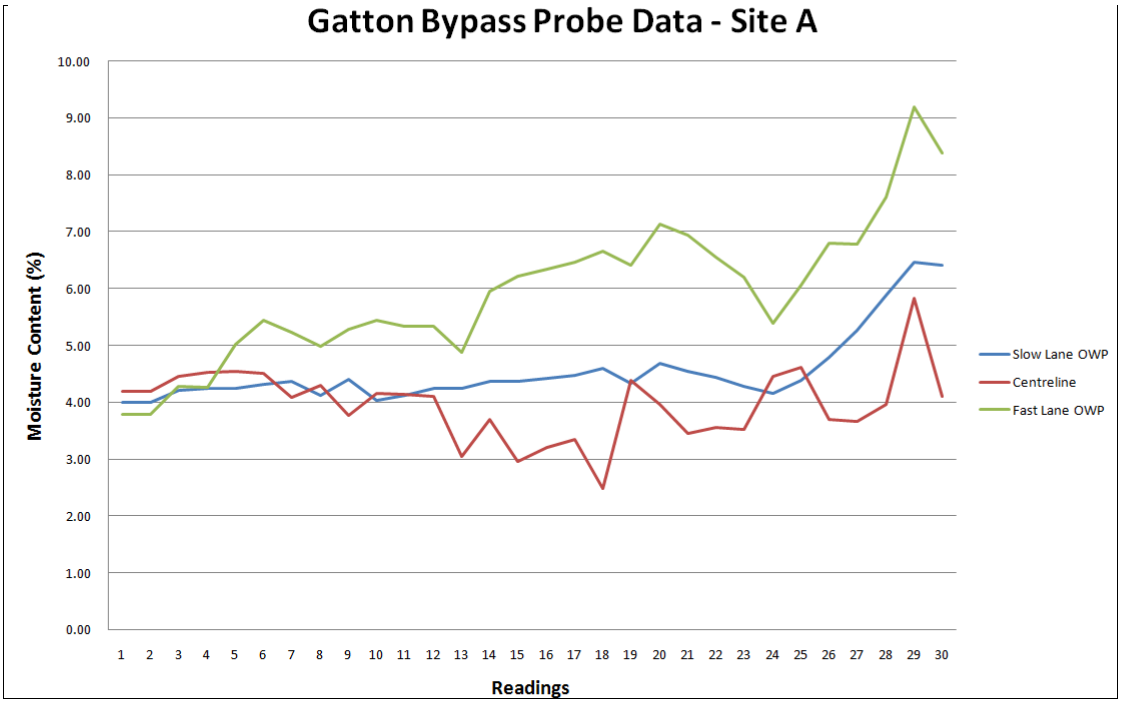
It can be seen in section 4.1.4 that seal thicknesses have a significant impact on the M/C’s in the wheel paths as well as the amount of moisture in the road.
See Appendix D for M/C recordings for each location.

4.3 Gatton Bypass Probe Data

4.3.1 Site A

This site is located at the Eastern end of the GBD project. Irrigation occurs beside the road reserve, which may have an impact on M/C to this site. The cross section has no verges, therefore there are no probes located in the shoulder.

As shown below in Figure 4.3.1.1, the average M/C in the fast lane is slowly increasing over time. This may indicate that the probe is unstable.
M/C’s in both lanes appear to be higher than the control line therefore depicting the trafficked area has higher moisture readings.



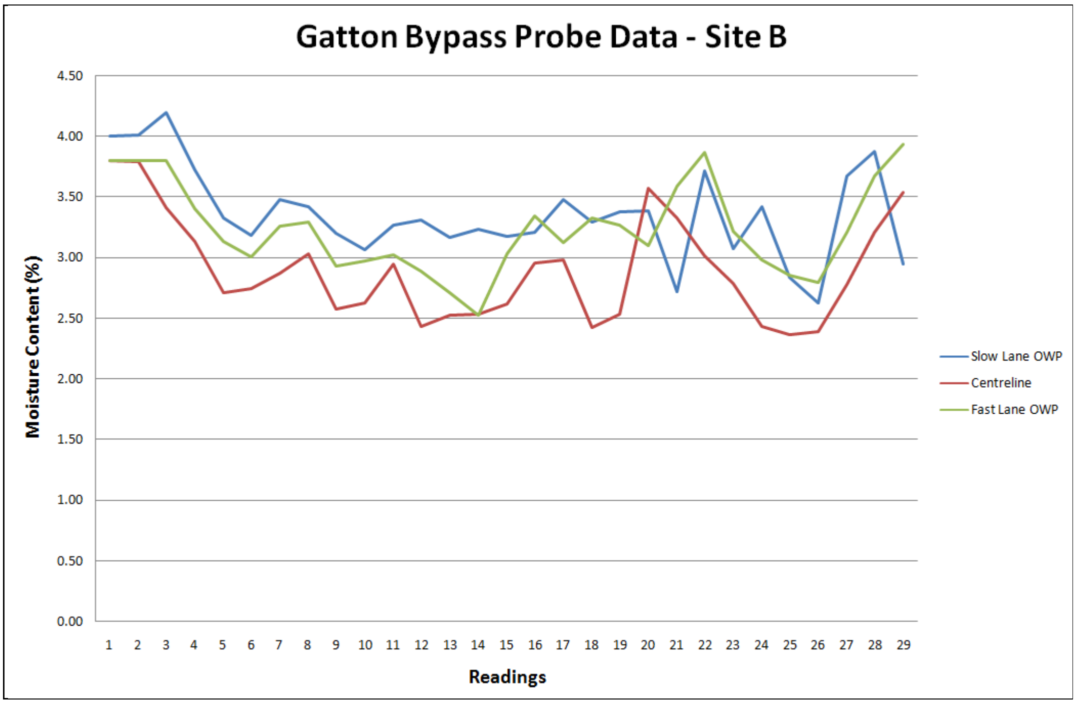
(49) Figure 4.3.1.1 – Gatton Bypass Probe Results – Site A

4.3.2 Site B

Site B is located only 480m from site A and it should have the same influences from irrigation as site A. The cross section of site B has two verges constructed of black soil.

The trend remains relatively level which indicates that there is no deficiency in the probe. At the beginning of the installation there was a slight rain event which is visible on Figure 4.3.2.1. The OWP of the slow lane jumps to 4.19% after the third reading and then drops with the other probes as the road dries out.

The moisture readings of the slow lane (average = 3.35%) are slightly higher than the fast lane (average = 3.24%). This may indicate that there is more traffic in the slow lane, however there is no AADT to support this. Infiltration through the shoulder is possible as the moisture readings at the shoulder of the slow lane is higher (average = 4.37%) than the OWP of the slow lane (average = 3.35%). Infiltration into the fast lane is unlikely as the OWP of the fast lane (average = 3.24%) is higher than the shoulder of the fast lane (average = 2.97%). It is evident that there is more moisture in the wheel paths compared to the control line.



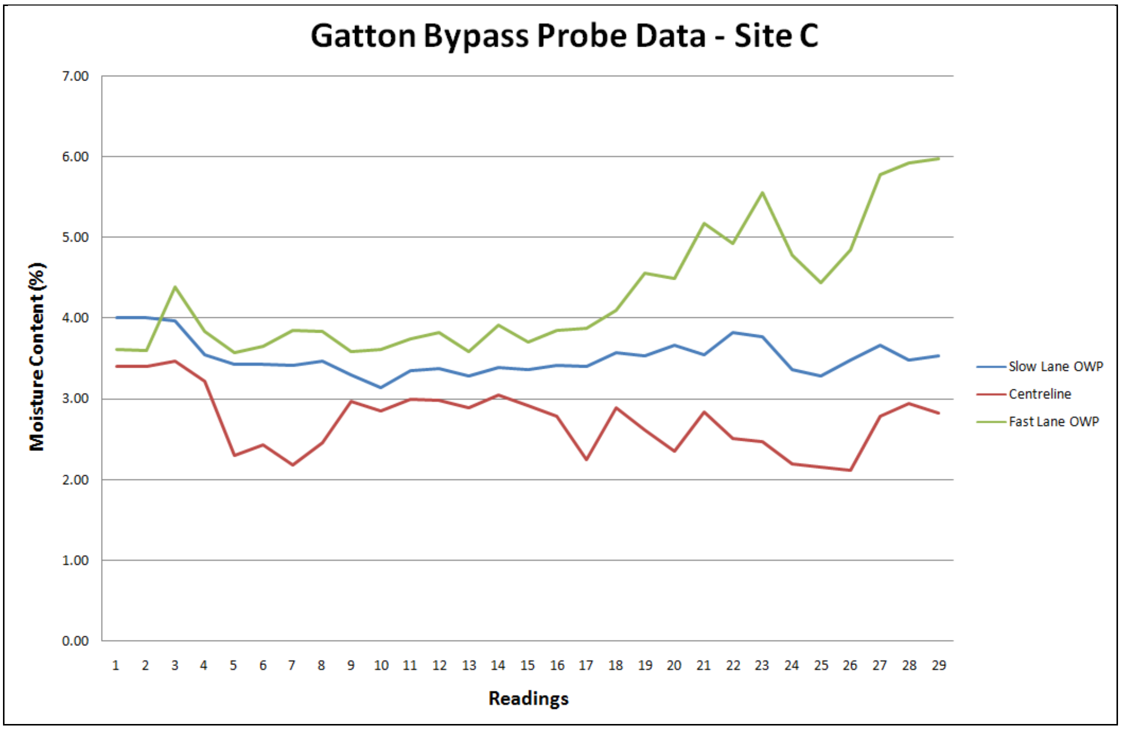
(50) Figure 4.3.2.1 – Site B

4.3.3 Site C

This site is located in a cut / fills transition at the Western side of the Eastern most cut on the project.

The M/C has remained stable within the pavement layers under the control line and slow lane OWP. The fast lane OWP slowly increases over time showing signs of instability. Both the fast lane and slow lane have significantly higher moisture readings than the control line.

The average M/C in the slow lane shoulder is 3.89% compared to that of the wheel path which is 3.56%. It is possible that infiltration was occurring here as the shoulder moisture readings are slightly higher than the slow lane OWP. The fast lane shoulder probe has an average M/C of 3.30% compared to the OWP of 4.32%. This shows that infiltration is not occurring in the fast lane (if the probes are stable).



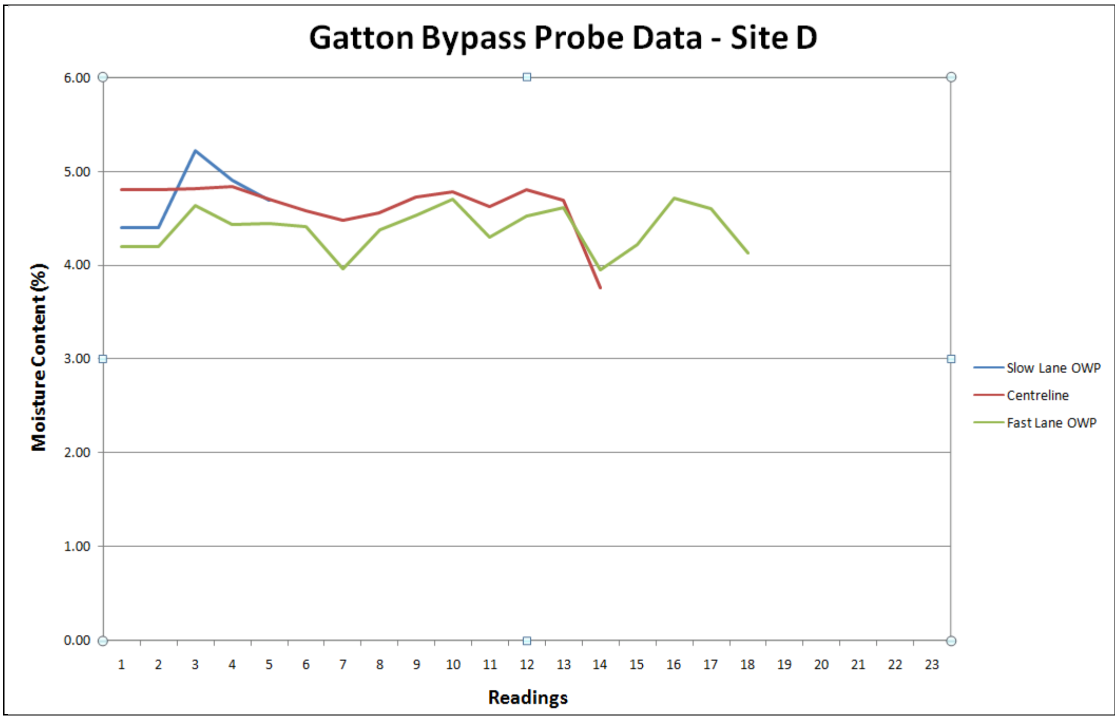
(51) Figure 4.3.3.1 – Site C

4.3.4 Site D

Site D is located in a low lying area with many drainage structures designed to carry water under the road.

Probe D3 ceased working in September 2003 and no data has been recorded since this date. The M/C in the control line is higher than that of the fast lane – OWP. The average M/C in the fast lane's OWP is 4.39% compared to the control line which is 4.74%. This may be because Site D is located in a very low lying flat and influence of lateral movement of moisture into the pavement is likely.

Both the slow lane and the fast lane OWP ceased taking readings prematurely due to unknown faults. From the data in Appendix E5 and Figure 4.3.4.1, it appears that the control line has higher M/C than the wheel paths.

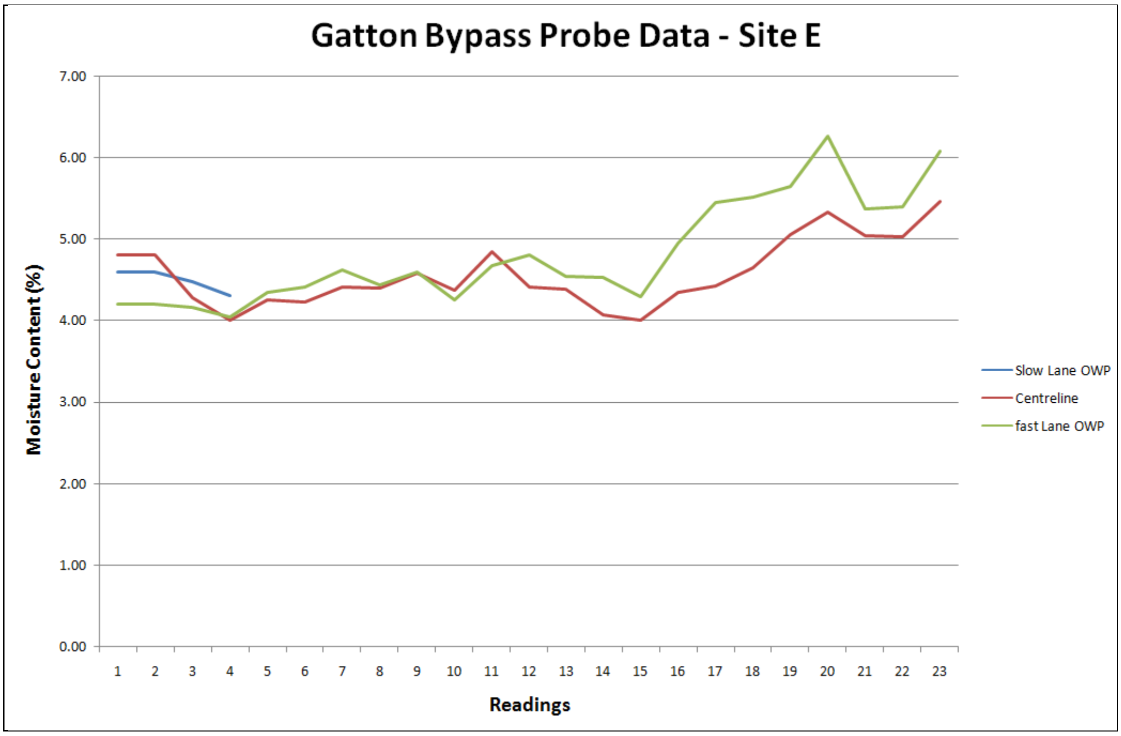


(52) Figure 4.3.4.1 – Site D

4.3.5 Site E

Site E is the only probe that has been installed within a cut.

The M/C has shown a gradual increase within the pavement layers. Once again the slow lane OWP ceased working sometime in September 2003 and only recorded four readings. The M/C in the fast lane OWP is higher than the control line. The average M/C in the control line is 4.57% compared to 4.82% in the fast lane OWP. The average M/C in the fast lane shoulder is 5.23%, therefore infiltration is possible.



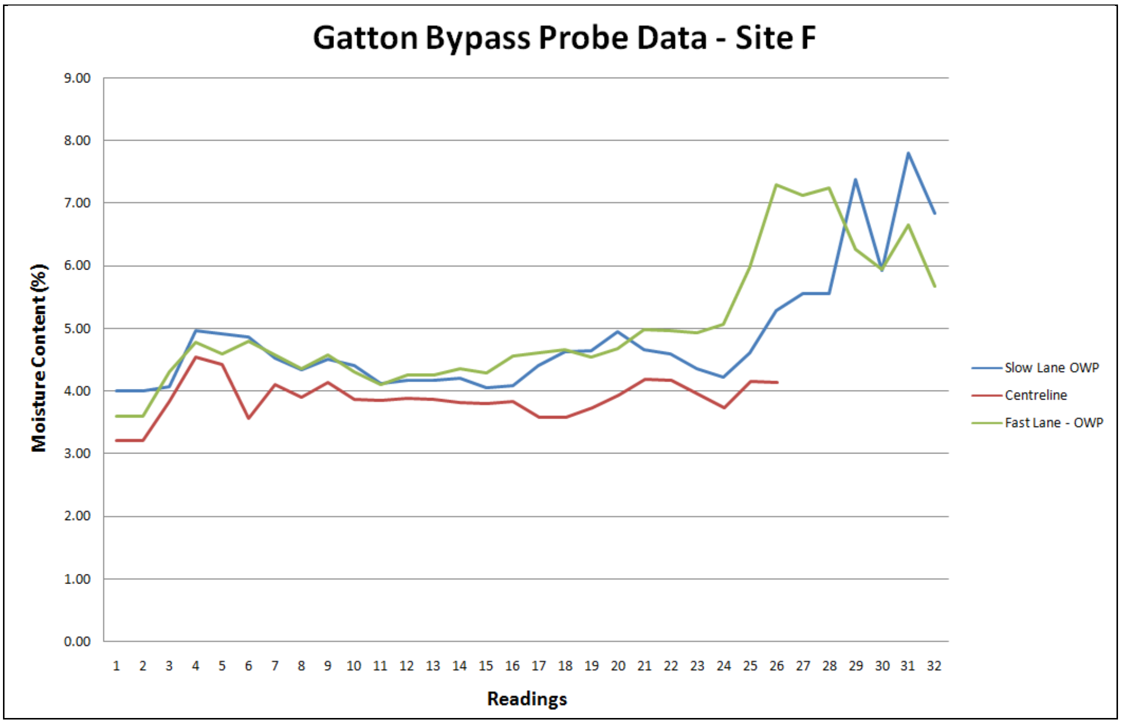
(53) Figure 4.3.5.1 – Site E

4.3.6 Site F

Site F is located in a high fill area with a water table influence. Pavement and selected sub-grade were constructed on four metres of embankment.

In Figure 4.3.6.1 the M/C has remained relatively constant throughout the duration of the readings until the most recent reading. The control line stopped recording in approximately April 2005. At this time the M/C of the fast and slow lanes jumped significantly to almost 8% which is out of the ordinary considering there were no major rain events around that time.

It is obvious that the M/C's of the fast and slow lanes are higher than the control line. Both of the shoulder probes have average M/C readings higher than the OWP's. This may indicate that infiltration through the shoulder is a possibility at this location.

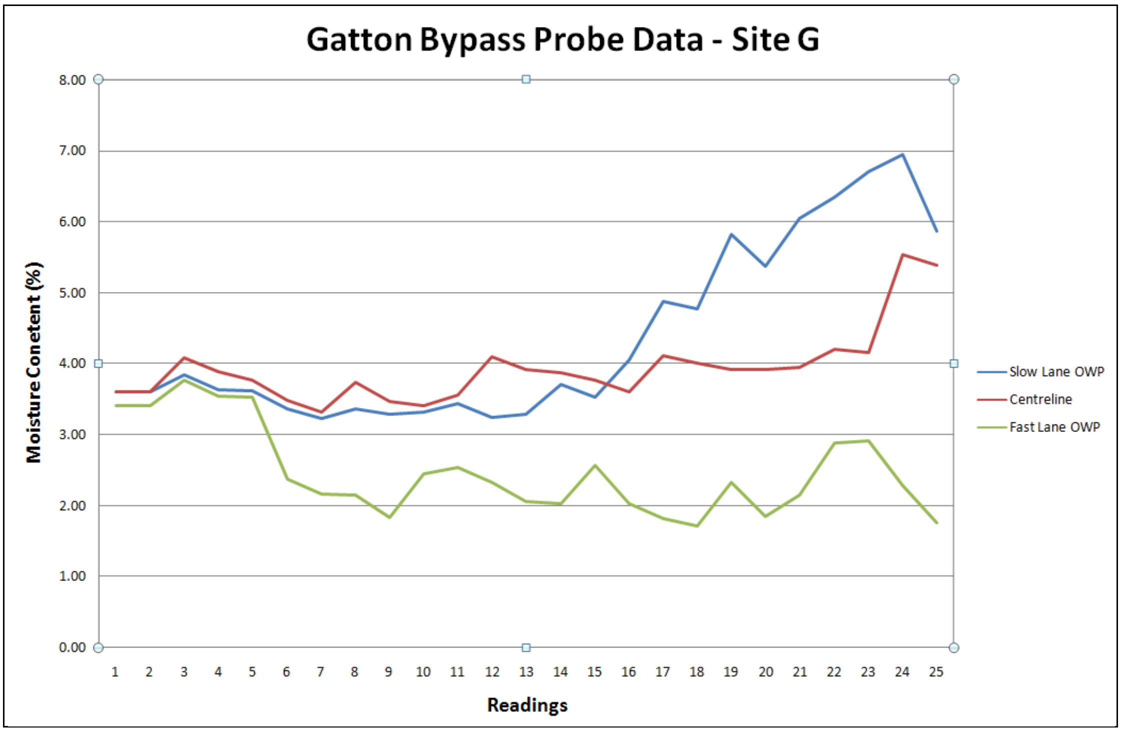


(54) Figure 4.3.6.1 – Site F

4.3.7 Site G

Site G is located on the most Westerly region of the GBD. The pavement is constructed on a high fill. The pavement and sub-grade were constructed on four metres of embankment.

Figure 4.3.7.1 indicates that the slow lane has the highest moisture readings with an average of 4.35% compared to the control line (average = 4.02%) and the fast lane (average = 2.44%).



(55) Figure 4.3.7.1 – Site G

4.3.8 Conclusion

In conclusion by viewing the above figures (Figure 4.3.1.1 – Figure 4.3.7.1), the M/C in the wheel paths is generally higher than the M/C in the control line. At times infiltration through the shoulder and the water table may have affected the readings.

Some readings may not be accurate and as a result of this may therefore show obscurities in the data such as dramatic jumps in M/C (Figure 4.3.6.1). The M/C in the fast lane is at times higher than the M/C of the slow lane. This may be because of infiltration into the pavement, inaccurate readings, or the location of the probes.

On average, the M/C in the slow lane OWP and fast lane OWP is higher than the control line. As this is a constant trend in most readings, it can be suggested that traffic plays a part in the moisture penetration into the road pavement.

4.4 Permeameter Testing

Permeameter testing was conducted on the 3rd and 4th October under typical fine weather conditions. Rapidflow and Evenflow Field Permeameters were used to test the permeability of the spray seal.

The permeameter testing was conducted in a quiet cul-de-sac with little AADT. The permeameters were positioned in the traffic path within 4 metres of each other. For ease of testing, safety and proximity to power, the tests were conducted close together to avoid traffic and minimise the testing area.

Four permeameter beacons where installed to test the bitumen spray seal permeability. Two evenflow field permeameters and two rapidflow field permeameters were installed. See section 3.5 for description and installation details.

The water level drop was not rapid; therefore measurements were taken at large intervals. Measurements were taken after 90 minutes and 150 minutes for both of the types of permeameters under normal atmospheric pressure head. Four tests were completed under pressurised (30kPa) conditions for a period of 30 minutes. Two of the pressurised tests failed (evenflow) due to a weak joint/seal and therefore as a result of this no results were recorded. The results are as follows:

Atmospheric Pressure Results at 90 minutes

Test No	Test Type	90min drop (mm)	Radius (mm)	V=π*r^2*h (mm^2)	k=25.5V/s (µm/s)	Description
1	Rapidflow	0.5	72.5	8256.50	38.99	C
2	Rapidflow	0.6	72.5	9907.80	46.79	C
3	Evenflow	7	20	8796.46	41.54	C
4	Evenflow	2	20	2513.27	11.87	C
5	Evenflow	6	20	7539.82	35.60	C

(7) Table 4.4.1 – Permeameter results at atmospheric pressure after 90 minutes

Table 4.4.1 shows measurements after a period of 90 minutes under atmospheric pressure. The water level dropped relatively evenly throughout the timeframe providing volume changes as shown. The volume (V) was calculated using equation (1) in section 3.5.5. The volume (V) is then substituted into the permeability equation (2) in section 3.5.5. The permeability equation calculated the ‘k’ value which ranges from 11.87(μm/s) to 46.79(μm/s) in Table 4.4.1. The ‘k’ values are then categorised in the ‘Permeability Category and Description Table’ (Table 3.5.5.1). All of the values are described as category ‘C’ which is described as permeable.

Tests four and five differ from tests one, two and three as tests four and five were emptied and re-filled the next day. This is the reason for the low ‘k-values’ as the seal already has a significant amount of moisture in it.

Atmospheric Pressure Results at 150 minutes

Test No	Test Type	150min drop (mm)	Radius (mm)	V=π*r^2*h (mm^2)	k=25.5V/s (μm/s)	Description
1	Rapidflow	1	72.5	16513.00	46.79	C
2	Rapidflow	1.25	72.5	20641.25	58.48	C
3	Evenflow	14	20	17592.92	49.85	C
4	Evenflow	3	20	3769.91	10.68	C
5	Evenflow	8	20	10053.10	28.48	C

(8) Table 4.4.2 – Permeameter results at atmospheric pressure after 150 minutes

Table 4.4.2 shows measurements from the same permeameters after 150 minutes under atmospheric pressure. The drop in the permeameters are not significant, however all of the k-values show that the seal is permeable (Table 3.5.5.1). Once again, tests four and five differ from tests one, two and three as these permeameters were emptied and re-filled the next day. Despite the low readings, the description is still classed as permeable. If this is the case for a low volume residential cul-de-sac, then it can be assumed that under heavy volume AADT the seal will be equally or more permeable.

30kPa Pressure Results at 30 minutes

Test No	Test Type	30min drop	Radius	V=π*r^2*h	k=25.5V/s	Description
1	Rapidflow	5	72.5	82564.98	233.93	D
2	Rapidflow	6	72.5	99077.98	280.72	D
3	Evenflow	--	--	Failed	Failed	Failed
4	Evenflow	--	--	Failed	Failed	Failed

(9) Table 4.4.3 – Permeameter results at 30 kPa after 30 minutes

The same permeameters were then pressurised to a constant pressure of 30kPa. After attaching the pressure hose and slowly releasing the pressure, the silicone seals broke between the base plate and the plastic conical funnel. This was to be expected as these permeameters are not constructed to withstand force other than 200mm of water head. Due to the broken seals, only two (2) rapidflow permeameter were used under 30kPa pressure.

The pressurised tests were conducted on the 4th October 2009. After the permeameters were filled with water, the custom made lid was then attached. While the silicone was drying the water level still decreased, therefore before pressurising the permeameters the water level was re-measured to account for the drop in water level. This ensured that the readings did not account for any water loss prior to pressurising the permeameter.

As can be seen in Table 4.4.3, the k-values are much higher and therefore the description has moved to a level where it is classed as ‘moderately free draining’. This is a significant increase at just 30kPa. From Figure 2.2.2.1 the pressure that truck tyres will exert onto the road pavement is 1120kPa. If a permeameter was constructed to withstand this force, the ‘k’-values would increase significantly. At this higher pressure the seal can be assumed to be classed as ‘free draining’.

Therefore Table 4.4.3 shows that by slightly replicating actual traffic conditions by pressurising the permeameters at a low pressure the seal becomes much more permeable when compared to standard atmospheric pressure. Pressurised permeameters may revolutionise permeability testing in the future.

4.6 General Discussion of Results

By comparing the existing data (Table 4.6.1) with the new data certain trends have developed. By comparing the AADT, rainfall, date, location and seal types, some sample locations have more prominent data than others. A comparison of these results is shown below in table 4.6.1.

When comparing the sample moisture results it is clear that the top four locations (Gatton Bypass, Bowenville/Dalby, Drayton Connection and Toowoomba/Cecil Plains) have more desired results than the latter four samples (Esk/Hampton, Chinchilla/Tara, Byee, Gatton/Clifton) showing greater differences in the wheel paths and BWP's.

From Table 4.6.1, the OWP has consistently higher M/C than BWP's and IWP's. The data states that the IWP has higher moisture content than BWP. It was expected that BWP would have the lowest moisture content results as it is not trafficked. The existing data (the top four roads) have all received large amounts of recent rainfall and high AADT and heavy vehicles. This is evident as these roads have larger margins between the OWP, IWP and BWP when comparing it to the other four roads.

It is noticeable that the first four (4) roads have higher moisture readings than that of the bottom four (4) roads. It is clear that when looking at past and present M/C results that there is more moisture in the OWP and IWP than BWP. The reason for the OWP having higher M/C than the IWP is because of the high wear of the OWP due to the cross-fall of the road, and infiltration from the shoulder. The major underlying reason as to why the IWP consistently has higher M/C may be that it is due to traffic induced moisture. It can therefore be assumed that the compounding nature of traffic during rain periods assists in inducing moisture into the road pavement.

Road Name	Sample Date	Seal Thickness	AADT		% Average Recent Rainfall	Average Moisture Content (%)		
			Vehicles	Heavy		OWP	BWP	IWP
(Existing) Gatton Bypass	25-Jul-07	Unknown	12958	1014	141%	5.31	--	4.95
(Existing) Bowenville / Dalby	10-Jan-08	Unknown	4433	482	137%	5.08	3.75	--
(Existing) Drayton Connection	18-Dec-08	Spray 30mm	3745	231	90.20%	--	5.87	6.49
(Existing) Toowoomba / Cecil Plains	4-Mar-08	Spray 20-60mm	1624	106	118.90%	7.48	5.48	7.13
(New) Esk / Hampton	10-Sep-09	Spray 20-70mm	363	35.6	8.40%	6.9	6.8	--
(New) Chinchilla / Tara	20-Aug-09	Spray 30-80mm	360	51	7.50%	1.6	1.3	--
(New)Byee Rd	1-Oct-09	Spray 30-50mm	68.5	6.65	?	--	3.57	4.15
(New) Gatton / Clifton	30-Sep-09	Spray 80-100mm & 10-20mm	333	53	8.40%	3.87	2.56	2.32

(10) Table 4.6.1 – Existing data, and new data comparison

The (TDR) probes were installed at various locations within the road pavement including the subgrade, verge, lower subbase and base at seven locations within the GBD. Understanding of the long term trends in moisture content within the pavement structure was limited by the reliability of probes and the frequency of the data collection.

The GBD probe data shows that there is more moisture in the OWP of both lanes when compared to the control line. Although there are some inaccuracies in the probe readings over time at some of the locations the moisture content in the wheel paths is consistently higher. The readings from the probes in some of the shoulders show that the OWP has higher M/C than the shoulder. This suggests that at some of the locations there is no infiltration through the shoulder (as the moisture content should be higher if infiltration is occurring).

Without knowing the AADT and heavy vehicle percentages in each lane, it is difficult to define why the fast lane has higher M/C's at certain locations. There is a possibility that the higher moisture readings in the fast lane are due to higher AADT.

Although the past data, new data and the probe readings show that there is more M/C in the wheel paths when compared to the control line or BWP's, there is no evidence proving that the seals are permeable. Permeameter testing was therefore used to determine the permeability of spray seals using the evenflow and rapid flow permeameters. The atmospheric and pressurised tests revealed that spray seals are permeable.

The atmospheric permeameter test results show that the seals are indeed permeable for both types of permeamters. Even though the permeameter water level dropped very slowly, it was revealed after calculating the 'k-values' that the permeability of the seal was quite evident.

The pressurised permeameter test was simply a modification of the original permeameters to see if there was any effect of the flow rate under a small pressure. Further testing revealed that water under pressure increases the permeability of the seal even at a low pressure. This proves that the force of any vehicle will have an effect on the M/C in the wheel paths, not only heavy vehicles. To achieve better results at higher pressures specialised permeameters will need to be constructed that can withstand higher forces.

From the various testing methods and past data, it is clear that spray seals are permeable. Evidence suggests that there is more moisture in the wheel paths; therefore traffic does have an effect on the M/C within the wheel paths. The extent of this is unknown and further testing and research will need to be conducted.

4.7 Further Work

A formal investigation detailing traffic induced moisture into road pavements has not been undertaken in the Toowoomba region and therefore on site sampling for M/C's in the wheel paths and BWP's has not been a priority for QDTMR. Further investigation and more samples of moisture readings over a longer period of time would help confirm that there is consistently more moisture in wheel paths.

The permeameter tests did prove that seals are permeable; however the pressurised test was not constructed to withstand high pressures equivalent to that of a heavy vehicle. Therefore further research into the design and construction of a permeameter that can withstand high pressures and emulate the movements of traffic (pulsing motion similar to the New Zealand Report *'Permeabilities of Chipseals in New Zealand')* will greatly assist in proving that traffic induces moisture into road pavement.

Due to limited time and resources the present analysis was limited to a broad overview of past and present data and testing throughout the Toowoomba Region. If additional time and resources were available to undertake further studies, then more testing locations over a longer period of time would paint a clearer picture into this study. Once it is certain that traffic induces moisture into the road pavement, then preventative actions that need to be taken can then be researched. Due to the limited number of samples it is not possible to draw definite conclusions at this stage.

Chapter 5 CONCLUSION

In Australia sprayed seal surfacing is used on most rural, arterial and rural local roads. Tyre pressures, traffic volumes, speed, loads and the amount of heavy vehicles have increased dramatically over time. This has led to an increase in pavement failures particularly in the wheel paths. An logical cause of these failures is excessive amounts of moisture in these failure zones.

Moisture ingress into the road pavement due to traffic requires a combination of rainfall, high AADT and minimal surface texture. From the literature review, spray seals appear to have the greatest amount of defects in regards to traffic induced moisture into road pavements. Spray seals provide a thin layer of protection for the pavement. This thin layer provides a shorter path for the moisture to travel before it reaches the pavement layers.

Sprayed seal surfacing is successfully used on local roads carrying only a few vehicles per day through to major highways carrying thousands of vehicles per day. There is a hierarchy of sealing treatments depending on the location, AADT and the purpose of the road. Therefore a ‘quick fix’ is not possible as each road is unique and will require different preventative treatments which will need much more research and testing.

This study utilises M/C data collected through QDTMR - Soil Laboratories, and on site testing to compare moisture penetration at various locations throughout the lane width. This has shown a comparison between trafficked areas and non-trafficked areas at the same location. Proving that traffic induced moisture is a phenomenon that occurs frequently will allow road designers to apply preventative actions such as transverse variable spray rates, polymer modified bitumen etc.

The reason for undertaking this study is that an extensive literature review revealed that even though traffic induced moisture has already been tested, it has not been tested in Toowoomba. This topic has always been a thought on many engineer’s minds, however there was no research to back it up.

Previous data, present data and permeability testing was undertaken and the results were then analysed and compared to determine whether traffic contributes to moisture within the road pavement. Eight (8) sample locations were compared as well as seven (7) probe locations at GBD and seven (7) permeameter tests.

This analysis indicated that there was more moisture in the wheel paths compared to BWP’s. Although the majority of locations had higher M/C in the OWP than the IWP, infiltration through the shoulder was an unlikely cause due to the M/C in the shoulder being less than that of the OWP in some cases. It was also evident that the more re-seals there were, the less M/C there was within the pavement (see Figure 4.1.4.3 and Figure 4.1.4.4 for direct comparison).

The results of the permeameter tests revealed that spray seals are permeable under atmospheric pressure with k-values ranging between 10 and 50 µm/s. Under pressure of 30kPa at the same locations, these k-values increased to 200-300µm/s. This indicates that under more realistic traffic conditions, moisture does penetrate spray seals.

The results of this study show that moisture does penetrate the pavement due to the compounding nature of traffic. Due to the lack of funding and minimal data available, further work will need to be undertaken to verify these results.

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APPENDIX A1 – Project Specification

University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING
ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR:	**Aaron George LANGDON**
TOPIC:	Traffic Induced Moisture Entry into Road Pavements
SPONSORSHIP:	Queensland Department of Transport and Main Roads / Faculty of Engineering
PROJECT AIM:	This project seeks to investigate the penetration of water into road pavements due to the compounding nature of traffic. This project will determine if there is excess moisture in the wheel path of traffic, quantify the extent of the problem and recommend feasible preventative actions which could be applied.

PROGRAMME: Issue A – 03 April 2009

1. Research the background information relating to moisture entry into road pavements and pavement types. Investigate and utilise QDTMR resources and information, utilise previous projects which are similar in context, and utilise resources such as the internet and libraries for any information gathered across the world.
2. Create a testing procedure to be used on the GBD, and investigate particular test locations.
3. Analyse the new data, and compare to existing data to see if there are any similarities or significant differences.
4. Evaluate significant moisture readings and examine preventative strategies.
5. Outline possible preventative strategies and research these and their major uses.
6. Report on the work in the required oral and written formats.

If Time Permits:

7. Test these possible preventative strategies and present these results in my report.

AGREED:

________________ Aaron Langdon, __/__/2009

________________ Ron Ayers __/__/2009

Examiner/Co-examiner: ____

APPENDIX A2 – Project Methodology

Funding

To begin testing and analysis, I first need sponsorship from QDTMR – RoadTek. For this to be achieved, I have put together a brief business case of costs, tasks, resources etc to justify why this project needs funding. This has been approved by Chris Lunson (RoadTek Works Manager) and passed on to QDTMR in Brisbane. Costs associated to the project are:

- Traffic control for taking samples
- Soil labs for samples and tests
- Coring machine (possibly) – for samples
- Maintenance – fixing the road where samples were taken
- Travel – To liaise with Brisbane soil labs and data

This is the major features of the costs associated. The main costs will be for the soil labs and taking the samples.

Road Data

Data for the roads that are to be tested need to be analysed in order to achieve the best results. Data that needs to be acquired before selecting a site to be tested is:

- AADT for Darling Darling Downs road network
- Age of seals and roads to determine if water is penetrating from age, or from traffic induced moisture
- Seal type – Some seals may perform better than others, so knowledge of this will be necessary in the overall outcome.
- Aggregate type – Larger aggregate may have less change of penetration or visa versa.

Once all of the road data is collected, then it will be suitable to select locations throughout the Darling Downs area.

Testing

After the locations of the tests have been analysed, then the samples need to be taken. This will involve setting up traffic control at the desired location. One lane will be blocked off, and samples taken from that particular lane. Once traffic control is set up, the samples will be gathered.

Due to cost restrictions, only the M/C testing will be analysed from samples located on the wheel path, and BWP. Other data that has previously been taken by QDTMR will also be analysed if it is applicable.

Once the samples have been collected, testing will take place. The main focus is the M/C, and a visual test on the seal surface.

Sample testing has been organised to be completed by the end of July 2009.

Analysis

This will involve reviewing the data and presenting the results in my final report and dissertation. The expected results are that in chipseals there will be high M/C in the OWP than any of the other seal types.

APPENDIX A3 – Consequential Effects, Implications and Ethics

Aspects of Sustainability

1. **What impact will this project have on finite resources and waste production?**
   This project will have to impact on finite resources or waste production. The only waste that will be a result of this project will be the soil samples after analysis. Cold mix asphalt will also be used to repair any damage of the road where the samples will be taken.
2. **Identify any environmental protection dimension?**
   This project will not impact the environment in any way. All field work will be done on the road, and within the road reserve. Sample testing will be completed within the soil labs, and reporting and analysis will be done in the RoadTek office.
3. **What could be the global impact of this project?**
   This project may impact the future by re-assessing pavement seal designs on heavy vehicle travel paths. In the future, new seal types may be developed to prevent water infiltration through road seals. Further studies and testing may need to be done in this area.
4. **Is there any uncertainty about researching this project topic?**
   There is uncertainty as to whether traffic is the cause of water in pavements; however the need for action is required. Testing will be needed to conclude whether this is evident or not. From other research, there is proof that traffic is a contributing factor in water penetration through road seals. The purpose of this project is to find out if this occurs in the Toowoomba area.
5. **Who might impact the environment, and set out a plan for their involvement?**
   N/A
6. **If there are any environmental concerns, does the community have access?**

N/A

7. **Are there any costs to reduce pollution within this project work?**
   There are nil costs for pollution as there are no environmental effects due to this project.
8. **Identify any impact on women, youth and indigenous people?**
   Those involved in this project will be anyone working for QDTMR, Soil Labs, and RoadTek. The Queensland Government gives equal opportunity to those wish to apply to work for them. There are many types of races, and religious views in which QDTMR does not discriminate against.
9. **Are sustainability outcomes the same if this project outcomes were ised in all countries around the world? Would it be different for undeveloped countries?**
   If the outcomes of this project work were to be utilised in all countries around the word, undeveloped as well as developed, then this would result in roadways to last longer due to minimal water penetration. It would not be different for undeveloped countries if the construction processes were the same, however maintenance and monitoring of the roads may be difficult for undeveloped countries.
10. **How might this project and its outcomes contribute to international understanding?**
    This project and its outcomes will contribute to international understanding as roads are located throughout the world. If there is a chance that these roads could be improved, than it would be understood throughout the world.

The purpose of this project is to conclude whether traffic is a problem in moisture entry into road pavements. If this is evident and a viable solution is discovered, it would be my ethical responsibility to present this to the correct authorities in order to improve roads in Toowoomba, and even around the world.

APPENDIX A4 – Risk Assessment

Risk Identification:

As part of the testing is to be done on highly trafficked roads, there is risk that someone may get hit by oncoming traffic. Tasks that need to be completed while on the road are:

1. Road analysis – This is simply checking roads to see if they are able to be tested or not, and to gather photos and information. This is a very short task and will only take a few minutes at each location.
2. Sample collection – This involves stopping one traffic lane for enough time to take samples out of the road. This will involve me as the supervisor, traffic control, possibly machinery, soil testers and maintenance. This task will take a lengthy amount of time and at least half a day should be set aside per location.

Risk Evaluation: - Slight (possible but unlikely)

Without any safety precautions' (eg traffic control) this would be assessed as a substantial risk event. However, with traffic control, and the correct supervision there is slight chance that this event will occur, however it is unlikely.

Exposure: Occasionally (Once or twice a month)

Consequences: Possible death/major destruction if someone is hit without any safety precautions in place, however with the speed dropped to 40km/h, I would classify it to be minor equipment / minor injury.

For the entire project, I would set aside approximately 5 days for sample collecting.

Risk Management:

Risk 1 - This will be a relatively short exercise, and assessing the road from the shoulder can be done. To be on the safe side, a spotter (someone to look out for oncoming traffic) will accompany me during this exercise.

Risk 2 - The risk will be managed by the use of traffic control when taking the samples. It is part of QDTMR and RoadTeks policy under the WPH&S act that a traffic control plan is submitted and approved prior to any works is begun. Below is a Risk management chart:

Risk Management Chart

Description of Hazard	People at Risk	Number at Risk	Parts of Body	Risk Level
Someone getting hit by oncoming traffic	Persons working on the traffic lane	Up to 8	All	Low

Categories	Short Term Controls	Long Term Controls	Completion Details
Road Analysis	Work on the shoulder as much as possible.	Have a spotter on site at all times	**Employer:** QDTMR RoadTek **Prepared By:** Aaron Langdon **Date:** 26/05/09 Assented By: Chris Lunson Position: Works Manager Signature: Date: 02/07/09
Sample Collecting	Use data already acquired previously – No Works on the Road	Use traffic control, and submit a traffic control plan	

APPENDIX A5 – Resource Analysis

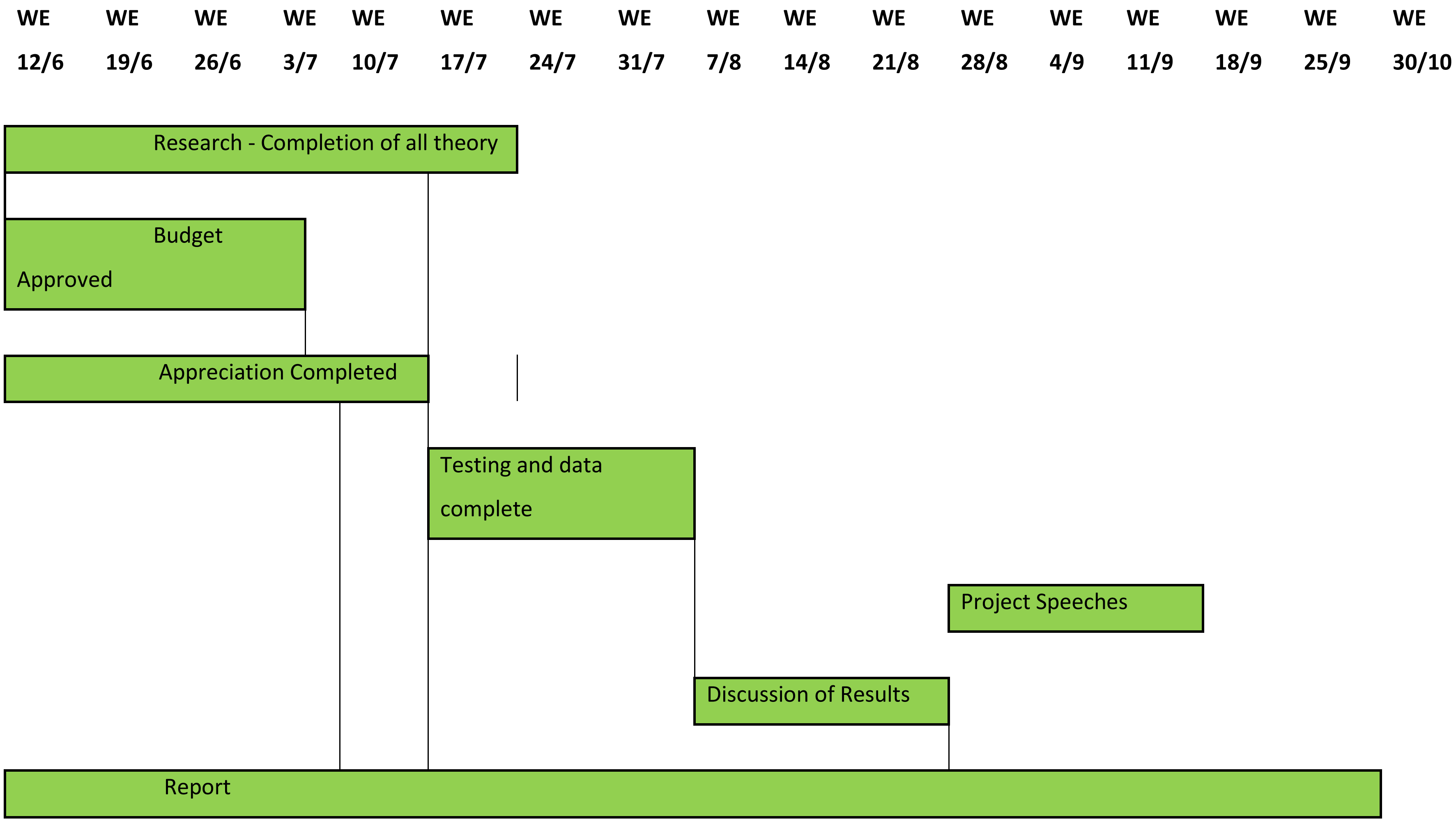
The major resources that will be required for this project are:

- Office equipment – Computer, printer, scanner, internet etc
- RoadTek's Maintenance crew – Fix up soil sample locations
- QDTMR Soil testers & equipment– Toowoomba and Brisbane
- Traffic control
- USQ library and resources
- QDTMR library and resources

These resources will be supplied by QDTMR – RoadTek. I am assured of the availability of the above items if there is enough notice given. Generally about 1 week should be enough notice.

There is currently budget approved by RoadTek which was derived from actual costs from the soil lab, maintenance and traffic control. The budget will be minimal and cost effective. This budget was declined as of 8th September 2009 (see Appendix . There is no direct cash involved, however if a purchase is required, RoadTek will reimburse the person who purchased the item.

APPENDIX A6 – Project Timeline



APPENDIX A7 – Extended Abstract

Paper Number: 09-121

COURSE ENG4903 PROFESSIONAL PRACTICE: Project Conference, 2009

TRAFFIC INDUCED MOISTURE ENTRY INTO PAVEMENTS

Sponsorship: QDTMR, QLD – Southern District / Faculty of Engineering & Surveying

Aaron LANGDON
DEGREE: Bachelor of Engineering – Civil

Supervisors:
Associate Professor Ron AYERS
Mr Trevor DRYSDALE

1. INTRODUCTION

Most Australian roads have experienced potholes and other types of pavement failures. An excessive amount of moisture in road pavements is often a major contributing factor to these pavement failures.

This project seeks to investigate the penetration of water into road pavements due to the compounding nature of traffic. This project will determine if there is excess moisture in the wheel path of traffic, quantify the extent of the problem and recommend feasible preventative actions which could be applied.

2. BACKGROUND

QDTMR is responsible for over 34000km's of Queensland's roads. Freight movement is largely responsible for heavy vehicles on road networks. Due to the amount of heavy vehicles using these roads, there is a crucial need to provide durable and reliable surfacing techniques to prevent pavement damage.

3. OBJECTIVES

To quantify the extent of M/C located in wheel paths when compared to BWP. By using testing data, AADT data, rainfall data and seal data a model will be developed to discover the extent of the problem and to examine preventative actions.

4. SURFACING TREATMENTS

- Open Graded Asphalt
- Dense Graded Asphalt
- Sprayed Seal

5. TYPES OF DEFECTS AND CAUSES

Investigates the major causes of pavement failures, and illustrates how these failures occur within the road pavement.

6. DATA AQUISITION

- Testing procedures
- ARMIS data
- BOM rainfall data
- AADT - heavy vehicles

7. METHODOLOGY & RESULTS

- Using existing data
- Selecting and analysing locations
- Comparison sections
- Results

8. CONCLUSION

The conclusion will compare the results of the literature review to the data obtained in the field. From these results, preventative solutions will be discussed.

APPENDIX B1 – Funding Request

10 June 2009

Dear Sir,

I am a final year Engineering student at the University of Southern Queensland working for QDTMR – RoadTek, and I in the process of completing my Thesis titled 'Traffic Induced Moisture into Road Pavements'. This thesis is based with QDTMR. I would like to apply for the use of the QDTMR soil labs and staff to complete testing in the Toowoomba area.

I believe this funding is directly relevant to the efficiency and effectiveness of the department because:

- I feel this funding will contribute to the success of road seals in the Tooowoomba region. The outcomes of this project will be to find out whether traffic is a large contributor of water penetration into road pavements. Solutions that could be applied to resolve this water penetration will also be examined. This research which will have a significant impact on the Departments operation.
- I will gain skills and knowledge on seals and testing that are required by the department and are also in scarce supply. By completion of this research I will have the opportunity to learn and manage my own project through this funding.
- As part of this funding, I will be part of an intricate team that will help me find the right data and resources to provide an accurate outcome to this project.

Costs associated with this project involve sample collection (2 x soil testers), soil testing, 2 x traffic control / maintenance (4 hours per location). A dissection of the costs associated with this funding are detailed below:

Cost per Location

Description	**Cost**	**Qty**	**Total**
Soil Testers - Sample Collection	$120.00/hour	8	$960.00
Traffic Control / Maintenance	$65.00/hour	8	$520.00
Soil Testing	$40.00/each	2	$80.00
Variations	$120.00/each	1	$120.00
$1,680.00			

To give me accurate results, I will need testing on the following:

Description	**Locations**	**Cost**
Open Graded Asphalt	2	$3,360.00
Dense Graded Asphalt	2	$3,360.00
Spray Seals	6	$10,080.00
		$16,800.00

I will allow $3200 for additional costs such as travels to Brisbane soil labs, unforseen costs and accommodation. These costs are maximum costs, and alternative data collection may be suitable.

As you can see by the number of tests, I am emphasising my studies on spray seals. Due to my research to-date, I think spray seals have the most problems in terms of moisture entry through the seal surface.

Please note, the above outlined costs are absolute maximums and I will be using data that has already been collected, and data that will be collected in the future to minimise costs.

I intend on competing this testing by the end of September, where I will then analyse the data to present in my final dissertation at USQ.

Thank for your time, and I look forward to hearing from you.

Regards,
Aaron Langdon
Ph 0401 286 825

APPENDIX B2 – Response to Funding Request - RoadTek

RoadTek
Queensland Government
A commercial business unit of the Department of
Main Roads

8 September 2009

Mr Aaron Langdon
C/- RoadTek Asset Services South
Greenwattle Street
Toowoomba Q 4350

Dear Aaron

I refer to your recent application for funding of $20,000 to assist you with completing your thesis.

I apologise for the delayed response but I needed to undertake some research in relation to your request.

I understand that you are currently on full time study leave for Semester 2 of the 2009 education year and receive a living allowance commensurate with your substantive position salary level.

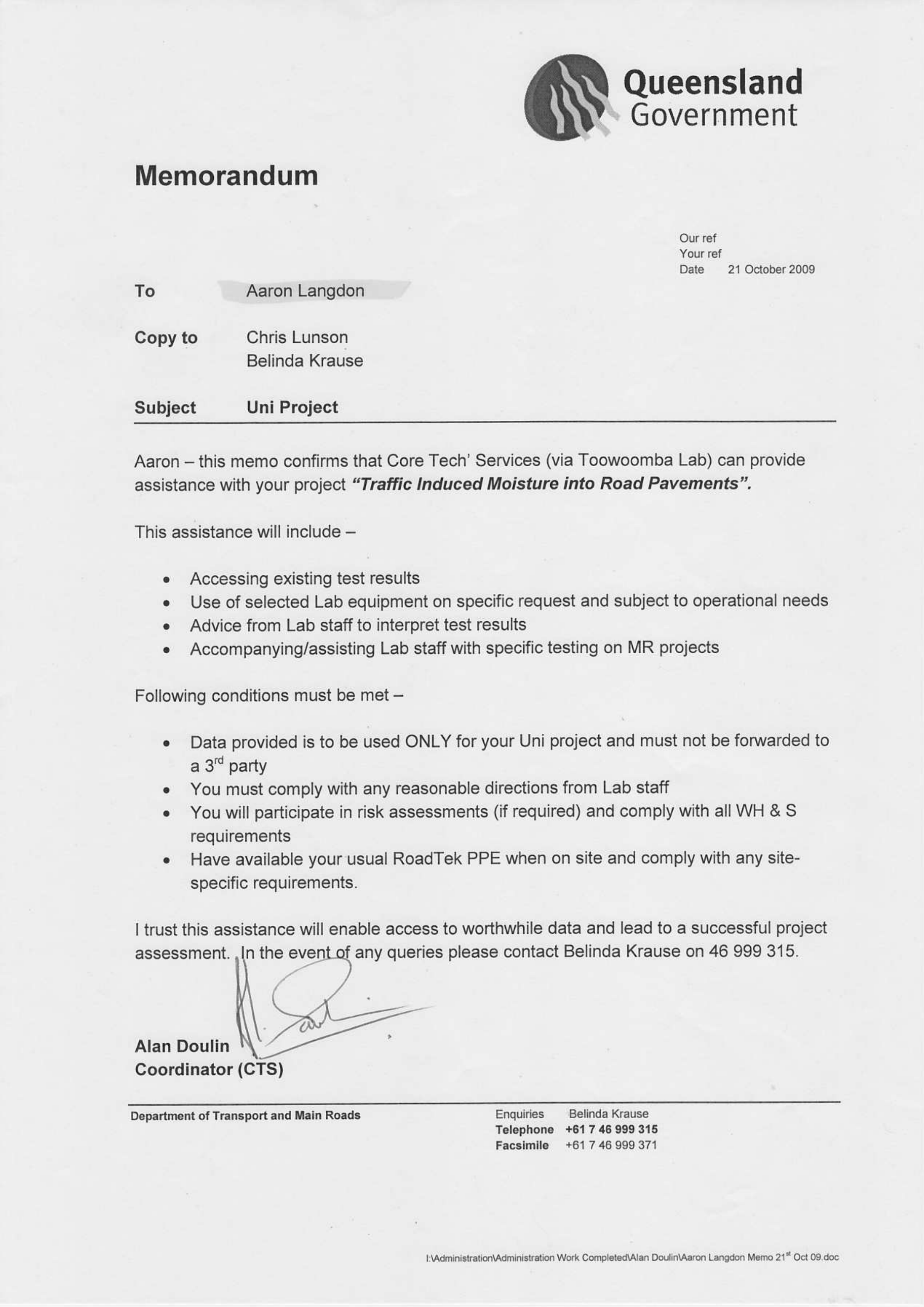
Due to current economic conditions the Department is required to be more prudent than in previous times when it comes to the expenditure of public monies. Unfortunately given this situation, I regretfully am unable to approve your request for funding assistance.

I have made my decision in accordance with the Department's SARAS Policy-Guidelines for Financial and Leave Assistance for Study Purposes.

Yours sincerely

Grant McDonald
Executive Director (RoadTek Asset Services South)

APPENDIX B3 – Response to Funding Request – QDTMR (Toowoomba)



Queensland Government

Memorandum

Our ref
Your ref
Date 21 October 2009

To Aaron Langdon

Copy to Chris Lunson
Belinda Krause

Subject **Uni Project**

Aaron – this memo confirms that Core Tech' Services (via Toowoomba Lab) can provide assistance with your project ***"Traffic Induced Moisture into Road Pavements".***

This assistance will include –

- Accessing existing test results
- Use of selected Lab equipment on specific request and subject to operational needs
- Advice from Lab staff to interpret test results
- Accompanying/assisting Lab staff with specific testing on MR projects

Following conditions must be met –

- Data provided is to be used ONLY for your Uni project and must not be forwarded to a 3rd party
- You must comply with any reasonable directions from Lab staff
- You will participate in risk assessments (if required) and comply with all WH & S requirements
- Have available your usual RoadTek PPE when on site and comply with any site-specific requirements.

I trust this assistance will enable access to worthwhile data and lead to a successful project assessment. In the event of any queries please contact Belinda Krause on 46 999 315.

Alan Doulin
Coordinator (CTS)

Department of Transport and Main Roads

Enquiries Belinda Krause
Telephone **+61 7 46 999 315**
Facsimile +61 7 46 999 371

I:\Administration\Administration Work Completed\Alan Doulin\Aaron Langdon Memo 21st Oct 09.doc

APPENDIX C1 – Previous Data (Gatton Bypass Duplication)

Gatton Bypass Duplication (Easbound)

Location	Base						Heavy Vehicle AADT	
Chainage	Unknown	IWP	OWP	BWP	Widening	Shoulder		Notes
63.47		4.5	4.9			4.3	15.65% or 1014	Outer Lane - slow lane
63.67		3.7	4.4			4.3	15.65% or 1014	Outer Lane - slow lane
67.94			4.6			4.2	15.65% or 1014	Outer Lane - slow lane
67.75				3.6		3.6	15.65% or 1014	Outer Lane - slow lane
67.31	4.3						15.65% or 1014	Outer Lane - slow lane
103.42		5.5	6.1				15.65% or 1014	Outer Lane - slow lane
103.42		4.9	5.6				15.65% or 1014	Inner Lane - Overtaking lane
103.577	5.5						15.65% or 1014	Outer Lane - slow lane
103.605		6.1	6.6				15.65% or 1014	Outer Lane - slow lane
103.605		6.2	6.4				15.65% or 1014	Inner Lane - Overtaking lane
103.611	6.2						15.65% or 1014	Outer Lane - slow lane
103.611	6.1						15.65% or 1014	Inner Lane - Overtaking lane
103.769		3.8	5.3				15.65% or 1014	Outer Lane - slow lane
103.769		4.2	3.8				15.65% or 1014	Inner Lane - Overtaking lane
104.045	4.9						15.65% or 1014	Good Condition
104.15	6						15.65% or 1014	Failure
104.158		5.2	6				15.65% or 1014	Outer Lane - slow lane
104.158		5.4	4.7				15.65% or 1014	Inner Lane - Overtaking lane
104.16	5.4						15.65% or 1014	Failure
	5.485714	4.95	5.30909	3.6				

APPENDIX C2 – Previous Data (Bowenville / Dalby Road)

Warrego HWY, Bowenville - Dalby 10/01/08

Site No.	Seal Type	Location	Base							
		Chainage	Unknown	IWP	OWP	BWP	Widening	Shoulder	Heavy Vehicle AADT	Notes
	Spray	72.65			5.2	3.7		5.3	21.75% or 482	
	Spray	72.64			4	2.7		4.8	21.75% or 482	Type 2.1 material
	Spray	72.54			4.7	3.9		5.5	21.75% or 482	Type 2.1 material
	Spray	72.54			6.4	4.7		6.3	21.75% or 482	
					5.075	3.75				

APPENDIX C3 – Previous Data (Drayton Connection Road)

Drayton Connection Road

Site No.	Seal Type	Location	Base						Heavy Vehicle AADT	
		Chainage	Unknown	IWP	OWP	BWP	Widening	Shoulder		Notes
1	Asphalt 70-125mm	1.72km left		6.8		6.6			12.31% or 231	
2	Asphalt 30-60mm	2.10km Right		4.9		4.4			12.31% or 231	
3	Spray 25-40mm	2.45km Left		8		7.3	5.5		12.31% or 231	
4	Asphalt 80-190mm	2.75km right		8.1		9.3	13.7		12.31% or 231	
5	Spray 30mm	3.05km left		5.7		3.8			12.31% or 231	
6	Asphalt 175mm	3.35km left		7.1		6.5			12.31% or 231	
7	Spray 20mm	3.60km right		4.8		3.2			12.31% or 231	
				6.48571		5.87				

APPENDIX C4 – Previous Data (Toowoomba / Cecil Plains Road)

Toowoomba Cecil Plains Road

Site No.	Seal Type	Location	Base						Heavy Vehicle AADT	
		Chainage	Unknown	IWP	OWP	BWP	Widening	Shoulder		Notes
1	Spray 15-50mm	28.4	5.5						16.22% or 23.8	Rut at outer wheelpath
2	Spray 34-40mm	29.18		11.5	10	6.9			16.22% or 23.8	Crocodile & lateral cracking
3	Spray 25-60mm	30.2		4.6	6.2	4.5			16.22% or 23.8	rutting, cracking
4	Spray 35mm	42.33		4.3	5	3.4			16.22% or 23.8	
5	Spray - 20mm	44.22	7						16.22% or 23.8	
6	Spray 10-40mm	45.5	7						16.22% or 23.8	
7	Spray 35mm	46.68	4.6						16.22% or 23.8	
8	Spray 40-60mm	47.6	4.2						16.22% or 23.8	
9	Spray 30mm	48.96	4.1						16.22% or 23.8	
10	Spray - 10-20mm	50.6		8.1	8.7	7.1			16.22% or 23.8	Crocodile cracking
11	Spray 50-60mm	59.33	8.6						16.22% or 23.8	
12	Spray 60-60mm	59.76	7.4						16.22% or 23.8	
13	Spray 30-35	60.9	6.6						16.22% or 23.8	
14	Spray 10-15	62	9.4						16.22% or 23.8	
15	Spray 30-60mm	63.2	5						16.22% or 23.8	
16	Spray 30-70mm	64.5	6.2						16.22% or 23.8	

APPENDIX D1 – 2009 Data (Esk / Hampton Road)

Esk - Hampton Road - 414 - 10/09/09

Site No.	Seal Type	Chainage	Moisture Content (%)			Heavy Vehicle AADT/day	Notes
			IWP	OWP	BWP		
1	Asphalt 90-120mm	41.5	-	6.1	6.9	8.08% or 29	Widening section, OWP is different material
2	Spray 40-80mm	41.55	-	9.2	6.8	8.08% or 29	Widening section, OWP is different material
3	Spray 50-60mm	4.14	-	5.3	6.5	8.08% or 29	Widening section, OWP is different material
4	Spray 20-25mm	41.35	-	7	7.2	8.08% or 29	Widening section, OWP is different material
5	Spray 25mm	41.3	-	6.9	6.6	8.08% or 29	Widening section, OWP is different material
			Average	6.9	6.8		

APPENDIX D2 – 2009 Data (Chinchilla / Tara Road)

Chinchilla / Tara Road

Site No.	Seal Type	Chainage	Moisture Content (%)			Heavy Vehicle AADT/day	Notes
			IWP	OWP	BWP		
1	Spray		-	1.7	1.5	9.8% or 35.6	
2	Spray		-	1.7	1.2	9.8% or 35.6	
3	Spray		-	2.5	1.8	9.8% or 35.6	
4	Spray		-	0.9	0.8	9.8% or 35.6	
5	Spray		-	1.2	1.2	9.8% or 35.6	

1.6 1.3

APPENDIX D3 – 2009 Data (Byee Road)

Byee Road - 4635 - 01/10/09

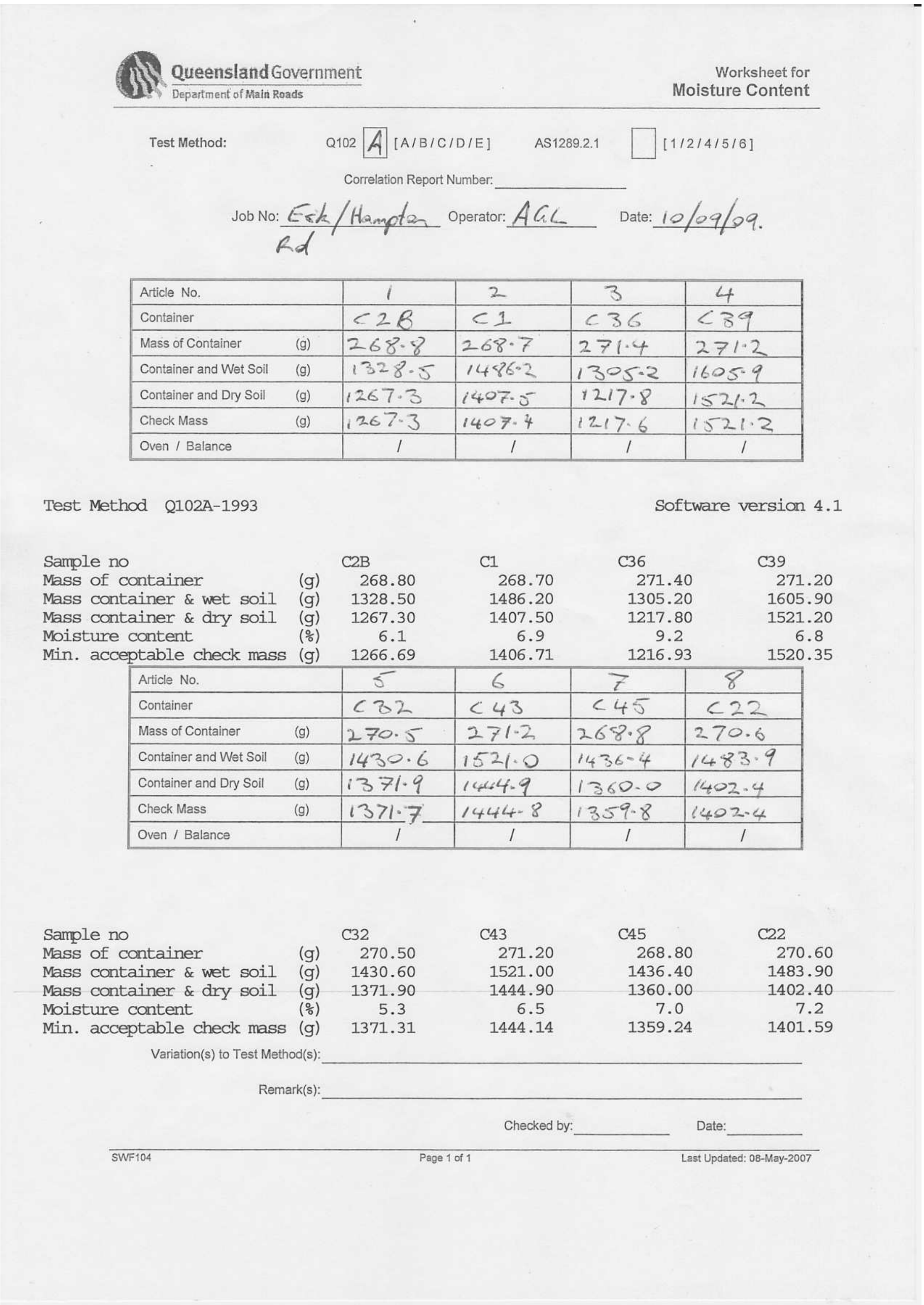
Site No.	Seal Type	Chainage	Moisture Content (%)			Heavy Vehicle AADT/day	Notes
			IWP	OWP	BWP		
1	Spray	4.15	4.7	-	3.3	14.11 % or 51	
2	Spray	4.26	4.6	-	3.7	14.11 % or 51	
3	Spray	4.3	4.1	-	4	14.11 % or 51	
4	Spray	4.43	3.5	-	3.8	14.11 % or 51	
5	Spray	5	4.6	-	3.3	14.11 % or 51	
6	Spray	5.1	3.4	-	3.3	14.11 % or 51	
			4.15		3.566667		

APPENDIX D4 – 2009 Data (Gatton / Clifton Road)

Gatton / Clifton Road - 313 - 30/09/09

Site No.	Seal Type	Chainage	Moisture Content (%)			Heavy Vehicle AADT/day	Notes
			IWP	OWP	BWP		
1	Spray 80-100mm	32.35	2		1.8	9.7% or 68.5	Heifer Creek
2	Spray 80-100mm	32.4	1.5		1.8	9.7% or 68.5	
3	Spray 120-150mm	32.51	1.3		1.8	9.7% or 68.5	
4	Spray10-20mm	32.72	3.2		3.4	9.7% or 68.5	
5	Spray10-20mm	32.79	3.6		3.2	9.7% or 68.5	
6	Spray10-20mm	32.85		4.2	2.4	9.7% or 68.5	
7	Spray10-20mm	32.9		3.7	2.7	9.7% or 68.5	
8	Spray10-20mm	32.96		3.7	3.4	9.7% or 68.5	
			2.32	3.866667	2.5625		

APPENDIX D5 – 2009 Site Recording Sheet (Esk / Hampton Road)



Queensland Government
Department of Main Roads

Worksheet for
Moisture Content

Test Method: Q102 A [A / B / C / D / E] AS1289.2.1 ☐ [1 / 2 / 4 / 5 / 6]

Correlation Report Number: ____________

Job No: Esk/Hampton Rd Operator: AGL Date: 10/09/09.

Article No.	1	2	3	4
Container	C2B	C1	C36	C39
Mass of Container (g)	268·8	268·7	271·4	271·2
Container and Wet Soil (g)	1328·5	1486·2	1305·2	1605·9
Container and Dry Soil (g)	1267·3	1407·5	1217·8	1521·2
Check Mass (g)	1267·3	1407·4	1217·6	1521·2
Oven / Balance	/	/	/	/

```
Test Method  Q102A-1993                                      Software version 4.1

Sample no                         C2B          C1           C36          C39
Mass of container            (g)   268.80       268.70       271.40       271.20
Mass container & wet soil    (g)  1328.50      1486.20      1305.20      1605.90
Mass container & dry soil    (g)  1267.30      1407.50      1217.80      1521.20
Moisture content             (%)     6.1          6.9          9.2          6.8
Min. acceptable check mass   (g)  1266.69      1406.71      1216.93      1520.35
```

Article No.	5	6	7	8
Container	C32	C43	C45	C22
Mass of Container (g)	270·5	271·2	268·8	270·6
Container and Wet Soil (g)	1430·6	1521·0	1436·4	1483·9
Container and Dry Soil (g)	1371·9	1444·9	1360·0	1402·4
Check Mass (g)	1371·7	1444·8	1359·8	1402·4
Oven / Balance	/	/	/	/

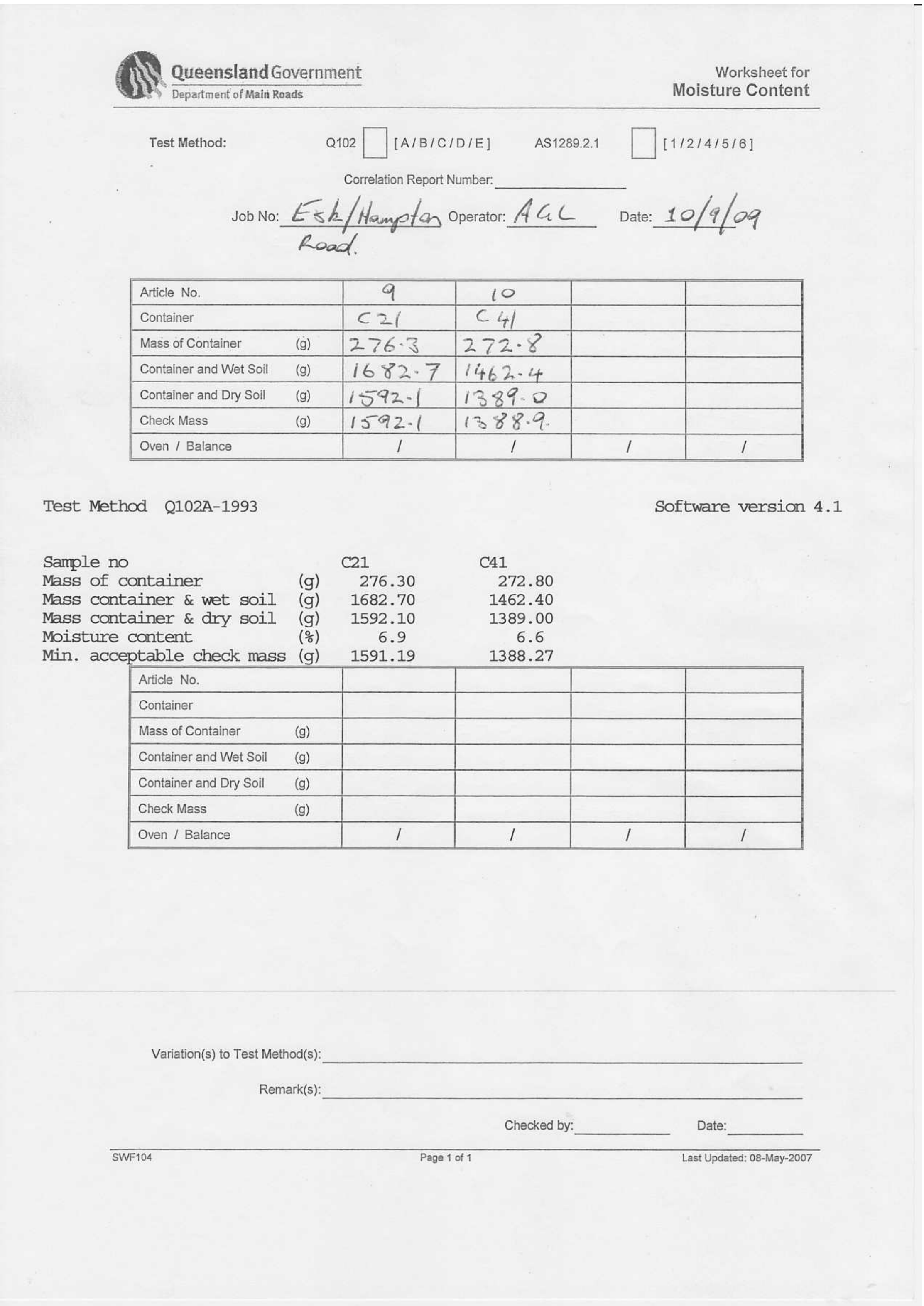
```
Sample no                         C32          C43          C45          C22
Mass of container            (g)   270.50       271.20       268.80       270.60
Mass container & wet soil    (g)  1430.60      1521.00      1436.40      1483.90
Mass container & dry soil    (g)  1371.90      1444.90      1360.00      1402.40
Moisture content             (%)     5.3          6.5          7.0          7.2
Min. acceptable check mass   (g)  1371.31      1444.14      1359.24      1401.59
```

Variation(s) to Test Method(s): ____________

Remark(s): ____________

Checked by: ____________ Date: ____________

SWF104 Page 1 of 1 Last Updated: 08-May-2007



Queensland Government
Department of Main Roads

Worksheet for
Moisture Content

Test Method: Q102 ☐ [A/B/C/D/E] AS1289.2.1 ☐ [1/2/4/5/6]

Correlation Report Number: ____________

Job No: Esk/Hampton Road. Operator: AGL Date: 10/9/09

Article No.	9	10		
Container	C21	C41		
Mass of Container (g)	276·3	272·8		
Container and Wet Soil (g)	1682·7	1462·4		
Container and Dry Soil (g)	1592·1	1389·0		
Check Mass (g)	1592·1	1388·9		
Oven / Balance	/	/	/	/

```
Test Method  Q102A-1993                                    Software version 4.1

Sample no                           C21           C41
Mass of container           (g)     276.30        272.80
Mass container & wet soil   (g)    1682.70       1462.40
Mass container & dry soil   (g)    1592.10       1389.00
Moisture content            (%)      6.9           6.6
Min. acceptable check mass  (g)    1591.19       1388.27
```

Article No.				
Container				
Mass of Container (g)				
Container and Wet Soil (g)				
Container and Dry Soil (g)				
Check Mass (g)				
Oven / Balance	/	/	/	/

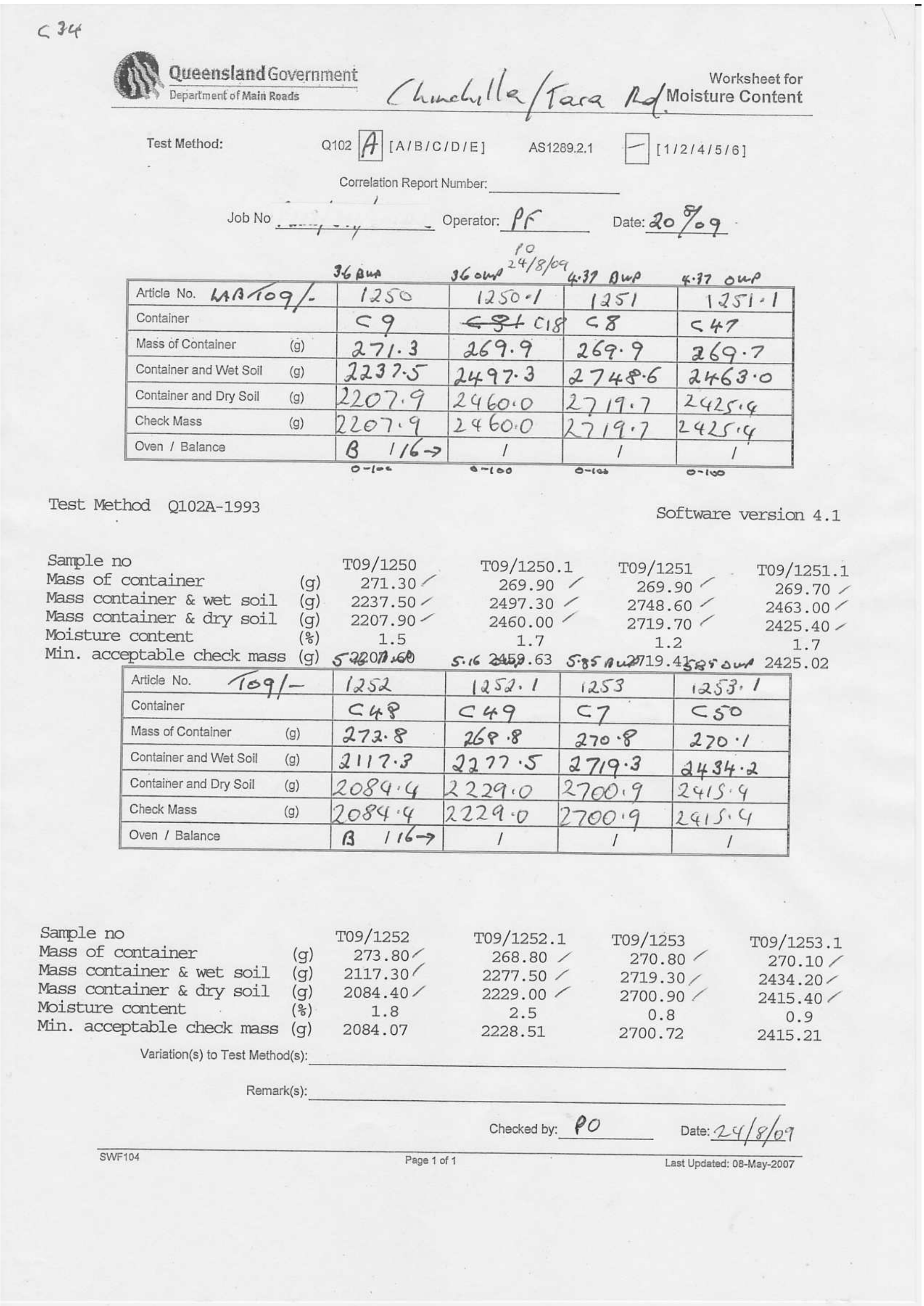
Variation(s) to Test Method(s): ____________

Remark(s): ____________

Checked by: ____________ Date: ____________

SWF104 Page 1 of 1 Last Updated: 08-May-2007

APPENDIX D6 – 2009 Site Recording Sheet (Chinchilla / Tara Road)



C 34

Queensland Government
Department of Main Roads

Chinchilla / Tara Rd.

Worksheet for Moisture Content

Test Method: Q102 A [A / B / C / D / E] AS1289.2.1 – [1 / 2 / 4 / 5 / 6]

Correlation Report Number: ____________

Job No ____________ Operator: PF Date: 20 8/09

10 24/8/09

	36 BWP	36 OWP	4·37 BWP	4·37 OWP
Article No. LAB T09/-	1250	1250·1	1251	1251·1
Container	C9	~~C 81~~ C18	C8	C47
Mass of Container (g)	271.3	269.9	269.9	269.7
Container and Wet Soil (g)	2237.5	2497.3	2748.6	2463.0
Container and Dry Soil (g)	2207.9	2460.0	2719.7	2425.4
Check Mass (g)	2207.9	2460.0	2719.7	2425.4
Oven / Balance	B 116→	/	/	/
	0-100	0-100	0-100	0-100

Test Method Q102A-1993

Software version 4.1

Sample no		T09/1250	T09/1250.1	T09/1251	T09/1251.1
Mass of container	(g)	271.30 ✓	269.90 ✓	269.90 ✓	269.70 ✓
Mass container & wet soil	(g)	2237.50 ✓	2497.30 ✓	2748.60 ✓	2463.00 ✓
Mass container & dry soil	(g)	2207.90 ✓	2460.00 ✓	2719.70 ✓	2425.40 ✓
Moisture content	(%)	1.5	1.7	1.2	1.7
Min. acceptable check mass	(g)	5[illegible] 2207.60	5.16 2459.63	5.85 BWP 2719.41	5.85 OWP 2425.02

Article No. T09/–	1252	1252·1	1253	1253·1
Container	C48	C49	C7	C50
Mass of Container (g)	272.8	268.8	270.8	270.1
Container and Wet Soil (g)	2117.3	2277.5	2719.3	2434.2
Container and Dry Soil (g)	2084.4	2229.0	2700.9	2415.4
Check Mass (g)	2084.4	2229.0	2700.9	2415.4
Oven / Balance	B 116→	/	/	/

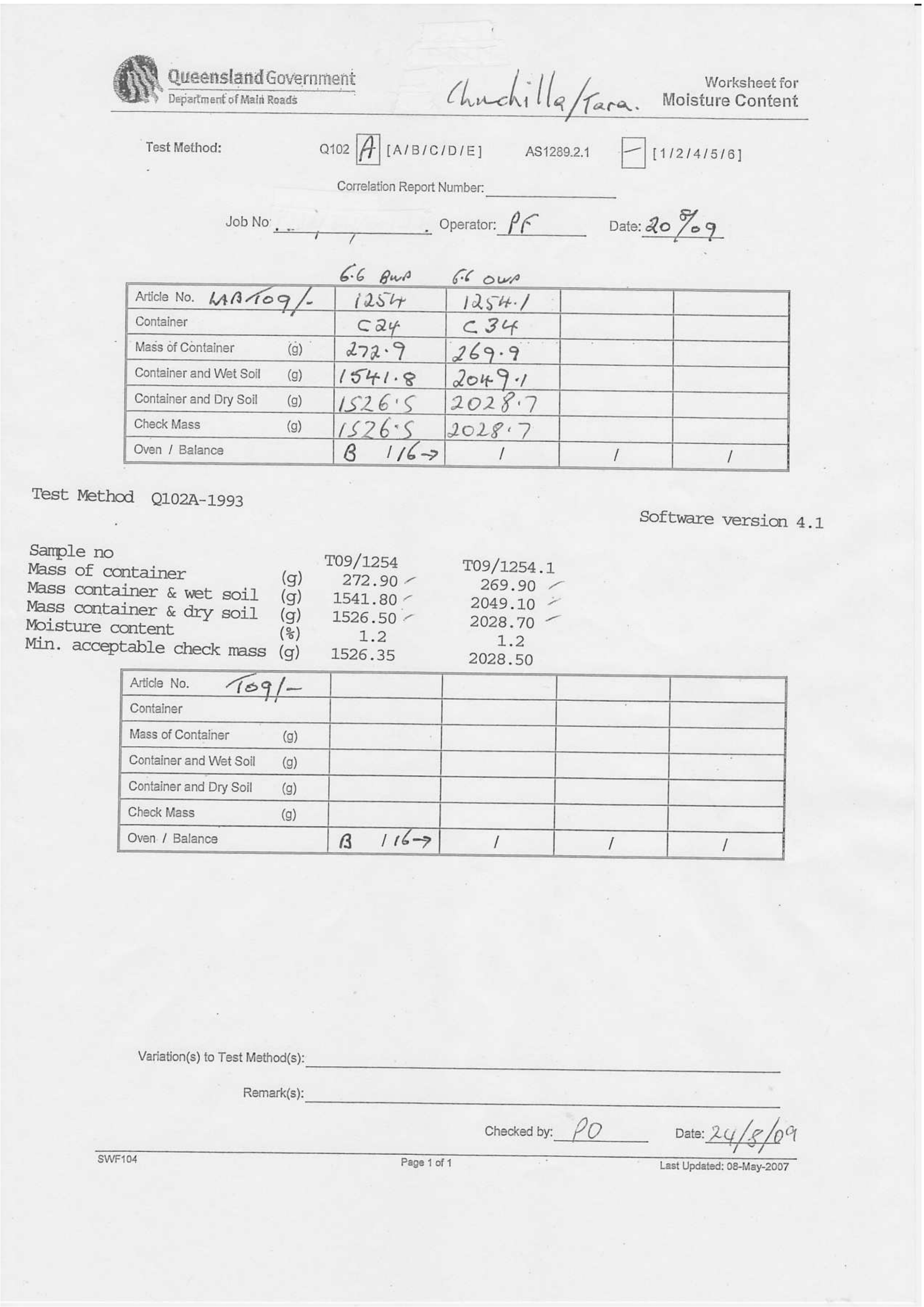
Sample no		T09/1252	T09/1252.1	T09/1253	T09/1253.1
Mass of container	(g)	273.80 ✓	268.80 ✓	270.80 ✓	270.10 ✓
Mass container & wet soil	(g)	2117.30 ✓	2277.50 ✓	2719.30 ✓	2434.20 ✓
Mass container & dry soil	(g)	2084.40 ✓	2229.00 ✓	2700.90 ✓	2415.40 ✓
Moisture content	(%)	1.8	2.5	0.8	0.9
Min. acceptable check mass	(g)	2084.07	2228.51	2700.72	2415.21

Variation(s) to Test Method(s): ____________

Remark(s): ____________

Checked by: PO Date: 24/8/09

SWF104 Page 1 of 1 Last Updated: 08-May-2007



Queensland Government
Department of Main Roads

Chinchilla/Tara.

Worksheet for Moisture Content

Test Method: Q102 [A] [A/B/C/D/E] AS1289.2.1 [–] [1/2/4/5/6]

Correlation Report Number: ____________

Job No: ____________ Operator: PF Date: 20/8/09

	6.6 BWP	6.6 OWP		
Article No. LAB T09/-	1254	1254.1		
Container	C24	C34		
Mass of Container (g)	272.9	269.9		
Container and Wet Soil (g)	1541.8	2049.1		
Container and Dry Soil (g)	1526.5	2028.7		
Check Mass (g)	1526.5	2028.7		
Oven / Balance	B / 116→	/	/	/

```
Test Method  Q102A-1993
                                                   Software version 4.1

Sample no                          T09/1254        T09/1254.1
Mass of container          (g)      272.90           269.90
Mass container & wet soil  (g)     1541.80          2049.10
Mass container & dry soil  (g)     1526.50          2028.70
Moisture content           (%)        1.2              1.2
Min. acceptable check mass (g)     1526.35          2028.50
```

Article No. T09/-				
Container				
Mass of Container (g)				
Container and Wet Soil (g)				
Container and Dry Soil (g)				
Check Mass (g)				
Oven / Balance	B / 116→	/	/	/

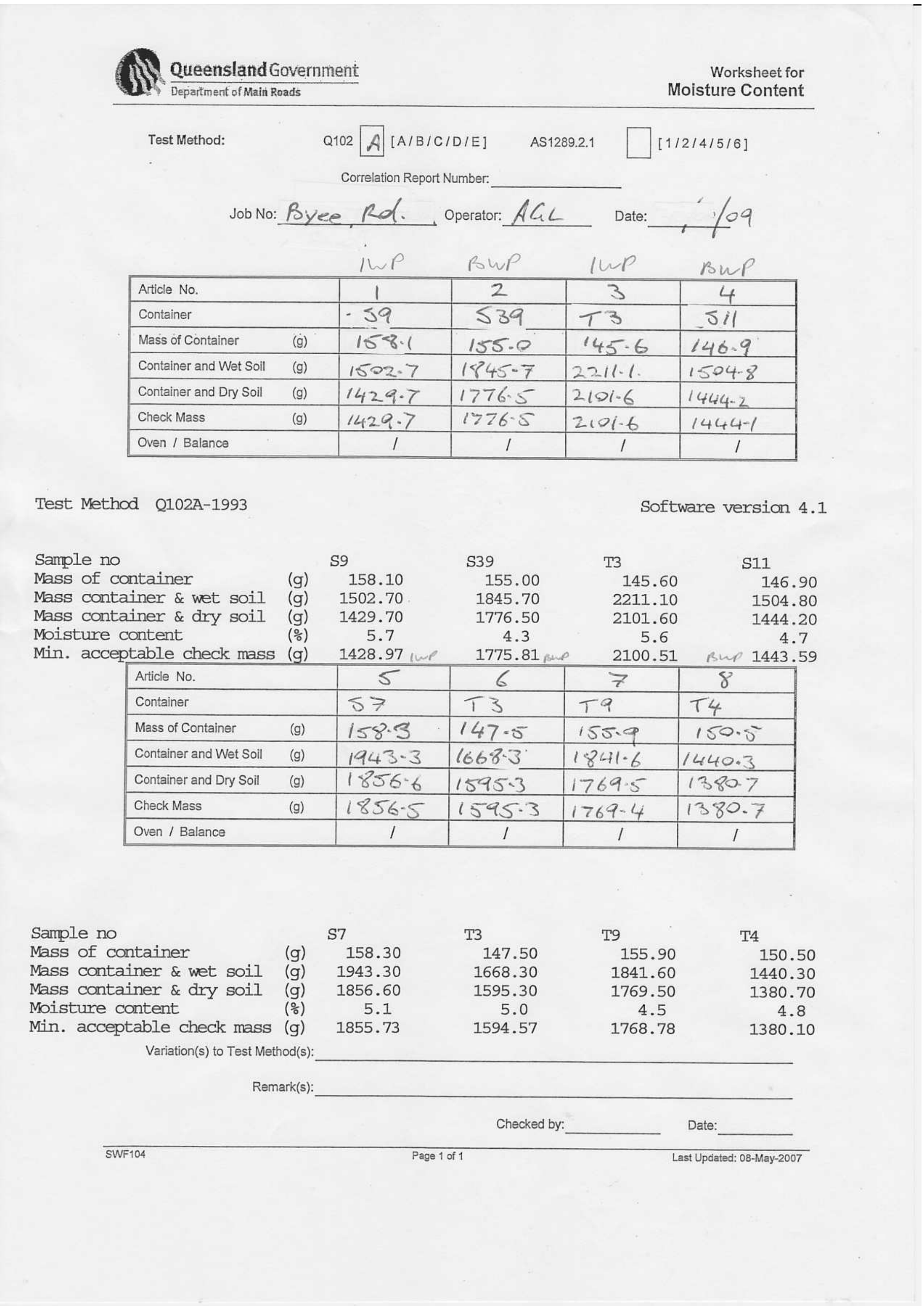
Variation(s) to Test Method(s): ____________

Remark(s): ____________

Checked by: PO Date: 24/8/09

SWF104 Page 1 of 1 Last Updated: 08-May-2007

APPENDIX D7 – 2009 Site Recording Sheet (Byee Road)



Queensland Government
Department of Main Roads

Worksheet for
Moisture Content

Test Method: Q102 [✓ A] [A / B / C / D / E] AS1289.2.1 ☐ [1 / 2 / 4 / 5 / 6]

Correlation Report Number: ____________

Job No: Byee Rd. Operator: AGL Date: [illegible]/09

	IWP	BWP	IWP	BWP
Article No.	1	2	3	4
Container	S9	S39	T3	S11
Mass of Container (g)	158.1	155.0	145.6	146.9
Container and Wet Soil (g)	1502.7	1845.7	2211.1	1504.8
Container and Dry Soil (g)	1429.7	1776.5	2101.6	1444.2
Check Mass (g)	1429.7	1776.5	2101.6	1444.1
Oven / Balance	/	/	/	/

Test Method Q102A-1993 Software version 4.1

Sample no		S9	S39	T3	S11
Mass of container	(g)	158.10	155.00	145.60	146.90
Mass container & wet soil	(g)	1502.70	1845.70	2211.10	1504.80
Mass container & dry soil	(g)	1429.70	1776.50	2101.60	1444.20
Moisture content	(%)	5.7	4.3	5.6	4.7
Min. acceptable check mass	(g)	1428.97 IWP	1775.81 BWP	2100.51	BWP 1443.59

Article No.	5	6	7	8
Container	S7	T3	T9	T4
Mass of Container (g)	158.3	147.5	155.9	150.5
Container and Wet Soil (g)	1943.3	1668.3	1841.6	1440.3
Container and Dry Soil (g)	1856.6	1595.3	1769.5	1380.7
Check Mass (g)	1856.5	1595.3	1769.4	1380.7
Oven / Balance	/	/	/	/

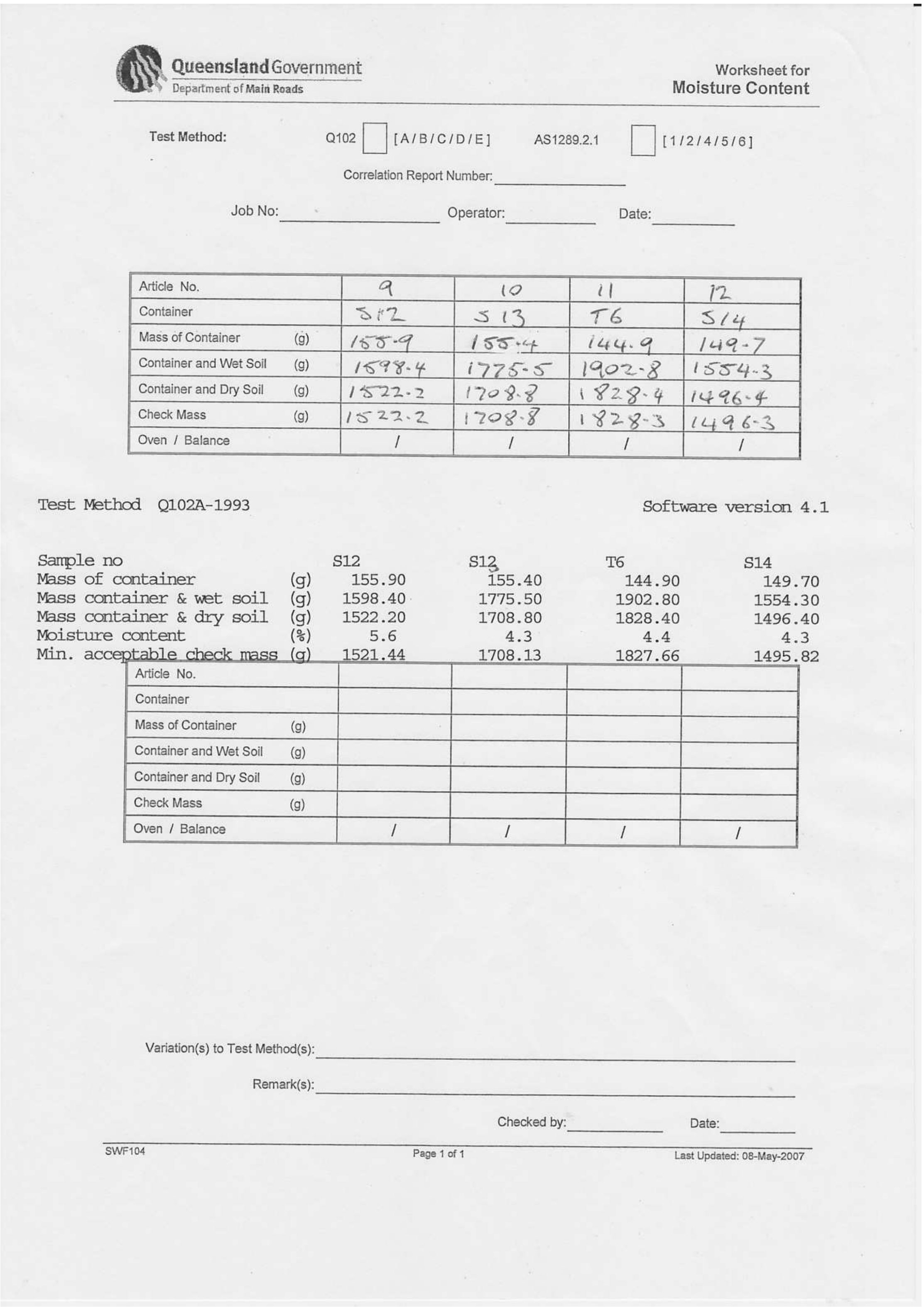
Sample no		S7	T3	T9	T4
Mass of container	(g)	158.30	147.50	155.90	150.50
Mass container & wet soil	(g)	1943.30	1668.30	1841.60	1440.30
Mass container & dry soil	(g)	1856.60	1595.30	1769.50	1380.70
Moisture content	(%)	5.1	5.0	4.5	4.8
Min. acceptable check mass	(g)	1855.73	1594.57	1768.78	1380.10

Variation(s) to Test Method(s): ____________

Remark(s): ____________

Checked by: ____________ Date: ____________

SWF104 Page 1 of 1 Last Updated: 08-May-2007



Queensland Government
Department of Main Roads

Worksheet for
Moisture Content

Test Method: Q102 ☐ [A / B / C / D / E] AS1289.2.1 ☐ [1 / 2 / 4 / 5 / 6]

Correlation Report Number: ____________

Job No: ____________ Operator: ____________ Date: ____________

Article No.		9	10	11	12
Container		S12	S13	T6	S14
Mass of Container	(g)	155.9	155.4	144.9	149.7
Container and Wet Soil	(g)	1598.4	1775.5	1902.8	1554.3
Container and Dry Soil	(g)	1522.2	1708.8	1828.4	1496.4
Check Mass	(g)	1522.2	1708.8	1828.3	1496.3
Oven / Balance		/	/	/	/

```
Test Method  Q102A-1993                              Software version 4.1

Sample no                         S12        S123        T6         S14
Mass of container          (g)   155.90     155.40     144.90     149.70
Mass container & wet soil  (g)  1598.40    1775.50    1902.80    1554.30
Mass container & dry soil  (g)  1522.20    1708.80    1828.40    1496.40
Moisture content           (%)      5.6        4.3        4.4        4.3
Min. acceptable check mass (g)  1521.44    1708.13    1827.66    1495.82
```

Article No.					
Container					
Mass of Container	(g)				
Container and Wet Soil	(g)				
Container and Dry Soil	(g)				
Check Mass	(g)				
Oven / Balance		/	/	/	/

Variation(s) to Test Method(s): ____________

Remark(s): ____________

Checked by: ____________ Date: ____________

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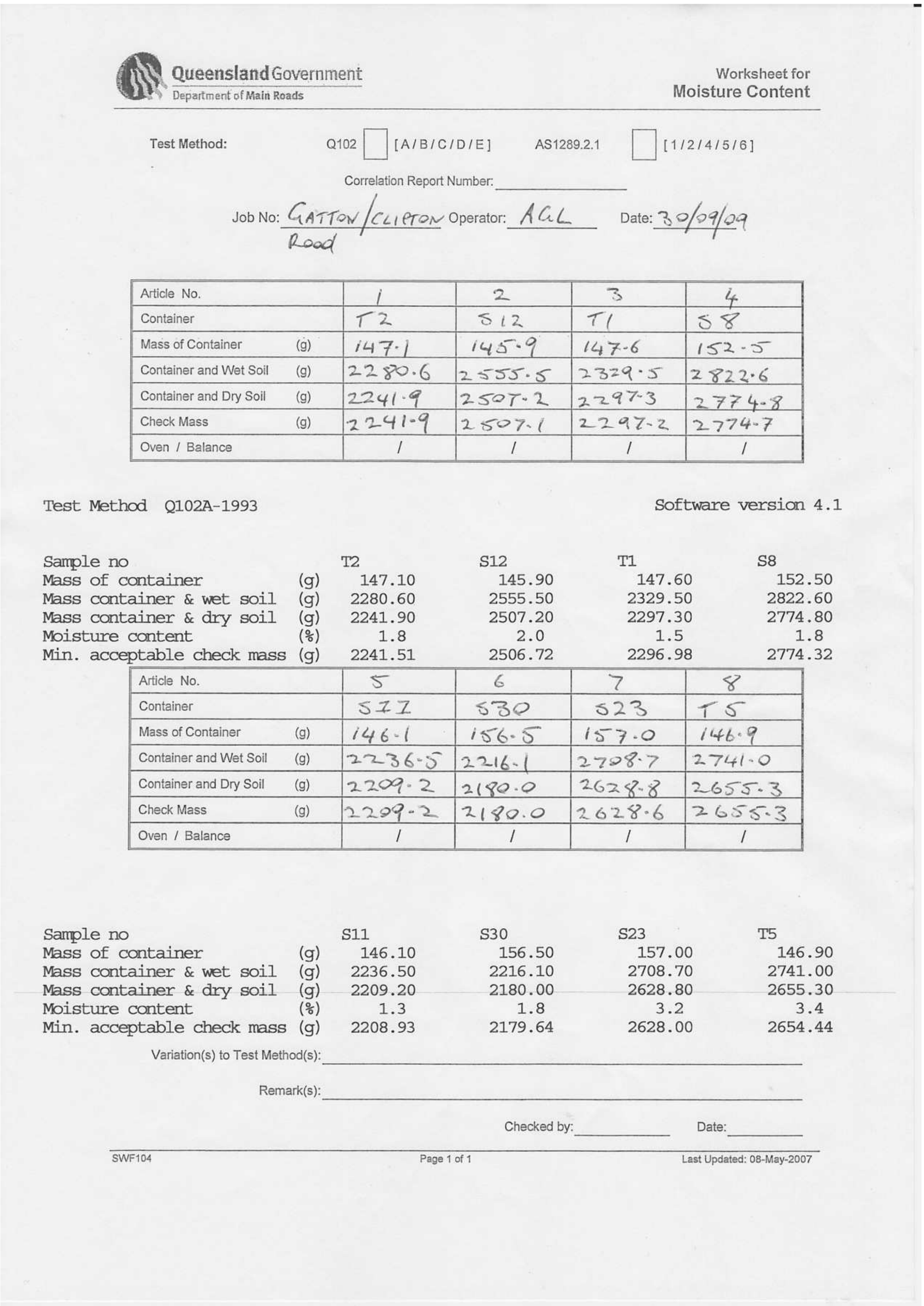
APPENDIX D8 – 2009 Site Recording Sheet (Gatton / Clifton Road)



Queensland Government
Department of Main Roads

Worksheet for
Moisture Content

Test Method: Q102 ☐ [A / B / C / D / E] AS1289.2.1 ☐ [1 / 2 / 4 / 5 / 6]

Correlation Report Number:

Job No: GATTON / CLIFTON Road Operator: AGL Date: 30/09/09

Article No.	1	2	3	4
Container	T2	S12	T1	S8
Mass of Container (g)	147·1	145·9	147·6	152·5
Container and Wet Soil (g)	2280·6	2555·5	2329·5	2822·6
Container and Dry Soil (g)	2241·9	2507·2	2297·3	2774·8
Check Mass (g)	2241·9	2507·1	2297·2	2774·7
Oven / Balance	/	/	/	/

```
Test Method  Q102A-1993                          Software version 4.1


Sample no                        T2          S12          T1          S8
Mass of container          (g)   147.10      145.90       147.60      152.50
Mass container & wet soil  (g)  2280.60     2555.50      2329.50     2822.60
Mass container & dry soil  (g)  2241.90     2507.20      2297.30     2774.80
Moisture content           (%)     1.8         2.0          1.5         1.8
Min. acceptable check mass (g)  2241.51     2506.72      2296.98     2774.32
```

Article No.	5	6	7	8
Container	S11	S30	S23	T5
Mass of Container (g)	146·1	156·5	157·0	146·9
Container and Wet Soil (g)	2236·5	2216·1	2708·7	2741·0
Container and Dry Soil (g)	2209·2	2180·0	2628·8	2655·3
Check Mass (g)	2209·2	2180·0	2628·6	2655·3
Oven / Balance	/	/	/	/

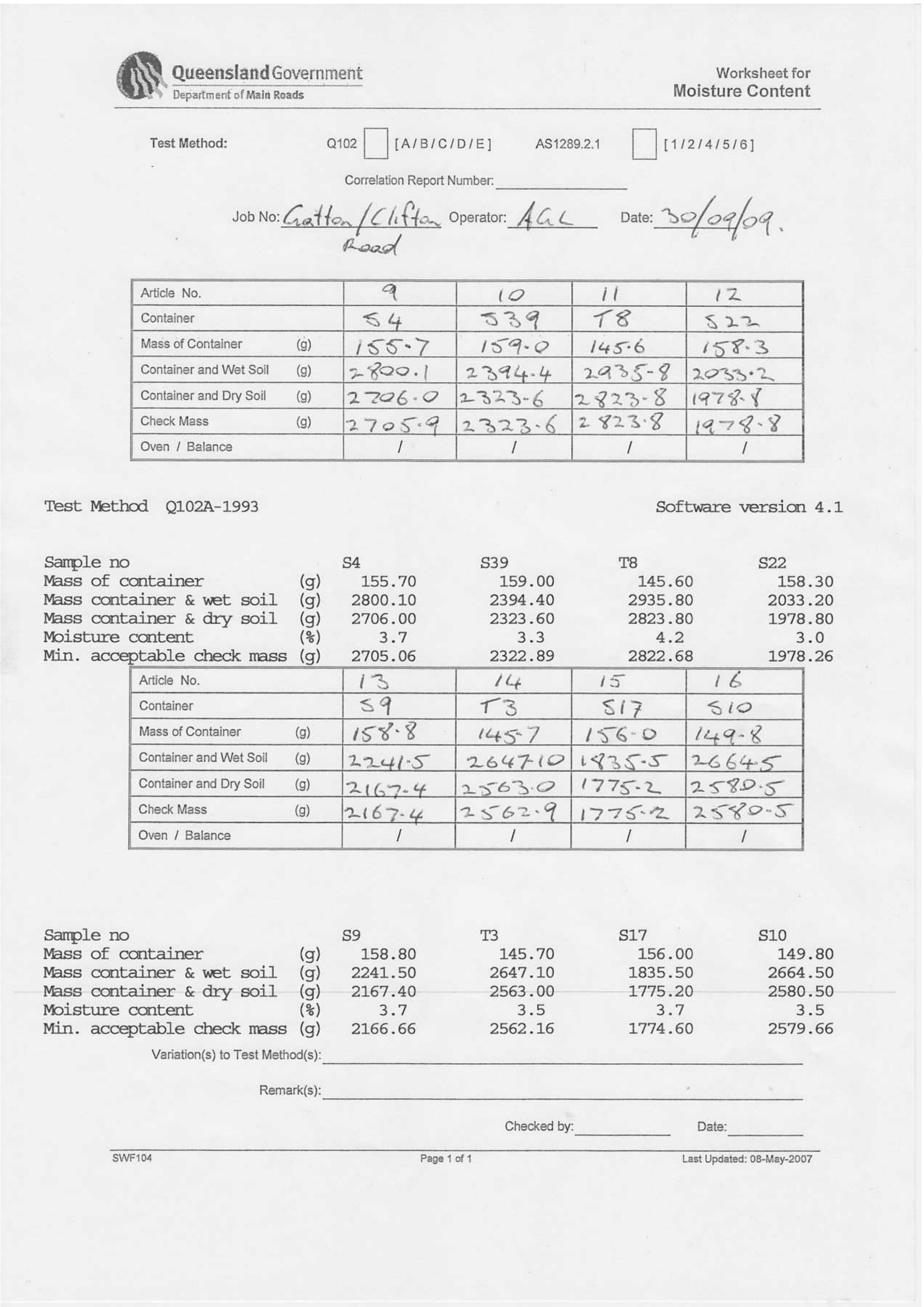
```
Sample no                        S11         S30          S23         T5
Mass of container          (g)   146.10      156.50       157.00      146.90
Mass container & wet soil  (g)  2236.50     2216.10      2708.70     2741.00
Mass container & dry soil  (g)  2209.20     2180.00      2628.80     2655.30
Moisture content           (%)     1.3         1.8          3.2         3.4
Min. acceptable check mass (g)  2208.93     2179.64      2628.00     2654.44
```

Variation(s) to Test Method(s): ____________________

Remark(s): ____________________

Checked by: __________ Date: __________

SWF104 Page 1 of 1 Last Updated: 08-May-2007



Queensland Government
Department of Main Roads

Worksheet for
Moisture Content

Test Method: Q102 ☐ [A / B / C / D / E] AS1289.2.1 ☐ [1 / 2 / 4 / 5 / 6]

Correlation Report Number: ____________

Job No: Gatton / Clifton Road Operator: AGL Date: 30/09/09.

Article No.	9	10	11	12
Container	S4	S39	T8	S22
Mass of Container (g)	155·7	159·0	145·6	158·3
Container and Wet Soil (g)	2800·1	2394·4	2935-8	2033·2
Container and Dry Soil (g)	2706·0	2323-6	2823-8	1978·8
Check Mass (g)	2705·9	2323·6	2823·8	1978·8
Oven / Balance	/	/	/	/

```
Test Method  Q102A-1993                                    Software version 4.1

Sample no                       S4          S39          T8          S22
Mass of container        (g)    155.70      159.00      145.60      158.30
Mass container & wet soil (g)   2800.10     2394.40     2935.80     2033.20
Mass container & dry soil (g)   2706.00     2323.60     2823.80     1978.80
Moisture content          (%)      3.7         3.3         4.2         3.0
Min. acceptable check mass (g)  2705.06     2322.89     2822.68     1978.26
```

Article No.	13	14	15	16
Container	S9	T3	S17	S10
Mass of Container (g)	158·8	145·7	156·0	149-8
Container and Wet Soil (g)	2241·5	2647·10	1835·5	2664·5
Container and Dry Soil (g)	2167-4	2563·0	1775-2	2580·5
Check Mass (g)	2167-4	2562·9	1775·2	2580-5
Oven / Balance	/	/	/	/

```
Sample no                       S9          T3          S17         S10
Mass of container        (g)    158.80      145.70      156.00      149.80
Mass container & wet soil (g)   2241.50     2647.10     1835.50     2664.50
Mass container & dry soil (g)   2167.40     2563.00     1775.20     2580.50
Moisture content          (%)      3.7         3.5         3.7         3.5
Min. acceptable check mass (g)  2166.66     2562.16     1774.60     2579.66
```

Variation(s) to Test Method(s): ____________

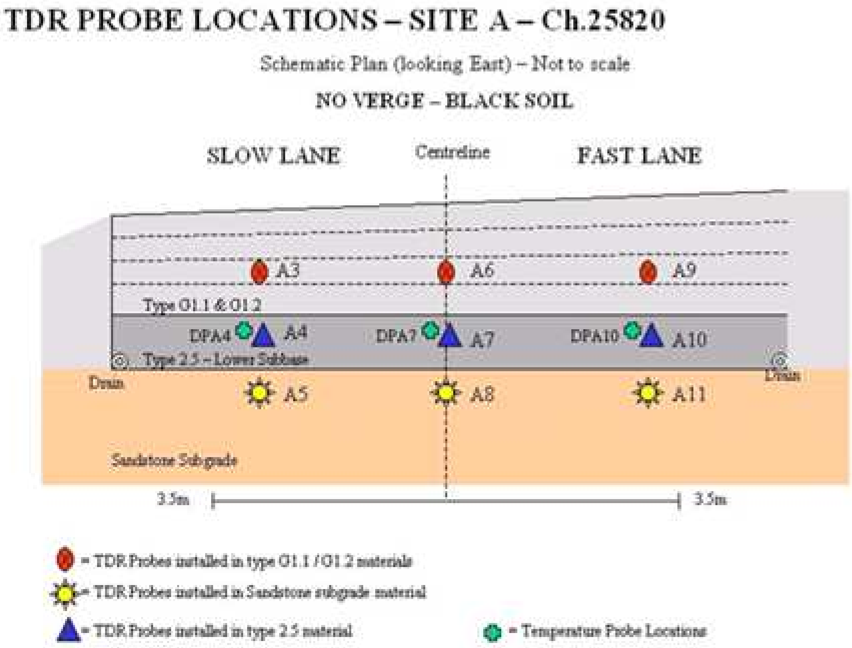
Remark(s): ____________

Checked by: ____________ Date: ____________

SWF104 Page 1 of 1 Last Updated: 08-May-2007

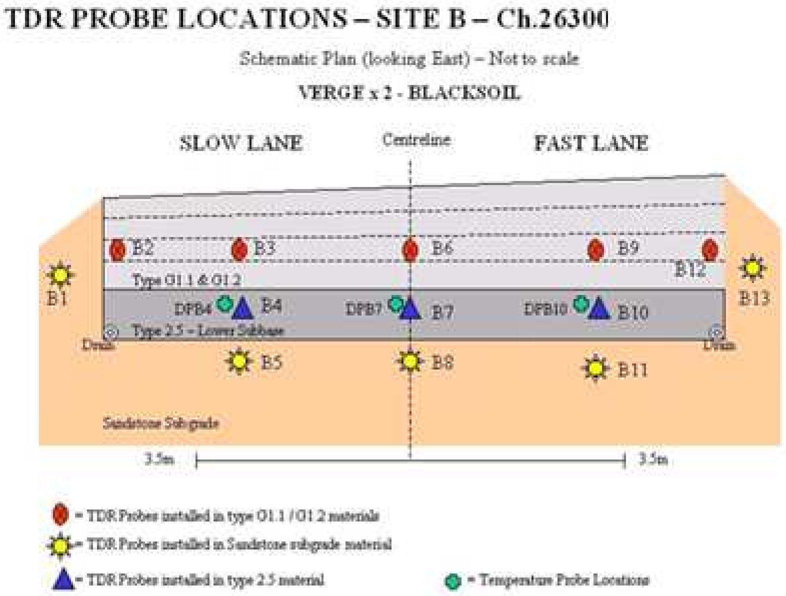
APPENDIX E1– Probe Instrumentation

Site A



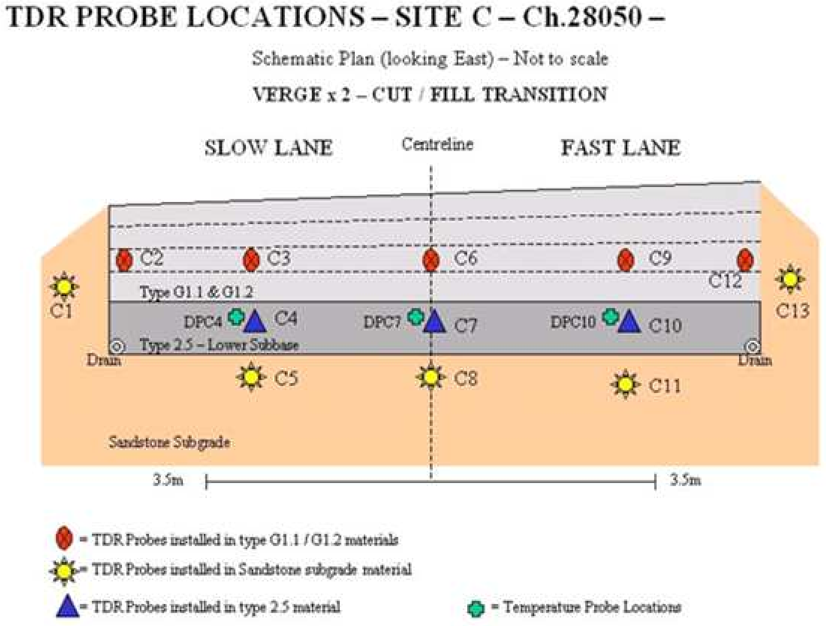
(O’May, 2007, Appendix B)

Site B



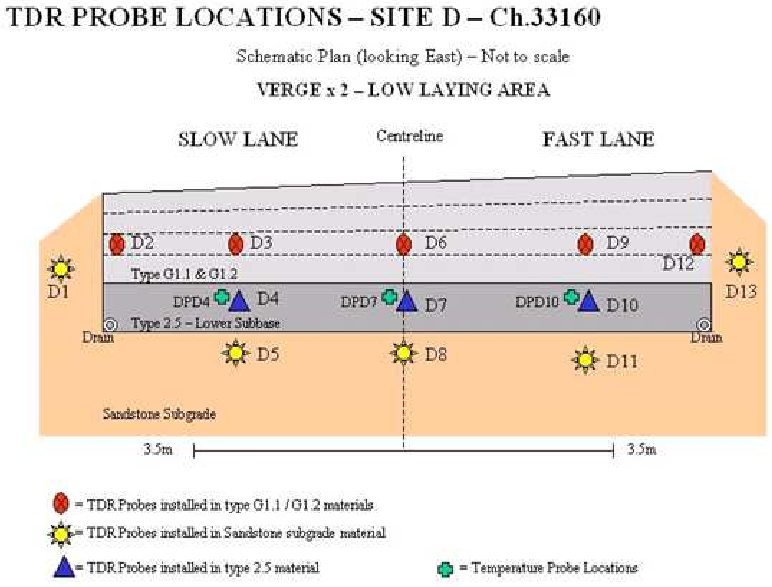
(O’May, 2007, Appendix B)

Site C



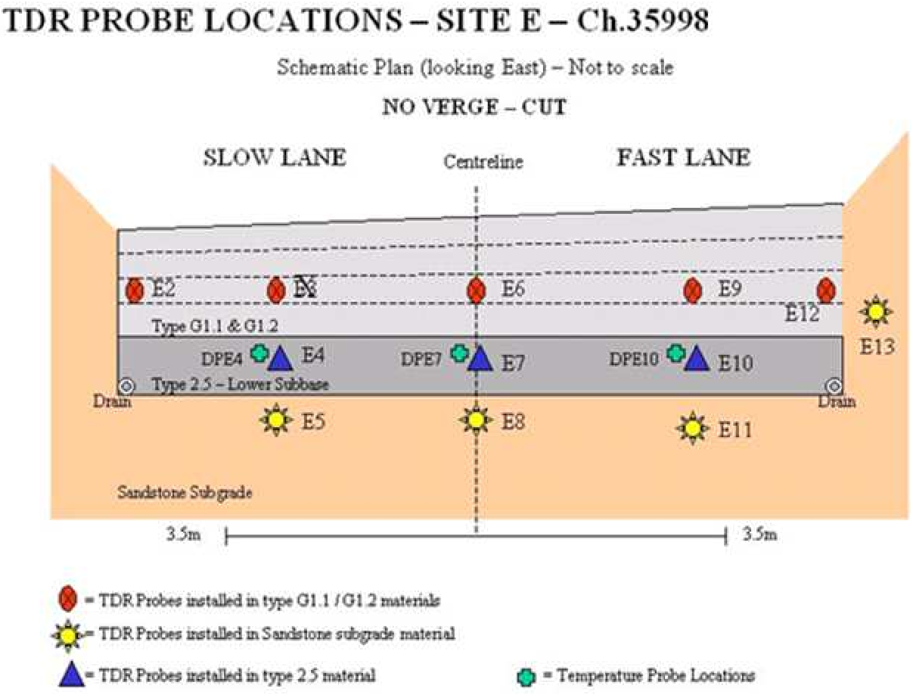
(O'May, 2007, Appendix B)

Site D



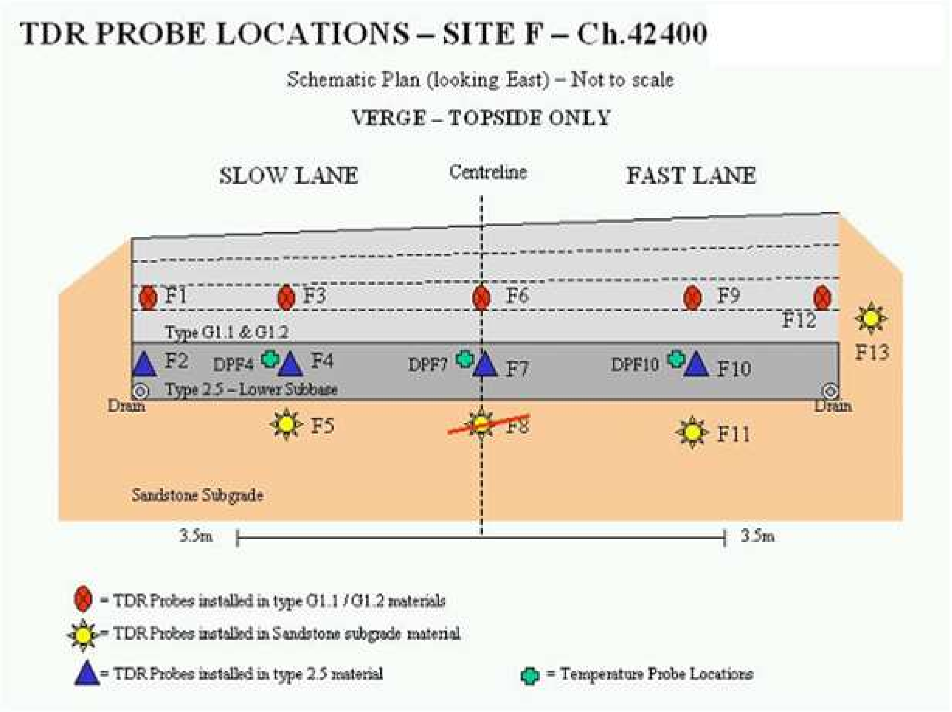
(O'May, 2007, Appendix B)

Site E



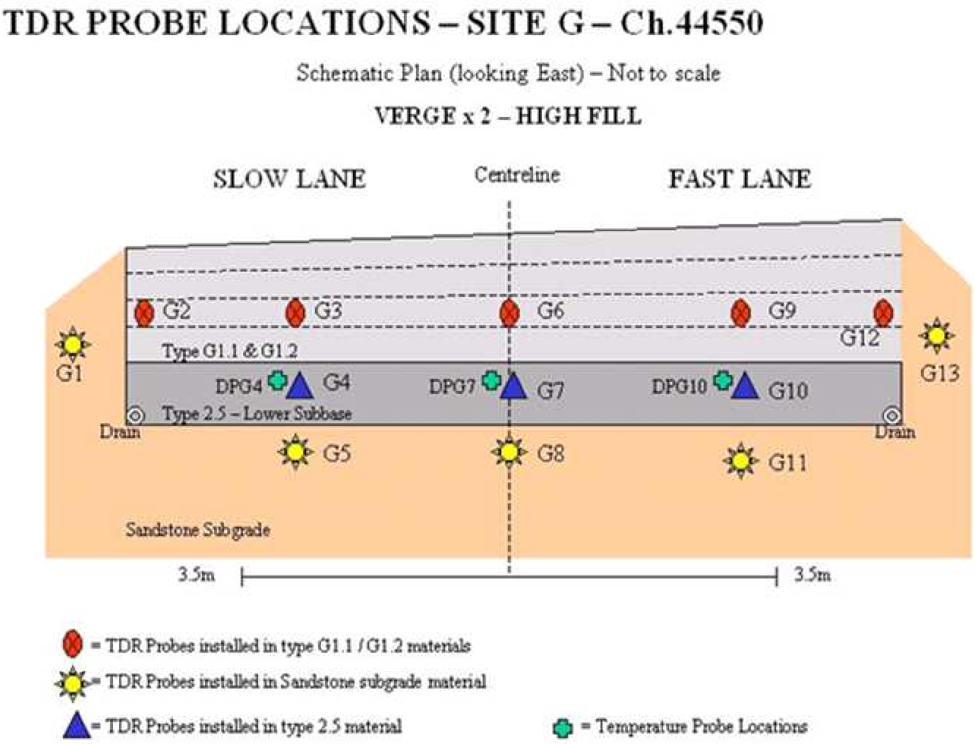
(O'May, 2007, Appendix B)

Site F



(O'May, 2007, Appendix B)

Site G



(O'May, 2007, Appendix B)

APPENDIX E2 – TDR Data (Location A)

	Site A* Ch 25820		**A3**	**A6**	**A9**	**A4**	**A7**	**A10**	**A5**	**A8**	**A11**
			MC %	**MC %**	**MC %**	**MC %**	**MC %**	**MC %**	**MC %**	**MC %**	**MC%**
			1.1	**1.1**	**1.1**	**2.5**	**2.5**	**2.5**	**SS**	**SS**	**SS**
Reading No.	**DATE**	**Days**	**A3**	**A6**	**A9**	**A4**	**A7**	**A10**	**A5**	**A8**	**A11**
1	17-Jun-03	**1**	*4.00*	*4.20*	*3.80*	*4.40*	*4.20*	*4.80*	*10.20*	*9.20*	*11.20*
2	18-Jun-03	**2**	**4.00**	**4.20**	**3.80**	**4.40**	**4.20**	**4.80**	**10.20**	**9.20**	**11.20**
3	24-Jun-03	**8**	**4.21**	**4.45**	**4.29**	**4.56**	**4.32**	**4.92**	**10.23**	**9.21**	**11.37**
4	4-Jul-03	**18**	**4.25**	**4.53**	**4.26**	**4.56**	**4.25**	**4.89**	**10.12**	**9.09**	**11.32**
5	11-Jul-03	**25**	**4.24**	**4.55**	**5.03**	**4.61**	**4.35**	**6.20**	**10.43**	**9.27**	**12.06**
6	18-Jul-03	**32**	**4.31**	**4.50**	**5.45**	**4.73**	**4.42**	**5.69**	**10.60**	**9.34**	**12.01**
7	25-Jul-03	**39**	**4.38**	**4.09**	**5.25**	**4.64**	**3.91**	**5.45**	**10.28**	**9.15**	**11.74**
8	1-Aug-03	**46**	**4.13**	**4.30**	**4.99**	**4.53**	**4.23**	**5.44**	**10.17**	**9.07**	**11.65**
9	8-Aug-03	**53**	**4.41**	**3.77**	**5.29**	**4.74**	**3.91**	**5.40**	**10.37**	**9.09**	**11.84**
10	18-Aug-03	**63**	**4.04**	**4.16**	**5.46**	**4.56**	**4.06**	**5.40**	**10.16**	**8.41**	**11.14**
11	26-Aug-03	**71**	**4.12**	**4.14**	**5.34**	**4.58**	**4.02**	**5.43**	**10.19**	**8.30**	**10.77**
12	5-Sep-03	**81**	**4.25**	**4.10**	**5.34**	**4.68**	**4.06**	**5.52**	**10.17**	**8.58**	**11.02**
13	16-Sep-03	**92**	**4.25**	**3.05**	**4.88**	**4.85**	**3.23**	**5.46**	**10.09**	**8.40**	**11.20**
14	6-Oct-03	**112**	**4.37**	**3.71**	**5.96**	**4.85**	**3.60**	**5.82**	**10.21**	**8.78**	**11.58**
15	13-Oct-03	**119**	**4.37**	**2.96**	**6.22**	**4.91**	**3.07**	**5.93**	**10.91**	**8.46**	**12.19**
16	30-Oct-03	**136**	**4.42**	**3.20**	**6.35**	**4.97**	**3.24**	**6.03**	**11.09**	**8.54**	**12.43**
17	10-Nov-03	**147**	**4.48**	**3.34**	**6.47**	**4.95**	**3.30**	**5.92**	**11.24**	**8.41**	**12.08**
18	1-Dec-03	**168**	**4.60**	**2.49**	**6.67**	**5.18**	**2.97**	**6.12**	**11.58**	**8.64**	**12.33**
19	17-Dec-03	**184**	**4.34**	**4.39**	**6.41**	**5.01**	**4.02**	**6.00**	**11.62**	**8.80**	**12.14**
20	30-Jan-04	**228**	**4.69**	**3.97**	**7.13**	**5.36**	**3.13**	**6.55**	**12.40**	**9.10**	**12.67**
21	12-Mar-04	**270**	**4.54**	**3.46**	**6.94**	**5.40**	**3.39**	**6.26**	**12.90**	**9.19**	**12.46**
22	6-Apr-04	**295**	**4.43**	**3.56**	**6.56**	**5.17**	**3.39**	**5.96**	**11.98**	**9.36**	**12.27**
23	7-May-04	**326**	**4.29**	**3.53**	**6.21**	**5.02**	**3.34**	**5.88**	**11.00**	**10.33**	**11.63**
24	20-Jul-04	**400**	**4.16**	**4.47**	**5.39**	**5.08**	**4.23**	**5.40**	**10.43**	**10.60**	**10.95**
25	22-Oct-04	**494**	**4.39**	**4.61**	**6.07**	**5.14**	**4.25**	**5.60**	**11.33**	**12.02**	**11.52**
26	16-Nov-	**519**	**4.79**	**3.70**	**6.79**	**5.73**	**3.25**	**6.03**	**11.5**	**11.7**	**12.19**

	04								2	6	
27	8-Apr-05	**662**	**5.27**	**3.66**	**6.78**	**5.70**	**3.32**	**5.82**	**11.76**	**13.57**	**12.02**
28	19-Oct-05	**856**	**5.89**	**3.97**	**7.62**	**5.84**	**3.50**	**5.09**	**X**	**12.73**	**11.57**
29	11-Jan-06	**940**	**6.47**	**5.83**	**9.19**	**6.00**	**4.74**	**5.48**	**X**	**13.46**	**12.56**
30	10-Jul-06	**1120**	**6.41**	**4.12**	**8.39**	**5.94**	**3.56**	**5.45**	**X**	**X**	**11.08**
	2-Dec-06	**1265**	**7.95**	**5.12**	**X**	**6.71**	**4.45**	**5.40**	**X**	**X**	**12.21**
	26-Jul-07	**1501**	**6.27**	**X**	**7.52**	**4.47**	**X**	**X**	**X**	**12.33**	**X**

APPENDIX E3 – TDR Data (Location B)

Site B Ch 26300		B2	B3	B6	B9	B12	B4	B7	B10	B1	B5	B8	B11	B13
		MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%
		1.1	1.1	1.1	1.1	1.1	2.5	2.5	2.5	SS	SS	SS	SS	SS
DATE	**Days**	**B2**	**B3**	**B6**	**B9**	**B12**	**B4**	**B7**	**B10**	**B1**	**B5**	**B8**	**B11**	**B13**
23-Apr-03	1	*4.40*	*4.00*	*3.80*	*3.80*	*4.00*	*4.40*	*4.20*	*4.20*	*7.20*	*9.40*	*8.00*	*10.00*	*11.60*
1-May-03	9	4.40	4.00	3.80	3.80	4.00	4.40	4.20	4.20	7.20	9.40	8.00	10.00	11.60
19-May-03	27	4.85	4.19	3.41	3.80	3.83	4.13	4.01	3.97	8.64	9.88	8.09	10.09	11.38
3-Jun-03	42	4.41	3.72	3.13	3.40	3.25	3.86	4.06	3.95	7.90	9.46	8.26	10.24	11.47
18-Jun-03	57	4.16	3.32	2.72	3.14	2.73	3.51	3.90	3.67	8.15	9.20	8.01	9.96	10.96
4-Jul-03	73	4.18	3.18	2.74	3.01	2.82	3.51	3.97	3.63	7.73	8.91	8.08	9.92	11.09
11-Jul-03	80	4.24	3.47	2.87	3.26	2.84	3.58	4.10	3.78	8.06	9.20	8.16	9.92	10.95
18-Jul-03	87	4.24	3.42	3.03	3.30	2.90	3.61	4.08	3.75	8.06	9.01	8.22	10.16	11.13
25-Jul-03	94	4.03	3.19	2.58	2.93	2.55	3.44	3.95	3.57	7.84	8.96	8.13	9.99	11.19
1-Aug-03	101	3.96	3.06	2.62	2.98	2.47	3.45	3.91	3.64	7.48	8.55	8.11	8.97	10.80
8-Aug-03	108	4.03	3.26	2.95	3.02	2.63	3.48	3.99	3.70	7.63	8.74	8.08	9.19	11.02
18-Aug-03	118	4.11	3.30	2.43	2.89	2.78	3.39	3.96	3.61	7.74	8.72	8.14	9.14	11.13
26-Aug-03	126	4.04	3.16	2.52	2.71	2.61	3.36	3.96	3.08	7.74	8.63	8.12	8.92	10.70
5-Sep-03	136	4.14	3.23	2.53	2.53	2.81	3.37	4.04	3.00	8.16	8.78	8.25	8.93	11.20
16-Sep-03	147	4.16	3.17	2.62	3.03	2.77	3.43	4.00	3.72	7.98	8.80	8.18	9.00	11.32
6-Oct-03	167	4.03	3.20	2.96	3.34	2.79	3.50	3.94	3.58	8.25	9.23	8.59	9.24	12.08
13-Oct-03	174	4.56	3.47	2.98	3.12	2.80	3.54	4.05	3.46	8.60	8.66	9.18	9.36	11.87
30-Oct-03	191	4.64	3.29	2.43	3.32	3.85	3.61	4.12	3.68	8.66	9.26	8.63	9.59	11.73
10-Nov-03	202	4.75	3.38	2.53	3.27	3.57	3.66	4.13	3.72	8.50	9.21	8.74	9.50	11.35
1-Dec-03	223	4.24	3.38	3.57	3.10	3.22	3.57	4.22	3.90	9.00	9.74	9.95	9.39	12.59
17-Dec-03	239	4.79	2.72	3.32	3.59	3.97	3.63	4.05	3.74	8.92	9.23	9.94	9.60	12.52
30-Jan-04	283	4.68	3.71	3.01	3.86	3.73	3.60	4.29	3.81	9.35	9.83	9.68	9.62	13.29
12-Mar-04	325	5.57	3.07	2.79	3.22	3.83	3.75	4.24	3.33	9.56	9.75	10.01	9.89	13.68
6-Apr-04	350	4.84	3.42	2.44	2.98	3.37	3.52	3.99	3.82	8.72	9.09	9.92	9.23	13.21
7-May-04	381	5.39	2.84	2.37	2.85	3.33	3.47	4.07	3.71	9.29	8.42	8.68	9.46	12.63
20-Jul-04	455	4.81	2.62	2.39	2.79	2.32	3.28	3.90	3.61	7.40	8.21	X	9.30	11.83
22-Oct-04	549	4.59	3.67	2.78	3.21	2.38	3.42	4.00	3.77	8.25	10.43	11.62	9.79	14.01
16-Nov-04	574	5.81	3.87	3.21	3.67	3.47	3.53	4.22	3.47	8.92	9.67	10.22	X	17.00
8-Apr-05	717	3.00	2.95	3.54	3.93	2.13	3.40	4.08	3.75	5.96	9.26	9.98	X	14.10
6-Oct-05	898	3.95		4.15	4.30	2.25	3.34	4.26	3.49	8.63	9.16	9.15	X	13.03
11-Jan-06	995	4.79		4.09	4.82	3.53	2.11	4.20	3.62	9.60	11.46	10.11	X	15.94
10-Jul-06	1175	3.45		2.72	4.33	1.59	2.55	3.92	3.42	8.26	9.55	7.73	X	12.50
2-Dec-06	1320	3.80		5.20	5.67	2.14	2.08	4.19		7.41	X	7.35	X	X
26-Jul-07	1556	3.44		4.43	3.84	1.84	3.03	4.02		8.01	9.86	7.56	X	10.05

APPENDIX E4 – TDR Data (Location C)

Site C		C2	C3	C6	C9	C12	C4	C7	C10	C1	C5	C8	C11	C13
Ch 28050		MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%
		1.1	1.1	1.1	1.1	1.1	2.5	2.5	2.5	SS	SS	SS	SS	SS
DATE	**Days**	**C2**	**C3**	**C6**	**C9**	**C12**	**C4**	**C7**	**C10**	**C1**	**C5**	**C8**	**C11**	**C13**
24-Apr-03	1	*3.60*	*4.00*	*3.40*	*3.60*	*3.20*	*4.20*	*3.60*	*3.20*	*6.40*	*9.00*	*8.60*	*10.60*	*7.40*
1-May-03	8	3.60	4.00	3.40	3.60	3.20	4.20	3.60	3.20	6.40	9.00	8.60	10.60	7.40
19-May-03	26	4.39	3.97	3.46	4.38	3.87	3.86	3.31	3.08	5.52	8.18	7.92	10.52	7.40
3-Jun-03	41	4.00	3.55	3.22	3.82	3.41	3.64	3.18	2.92	5.35	8.17	7.65	10.47	7.74
18-Jun-03	56	3.86	3.42	2.29	3.57	3.07	3.63	3.05	2.76	5.33	7.93	7.17	10.10	7.29
4-Jul-03	72	3.82	3.42	2.43	3.65	3.03	3.53	3.05	2.71	5.18	7.85	6.83	9.95	7.21
11-Jul-03	79	3.98	3.41	2.18	3.84	3.12	3.53	2.98	2.82	5.43	7.88	6.76	9.98	7.65
18-Jul-03	86	3.86	3.46	2.44	3.83	3.11	3.58	3.06	2.66	5.51	7.78	6.81	10.16	7.55
25-Jul-03	93	3.73	3.30	2.96	3.58	2.84	3.36	2.92	2.63	5.34	7.81	7.03	9.96	7.39
1-Aug-03	100	3.79	3.13	2.85	3.60	2.86	3.46	2.98	2.65	5.19	7.64	6.95	9.98	7.20
8-Aug-03	107	3.86	3.34	2.99	3.74	2.96	3.47	3.02	2.72	5.49	7.84	7.16	9.98	7.65
18-Aug-03	117	3.63	3.37	2.97	3.82	2.99	3.47	3.08	2.68	5.08	7.64	7.18	10.04	7.82
26-Aug-03	125	3.64	3.28	2.89	3.58	2.76	3.41	2.94	2.64	5.25	7.72	7.03	9.91	7.54
5-Sep-03	135	3.67	3.39	3.04	3.91	2.91	3.43	3.10	2.74	5.31	7.77	7.01	10.22	7.64
16-Sep-03	146	3.57	3.35	2.91	3.69	3.02	3.43	3.02	2.81	5.15	7.92	7.22	10.38	8.68
6-Oct-03	166	3.63	3.41	2.78	3.84	3.00	3.55	3.05	2.80	5.34	8.00	7.16	10.78	9.01
13-Oct-03	173	3.62	3.40	2.23	3.87	2.95	3.44	3.00	2.70	5.42	7.88	7.18	10.63	8.84
30-Oct-03	190	3.80	3.57	2.89	4.09	2.98	3.56	3.10	2.78	5.98	8.28	7.37	11.05	10.43
10-Nov-03	201	3.79	3.53	2.61	4.55	3.16	3.62	3.11	2.84	6.12	8.40	7.44	10.78	10.47
1-Dec-03	222	3.73	3.67	2.35	4.48	3.25	3.75	3.14	2.96	6.12	8.64	7.59	11.01	10.17
17-Dec-03	238	3.65	3.55	2.84	5.18	2.98	3.53	3.05	2.76	6.41	8.54	7.52	11.19	9.50
30-Jan-04	282	3.84	3.83	2.51	4.92	3.34	3.64	3.29	2.94	7.89	8.74	7.90	11.74	9.75
12-Mar-04	324	3.96	3.76	2.47	5.55	3.27	3.64	3.34	2.72	8.29	8.59	7.98	11.42	9.06
7-May-04	380	3.33	3.36	2.19	4.77	2.92	3.41	2.96	2.45	6.40	7.81	7.21	10.65	9.12
20-Jul-04	454	3.64	3.27	2.15	4.43	2.98	3.38	2.88	2.51	6.49	7.51	6.85	10.56	9.34
22-Oct-04	548	3.59	3.48	2.11	4.85	3.07	3.52	3.03	2.50	6.56	7.99	7.24	11.40	8.79
16-Nov-04	573	4.43	3.66	2.78	5.78	3.75	3.66	3.10	2.76	9.49	8.18	8.03	12.05	10.74
8-Apr-05	716	3.98	3.48	2.93	5.92	3.46	3.61	3.25	2.75	5.16	8.39	8.06	11.71	7.08
19-Oct-05	910	5.10	3.53	2.82	5.97	4.18	3.21	3.19	2.68	9.01	8.60	7.79	11.21	8.70
11-Jan-06	994	5.13	3.68	2.81	X	5.14	2.79	3.37	2.82	8.57	9.64	8.31	X	8.79
10-Jul-06	1174	3.91	3.61	2.51	X	3.80	3.02	3.14	2.60	5.20	8.53	7.06	X	5.94
2-Dec-06	1319	3.93	4.09	2.51	X	3.96	3.02	3.18	2.67	5.71	8.97	7.11	X	6.81
26-Jul-07	1555	4.44	4.14	2.57	5.24	4.37	3.04	3.06	2.73	6.80	8.00	6.75	X	6.54

APPENDIX E5 – TDR Data (Location D)

Site D		D2	D3	D6	D9	D12	D4	D7	D10	D1	D5	D8	D11	D13
Ch 33160		MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%
		1.1	1.1	1.1	1.1	1.1	2.5	2.5	2.5	SS	SS	SS	SS	SS
DATE	DATE	D2	D3	D6	D9	D12	D4	D7	D10	D1	D5	D8	D11	D13
15-Aug-03	1	*4.80*	*4.40*	*4.80*	*4.20*	*3.80*	*6.60*	*6.60*	*6.20*	*10.20*	*7.60*	*8.00*	*8.20*	*9.20*
18-Aug-03	4	4.80	4.40	4.80	4.20	3.80	6.60	6.60	6.20	10.20	7.60	8.00	8.20	9.20
26-Aug-03	12	4.39	5.22	4.82	4.63	3.68	6.89	6.59	6.21	10.17	7.65	8.05	8.20	9.16
5-Sep-03	22	4.53	4.90	4.84	4.43	3.74	7.05	6.74	6.29	10.32	7.70	8.01	8.23	9.36
16-Sep-03	33	4.52	4.69	4.70	4.44	3.84	8.18	6.76	6.57	10.41	7.77	8.08	8.24	9.28
6-Oct-03	53	5.62		4.58	4.41	3.86	8.18	7.03	6.68	12.74	7.85	7.97	8.68	9.73
13-Oct-03	60	5.10		4.47	3.97	4.07	8.09	7.01	6.69	13.78	7.98	8.35	8.65	9.65
30-Oct-03	77	5.88		4.55	4.38	4.06	7.97	6.98	6.63	13.79	7.77	8.50	8.63	9.31
10-Nov-03	88	5.18		4.72	4.53	4.19	7.18	7.08	7.09	13.40	7.97	7.93	8.79	9.58
1-Dec-03	109	5.37		4.78	4.70	4.34	7.15	7.25	7.27	13.92	7.90	8.54	8.94	10.13
17-Dec-03	125	6.16		4.63	4.30	4.27	7.85	7.06	7.07	14.27	8.03	8.73	8.80	9.98
30-Jan-04	169	6.37		4.80	4.52	4.38	8.25	7.49	7.55	14.34	9.10	9.05	8.99	10.22
12-Mar-04	211	5.57		4.69	4.62	4.37	8.43	7.30	7.49	13.35	9.81	8.88	9.12	10.10
6-Apr-04	236	4.95		3.76	3.95	3.62	8.78	7.30	8.13	12.76	9.86	8.03	8.77	9.48
7-May-04	267	5.51		4.45	4.22	3.91	8.80	6.17	7.03	12.33	9.76	8.56	8.88	9.40
22-Oct-04	435	6.20		4.56	4.71	4.41	8.66	6.58	7.37	13.27	10.30	9.00	9.32	9.84
16-Nov-04	460	5.75		4.88	4.60	4.22	9.12	6.99	8.15	12.98	10.62	9.13	9.85	9.76
8-Apr-05	603	4.87		4.90	4.14	3.99	9.04	7.30	8.26	12.10	10.27	8.69	10.11	9.38
6-Oct-05	784	5.50		5.37		3.77	8.68	7.96	8.25	13.57	10.27	9.58	X	9.50
11-Jan-06	881	6.16		5.84		4.25	10.64		8.40	14.08	11.11	11.72	X	10.26
10-Jul-06	1061	4.67		5.15		3.57	9.52		6.65	11.01	9.94	10.14	X	8.82
2-Dec-06	1206	4.51		5.86		3.75	9.98		7.63	11.68	10.35	11.10	X	10.06
26-Jul-07	1442	2.17		3.08		2.64	7.62		4.92	7.83	7.79	5.98	X	7.72

APPENDIX E6 – TDR Data (Location E)

Site E		E2	E3	E6	E9	E12	E4	E7	E10	E5	E8	E11	E13
Ch 35998		MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%
		1.1	1.1	1.1	1.1	1.1	2.5	2.5	2.5	SS	SS	SS	SS
DATE	**DATE**	**E2**	**E3**	**E6**	**E9**	**E12**	**E4**	**E7**	**E10**	**E5**	**E8**	**E11**	**E13**
25-Aug-03	1	*5.20*	*4.60*	*4.80*	*4.20*	*5.40*	*6.00*	*5.60*	*6.20*	*10.40*	*10.60*	*10.00*	*12.20*
26-Aug-03	2	5.20	4.60	4.80	4.20	5.40	6.00	5.60	6.20	10.40	10.60	10.00	12.20
5-Sep-03	12	5.01	4.48	4.27	4.17	5.12	6.31	5.81	6.69	10.47	10.80	10.00	12.32
16-Sep-03	23	4.59	4.30	4.00	4.05	4.84	6.36	5.76	6.70	10.84	10.91	10.82	12.91
6-Oct-03	43	5.40		4.24	4.34	5.16	6.43	6.89	6.83	11.21	11.81	10.92	13.82
13-Oct-03	50	5.27		4.22	4.41	5.17	6.57	7.67	6.68	11.29	11.76	X	15.07
30-Oct-03	67	6.40		4.41	4.62	5.30	6.76	7.85	7.11	11.52	12.24	X	13.64
10-Nov-03	78	6.17		4.39	4.44	5.25	6.55	7.50	7.09	12.68	12.35	X	13.87
1-Dec-03	99	6.03		4.57	4.59	5.28	7.18	7.88	7.28	14.90	12.79	X	13.25
17-Dec-03	115	6.00		4.37	4.26	5.40	7.67	6.60	7.18	14.70	12.46	X	13.11
30-Jan-04	159	6.11		4.84	4.67	5.46	8.61	7.09	7.69	16.07	13.11	X	14.57
12-Mar-04	201	6.56		4.41	4.81	5.60	7.87	6.72	7.68	15.19	12.96	X	13.17
6-Apr-04	226	6.15		4.37	4.54	5.44	8.40	7.09	7.51	15.26	12.63	X	13.43
7-May-04	257	6.02		4.07	4.54	4.91	8.03	X	7.19	14.32	11.61	X	13.12
20-Jul-04	331	5.55		4.00	4.29	5.03	7.54	X	6.69	13.34	11.04	X	12.44
22-Oct-04	425	6.13		4.34	4.95	5.43	8.10	X	7.37	14.39	12.19	X	12.50
16-Nov-04	450	6.33		4.42	5.44	5.03	8.81	X	8.20	15.05	12.62	X	13.30
8-Apr-05	593	5.56		4.64	5.51	4.68	8.94	X	8.02	14.84	13.95	X	13.12
6-Oct-05	774	6.23		5.05	5.64	5.25	9.83	X	7.69	14.44	14.99	X	13.46
11-Jan-06	871	6.30		5.32	6.25	5.55		X	8.32	X	X	X	13.42
10-Jul-06	1051	5.90		5.03	5.36	4.97		X	6.99	X	X	X	13.15
2-Dec-06	1196	6.14		5.03	5.40	5.15		X	7.34	X	X	X	13.69
26-Jul-07	1432	5.71		5.46	6.07	5.46		X	6.95	X	X	X	11.19

APPENDIX E7 – TDR Data (Location F)

Site F		**F1**	**F3**	**F6**	**F9**	**F12**	**F2**	**F4**	**F7**	**F10**	**F5**	**F8**	**F11**	**F13**
Ch 42400		**MC%**	**MC%**	**MC%**	**MC%**	**MC%**	**MC%**	**MC%**	**MC%**	**MC%**	**MC%**	**MC%**	**MC%**	**MC%**
		1.1	**1.1**	**1.1**	**1.1**	**1.1**	**2.5**	**2.5**	**2.5**	**SS**	**SS**	**SS**	**SS**	**SS**
DATE	**DATE**	**F1**	**F3**	**F6**	**F9**	**F12**	**F2**	**F4**	**F7**	**F10**	**F5**	**F8**	**F11**	**F13**
19-Jun-03	**1**	*4.40*	*4.00*	*3.20*	*3.60*	*4.20*	*4.00*	*4.40*	*4.20*	*4.60*	*8.80*	*8.40*	*10.40*	*11.20*
20-Jun-03	**2**	**4.40**	**4.00**	**3.20**	**3.60**	**4.20**	**4.00**	**4.40**	**4.20**	**4.60**	**8.80**	**8.40**	**10.40**	**11.20**
24-Jun-03	**6**	**5.01**	**4.06**	**3.82**	**4.31**	**4.64**	**4.27**	**4.70**	**3.53**	**4.77**	**8.56**	**7.56**	**10.46**	**11.08**
4-Jul-03	**16**	**5.16**	**4.97**	**4.54**	**4.78**	**4.78**	**4.38**	**4.75**	**3.88**	**4.90**	**8.72**	**7.92**	**10.61**	**11.19**
11-Jul-03	**23**	**5.22**	**4.91**	**4.42**	**4.58**	**4.79**	**4.31**	**4.74**	**4.69**	**4.96**	**8.93**	**8.40**	**11.50**	**11.11**
18-Jul-03	**30**	**5.50**	**4.86**	**3.55**	**4.79**	**4.90**	**4.58**	**4.82**	**3.82**	**5.07**	**9.24**	**7.18**	**11.03**	**11.46**
25-Jul-03	**37**	**5.22**	**4.52**	**4.11**	**4.57**	**4.72**	**4.47**	**4.70**	**4.56**	**4.97**	**9.37**	**8.56**	**11.35**	**11.04**
1-Aug-03	**44**	**5.00**	**4.33**	**3.90**	**4.36**	**4.50**	**4.46**	**4.63**	**4.46**	**4.87**	**9.12**	**8.55**	**10.93**	**10.89**
8-Aug-03	**51**	**5.18**	**4.50**	**4.14**	**4.57**	**4.76**	**4.38**	**4.69**	**4.61**	**5.08**	**9.28**	**8.39**	**11.53**	**10.92**
18-Aug-03	**61**	**5.11**	**4.41**	**3.86**	**4.31**	**4.60**	**4.49**	**4.73**	**4.51**	**4.88**	**9.50**	**8.86**	**11.20**	**10.56**
26-Aug-03	**69**	**5.10**	**4.11**	**3.85**	**4.10**	**4.48**	**4.43**	**4.67**	**4.37**	**4.84**	**9.14**	**8.76**	**10.83**	**10.54**
5-Sep-03	**79**	**5.20**	**4.16**	**3.88**	**4.25**	**4.49**	**4.32**	**4.78**	**4.33**	**4.85**	**8.80**	**8.53**	**11.42**	**10.59**
16-Sep-03	**90**	**4.98**	**4.17**	**3.86**	**4.25**	**4.55**	**4.39**	**4.66**	**3.63**	**4.88**	**8.69**	**8.76**	**11.34**	**11.83**
6-Oct-03	**110**	**5.36**	**4.20**	**3.81**	**4.35**	**4.67**	**4.70**	**4.75**	**3.45**	**5.09**	**9.49**	**9.00**	**11.43**	**11.92**
13-Oct-03	**117**	**5.74**	**4.05**	**3.80**	**4.29**	**4.61**	**4.93**	**4.50**	**3.60**	**4.92**	**9.42**	**8.65**	**11.46**	**11.57**
30-Oct-03	**134**	**6.02**	**4.09**	**3.83**	**4.55**	**5.05**	**5.31**	**4.58**	**3.15**	**5.21**	**9.57**	**8.77**	**12.38**	**12.32**
10-Nov-03	**145**	**5.93**	**4.41**	**3.57**	**4.60**	**5.14**	**4.87**	**4.67**	**3.49**	**5.23**	**9.78**	**8.79**	**12.31**	**12.30**
1-Dec-03	**166**	**5.62**	**4.62**	**3.57**	**4.66**	**5.30**	**4.88**	**4.62**	**3.49**	**5.46**	**10.01**	**9.26**	**13.29**	**12.77**
17-Dec-03	**182**	**6.17**	**4.64**	**3.73**	**4.53**	**5.03**	**5.51**	**4.84**	**3.28**	**5.34**	**10.49**	**X**	**13.15**	**12.54**
30-Jan-04	**226**	**6.54**	**4.94**	**3.92**	**4.67**	**5.68**	**5.38**	**4.83**	**3.80**	**5.73**	**10.95**	**X**	**14.69**	**13.04**
12-Mar-04	**268**	**6.21**	**4.66**	**4.19**	**4.97**	**4.61**	**4.77**	**4.63**	**4.94**	**5.50**	**10.17**	**X**	**12.51**	**13.06**
6-Apr-04	**293**	**6.40**	**4.59**	**4.17**	**4.96**	**5.35**	**5.29**	**4.86**	**3.95**	**5.45**	**10.10**	**X**	**12.33**	**13.03**
7-May-04	**324**	**6.22**	**4.36**	**3.95**	**4.93**	**5.17**	**5.35**	**4.72**	**4.44**	**5.08**	**11.78**	**X**	**11.26**	**12.43**
20-Jul-04	**398**	**5.47**	**4.21**	**3.72**	**5.06**	**5.02**	**4.65**	**4.68**	**4.34**	**4.55**	**9.14**	**X**	**10.20**	**11.71**
22-Oct-04	**492**	**5.73**	**4.60**	**4.15**	**5.97**	**5.42**	**5.07**	**4.90**	**3.96**	**5.48**	**10.04**	**X**	**11.44**	**12.84**
16-Nov-04	**517**	**6.51**	**5.29**	**4.14**	**7.28**	**6.27**	**5.57**	**5.07**	**3.89**	**5.60**	**10.75**	**X**	**12.12**	**13.07**
8-Apr-05	**660**	**6.27**	**5.56**	**X**	**7.12**	**6.57**	**4.85**	**5.06**	**3.87**	**5.55**	**9.72**	**X**	**9.01**	**13.45**
6-Oct-05	**841**	**6.19**	**5.56**	**X**	**7.23**	**7.82**	**4.88**	**5.19**	**3.31**	**5.24**	**10.13**	**X**	**8.44**	**14.63**
11-Jan-06	**938**	**8.44**	**7.38**	**X**	**6.26**	**10.04**	**6.36**	**5.52**	**4.44**	**6.17**	**13.02**	**X**	**X**	**16.72**
10-Jul-06	**1118**	**5.94**	**5.93**	**X**	**5.94**	**6.74**	**5.15**	**4.76**	**4.48**	**5.14**	**9.02**	**X**	**X**	**12.30**
2-Dec-06	**1263**	**7.81**	**7.80**	**X**	**6.64**	**8.62**	**5.97**	**5.58**	**4.96**	**6.08**	**10.50**	**X**	**X**	**X**
26-Jul-07	**1499**	**6.44**	**6.83**	**X**	**5.67**	**#REF!**	**5.32**	**5.34**	**4.80**	**5.65**	**9.46**	**X**	**X**	**11.30**

APPENDIX E8 – TDR Data (Location G)

Site G		G2	G3	G6	G9	G12	G4	G7	G10	G1	G5	G8	G11	G13
Ch 44550		MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%	MC%
		1.1	1.1	1.1	1.1	1.1	2.5	2.5	2.5	SS	SS	SS	SS	SS
DATE	Days	G2	G3	G6	G9	G12	G4	G7	G10	G1	G5	G8	G11	G13
20-Jun-03	1	*4.40*	*3.60*	*3.60*	*3.40*	*3.80*	*6.40*	*6.40*	*7.60*	*8.40*	*9.40*	*10.20*	*10.80*	*10.40*
24-Jun-03	5	4.40	3.60	3.60	3.40	3.80	6.40	6.40	7.60	8.40	9.40	10.20	10.80	10.40
4-Jul-03	15	4.62	3.84	4.08	3.76	4.33	6.72	6.46	7.96	8.05	9.49	10.00	10.51	10.79
11-Jul-03	22	4.48	3.63	3.89	3.54	4.35	6.73	6.60	7.82	8.50	9.76	10.48	10.50	11.08
18-Jul-03	29	4.34	3.62	3.76	3.52	3.68	6.86	6.75	7.66	9.01	10.35	11.10	10.73	10.67
25-Jul-03	36	4.03	3.36	3.48	2.38	4.05	6.62	6.54	7.44	9.06	10.09	10.81	10.88	11.13
1-Aug-03	43	4.02	3.23	3.32	2.17	3.95	6.48	6.47	6.72	8.92	9.45	9.87	10.80	10.78
8-Aug-03	50	4.17	3.37	3.74	2.14	4.30	6.54	6.67	6.95	9.12	9.65	9.83	10.89	10.98
18-Aug-03	60	4.10	3.30	3.48	1.84	3.95	6.19	6.65	7.53	9.20	9.75	9.54	10.96	11.74
5-Sep-03	78	4.09	3.33	3.40	2.44	3.87	6.26	6.63	6.35	9.27	9.72	9.54	11.11	11.17
16-Sep-03	89	3.98	3.43	3.56	2.53	4.13	6.63	6.70	6.44	9.26	9.97	10.51	11.07	11.19
13-Oct-03	116	4.94	3.25	4.09	2.32	4.05	6.37	6.71	7.53	11.76	8.98	10.49	11.61	11.44
30-Oct-03	133	5.86	3.29	3.92	2.05	4.16	6.27	6.87	9.36	12.72	9.62	11.07	12.57	12.05
1-Dec-03	165	5.44	3.71	3.87	2.03	4.31	6.09	7.07	9.73	12.84	10.69	12.06	12.57	13.13
17-Dec-03	181	5.81	3.53	3.77	2.57	4.33	6.43	6.90	9.52	13.32	10.67	12.07	12.34	12.53
30-Jan-04	225	6.09	4.05	3.60	2.03	5.16	7.37	7.16	9.77	13.89	11.32	12.23	12.97	13.36
12-Mar-04	267	5.84	4.87	4.12	1.82	5.22	7.45	7.22	9.73	13.16	11.32	11.78	X	13.29
6-Apr-04	292	5.50	4.77	4.01	1.72	5.42	7.26	7.17	9.73	12.71	11.05	11.51	X	13.66
7-May-04	323	5.40	5.82	3.92	2.33	4.49	7.55	6.68	9.11	12.33	X	10.47	X	12.39
20-Jul-04	397	4.90	5.38	3.92	1.85	3.50	7.14	6.36	9.07	11.80	X	10.23	X	12.16
22-Oct-04	491	5.90	6.05	3.95	2.15	4.38	7.20	6.86	9.09	12.31	X	10.55	X	11.72
16-Nov-04	516	6.44	6.35	4.20	2.88	4.64	7.21	7.00	9.50	12.98	X	10.65	X	12.81
8-Apr-05	659	4.80	6.70	4.15	2.92	4.95	7.94	6.56	9.19	12.80	X	10.48	X	11.59
19-Oct-05	853	5.60	6.94	5.54	2.29	8.59	7.83	6.86	8.97	13.65	X	10.93	X	10.50
10-Jul-06	1117	4.93	5.86	5.40	1.77	4.57	7.12	6.38	8.73	12.66	X	10.75	X	10.78
2-Dec-06	1262	4.97	X	5.31	1.78	4.76	7.49	6.38	9.11	12.96	X	10.82	X	11.40
26-Jul-07	1498	5.25	X	4.86	2.22	5.40	7.14	6.69	7.57	11.78	X	12.01	X	11.42

APPENDIX F1 – Permeameter Results

Atmospheric Pressure Results at 90 minutes						
Test No	**Test Type**	**90min drop**	**Radius**	**V=π*r^2*h**	**k=25.5V/s**	**Description**
1	Rapidflow	0.5	72.5	8256.50	38.99	C
2	Rapidflow	0.6	72.5	9907.80	46.79	C
3	Evenflow	7	20	8796.46	41.54	C
4	Evenflow	2	20	2513.27	11.87	C
5	Evenflow	6	20	7539.82	35.60	C

Atmospheric Pressure Results at 150 minutes						
Test No	**Test Type**	**150min drop**	**Radius**	**V=π*r^2*h**	**k=25.5V/s**	**Description**
1	Rapidflow	1	72.5	16513.00	46.79	C
2	Rapidflow	1.25	72.5	20641.25	58.48	C
3	Evenflow	14	20	17592.92	49.85	C
4	Evenflow	3	20	3769.91	10.68	C
5	Evenflow	8	20	10053.10	28.48	C

30kPa Pressure Results at 30 minutes						
Test No	**Test Type**	**30min drop**	**Radius**	**V=π*r^2*h**	**k=25.5V/s**	**Description**
1	Rapidflow	5	72.5	82564.98	233.93	D
2	Rapidflow	6	72.5	99077.98	280.72	D
3	Evenflow	--	--	Failed	Failed	Failed
4	Evenflow	--	--	Failed	Failed	Failed