University of Southern Queensland

Faculty of Engineering and Surveying

Effective Road Pavement Design for Expansive Soils in Ipswich

A dissertation submitted by

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Abstract

Ipswich City is located in south-east Queensland and is underlain by predominantly impermeable subsoils which cause periodic subsurface water-logging and typically classified as expansive, CH and MH soils. Council has battled with effective pavement design and construction due to poor subgrade behaviour. Unbound pavements are historically the dominant design used in Ipswich and are typically based on the AUSTROADS and Department of Transport and Main Roads manuals and experience.

The subgrade of any foundation plays an important role in load bearing and support of traffic and pavement construction over expansive clays requires a suitable working platform to enable machinery to operate. Studies show the use of safe bearing capacity for subgrade assessment does not suit CH soils. Subgrade treatment needs to be a mandatory consideration coupled with using the lowest CBR readings to provide the maximum pavement thickness. The most effective method of subgrade treatment currently appears to be geosynthetics placed on the subgrade.

The latest Austroads and Department of Transport and Main Roads manuals align with current world best practice for pavement design and it is recommended the latest versions continue to be used for new pavements. The Ipswich Planning Scheme Policy should refer directly to these documents and be specific for Ipswich soils, i.e. the greater depth pavement should be chosen based on a low CBR value and realistic design ESA's number.

On expansive soils, a flexible surface should be constructed on an impermeable membrane or layer since flexible bases experience fatigue which can be easily maintained whereas rigid bases can crack rapidly and to the detriment of the entire foundation. Identification of the cause of pavement failure is necessary to determine the appropriate rehabilitation method for a failed pavement. Council should consider sustainable rehabilitation methods that maintain a flexible pavement with asphalt surfacing.

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27 Oct 2010

Date

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1 Introduction

Expansive soils are typically clays that demonstrate extensive volume and strength changes at varying moisture content due to their chemical composition. This change in soil volume has shown through history to cause significant structural damage to foundations, including pavements, due at large to the swelling and shrinking that occurs within the soil. For many decades Geologists and Engineers alike have studied these soils in an effort to determine the most appropriate methods of construction where these soils cannot be avoided. Some of the Countries experiencing road pavement design and construction difficulties over expansive soils, to name a few, include Australia, New Zealand, China, India, USA, UK, Israel and South Africa. Petry and Little (2002) discuss the history of clays and their engineering significance, dating back to papers written in the early 1930's.

In Australia, there is near one million kilometres of road with an asset value in the order of tens of billions of dollars. (Youdale 1996) Road pavement design practices have evolved over time largely by trial and error and good old Aussie innovation. As a past-Chairman for the Austroads Pavement Research Group, Youdale (1996) authored a consultant road note titled "Australian Pavement Research – the last 20 years" which outlines a view on the historical development of Australian pavement practices over the previous two decades. Although his paper does not focus on clays, it does demonstrate that much research has been undertaken into road design and construction practices through Australian history. Frost, Fleming and Rogers (2004) outline the primary roles that a subgrade or pavement foundation must play in pavement design. These include supporting construction vehicles, providing a suitable base for placement and compaction of pavement materials and provide support for service i.e. effective distribution of vehicular loads and stresses.

Austroads appears to provide the most widely used pavement design specifications in Australia (included in their publications "Guide to Road Design" and "Guide to Pavement Technology"). Pre-2010 publications provide mechanistic approaches which do not specify particular parameters for clay subgrades where the reader is guided to a trial pavement to be modified to suit the location environment and conditions. Past research suggests that whilst there are many tried methods for dealing with clay subgrades, there is no one method that appears to be completely satisfactory. In addition, testing methods to determine future clay behaviour under a pavement requires further development. The Department of Transport and Main Roads Queensland publish a pavement design manual that is based on the AUSTROADS manual but includes more specific procedures to suit Queensland conditions.

Ipswich City Council appears to be experiencing problems with longevity of road pavements in the Ipswich area, typically where expansive soils are dominant. Over the years there have been obvious problems such as longitudinal cracking, kerb rotation and crown heave. These issues have been experienced by the Planning and Development Department (with roads constructed by Developers following the Council Planning Scheme Policy) and the Engineering Services Department (through their own construction following typically Austroads and Main Roads Standards for pavement design).

Currently, the Ipswich Planning Scheme Policy 3 (Ipswich City Council 2006) outlines the standards for design of road works by Developers. Divison 1 - Site and Road Layout, states that arterial and sub-arterial road designs must be based on Queensland Department of Main Roads (QMDR) and AUSTROADS manuals whilst access streets/places and collector streets must be based on Queensland Streets produced by the Institute of Public Works Engineering Australia Queensland (Institute of Public Works Engineering Australia Queensland 1993). Division 2 - Flexible Pavement Design, does not specify the design manual to be adopted, however, suggests that division itself is to be used as a supplement to other design manuals.

2 Literature Review / Background

A literature review has been completed to determine the degree of previous research that has been under taken on this topic and to refine the intent of this project. Sources of information from around the globe have been sought to provide an understanding of the geological properties of expansive soils/clays, investigate current material test procedures for the determination of clay properties, research current subgrade treatment methods, rehabilitation of deformed pavements, the geological history of Ipswich and the formation of clay soil deposits.

Information from this research then enables soil test and results analysis methods to be determined and provides a good basis for comparison of current Ipswich City Council road pavement design and construction practices to worldwide practices, including new initiatives being tested or trialled around the world.

It is important to mention that similar topics have been undertaken by the University of Southern Queensland students over the past few years. The year and topics are outlined below -:

- 2009 - Alternate Pavement Types on Reactive Soils in the Ipswich Council Area by Jeffrey Crone.
- 2008 - Investigation of Construction Practices and Test Procedures for Road Pavements on Expansive Subgrades by Kieren Walters.
- 2005 - Road Stabilisation Issues in Southern District of the Department of Main Roads, Queensland by Elissa Harrison.
- 2005 - To determine if there is a correlation between the shrink swell index and Atterberg limits for soils within the Shepparton Formation by David Earl.
- 2004 - Forensic Investigation of Pavement Failures by Richard Smith.

Every effort will be made to ensure that relevant data is utilised and this research does not duplicate previous research. The stated outcomes from these previous papers by fellow students indicated that further research could be undertaken in the following areas (with respect to clays) -:

- Advantages of performance based testing over traditional empirical testing.
- Determination of the strength gain relationship between lime stabilization and black soils.
- Longer term testing of stabilisation efforts.
- Trial test methods such as soil suction during seasonal peaks to determine the active depth of expansive soils.
- Classification of clays using various methods.
- Whether a correlation exists between the shrink-swell index and the plasticity index or linear shrinkage for particular clay types.
- Investigate trial pavement cross-sections and develop construction guidelines.
- Stepped box excavation for lean mix pavements and successive layers.
- Polymer modified seals on stabilised pavements to minimise reflective cracking.

2.1 Geological Properties of Expansive Soils

West (1995) defines expansive soils as those soils that consist of clays which shrink and swell with the primary clay being Smectite (Montmorillonite).The in-situ moisture content of a soil, and hence its consistency, can be useful in determining the shear strength, compressibility and bearing capacity of the soil. When the soil's natural moisture level is near the liquid limit (LL), the soils will exhibit low strength. When the moisture content is near the plastic limit (PL) however, firmness should be apparent and greater strength results. Das (2006) explains that there are two main types of soil classification systems used around the world, the American Association of State Highway and Transportation Officials (AASHTO) and the Unified Soil Classification System (USCS). Both systems are based on texture (grain size) and plasticity (liquid limit and plasticity index). ACPA (2008) state that swelling clays have either an AASHTO group of A-6 or A-7 or a unified classification of CH, MH or OH with plasticity greater than 25 (by ASTM methods).

West (1995) believes that the Atterberg limits provide a means of determining the standard of performance and a level of sensitivity to volumetric change due to moisture influx. The Atterberg limits consist of the liquid limit (LL), plastic limit (PL) and similarly the liquidity and plasticity indices (LI and PI). For example, when a soil nears the LI it has little strength. The activity, A, of a soil is the measure of clay-like behaviour, defined as PI divided by the clay fraction of the sample. West (1995) defines active clays as those with an activity between 0.75 and 1.25, Smectite being a prime example. It is interesting to note that he believes the correlation between the aforementioned Atterberg limits and the presence of clay minerals is strongly positive (see Figure 2.1). It also seems that the smaller the particle sizes within the clay the greater the potential for swell (due to a larger surface area). Another property that appears to define clay types includes the cation exchange capacity (CEC), with Smectite having the highest capacity. (West 1995)

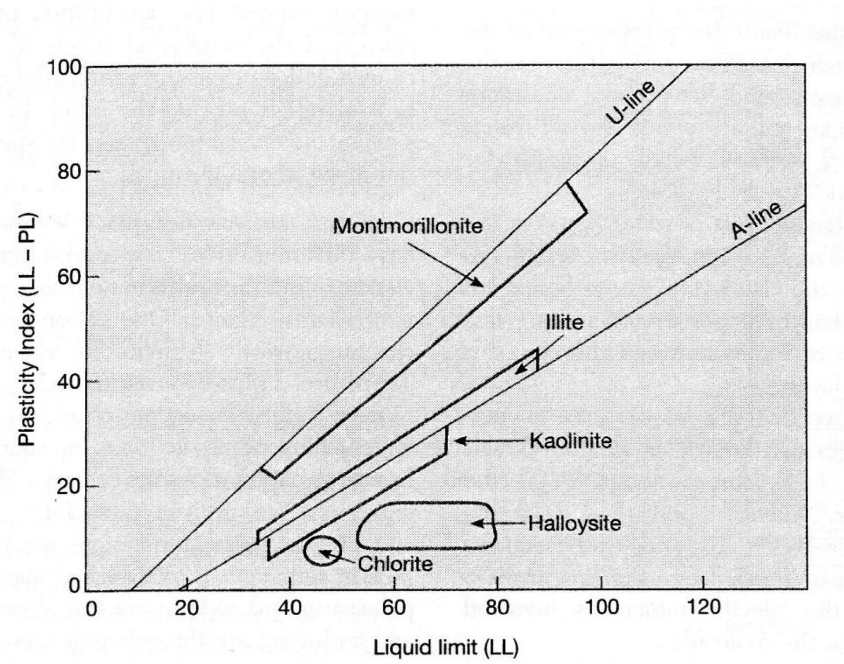


Figure 2.1 Positions of Clay Minerals on a Plasticity Chart (West 1995)

In addition to those properties mentioned above, Das (2006) explains that the shrinkage limit (SL) is a measure of moisture content at which the soil volume ceases to decrease. There is a history demonstrating the use of plasticity charts to classify clays (based on mineral content). Das (2006) goes on to explain the cohesive behaviour of clays and their flocculent behaviour. It is very interesting to note that when salt is added to a clay suspension, the Na+ cations suppress the double layer of water around the clay particle. This causes the particles to become more attracted to one another and aggregate, increasing the sensitivity ratio (in other words the speed with which the clay becomes viscous). Zheng, Zhang and Yang (2009) give acknowledgement to previous research that suggests the properties of total CEC, specific surface area (SSA) and Montmorillonite content are strongly representative of shrink-swell potential, however, testing of these properties is complicated. A new measure of this potential was identified by Yao and Yang (2004) called the standard absorption moisture content (w_f). This method, together with PI and the free-swelling ratio (f_s), have been utilised in China's 'Specification for the Design of Highway Subgrades'.

Similar to a shallow foundation, the soil-bearing capacity of the subgrade plays a large role in supporting a road pavement and transferring the vehicle loads. It is necessary that no shear failure occurs within the subgrade. Das (2006) outlines the method of Plate-Load testing – a field based test to check soil-bearing capacity. Reddy and Moorthy (2005) reviewed existing flexible pavement building technology to conclude that the safety against subgrade bearing capacity failure does not seem to be a consideration in modern pavement design methods. Natarajan and Shanmakha Rao (1979) and Steinberg (1985) report that the most apparent location of these failures occurs in the extremity of pavements where moisture changes are more likely. The potential that a particular subgrade and/or pavement material has for densification directly affects the likelihood of permanent deformation occurring, which can become visible on the surface. This deformation typically occurs in the wheel paths, and is noticeably worse in the outer path (i.e. closer to the shoulder or kerb and channel). It is for these reasons that authorities specify compaction standards.

2.2 Current Engineering Test Methods used in the Determination of a Pavement Design

It was in the late 1950's that McDowell (1959) published the first paper on pavement design incorporating laboratory testing on expansive soils. This lead to the development of the Texas Method which used stress and shear failure theories. Since that time much research has gone into assessing swell potential, soil suction and moisture content determination. As Petry and Little (2002) point out, even though there has been considerable geotechnical research suggesting that the determination of soil suction is important to gauge volume change potential, there appears to be no accepted method that practicing Engineers are using to achieve these results. They strongly support mechanistic pavement design using parameters such as resilient modulus and plastic deformation potential. This would require appropriate data from laboratory testing to allow pavement performance to be predicted and appropriate methods chosen.

2.2.1 Bearing capacity

In Ipswich and around the world, the California Bearing Ratio (CBR) method of pavement design is dominant. In order to design a pavement based on a particular CBR value it is usually necessary to assume a CBR value based on historical data and to confirm the assumptions when the subgrade level is reached during construction by carrying out testing both in-situ and on samples. Reddy and Moorthy (2005) find that CBR testing methods are limited due to the empirical nature and that the edge conditions are not properly accounted for. Other test methods such as Group Index, Mc Leod and AASHTO do not take into consideration the risk of shear failure in the subgrade.

Reddy and Moorthy (2005) propose the Safe Bearing Capacity (SBC) method. Design pavement thickness is found by considering vertical stress, due to vehicle loads and overburden, and safe bearing capacities. Comparisons of designs using SBC and CBR methods, found that the method producing the greater thickness should be chosen in all cases where possible. They also found that for CH soils, the SBC method could not determine a pavement thickness that would be safe against shear failure.

Zheng, Zhang and Yang (2009) state that the design thickness for a pavement in China is controlled by the subgrade stiffness, as measured by the CBR. They found that samples which were not soaked during testing exhibited higher CBR values than those tested according to the standard testing methods, which caused the sample to show differential moisture, i.e. only the upper and lower portions were saturated. In line with these comments, Zheng, Zhang and Yang (2009) state that the bearing capacity increases and swelling decreases with increasing overpressure. A modified test has been suggested to be suitable for determining bearing capacity of swelling clays. This consists of lateral soaking under a surcharge weight to simulate an overpressure on the pavement.

Brown (1996) makes the bold comment that the use of empirical approaches such as CBR testing does not provide a satisfactory indication of the potential subgrade performance. The UK Highways Agency saw an opportunity to fund research into the development of a pavement design method that was performance based and included testing of stiffness and resistance to permanent deformation both in the field and in the laboratory (Frost, Fleming & Rogers 2004).

ACPA (2008) state clearly that soil swell can be reduced by surcharge load (including weight of soil and pavement materials). The greater the pavement mass over the clay subgrade, the more weight that is available to resist upheaval due to moisture variations. This is a significant piece of information in the scheme of pavement design on swelling clays.

2.2.2 Strength

The Triaxial Shear Test, as described by Das (2006) is one of the most dependable test methods to determine shear strength parameters. Cheung

(1994) suggests that stiffness (resilient elastic modulus) is a function of confining stress, axial stress and matrix suction (pore water pressure) of the materials. Brown (1996) concluded from this research that permanent deformation must be a relationship between applied shear stress and shear strength of the soil. Frost, Fleming and Rogers (2001) propose that dynamic plate testing could play a role in assessing pavement design. It may be necessary to conduct testing for both short term and long term timeframes in order to determine best practice design and construction of pavements on swelling clays.

Frost, Fleming and Rogers (2004) support the method of repeated load triaxial testing (RLTT) but have also identified issues with modelling natural water absorption by a sample and predicting moisture variability over time. They also found at low applied stress the resilient modulus is difficult to measure due to sensitivity and that sample material inconsistency was an issue. The conclusion reached is that threshold stress of a subgrade is determined by correlation with shear strength and that designs using this method have proven comparable to those produced by conventional design methods.

2.2.3 Shrink/Swell

West (1995) suggests that the quantity of cations present (having a high base CEC) in a sample is indicative of the swelling potential of a clay. This is consistent with a comment by Das (2006) that the negative ions on dry clay attract ions such as magnesium (Mg^{2+}), Sodium (Na^{+}) and potassium (K^{+}) , all cations. Between the negative ions of the clay and the available surrounding cations, water dipoles are attracted and form a layer of water around the clay particles. At clay contents greater than 50%, the minerals will determine the engineering properties of the clay (Das 2006).

Thomas, Baker and Zelazny (2000) comment that there is no test method for accurately determining the shrink-swell potential for all soils. They clarify this statement by saying that a prediction can be made based on a variety of soil properties and that expansive soils can be considered to exhibit high CEC, SSA and LL. This is consistent with the comments above by West and Das. Thomas, Baker and Zelazny (2000) conducted laboratory analyses using particle-size distribution (pipette method), CEC (sum of cations method), Atterberg limits (ASTM method D4318), potential volume change (PVC) (by the method of Lambe 1960) and clay mineralogy. They found the PI showed little correlation with the expected shrink-swell class. They also found that of the indices measured (as outlined above) all positively correlated with swell index (a direct measurement).

In research conducted by Earl (2005) a poor correlation was between the shrink-swell index and LS, however, reasonably good correlations were shown between the shrink-swell index and the PI factored by the clay fraction and similarly with the shrink-swell and the PL factored by the clay fraction.

Brown et al. (2002) make an interesting point that the Australian Standard for Residential Slabs and Footings Construction (AS2870) does not refer to standards tests such as Atterberg limits or linear shrinkage to determine expansivity. Instead surface movement (y_s) is the primary characteristic used to classify the soils (this includes the use of soil suction data and the instability index derived from shrink-swell tests). The AASHTO guidelines for assessing expansive soils utilises LL, PI and soil suction. Brown (2002) quotes the Australian Standard, AS2870, stating that there are no clear tests to determine clay reactivity and that movement is simply a function of mineralogy, proportion of clay, moisture change, loading and lateral restraint.

2.3 Subgrade Treatment Methods

Petry and Little (2002) believe that the majority of treatment methods currently employed in the field have been around since 1960; including various forms of chemical or mechanical modification. The following six methods are but a few of the popular treatments.

2.3.1 Replacement

Das (2004) lists the first precaution of foundation construction on swelling clays as replacement of the expansive soil with a less expansive material. This is an interesting point since a large proportion of current research rates replacement as a last option. Ipswich City Council has found this appears to be the case in established urban areas where service pipes and conduits (such as telecommunications, water, sewerage, gas and oil) are often within the roadway and under the pavements that require reconstruction or rehabilitation. However, current practice shows that where ample depth is available, the preference is still to remove the weak clay soil and replace it with a less expansive material (usually profilings from the old surface).

2.3.2 Compaction

West (1995) states that the bearing capacity of a subgrade can be improved by densification or compaction of the soil; consequently the soil displays a decreased tendency to volume change (swell). Das (2006) states that if clay is compacted at less than OMC, inter-particle repulsion is minimized and the double layer surrounding the particle will be suppressed, leading to a random particle orientation. This means that the soil tends to swell as there is space for water molecules to occupy, however, a greater strength is achieved than those soils compacted greater than OMC. When the soil is on the 'wet' side of OMC, the particles align producing less voids but a slight reduction in strength. In addition to moisture, the degree of compactive effort plays a large role in the final outcome.

Low compactive effort + higher moisture ↔ Higher compactive effort + lower moisture

Low compactive effort leads to greater compression when the moisture is slightly greater than OMC. However, higher compactive effort requires moisture slightly below OMC to achieve the same degree of compression. In contrast to Das, Petry and Little (2002) comment that during construction the moisture content should be maintained 3-5% above the OMC until final compaction.

However, ACPA (2008) believe it is vital to compact the subgrade with moisture only 1-3% above OMC to produce a less permeable higher strength subgrade.

2.3.3 Pre-wetting

Petry and Little (2002) state pre-wetting had become a proven method by the end of the 1970's. McKinney, Kelly and McDowell (1974), Steinberg (1977) and Poor (1978) believe that ponding water on a foundation reduces the future swell initial, often assisted by moisture barrier installation. The idea of deliberately ponding water on the subgrade prior to the construction of a pavement may seem a little unusual; however, Das (2004) discusses the benefit of inducing heave. Water injection is yet another way of achieving moisture stabilisation of foundations/subgrades. A moistened soil can be immediately covered with a plastic barrier, sprinkled to keep moist or constructed upon immediately (Petry and Little 2002). The clear disadvantages of working on moist clays include an inability to support construction equipment and machinery and the process can be time consuming. Das (2004) further comments on the option of lime stabilization at this point to create a working platform.

2.3.4 Chemical Stabilization

Generally, there are three types of chemical stabilisers – traditional, by-product (kiln dust) and non-traditional (such as sulphonated oils, polymers, enzymes etc). Petry and Little (2002) make the comment that lime and Portland Cement are the most commonly used chemical stabilisers, however, moisture stabilisation (as previously described) is still the most widely used method.

Chen (2004) conducted research using various stabilizers including calcium lime, Portland Cement and lime/cement mixtures to conclude that lime shows the greatest improvement to compressibility, CBR and swelling. In the field it is extremely difficult to effectively mix the clay and lime due to natural moisture content. In the early 1960's Eades, Nichols and Grim (1963) identified the relationship between variable quantities of lime and different mineral properties of clays. Still common today, lime quantities are being incorrectly specified and as such many engineers do not consider the outcome effective.

Ramanujam and Jones (2007) explain that the main disadvantage of subgrade cement stabilisation is the high stiffness created and a tendency for the overlying pavement to crack. Over recent years road makers have moved to an alternative slow setting cement that contains additives in order to improve workability, however, this has proven to cause greater stiffness than the original cement stabilization process leading to increased cracking problems. In Australia, Europe and the USA, alternative mixtures such as pozzolans have been used to enhance strength. Some clay types will not undergo the desired lime reaction without some assistance. The use of a two coat seal rather than asphalt over lime stabilised areas has been suggested by Crone (2009).

Yong and Xiao-jun (2009) conducted research on the inclusion of glass fibers in cement stabilization to improve the usual brittle behaviour experienced with normal cement stabilisation. Findings were that the extent of strength increase was proportional to the glass fiber content and that the frequency of cracking and the crack widths were reduced and the subgrade strength (both compressive and tensile) had improved.

As a variant to the usual stabilization, Osinubi (2000) writes about the use of cement and pulversied coal bottom ash (PCBA) as an admixture for stabilization of black clay in Nigeria. The reaction of the PCBA with the clay produces cementing agents that produce an initial high strength followed by a pozzolanic reaction leading to longer-term strength. PCBA is very similar to Portland cement and has shown to decrease maximum dry density (MDD). Osinubi (2000) recommended 5% by weight of dry soil pulverized PCBA mixed with 8% cement stabilised CL soil to improve subgrade soils in a more economical fashion.

Petry and Little (2002) conclude that future research on stabilisation should include the establishment of protocols that allow the designer to determine the option best suited for a particular scenario. In addition the issues of sulphate heave, understanding of the mechanisms of stabilisation and assessment of field properties from laboratory results need to be refined. Harrison (2005) states that dynamic cone penetrometer (DCP) test results prove lime stabilisation improves the strength of black clay soils.

2.3.5 Geosynthetics

Das (2006) believes that geosynthetics (including geofabrics, geotextiles, geomembranes and the like) play a role in separating materials, reinforcing, filtering, draining and/or providing a moisture barrier. To be more descript - keeping a clay subgrade and sub-base material separate, increasing load bearing capacity, protection of fine-grained soils from transportation and channeling undesirable water away. This is supported by Zornberg and Gupta (2009) who state that geosynthetics reinforce the subgrade or base materials by providing lateral restraint (minimising spread), tensile membrane support and increasing the bearing capacity. These benefits are supported by field observations of the traffic benefit ratio (TBR) and the base course reduction (BCR).

Crone (2009) demonstrates a significant cost saving to be made by replacing an unbound layer with a geogrid. Zornberg and Gupta (2009) conclude that the absence of geofabric incorporation in design manuals appears to be due to a lack of understanding and actual testing on the contribution that these fabrics are delivering to improved pavement performance. Kwon, Tutumluer and Al-Qadi (2009) present a similar argument, stating cost benefit analyses have not yet been realised and an adequate design procedure is unavailable.

In 2008, Zornberg et al. (2008) reported their findings of a field evaluation of 35 projects over swelling clays in the USA (Forth Worth to Dallas) which were experiencing cracking. They found that 26 of the projects had been constructed using geosynthetics (with bi-axial grids the preference) with no well defined design procedures. Further investigations explained by Zornberg and Gupta (2009) proved to have significant outcomes, as follows -:

1. Geosynthetic reinforcement prevents the development of longitudinal cracks – the control section with no geogrid developed cracks within a few

months of construction whilst the sections reinforced with geogrid showed no cracking.

2. Geosynthetic reinforcements will relocate cracks beyond the reinforced area – it was found that a trial section was not constructed as directed and the area in the road shoulder where the geogrid did not cover cracked before the road was even opened to traffic.

3. Lack of understanding of geosynthetic specifications – tensile properties of geogrids can vary among manufacturers. Trials have shown that the junction efficiency (i.e. within the bonded portion of the longitudinal and transverse ribs) plays a large role in the performance of the grid. In this case the polyester geogrid failed and the polypropylene grid performed well.

There is a significant amount of recent research material available for geosynthetic materials. Of particular interest is the geogrids currently being trialed in many countries as a subgrade or base reinforcement for flexible pavements. It is believed these geogrids are most effective when utilised in lower traffic volume environments and particularly within an unbound pavement as a base reinforcement (Kwon, Tutumluer and Al-Qadi 2009). Testing undertaken by Kwon, Tutumluer and Al-Qadi (2009) revealed that a greater degree of stiffness exists within a reinforced section of pavement. They found that the unbound material interaction with the geogrid created a higher level of anisotropy (ratio of horizontal to vertical moduli) due to aggregate confinement. They also found that two layers of geogrid minimised horizontal aggregate movement and intermixing of layers.

Black and Holtz (1999) conducted research into the performance of geotextile separators five years after installation on soft silty subgrades with pavements having a history of rutting and fatigue. They found that aggregate damage due to construction methods caused fraying in non-woven geotextiles and breakage or separation of the woven geotextiles. They found that no one type of geotextile was out performing others when it came to the migration of fines into the pavement. Heat-bonded geotextiles appear to experience more clogging than other types. Black and Holtz (1999) concluded their paper with a comment that subgrade sections beneath geotextiles become more consolidated with time than areas without the geotextile. In conclusion, the use of geogrids comes strongly recommended by all research read to date.

2.3.6 Moisture Barriers

As the title here suggests, moisture barriers around a foundation or pavement can assist in controlling the movement of water causing differential heave. This may include a geosynthetic material or plastic layer that lines the pavement box to contain the pavement materials. Of all the research carried out for this review, there was little mention of the use of moisture barriers and no elaboration on successful methods.

2.4 Rehabilitation Methods for Deformed Pavements

Pavement rehabilitation refers to the application of a treatment to an existing pavement experiencing distress, often due to fatigue. Deep rutting of an asphalt surface can lead to longitudinal cracking and consequently infiltration of water into any underlying unbound materials. As Oscarsson (2010) points out, factors such as traffic, materials and climate can cause this rutting which ultimately facilitates a greater rate of deterioration of the whole pavement. Walters (2008) outlines a vast array of pavement deformations such as roughness, cracking, corrugations, depressions, potholes, shoving, edge defects and rutting. His dissertation goes on to recommend construction practices to minimise these deformations, most of which have been described in subsection 4.3. Walters (2008) concludes that pavement failures in areas of expansive soils are generally caused by poor subgrade strength, a high degree of shrink-swell behaviour, high proportion of clay and variable moisture content. This dissertation did not suggest alternative rehabilitation methods to cope with expansive soil behaviour.

Ali, Sadek and Shahrour (2009) suggest that the cost to rehabilitate urban roads is substantial and that new methods require verification by testing to validate their use. Their paper presents a finite element model for rutting and analyses rehabilitation methods. Testing shows that lower traffic speeds cause an increase in the degree of rutting due to amplified loading; typically at intersections, bus stops and traffic lights. They suggest that high modulus asphalt (such as EME) provides good rut resistance and is the preferred rehabilitation method. (Ali, Sadek and Shahrour 2009)

Smith (2004) presents similar information to Walters regarding forms of pavement failures. In contrast, he outlines a myriad of rehabilitation options including moisture control, drainage, surface treatments, overlays, in-situ stabilisation, fibre reinforced seals, Novachip, stone mastic asphalt and high pressure water retexturing. Similarly, Crone (2009) discusses innovative pavement alternatives such as stabilisation of the outer wheel path only, crushed glass additives, Fibredec spray seals, polyroad, geotextiles seals, cationic slow setting bituminous emulsions and plastic sheeting over clays. Smith (2004) concludes that unbound pavements should not be used for high volume traffic; however, experienced technical officers within Ipswich City Council find unbound pavements are the easiest pavement type to rehabilitate and provide a good platform for staged construction or future changes to the pavement to cater for growth.

Foamed-bitumen stabilization is becoming a popular rehabilitation product, and has been trialed in Queensland since the late 1990's by the Department of Main Roads. Ramanujam and Jones (2007) explain how over recent years constructors have moved away from stabilisation and toward modification of existing base materials to improve properties such as strength and permeability and reduce the chance of cracking due to stiffness. Foamed-bitumen, a mixture of bitumen, water and air, has so far shown to be satisfactory, however, still in its infancy requiring future observation and testing. Ramanujam and Jones (2007) elaborate on the immediate problems that foamed bitumen stabilised pavements exhibit, including poor rut resistance often due to the lack of curing time available. They found from test results that immediate rut resistance with foamed-bitumen was relatively good, and after a 24 hour period developed to provide excellent rut resistance. It is important to note that they found this treatment is more beneficial with material having some plasticity and that a Class 170 bitumen is suitable. Mohammad et al. (2003) report that foamed asphalt treated with reclaimed asphalt pavement (RAP) and Portland cement demonstrates greater stiffness during construction than comparative pavements with lime.

Deeplift recycling, or full-depth asphalt construction, is becoming a common method of both pavement construction and rehabilitation. This is largely due to the reduced pavement thickness that current design manuals suggest when incorporating asphalt as a base layer. Deeplift has been very successful with pavement construction for the Ipswich City Council projects as it can be constructed in a shorter time frame allowing traffic to return to the pavement. Cost comparisons show that a deeper unbound pavement is approximately $\$20/m^2$ more cost effective than a full-depth asphalt pavement. However, the other benefits appear to outweigh the cost on many occasions.

Methods of pavement rehabilitation still popular today include lime stabilisation with a nominal asphalt overlay (typically 30mm to 40mm) or a simple mill/profile and resurface by means of bitumen seal. Harrison (2005) believes that small quantities of lime added to a material may cause reversible modifications of properties under different moisture conditions. It seems there is currently a greater understanding of lime quantity determination, however, conformance testing and determination of the strength gain is not so implicit. (Harrison 2005)

3 Research Design and Methodology

3.1 Aims and Objectives

The broad aim of this project was to develop effective road pavement design standards for expansive soil subgrades in the Ipswich area.

As taken from the Project Specification, the specific objectives included -:

1. Researching current Australian and international information relating to road pavements on expansive soil subgrades, and in particular information regarding:

    a. Road pavement design;
    b. Subgrade treatment methods;
    c. Engineering test methods for expansive clays; and
    d. Rehabilitation methods employed for deformed pavements.

2. Researching geological history of Ipswich and formation of expansive clay soil deposits.

3. Gathering soil test information for expansive clays in Ipswich. Classify the clays of the Ipswich area based on their material properties e.g. liquid limit, plastic limit, shrinkage limit, activity, potential swell, etc.

4. Carrying out a survey of pavement condition for road pavements on expansive clays throughout the Ipswich area.

5. Assessing the effectiveness, in regard to world's best practice and actual performance, of current Ipswich City Council pavement design practices for both flexible and rigid pavements.

6. Proposing and evaluating improvements to the Ipswich City Council current pavement design practices.

7. Presenting information, results and recommendations in the required written and oral formats.

As time permitted:

8. Produce tables and/or graphs for pavement design in Ipswich.

9. Develop a policy for pavement design for incorporation in the Ipswich City Council Planning Scheme.

The aims and objectives of this project were approved by the sponsor, Ipswich City Council, as modified from a topic offered for research by USQ in late 2009.

3.2 Consequential Effects/Implications/Ethics

The purpose of this section is to identify resulting sustainability, safety and ethical issues implicated by this research project.

3.2.1 Sustainability

The Institution of Engineers Australia (1997) put together a framework containing ten important aspects. These are presented below with relevant discussion.

- "Development today should not undermine the development and environmental needs of future generations"

  The major physical resource required for this project was clay soil samples from around Ipswich. Whilst clays are certainly not an infinite resource, the quantities required for testing are very small in comparison. Any samples collected were taken from excavation areas where new pavements were being constructed or from material spoiled during pavement rehabilitation. As part of effective pavement design, including both new pavements and rehabilitation, it is important to ensure that all material use is sustainable. This may include recycling of materials or minimising current finite resource usage.

- “Environmental protection shall constitute an integral part of the development process”

  The research portion of the project involved the collection and disposal of soil samples, the process by which this was achieved was environmentally safe. This involved the filling of voids after samples were taken, appropriate disposal facilities used or material reused where possible for fill. For the ultimate outcome, future pavement designs, it was necessary to consider the choices of materials and the effects that usage of these would have. Some of these effects include –

  - choosing a quarry for unbound material that is close to site to minimise transport and air pollution,
  - ensuring appropriate site environmental protection such as pollutant and sediment traps to limit the effect of runoff (particularly when chemical stabilisers are being utilised),
  - installation of shaker pads to minimise soil transportation out of the site area on vehicle wheels,
  - Wash down facilities for vehicles working with chemicals such as lime

- “Engineering [and surveying] people should take into consideration the global environmental impacts of local actions and policies”

  The large-scale effect of the development of a pavement design policy within Ipswich City could be significant. Some examples include –

  - The specification of particular material such as pugged gravel means that the process by which the material is produced has an increased environmental impact. In this example, the gravel undergoes extra processing at the quarry where moisture is added to achieve a specification such as 6%, this process not only has a higher carbon footprint due to machinery involved but at a higher cost to the customer.

- Mandatory inclusion of chemical stabilisation will increase environmental (and human) exposure to these chemicals,
- Inclusion of ‘new’ rehabilitation processes such as foamed bitumen, rubberized bitumen, reclaimed asphalt etc may have long-term environmental effects that have not yet been identified.
- A policy that minimises soil replacement should minimise the impact that spoil placed at the disposal sites has on the environment.

Some examples of potential economic effects –

- The mandatory inclusion of a particular geosynthetic material for all pavements on clay soil – this could exclude current suppliers of geosynthetics whom do not produce that particular type required.
- The follow-on effect may be that the depths of quarry material is reduced, hence supply demands will decrease,
- The stipulation of particular specifications which local producers cannot meet e.g. tighter plasticity requirements on gravel may limit supply to one supplier, effectively ruling out any competition. This not only affects the companies not supplying but has the potential to increase the cost of materials.

- “The precautionary approach should be taken – scientific uncertainty should not be used to postpone measures to prevent environmental degradation”

- “Environmental issues should be handled with the participation of all concerned citizens”

This statement really says that everyone is responsible for the environment. For this project work participants included civil engineers, technical officers, laboratory staff and field workers. Indirectly there was involvement by Workplace, Health and Safety officers, Quality Assurance officers, environmental representatives and other professionals. As with any project, the roles and responsibilities of staff were outlined in ICC and project specific documentation. For this research, Ipswich City

Council policies were followed and standard roles/responsibilities applied.

- “The community has a right of access to, and an understanding of, environmental information”

  All information on environmental aspects of this project was clearly set within well-defined sections of the appreciation. There were no specific headings for environmental issues; however, where information was required it was readily available within each specific section.

- “The polluter should bear the cost of pollution and so environmental costs should be internalised by adding them to the cost of production”

  Potentially there were costs associated with environmental protection evolving from the outcomes of this project work; examples included -:

  - Increased construction site environmental requirements such as sediment/pollutant traps,
  - Increased water quality monitoring and assessment,
  - Unsuitable or spoil material disposal costs usually incur a levy, e.g. a new levy has just been introduced by the Environmental Protection Agency for the disposal of spoil, hence it would be both beneficial (both economic and environmentally) to recycle or reuse materials.

- “The eradication of poverty; the reduction in differences in living standards and the full participation of women, youth and indigenous people are essential to achieve sustainability”

  With regards to the immediate research area, Ipswich, the benefits of this research are longer lasting pavements for the public to utilise (a community resource). Since future pavements will be constructed by Council staff and contractors, the workplace policies with regard to Equal Employment Opportunity apply and consequently full participation is achieved.

- “People in developed countries bear a special responsibility to assist in the achievement of sustainability”

  The utilisation of the outcomes from this project around the world would have varying consequences on sustainability. For example, most developed countries would experience similar issues to that of Australia with the likely exception of material variances. However, undeveloped countries may struggle with resource availability (such as materials, plant, labour) and the skills necessary to carry out the procedures necessary to achieve the desired designs. It is important that pavement options are available which incorporate available resources. However, since this project focuses on design in Ipswich, this outcome may not be achieved.

- “Warfare is inherently destructive of sustainability, in contrast, peace, development and environmental protection are interdependent and indivisible”

  On a large scale, the development of pavement design techniques based on current research and past experiences can provide valuable information to those developing countries that do not have the resources or expertise to conduct their own research and design. As Youdale (1996) points out, the states and territories of Australia work well together to achieve the best practice through effective resourcing. If Australia can share this information with other countries, the benefits to living standards are obvious.

3.2.2 Safety

As with any road works, there a number of general safety issues that that were experienced throughout the project work. The Guide to Safety in the Civil Construction Industry (Queensland Government 2000) provides the required practices (including regulations and legislation) that all personnel are required to comply with. It was vital that all personnel entering a work site were inducted onto that site and made aware of specific hazards and rules. These include but are not limited to the following -:

- Traffic – appropriate personal protective clothing required (WH&S Act); including safety boots, long pants, retro-reflective vest or jacket, safety glasses and sun protection. When working with soils it was also appropriate to wear gloves.
- Plant Operation – awareness of plant movements and caution outside the exclusion zone.
- Construction hazards – material locations, trip hazards, exclusion zones, storage facilities etc
- Chemicals – knowledge of the location of material safety data sheets (MSDS). Avoidance of contact with chemicals where possible. Usage of appropriate protective devices e.g. face masks may be required if using lime.

3.2.3 Ethical Issues

The Code of Ethics as published by Engineers Australia clearly outlines the values and principles which members are bound in order to promote engineering and to facilitate the practice for the common good. The Principles of the code are:

> "to respect the inherent dignity of the individual, to act on the basis of a well informed conscience, and to act in the interest of the community".
> (The Institution of Engineers Australia 2000)

Therefore, the project research was ethical by these definitions and monitored as work proceeded to ensure these standards were upheld.

Consideration of previous research by fellow colleagues and the initial project topic revealed that the objectives can be further defined through the methodology to achieve outcomes which are not only synonymous with the original intent of the project but build on existing knowledge within the

Engineering community. The broad aim of the project, to develop effective road pavement design standards for expansive soil subgrades in the Ipswich area, does not appear to have been covered in the past. However, some of the specific objectives to achieve this aim are well covered. It makes good sense to utilise this material as building blocks for the development of this methodology. The objectives have been reproduced below together with the chosen methodologies and justification of each.

3.2.3.1 Objective 1

Research current Australian and International information relating to road pavements on expansive soil subgrades, and in particular road pavement design, subgrade treatment methods, engineering test methods for expansive clays, and rehabilitation methods employed for deformed pavements.

Methodology – research was undertaken using the Internet (academic libraries – journals, ebooks, dissertations etc) and Ipswich City Council Engineering Services libraries (books, publications, journals, notes etc).

Justification – the Internet was easily accessible and provides access to information from around the world that is current. By using university libraries a certain degree of reliability of source is provided. The focus was on using the most up to date academic information in an effort to use current thinking and not to re-hash old methods. Whilst there is obviously merit to the older research paper and information, current research already incorporates these learnings and experiences.

3.2.3.2 Objective 2

Research geological history of Ipswich and formation of expansive clay soil deposits.

Methodology – As a first point the Internet was searched to determine the accessibility of this information. It would have been useful to search historical data from Geotechnical Professionals within the area.

Justification – The geological history provided an indication of the types of clays and their location within the Ipswich area. However, information on the formation of these clay deposits may not be necessary to achieve the aim, i.e. it was more important to know the type of clay and its properties to determine the best action. As such, the paper focused on the former part of the objective.

3.2.3.3 Objective 3

Gather soil test information for expansive clays in Ipswich. Classify the clays of the Ipswich area based on their material properties e.g. liquid limit, plastic limit, shrinkage limit, activity, potential swell, etc.

Methodology – Determination of the most appropriate properties to classify clay based on previous research. Using a variety of test methods from Australian Standard AS1289, such as -:

- Method 2.2.1 – Soil Moisture Content – total suction
- Method 3.6.3 – Soil Classification – Particle Size
- Method 3.9 – Soil Classification – Cone LL
- Method 5.4.2 – Compaction and Density – compaction control (max. Dry density and OMC)
- Method 5.8.1 – Compaction and Density – Field using Nuclear Gauge
- Methods 6.1.1 & 6.1.3 – Soil Strength and Consolidation – CBR (remolded and field)
- Methods 6.2.1 & 6.2.2 – Soil Strength and Consolidation – Shear
- Method 6.4.2 – Soil Strength and Consolidation – Compressive (saturated, undrained triaxial test)
- Methods 7.1.1, 7.1.2 & 7.1.3 – Soil Reactivity – Shrinkage Index

Other methods suggested in research were not trialled due to a lack of resources and time. All test methods were discussed with the Laboratory Manager prior to testing.

Justification – In order to determine the most appropriate subgrade treatment for a particular location it is necessary to classify the clay and recognise its properties. The potential for swell and the shear capacity of the subgrade provides a good understanding of the mitigating design parameters.

3.2.3.4 Objective 4

Carry out a survey of pavement condition for road pavements on expansive clays throughout the Ipswich area.

Methodology – This objective builds on the substantial survey of local roads completed by Crone (2009). Information was sourced from the Ipswich City Council Materials Laboratory and Council records to determine the most appropriate areas with clay subgrades where pavements have been constructed. A range of these were chosen for survey. For each road project the ESA's (where known), subgrade condition, pavement design, material specifications and current condition were recorded. In order to assess the current condition, signs of distress (cracking, bleeding, rutting etc) were observed and laboratory testing of materials condicted.

Justification – The long term performance of a pavement is a result of pavement subgrade, design, construction and service life. In order to propose viable design guidelines it is necessary to know which techniques that are currently employed are successful and which are not. Longevity of a pavement is a primary aim of a good pavement design; hence, this aspect of the project is considerably important.

3.2.3.5 Objective 5

Assess the effectiveness, in regard to world's best practice and actual performance, of current Ipswich City Council pavement design practices for both flexible and rigid pavements.

Methodology – Research into pavement performance across the world provided some indication of the design specifications that are producing greater performance. Current ICC practices were compared to these 'best practices'.

Justification - Consideration of the pavement condition survey results and past design practices will provide an understanding of performance (as indicated in objective 4). Comparing current Ipswich City Council design practices to 'best practice' requires a degree of assumption for determining what is 'best practice'.

3.2.3.6 Objective 6

Propose and evaluate improvements to the Ipswich City Council current pavement design practices.

Methodology – As a direct result from objectives 4 and 5, potential improvements were formulated. This was an analytical process that was dependent on viable data and knowledge of proven practices across the world.
Justification – This objective is the culmination of research and analysis to really respond to the main aim of the project. As explained in the introduction, Ipswich City Council is experiencing issues, not unlike other countries around the world, with pavement performance over expansive soils. As a public entity, it is in the interest of the community for the Council to use 'best practice' design to achieve longevity of pavements.

3.2.3.7 Objective 7

Present information, results and recommendations in the required written and oral formats.
Methodology – Using guidelines provided by the University of Queensland, research information and outcomes were presented in the forms of a draft dissertation, an oral presentation and a final dissertation (this paper).
Justification – This objective represents the opportunity to obtain skills and knowledge for educational purposes and to develop as a professional in the field of Engineering.

As time permits the final objectives may be achieved -:

3.2.3.8 Objective 8

Produce tables and/or graphs for pavement design in Ipswich
Methodology – tables of information were developed for determination of preliminary subgrade CBR in various streets and suburbs of Ipswich for pavement design. It was desirable to produce graphs that simplify the design process, however, software analyses had not been completed for the mechanistic design process.
Justification – To enable professionals within Council access to pavement design information in a simple format that represents current world best-practice.

3.2.3.9 Objective 9

Develop a policy for pavement design for incorporation in the Ipswich City Council Planning Scheme

Methodology –The current Planning Scheme Policy amendments were suggested to reflect the outcomes of this research. These suggestions are to be further discussed with management in both ES and P&D at ICC in an effort to update the documents.

Justification – Developers adhering to the Planning Policy would be required to design pavements that are more suited to the specific subgrades. This has a benefit to the Council, whom ultimately own and maintain these roads, and to the community.

3.3 Risk Assessment

The Risk Management Code of Practice Supplement 1 (Workplace Health and Safety Queensland 2007) aides hazard identification, providing examples of those that may be found in the workplace. These have been used as a starting point to develop the 'working' risk analysis document outlined in figure 3.1.

	Identification	Evaluation					Control	
Item	Hazard	Risk	Likelihood	Exposure	Consequence	Risk Rating	Action	Revised Rating
1	Work Environment - Uneven Surfaces	Tripping and injury	substantial	continuously	minor injury	high	wear PPE	medium
2	Energy - underground electricity	electrocution	slight	rarely	possible death	high	have services located, proceed with caution, wear PPE	medium
3	Energy - power tools	electrocution or bodily harm	significant	regularly	major injury	very high	undergo equipment training, ensure equipment is regularly tested, wear PPE	very high
4	Manual Task - lifting equipment or bags of soil	Bodily injury	significant	frequently	minor injury	high	lift with another person when heavy, lift in the appropriate manner	medium
5	Noise - Equipment in use	Hearing impairment	significant	frequently	minor injury	high	wear hearing protection	low
6	Substances - chemicals	Bodily Injury	slight	regularly	minor injury	medium	read MSDS, wear PPE and gloves/glasses	low
7	Vehicles	Struck	significant	continuously	possible death	very high	wear PPE, setout traffic control signage where required	high
8	Equipment - handling	Bodily injury	substantial	continuously	minor injury	high	undergo equipment training, wear PPE	high
9	Plant - operating nearby	struck	substantial	regularly	possible death	very high	wear PPE, make drivers aware of your presence	high
10	Hygiene - contaminated soils	Bodily injury	substantial	continuously	minor injury	high	wear gloves	medium

Figure 3.1 Risk Analysis for this research project

3.4 Resource Planning

Computer – several sources are available as required

Internet – satellite connection from home should suffice for simple searching and small downloads, special permission can be sought from Ipswich City Council (as the sponsor) to allow some access as required

USQ Website Access – current student status and login is adequate

Geological Maps – consultation with local Geologists/Geotechnical Engineers to gain information and seek maps of the area

Soil samples – after consultation with the soil laboratory manager, soil samples will be collected in accordance with Australian Standards (AS1289)

Soil testing – laboratory, material tester for guidance, equipment, and time – all of these resources are available within the Ipswich City Council, whom have granted permission for access and time as required with the Laboratory Manager. Where specific equipment required is not available, requests will be made to other laboratories. Alternatively, a request will be made to the sponsors (Ipswich City Council) via a Business Case. If all else fails, the methods will be altered to suit available equipment.

Project information - previous pavement construction within Council – by day labour and by Developers – access has been granted by Ipswich City Council to these records.

Digital camera – Ipswich City Council have made one available as required. Alternatively, a personal camera is available.

Experienced Engineers and Technical staff to discuss past and current practices – Within the Engineering Services Department and the Planning and Development Department of Ipswich City Council there is a variety of experience to draw upon.

Access to the current design manuals – The Project Delivery and Construction Services Branches (of Engineering Services of Ipswich City Council) has suitable libraries available for access at no cost.

Ipswich City Council Planning Scheme – access via the Ipswich Online website

Software – word processor, spreadsheet, MikTex, WinEdt. Personal Microsoft licences have been sought and MikTex and WinEdt downloaded for free from the Internet. These are necessary to prepare the dissertation in the appropriate format.

The critical resources for this project included access to research material for literature studies and access to a laboratory with experienced staff to provide guidance and relevant data.

4 Ipswich Geology

Ipswich City is founded upon the area known as the Ipswich Basin which developed during the mid-late Triassic period and the Tertiary period. Geological survey of the area (figure 4.1) shows several dominant rock units – the Ipswich Coal Measure, the Marburg Formation, the Booval group, an unnamed Tertiary group, the Woogaroo subgroup and flood plains/river (key in Appendix A). The Coal Measures consist predominantly of shale, conglomerate, sandstone, coal, siltstone, basalt and tuff. The Booval group consists predominantly of claystone, basalt, magnesian limestone and sandstone.

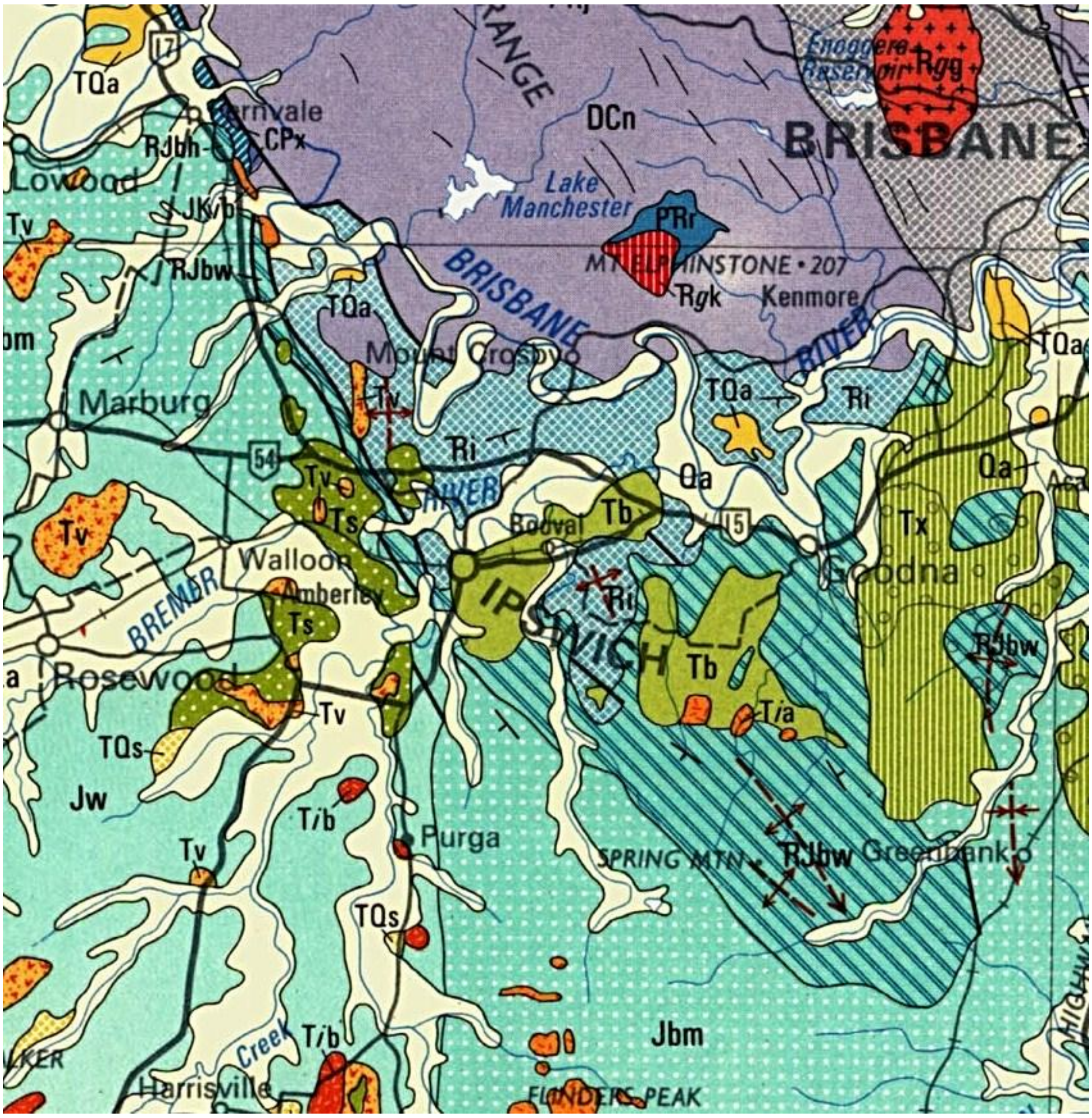
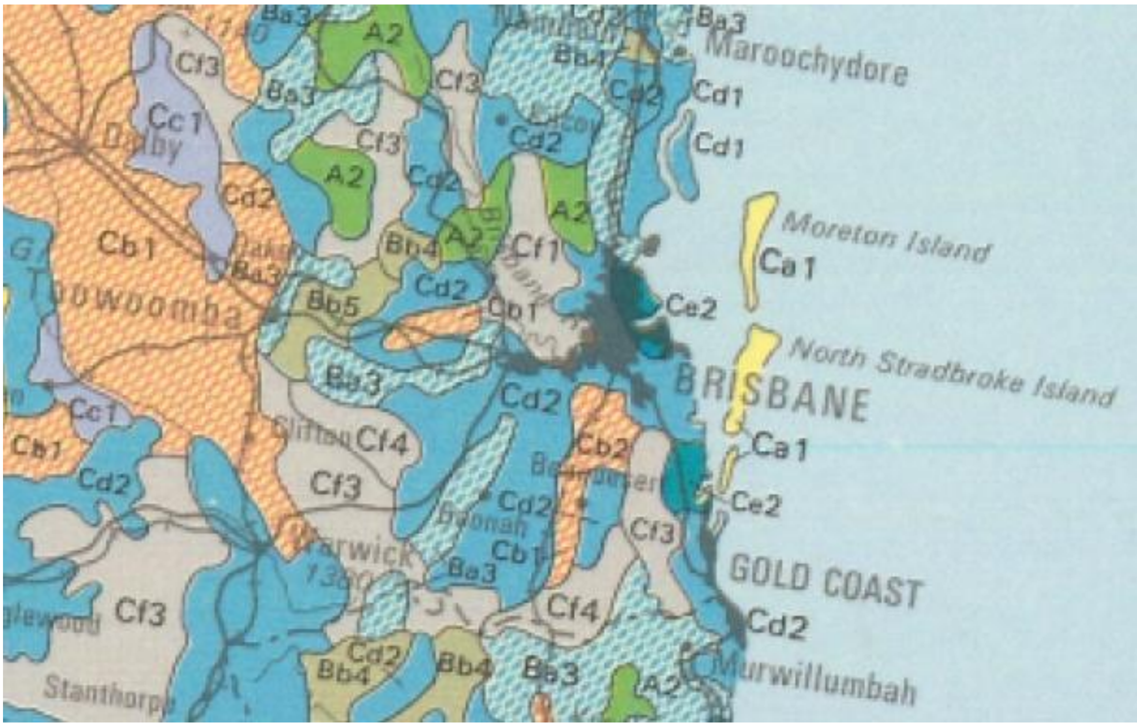


Figure 4.1 Moreton Geology Map (Geoscience 1980)

A segment of the Australia Soil Resources map (Figure 4.2) shows that Ipswich surface soils are predominantly those with physical limitations such as periodic subsurface water-logging (the blue areas) due to impermeable subsoil. A variety of test results from the Ipswich City Council laboratory classify the majority of clays encountered as CH clays (classified as per the Unified Soil Classification System). A large sample of soil test results were collected and plotted on a map of Ipswich to identify the extent of CH soils, these are discussed further on (data can be found in Appendix A). Figures 4.3 and 4.4 clearly support comments made by the ICC Laboratory Manager that Ipswich consists of mainly high plasticity clays. These clays varying in colour, yet all demonstrate high PI and LL.



Key: Cd2 – Soils with Periodic Subsurface Waterlogging
Ba3 – Deep highly structured soils with high initial fertility
Cb1 – Cracking Clays

Figure 4.2 Extract from the Australian Soil Resources Map

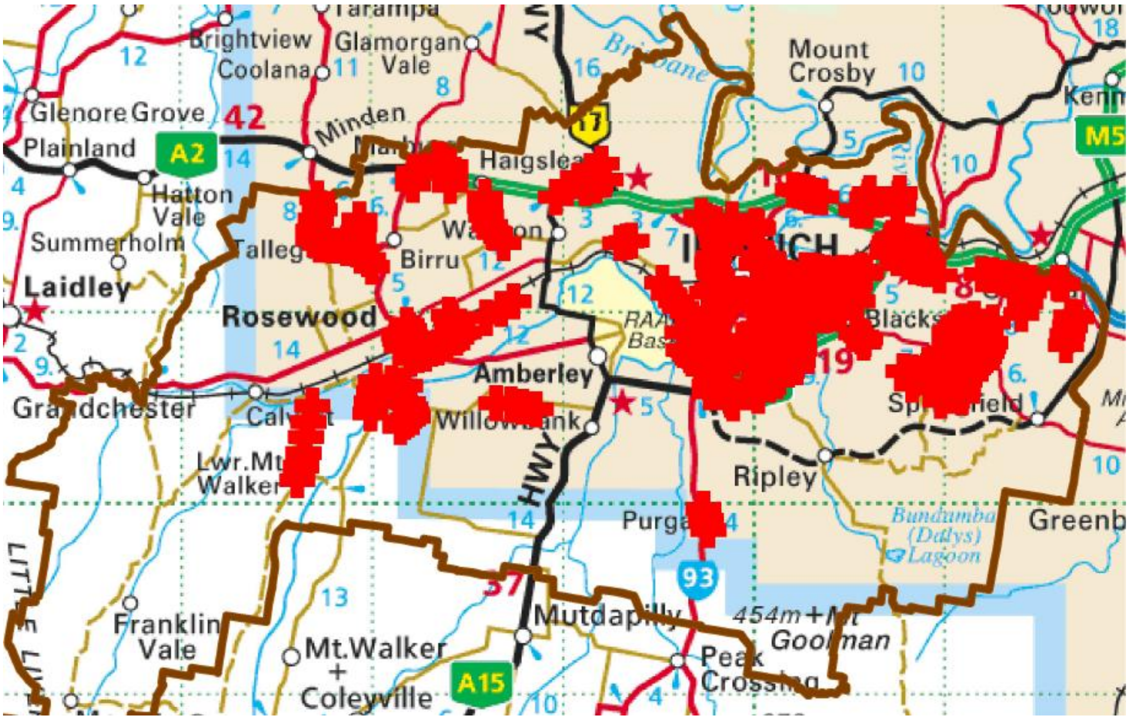


Figure 4.3 CH soil results (in red) within Ipswich (brown outlined area)

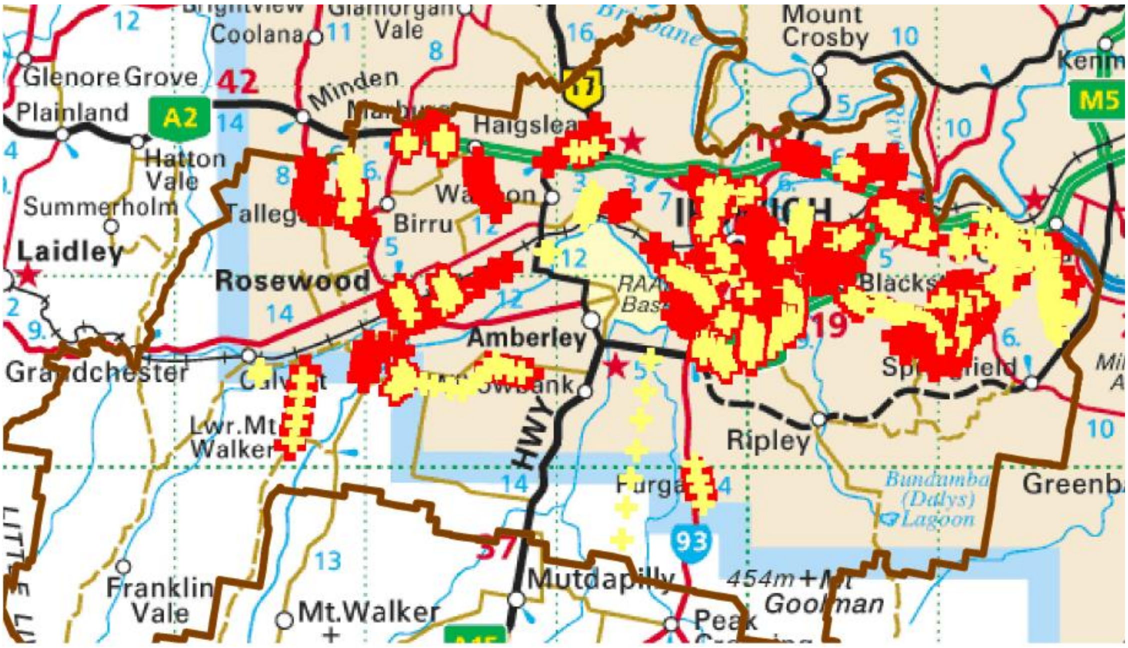


Figure 4.4 CH (red) and CI (yellow) soil results within Ipswich (brown outlined area)

Electronic records of subgrade soil test results, completed by ICC since the start of 1998, have been compiled in a spreadsheet as part of this research (Appendix B). The author of this dissertation has worked with the Laboratory on many of these projects over a period of three years to gather sufficient data to allow generalizations to be made regarding characteristics of subgrade soils in Ipswich. These records (1253 of them) include data from standard testing including moisture content of samples, CBR (in-situ, soaked, design), LL, PI, LS and soil description. Together with the Unified Soil Classification System (USCS), the subgrade soils have been classified. This data has been plotted in a variety of ways to ascertain whether there are any correlations for the Ipswich soil data. Figure 4.5 shows that there is quite a strong positive correlation (R=0.92) between the LL and PI.

West (1995) and Das (2006) describe two distinguishing lines, U-line and A-line, that fit onto the PI vs LL plot to differentiate between the cohesionless soil (above the U-line), inorganic clays (between the lines) and inorganic silts/organic silts and clays (below the A-line) (see Figure 2.1). The U-line, with equation 0.9(LL-8), and A-line, with equation 0.73(LL-20), have been included along with lines between low plasticity (LL<30) and high plasticity (LL>50) on the graph in figure 4.5. It can be seen that the majority of the data points lie within the bounds of inorganic clays with the majority medium to high plasticity, classifications ranging between CL or OL (low – medium) and CH or OH (high). The laboratory results collected identify the medium plasticity inorganics as CI, which is not a classification in the USCS. However, this naming is useful to distinguish between the low and medium plastic soils.

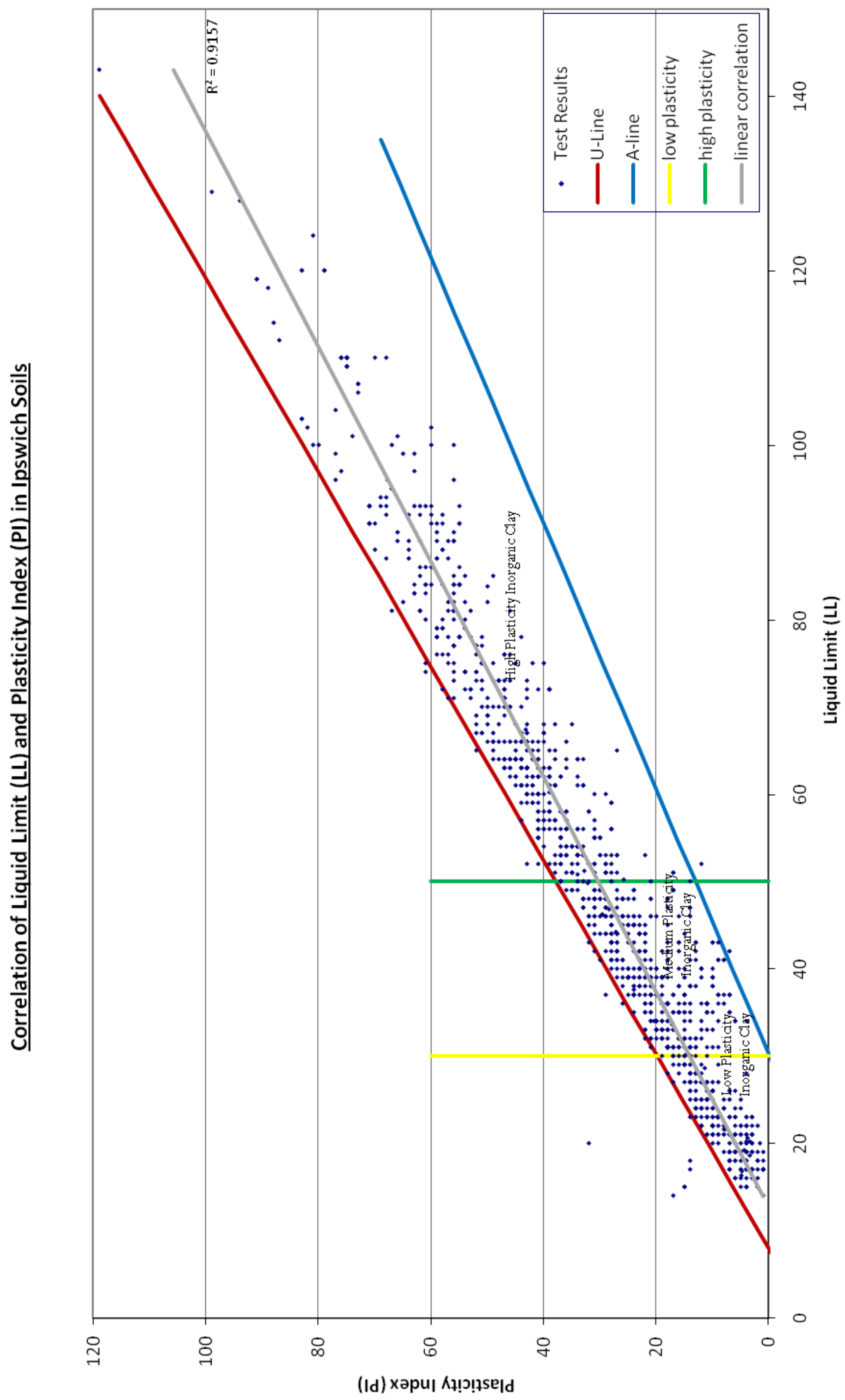


Figure 4.5 Correlation between the LL and PI for Ipswich subgrade soils

Figure 4.5 also shows that many of the samples lie along the bottom of the U-line in an area that is representative of Montmorillonite (Smectite), according to West (1995). As highlighted by Crone (2009) this mineral has a very high swelling capacity (due to fine particle size in the vicinity of 0.1 μm having a large surface area) and is considered highly active. West (1995) gives Montmorillonite a CEC of 80-150 milliequivalents per 100g of clay. This makes it one of the best soils for landfills since heavy cations can be removed from the leachate due to slower release. Das (2006) gives the following typical limit values for Montmorillonite -:

Liquid limit, LL	100 - 900	
Plastic limit, PL	50 - 100	
Activity, A	1.5 - 7.0	
Plasticity index, PI	50 - 800	(very high plasticity)
Shrinkage limit, SL	8.5 - 15	

<table>
<tr><th></th><th>LL (%)</th><th>PI (%)</th><th>LS (%)</th></tr>
<tr><td>Average Result</td><td>50</td><td>20</td><td>13</td></tr>
<tr><td>Highest Result</td><td>143</td><td>119</td><td>31</td></tr>
<tr><td>% Within Montmorillonite typical limits given by Das (2006)</td><td>3.7</td><td>4.4</td><td>-</td></tr>
<tr><td>% within Montmorillonite limits given by West (1995)</td><td colspan="2">20</td><td>-</td></tr>
</table>

Table 4.1 Data Results Summary for Liquid Limit, Plasticity Index and Linear Shrinkage

A summary of the results for the Ipswich soil tests, where LL, PI and LS were recorded, is seen in table 4.1. 43% of the samples were clearly identified as CH, with another 28% as CI-CH or CI. This gives 71% of all samples classified as medium to high plasticity. The values in table 1 do not support the idea that the majority of soils tested are Montmorillonite according to the typical values given by Das (2006). However, according to the placement of Montmorillonite on the plasticity chart (West 1995), the PI is linearly proportional to LL and a large proportion of the data points lay clearly within the given area (LL between 40-100 with corresponding PI between 20 – 80). In addition, 13% of the points lie within the Illite area (above and adjacent to the A-line). The majority of the remaining points are between these two areas within the medium to high plasticity section.

Montmorillonite (Smectite) is a three-layer clay containing considerably more substitution within the layers than other clays, in random fashion. Cations such as Ca^{2+}, Mg^{2+} and Na^{+} allow water to enter between the layers/sheets causing the swelling properties discussed herein. Montmorillonite exists only in relatively recent freshwater sedimentary layers, particularly from volcanic rocks of pyroplastic nature. It is more common in dry areas where sodium, potassium and particularly magnesium are present (West 1995). These fine-textured soils can cause the removal of subgrade and subbase material fines by pumping due to localized loads.

Figures 4.6 and 4.7 show a lesser degree of correlation between the PI - LS and the LL – LS results. In both cases, a logarithmic trend line is more suited than linear. In a dissertation by Earl (2005), it is recommended that LL, PL and percentage of clay particles should not be used to estimate swell index. In contrast, the USCS uses PI and LL to make the relevant clay classifications. Through experience over many years of testing in Ipswich, the ICC Laboratory Manager has found that the LL is the most definable property for determining the classification of clays given the equipment available for testing.

Figure 4.8 shows a graph of the estimated CBR versus the LL. It is clear that the higher the LL the greater the correlation with the estimated CBR. Since insitu CBR is a field measurement taken by DCP it would be beneficial to determine if a correlation exists with the laboratory results (estimated CBR). The Austroads (2010) manual, section 5, shows a graph with a clear correlation existing between the two results. However, Figure 4.9 shows that there is no correlation within the Ipswich data collected; hence **DCP results should not be used as indicative of design CBR**.

Reasons for this could include the variability of the subgrade material, such as grit inclusions and variability in material moisture, which could affect the reading. A very dry subgrade seems to produce higher DCP readings than the estimated or soaked CBR results. Comparison of all test results and reports show that the final design CBR is usually chosen from a combination of the three CBR values, with outliers typically excluded. DCP testing still has a place in field analysis of subgrades for identifying worst case CBR in soils that are very moist.

Given the high PI and LL correlation and the good correlation between the higher LL and estimated CBR values, it can be concluded that a subgrade exhibiting a high LL will generally have a low estimated CBR. The spreadsheet of data that has been created as part of this dissertation can be used by staff designing a pavement without any specific laboratory results. It is possible to filter the data to check a street or suburb for previous test results. An opportunity exists to build on this file by including previous pavement design information and adding all new soil test results.

From the data collected, there are clearly some suburbs within Ipswich that have soils which can generally be classified as having medium to highly plastic subgrade soils, with the most consistent suburb being Redbank Plains (Table 4.2). It is very interesting that nearly all of these suburbs also lie within the Booval group rock unit or the floodplains as seen in Figure 1.

Ipswich Suburb	
• Bellbird Park	• Flinders View
• Blackstone	• Goodna
• Booval	• Leichhardt
• Brassall	• North Ipswich
• Bundamba	• Raceview
• Calvert	• Redbank Plains
• East Ipswich	• Riverview
• Eastern Heights	• Rosewood
• Ebbw Vale	

Table 4.2 Ipswich suburbs with consistent medium to high plasticity subgrade test results

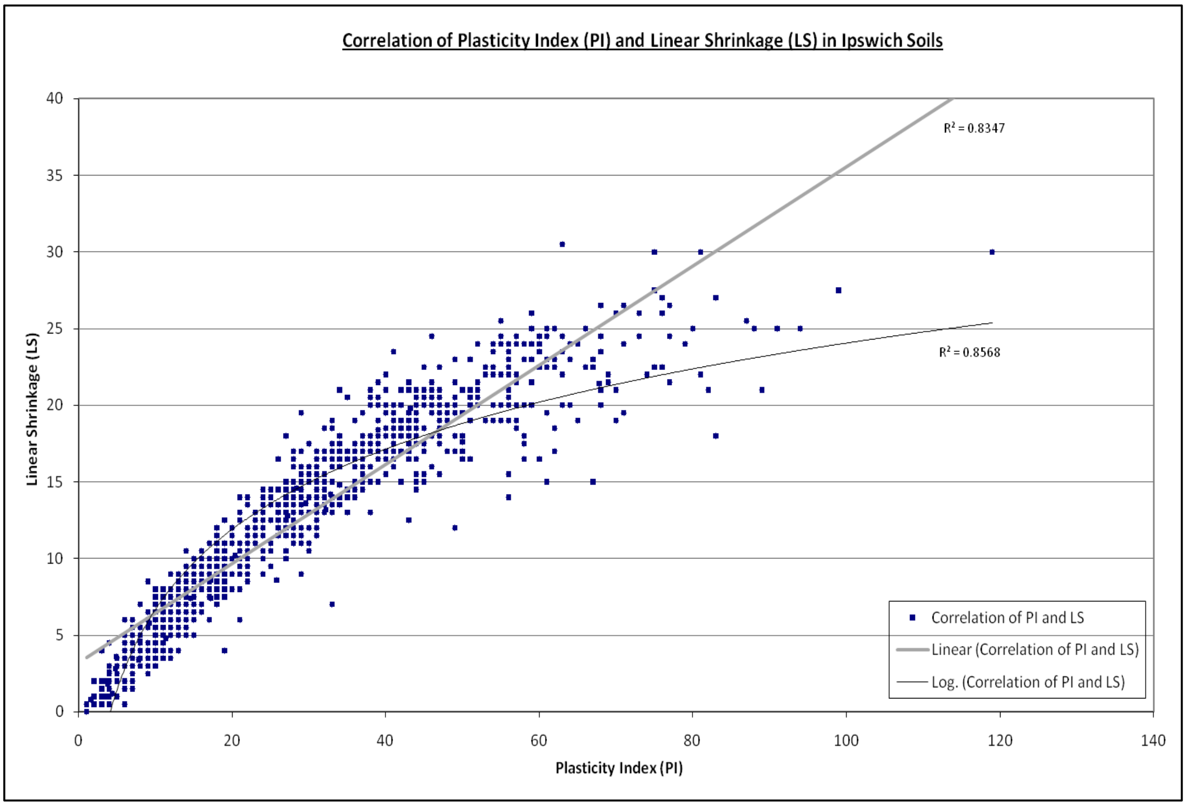


Figure 4.6 Correlation of PI and LS for Ipswich subgrade soils

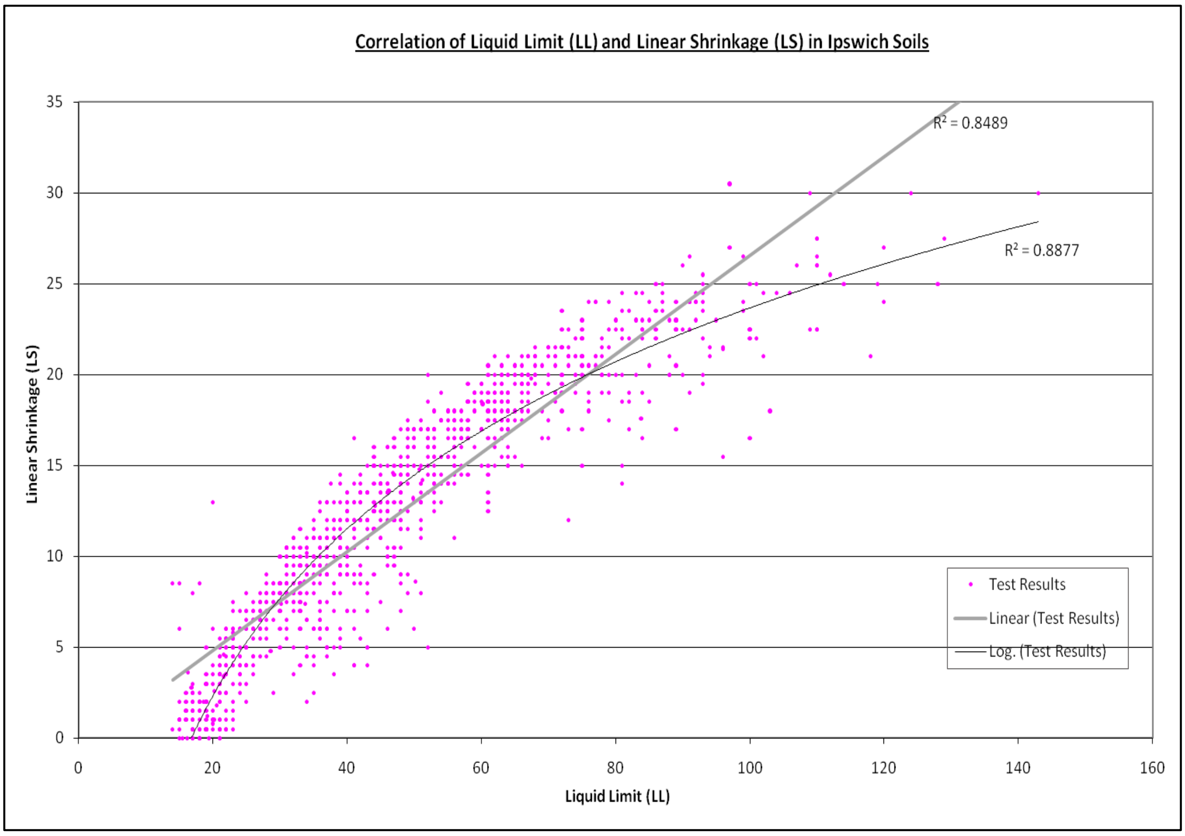


Figure 4.7 Correlation of LL and LS for Ipswich subgrade soils

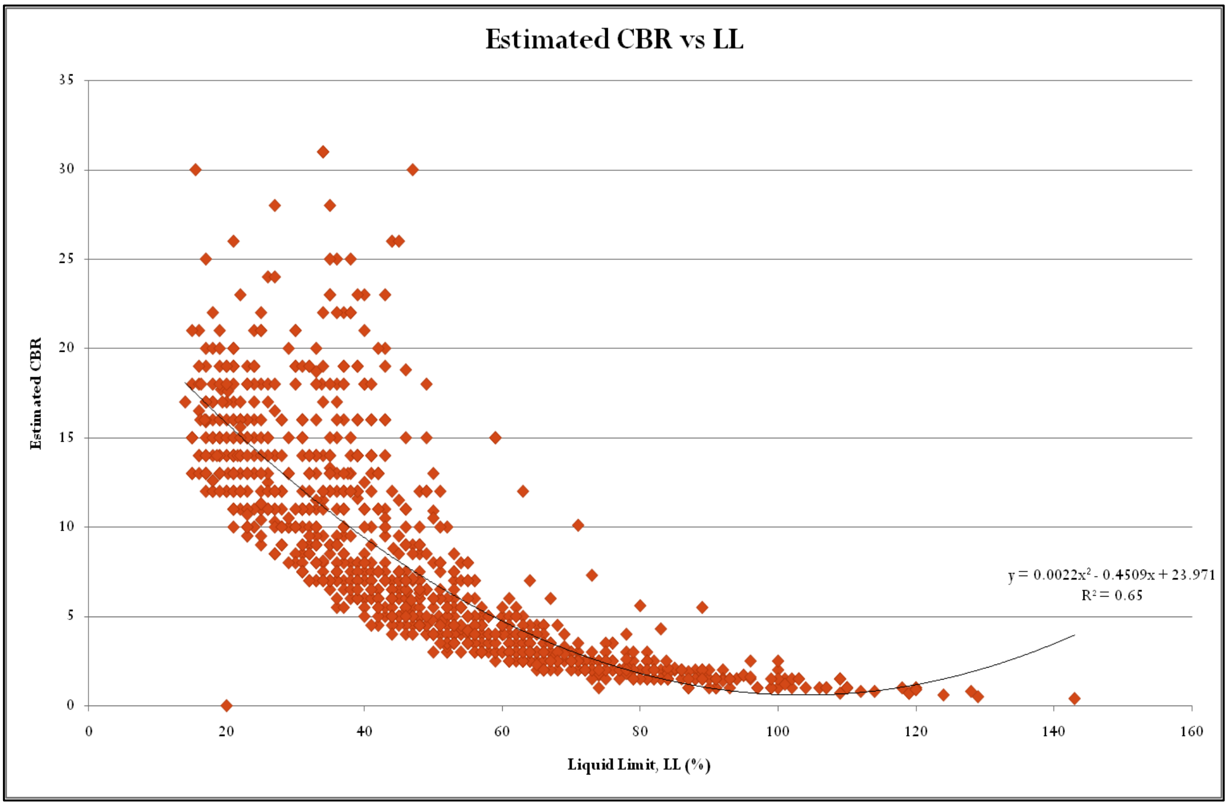


Figure 4.8 Correlation between the estimated CBR and the LL for Ipswich soils

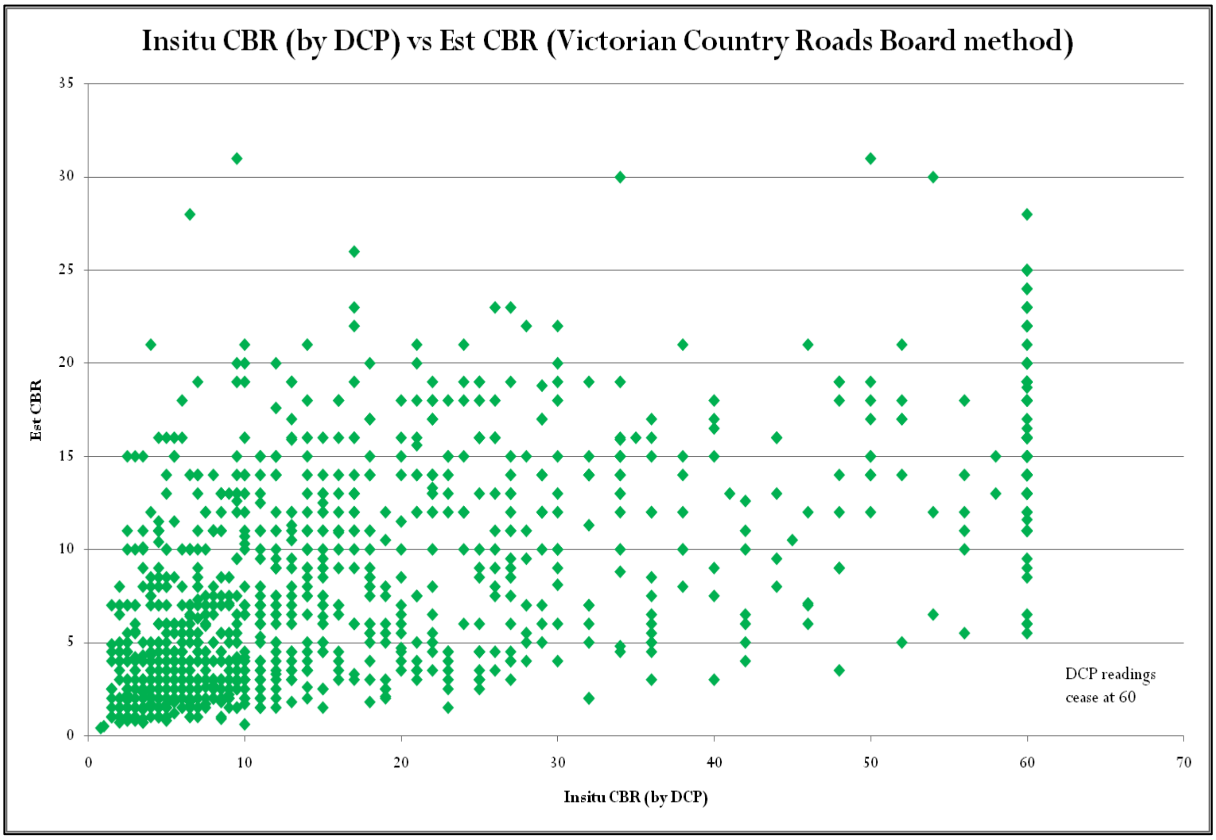


Figure 4.9 Correlation of Insitu CBR (by DCP) and Estimated CBR for Ipswich Soils

5 Pavement Survey of Local Ipswich Roads

The Rehabilitation section within Project Delivery, Engineering Services (ES) of ICC has devised a system of determining the priority of roads within the Ipswich area that require rehabilitation, known as the Pavement Management System. The survey method examines six facets of performance each scored out of five, including distortion, cracking, texture, disintegration, shoulders and appearance (as seen in Figure 5.1). These scores are factored and used within formulae to calculate a total score for each of rehabilitation and resealing. These scores are then weighted according to traffic volumes to determine the overall ranking. The roads are then programmed according to their ranking for rehabilitation in the relevant financial year.

Working with the experienced Pavement Rehabilitation Technical Officer within ES a pavement survey was completed for the strategic road network. A variety of these roads in known expansive soil areas were chosen for further examination, as presented below. Photographs were taken and geotechnical data was sourced to determine the pavement structure and condition to assist in the determination of common features that may have led to pavement failure. Figure 5.2 provides a summary of the survey for those six roads, followed by further explanation in sections 5.1 - 5.7.

PAVEMENT CONDITION						
ROAD CLASSIFICATION	Cul-de-Sac	Residential	Minor	Collector	Commercial & Industrial	Urban
IDENTIFICATION CODING	CS	RE	MI	CO	CI	UA

DISTRESS MODE	DISTRESS MANIFESTATION	PAVEMENT CONDITION FACTOR-RATING 1 Nil	2 Slight	3 Moderate	4 Severe	5 Very Severe	WEIGHTING FACTORS
CRACKING	Individual cracks	Not visibly cracked	Distinct cracks 500mm spacing (5%)	Open individual cracks, 3mm (5 - 15%)	Open individual cracks 7mm (15 - 30%)	Open individual cracks 10mm (30%)	3.0
	Crack pattern (reflection, craze, block)	Not visibly cracked	Faint pattern 500-1000mm (5%)	Crack pattern 500mm distinct pattern (5-15%)	Crack pattern 250mm distinct & slightly open joints (15-30%)	Crack pattern 150mm (30%)	
DISTORTION	Rutting, heave waves	Less than 5mm	20mm	30mm	50mm	80mm	4.0
	Riding Discomfort at speed limit	Nil. very smooth riding conditions	Occassional slight indication of road roughness	Moderate vibration through vehicle suspension	Frequent significant vibration	Extreme road user discomfort at normal travel speed	
SURFACE TEXTURE LOSS	Ravelling, stripping, peeling	No discernible loss of stone	3% of seal Area stone loss	3% to 15% of seal area, stone loss	15% to 30% of seal area stone loss	30% of seal area, stone loss	2.5
	Fatty & Slick surface	Stones well proud of binder 4mm projection	Good rough texture stone projection 3mm	Smooth appearance with stone projection 2mm	Smooth appearance with stone projection barely visible	Smooth appearance with no stone projection visible	
	Polished aggregate surface.	Stones sharp edges.	——	Stones sharp & angular-not-harsh	——	Stones rounded and smooth to touch	
DISINTEGRATION	Potholing - including repaired potholes	Nil	1 in 50m of lane length	1 per 10m of lane length	3m spacing	1.5m spacing	3.5
	Edge breaks	Nil	Width 50mm	Width 100mm	Width 200m	Width 300m	
SHOULDER EROSION	Depth below pavement	Less than 10mm	10mm - 40mm	40mm - 60mm	60mm - 100mm	100mm	3.5
APPEARANCE		Excellent appearance, visually pleasing. No obvious blemishes to discerning	Slight blemishes, but appearance pleasing.	Some obvious blemishes not pleasing or displeasing.	Major blemishes appearance suggests facility is neglected or or badly worn.	Appearance displeasant suggest facility requires replacement.	2.0

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Figure 5.1 Ipswich City Council Pavement Performance Criteria (Ipswich City Council, 1988)

					SURFACE TYPE	1/ DISTORTION	2/ CRACKING	3/ TEXTURE LOSS	4/ DISINTEGRATION	5/ SHOULDER EROSION	6/ APPEARANCE	Rehabilitation Score (1w1+2w2+3w3+4w4+6w6)	Reseal Score (2w2+3w3+4w4+6w6)	Overall Score	Traffic Vol.	Rating Score
				weighting, w		4	3	2.5	3.5	3.5	2					
	SUBURB	NAME	FROM	TO												
1	Redbank Plains	Redbank Plains Rd	Jones	Argyle	Asphalt	3	5	4	5	2	4	62.5	50.5	831	10	873
2	Carole Park	Cobalt St	Boundary	Emery	Aspahlt/Seal	4	5	4	4	2	5	65.0	49	865	8	848
3	Flinders View	Whitehill Rd	Wildey	Rockman	Asphalt	5	5	2	4	2	4	62.0	42	825	8	818
4	Eastern Heights	Robertson Rd	Kiah	Wildey	Asphalt	5	4	3	3	2	4	58.0	38	771	8	779
5	Silkstone	South Station Rd	Trumpy	Rodney	Asphalt	3	3	2	2	2	3	39.0	27	519	7	564
6	Redbank Plains	Josey St	Kerwin	no. 15	Asphalt	5	5	4	4	2	5	69.0	49	918	6	838

Geotechnical Notes					
		Visible signs of distress	**Existing Pavement**		**Subgrade CBR**
1	Arterial	rutting, depressions, potholing	20-70mm	AC	
			260-635mm	unbound	
			sandy to black clay		1 to 2
2	Subarterial	shoving, rutting, block cracking,	<10mm	Asphalt/spray seal	
		depression, crocodile cracking,	180-450mm	2% CTB	
		shrinkage cracking	up to 490mm	gravel & silt	
			clay		25
3	Trunk Collector	undulations, rutting, cracking	25mm	AC	
		(crazed, diagonal, longitudinal,	350mm	unbound	
		meandering), trench subsidence,	150mm	lime stabilised subgrade	
		potholes, patching, seal failure	CH clay - black		2
4	Subarterial	crocodile cracking, patches,	90mm	seal/AC	
		depressions, longitudinal cracking	335mm	unbound	
		in wheel paths, poor shape, high	CH clay		5
		rounded crown, high crossfalls			
5	Subarterial	loss of formation, rutting, cracking	70-90mm	AC	
		(craze, meandering, longitudinal,	180mm	unbound	
		transverse), leanmix repairs near	300mm	subrade replacement	
		centreline	CI clay		19
			CH clay		1 to 11
6	Local access	cracking (craze, meandering,	30-50mm	AC	
		longitudinal), rutting near kerb &	kerb on	leanmix	
		channel, minor deformation,		unbound	
		potholing, subsidence along	CH clay		2.5

Figure 5.2 Pavement Survey of six Ipswich Strategic Roads

5.1 Redbank Plains Road, Redbank Plains (Jones to Argyle)

Redbank Plains Road had become a major sub-arterial road connecting the older areas of Goodna and the heart of Ipswich with the relatively newer areas of Springfield (seen in Figures 5.3 and 5.4). The traffic volumes experienced on this road today are a far cry from those ever projected when the road was first constructed. Over the years there have been numerous upgrades and a variety of rehabilitation undertaken in an effort to provide for current traffic volumes. Testing of this road found that the subgrade conditions varied from being at optimum moisture (OMC) to half of OMC and from soaked CBR of 0.6 to 19. According to Austroads (2009), crocodile cracking and rutting are more indicative of structural deficiencies rather than the subgrade behaviour.

Figure 5.3 Pavement failures at Redbank Plains Rd, Redbank Plains

Figure 5.4 Severe crocodile cracking and rutting on Redbank Plains Rd, Redbank Plains

5.2 Cobalt Street, Carole Park (Boundary to Emery)

Cobalt Street lies in a heavy industrial area and consists of a 12m wide pavement, kerbed on either side. A twenty year design traffic value of approximately $7x10^6$ ESA's has been identified. Falling weight deflectometer (FWD) testing found the subgrade appears to have enough strength to resist subgrade deformation. The areas experiencing the most severe rutting and failure were found to have 90-140mm of asphalt surfacing. The areas with a thinner bitumen seal were generally moderately fatigued. Beneath the surface there was a variety of pavements including slurry seals, cement treated base, river gravel and previous polymer seals. It appears the failures are caused mostly by the traffic (a high percentage of heavy vehicles) rather than the subgrade.

5.3 Whitehill Road, Raceview

Whitehill Road is situated in a residential area, though experiences significant heavy vehicle movements as it is a trunk collector. A large portion of the road is low-lying and experiences drainage issues. The subgrade consists of black clay with a very low CBR, classified as CH. The surface consists of asphalt, varying in thickness, overlying a variety of gravel including cement treated. The ICC Laboratory Manager explains that this road had been cement treated several times in the past but the treatments have only lasted 10-15 years, after which time the concentration of lime in the pavement has diminished. As seen in figure 5.5, the pavement shows significant rutting, longitudinal cracking and crown heave and the subgrade is very moist with poor bearing strength.

The longitudinal cracks coincide with the outer wheel paths where rutting has occurred. This demonstrates a wide spread inability of the base materials and subgrade to support the loads. Austroads (2009) state that the moisture changes in an expansive subgrade manifest as longitudinal cracks usually 1 to 2m from the edge of the pavement. Asphalt fatigue has become apparent followed by moisture ingress, leading to further swell-shrink behaviour.

Figure 5.5 Longitudinal cracking and rutting on Whitehill Road, Raceview

5.4 Edward Street, Flinders View & Raceview

This sub-arterial road, crossing Whitehill Road, has been widened in the past to accommodate the increased traffic volumes. Sections of this road which contain under-pavement stormwater drainage visibly move under heavy traffic, as though resting on a water bed. The surfacing is bitumen seal down the centre (original pavement) and asphalt (over the widening) with unbound (gravel) pavement beneath. The gravel appears to be of variable quality and consisting of coalstone. The subgrade was found to be medium to high plasticity with unusually low moisture content. Visibly the road appears quite cracked and deformed with numerous patches.

5.5 Robertson Road, Eastern Heights (Kiah to Wildey)

This sub-arterial road, constructed in the 1960's, experiences traffic of approximately $2x10^6$ ESA's. In 1994 and 1995 (and some sections as recent as 2009) the surface had been overlaid with asphalt. Currently the pavement appears distorted and undulating with numerous types of cracking across the surface (seen in Figures 5.6 and 5.7). Current asphalt surfacing varies between 30mm and 180mm (deeplift) and the pavement consists of unbound materials of average thickness 295mm. The highly plastic subgrade appears to have contributed greatly to the failures observed. The pavement depths in total do not appear to be satisfactory for the given traffic volumes.

Figures 5.6 & 5.7 Robertson Road pavement failures

5.6 South Station Road, Silkstone (Trumpy to Rodney)

South Station Road is a sub-arterial road spanning several suburbs of Ipswich. The pavement has considerable cracking and loss of formation as seen in the representative section in figure 5.8. The existing pavement consists of 70-90mm of asphalt over 240-280mm of crushed soil aggregate with a soaked CBR 74. At some point there has been a fly-ash blend added to the aggregate to improve strength. The subgrade consists of CI soil overlying black CH soil. Deformation and failure appear to be due to the inadequate drainage and subgrade movement.

Figure 5.8 Crocodile cracking and kerb and channel deformation on South Station Rd

5.7 Josey St, Redbank Plains (Kerwin to no.15)

Josey Street is a local access road that has a low traffic volume servicing areas of Redbank Plains and is a bus route. The pavement as seen in Figure 5.9 was constructed in 1983 and is approximately 7.1m wide. There is layback kerb with channeling at the edges and stormwater (as seen by the manhole) down the centre of the road. The existing pavement predominantly consists of 30-45mm of asphalt surfacing over an average 210mm of poorly graded gravel with a CBR52. It appears the kerb and channel is sitting on approximately 100mm of lean-mix. The subgrade is a medium to high plasticity CH soil with an estimated CBR1 - CBR7 and a soaked CBR 2.5. There were differential moistures throughout the pavement subgrade.

The seal has failed and there is considerable longitudinal and crazing cracking and pavement distortion. It seems there is differential settlement particularly around the manhole and underground services within the pavement area. Cracks between the lean-mix concrete and the unbound pavement have allowed moisture ingress.

Figure 5.9 Josey Rd pavement condition

5.8 Comparison

In the six cases examined above, the clay subgrades were of varying strength. Those identified as CH and black clay exhibited CBR values less than 5. Two of the six appeared to have previous subgrade treatments (by way of replacement and lime stabilization) and all other pavement layers were quite variable. All of the pavements had common crown heave, wheel rutting and various types of cracking. There were really no correlations between the various pavement structures and failure modes other than the clay subgrades and in most cases the increased traffic volumes over the past 20 years.

Another interesting point is that all of these pavements demonstrated ‘old’ design and treatment methods. There has been a long running problem with the use of lean-mix and lime stabilization by ICC. In a paper written by Slect (1979), a former Engineer with Council, the issues that ICC experienced when carrying out stabilisations were discussed. These included trouble with achieving suitable clay particle size during the mixing process and the necessary experience required to carry out the stabilization processes in the correct manner. The use of lean-mix has often been undertaken without due consideration to the positioning and quality requirements of the product. To this date, ICC does not have an Inspection and Test Plan for its use. The use of lean-mix adjacent to flexible unbound pavements over a plastic subgrade causes longitudinal cracking leading to moisture ingress.

Moisture variability between differing patches of materials, such as trenches, infills, potholes and repairs, may create differential movement across the pavement when the subgrade swells and shrinks. The installation of subsoil drainage and the construction of kerb and channel on lean-mix material in urban areas may be creating differential moisture from the crown to the verge. It is common knowledge that when the waterproofing function of the surfacing fails, the pavement materials and subgrade experience distress due to infiltration of unwanted substances in turn causing further pavement variability. All of the cases examined in this survey consisted of asphalt surfacing (to a degree) overlying either unbound material or cement treated material; there were no full-depth asphalt pavements under investigation.

6 Best Practice Treatment of Expansive Subgrades

In order to name a 'best practice' method it is necessary to outline the primary objective of the treatment sought. As explained in the literature review, expansive soils undergo large volume changes causing not only difficulty in working on these surfaces but extensive damage to foundations. To treat an expansive subgrade requires control of the variables that cause undesirable behaviour, both short and long term. Historically this has been through compaction, subgrade replacement (removal of a quantity of soil and replacement with a higher strength material) and chemical treatments such as lime/cement additives. The aim of this research was to discover what methods and materials are being used successfully around the world in order to compare, and adopt where necessary, these as preferred options within Ipswich.

Current methodologies around the world are tending toward the use of geosynthetics as the most cost effective way of achieving a variety of outcomes such as material separation, filtration and drainage, a moisture barrier, reinforcement/increased bearing capacity and a working platform over expansive soils. A variety of geosynthetics are available, each with purpose specific material properties. For treatment of an expansive soil as a subgrade for road construction, the choice is dependent upon the pavement design and the intention of its use. Tutumluer and Kwon (2005) found that geotextiles and geogrids are being used extensively throughout the USA as a subgrade restraint (to increase bearing capacity) more than a base reinforcement in unbound pavements. Their research into these materials and successful uses concluded that they are beneficial for this purpose.

Qian et al (2010) conducted a study on triaxial geogrid performance on weak subgrades. They found that the triaxial geogrid provided more uniform resistance to material movement, reduced pavement displacement and vertical stresses (at the interface of the subgrade and subbase material) rather than uniaxial and biaxial grids. However, most geogrids do not provide a moisture barrier, drainage or particle separation. Geofabrics Australia produces a biaxial grid that is attached to a geofabric material backing ideal for placement within asphalt layers, as discussed in section 8.2.1.

A variety of software packages have been produced to enable the user to design a pavement that incorporates a geotextile or geogrid layer. These programs tend to create a design that has a reduced total pavement thickness. Given previous comments regarding the desirable greater pavement mass atop an expansive soil to 'weigh it down' and reduce heave, it is recommended that a geotextile or geogrid be used as an addition to the pavement design rather than a replacement of material. Should a geotextile or geogrid be used in a design as a means to minimize the pavement depth, to avoid underground services as discussed by Crone (2009), it is vital that the reduction is made in the lower subbase rather than the base course. These comments are supported by Tutumluer and Kwon (2005).

ElSharief and Mohamed (2001) have published a conference paper of a similar nature to this paper. They researched best practice from around the world in an effort to find means that would be applicable to the country of Sudan for dealing with expansive subgrades. They found that lime stabilization is still one of the most affordable and highly regarded methods to improve subgrade strength. However, it has been found that it is difficult to specify the optimal concentration required for a particular soil and to achieve the correct spread in the field. Chemical stabilizations are better suited to well-graded materials of a fine nature that allow a greater surface area for the necessary reactions to take place.

In addition to the issues already discussed for stabilization methods, ICC has found the use of lime or cement can be an environmental hazard. During application, the dust tends to become suspended in the air and settles on neighbouring property.

7 Best Practice Pavement and Rehabilitation Design for an Expansive Subgrade

As this paper focuses on pavement design on an expansive subgrade, only best practice for these will be considered here. The term 'best practice' will be defined as the process and choice of pavement design that is likely to have the greatest success on expansive soils. As explained in more detail in the literature review, expansive soils have caused many issues with pavements for as long as roads have been constructed in many countries around the world. The construction of rigid pavements has proven unsuccessful due to cracking as a result of subgrade expansion; however, flexible pavements require effective impervious base, subbase or a membrane below the surface. (Halliburton 1972)

The design of a flexible pavement can be done in various ways, including the use of well documented empirical and mechanistic methods. The older of the two, the empirical method, uses a recipe approach typically based on CBR as a performance indicator. Frost, Fleming and Rogers (2004) describe the use of the empirical method in the UK as a barrier to the use of recycled, new or marginal materials, lacking analytical analysis. The mechanistic method typically uses layered linear elastic theory to study pavement distress. Oscarrson (2010) states that the mechanistic-empirical model was recently introduced in the USA to account for material properties and field results, catering for a variety of distress modes. He carried out trials in Sweden using this new model and found that it under-predicted deformation in asphalt surfacing and permanent deformation modeling was not correctly distributed between asphalt layers.

Kwon, Tutumluer and Al-Qadi (2009) describe the mechanistic model as a means of determining pavement layer response to stress by finite element methods. Mechanistic models require local calibration and careful choice of materials and layer thickness. In contrast to Oscarrson, they found good correlation between the predicted behaviour of the mechanistic model and the observed pavement behaviour in the field. However, as the Queensland

Department of Main Roads (2009) points out, the user of such a model needs to be professional, trained, experienced and knowledgeable.

The Guide to Pavement Technology Part 2 (Austroads 2010) presents an empirical design method for unbound pavements with a thin bituminous surface (less than 40mm of asphalt) and a mechanistic model for the design of other flexible pavements. They found that the empirical approach produced similar results to that of the mechanistic approach for these flexible pavements. They also provide a set of graphs produced by the mechanistic approach for specific traffic volumes/loading, project reliability, construction/policy influences, environments, subgrade, materials and performance criteria. The mechanistic designs were produced using linear elastic models and Austroads recommend the use of software such as CIRCLY for analysis of these designs. They found critical responses for asphalt and cemented layers (the horizontal tensile strain of the bottom layer) and for the subgrade (vertical compressive strain at the top of the layer).

In order to use the mechanistic method from Austroads (2010) it is necessary to determine a variety of elastic parameters, choose subgrade strain and fatigue criterion, determine design standard axle repetitions (SAR), approximate wheel loadings, determine critical locations in the pavement to calculate strains, input these into a computer program (such as CIRCLY) to determine maximum strains, determine allowable SAR and compare with the design SAR and finally determine whether a new trial pavement is required for recalculation. The example charts given are for specific input and Austroads recommend that these are not used for thickness design.

Austroads (2010) state that the mechanistic modeling is less accurate for asphalt layers less than 40mm thick and that there is no historical data supporting a positive correlation between CIRCLY and pavement performance. Ali, Sadek and Shahrour (2009) show how a mechanistic approach can be useful to model pavement rutting (by finite-element modeling). This would improve pavement design for rehabilitation as various materials can be trialed in a virtual sense using real test data for the specific pavement to determine the anticipated behaviour of each.

Material choice for pavements is becoming a well considered issue for designers around the world. Sustainability and availability are important in the decision making process, along with proven performance and reliability. Best practice in one country may not be so in another and new materials are being trialed constantly since there is at present no truly reliable method for pavement design on expansive soils. However, much research suggests that flexible or semi-flexible pavement materials cope better with subgrade movement, particularly when reinforced with new geosynthetics materials.

Rubberised asphalt and polymer modified binders (PMB) are promising to be good performers for minimizing the effects of shrink swell behaviour and asphalt fatigue. According to Van Kirk (2000), the USA have been trialing rubberized asphalt since 1980 and have concluded that not only does the rubber assist in absorbing stress but it can improve impermeability and decrease pavement thickness. Used as a stress absorbing membrane interlayer (SAMI) prior to surfacing, it can reduce reflective cracking and is cost effective.

Other asphalt products that are proving successful include recycled asphalt with foamed bitumen, however, the process is still being developed to achieve optimum performance and mix design would need to be specific to the area. Kim and Lee (2006) state that this method has been more widely used in Europe and South Africa due to the need for environmentally friendly rehabilitation and scarcity of materials. Prasad and Prasada Raju (2009) tested the effects of reinforcing base or subbase gravels with shredded/chipped waste tyres (rubber). They found that cohesion, angle of internal friction, soaked CBR and load carrying capacity increased though there was no improvement to heave control. Given the large quantity of scrap rubber currently being wasted in Australia, there is real potential here for development of rubber recycling in pavement construction, though further testing is required.

Rehabilitation methods used within Ipswich vary for rural roads, which are typically bitumen sealed or unsealed gravel roads, and for urban roads, typically asphalt surfaced unbound pavements.

8 Effectiveness of Current Ipswich City Council Pavement Design Practices

8.1 Current Practice

Over the years, Engineers and Technical staff within the Engineering Services Department of Ipswich City Council have battled with pavement design on expansive clays. Pavement design has evolved over the years from methods not unlike the current empirical methods that exist around the world. Figures 8.1 and 8.2 shows design curves that have been used by ICC since 1979. These charts, adopted from Main Roads and Country Roads Board manual, use CBR and future traffic projections to determine the desired pavement depth. Many of the staff from this era still work for ICC and these design methods seem entrained. The new Austroads empirical chart does not vary greatly from these old charts.

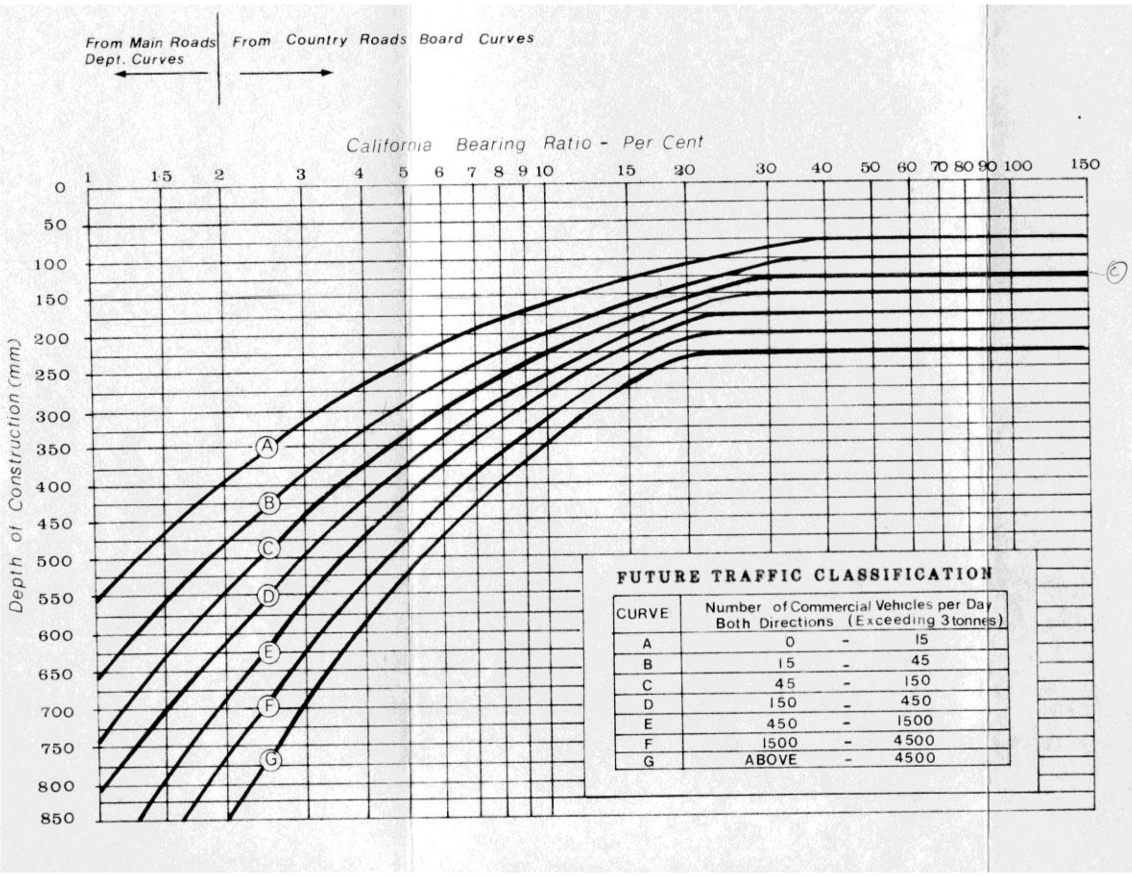


Figure 8.1 Ipswich City Council Granular Pavement Design Curves, 1979

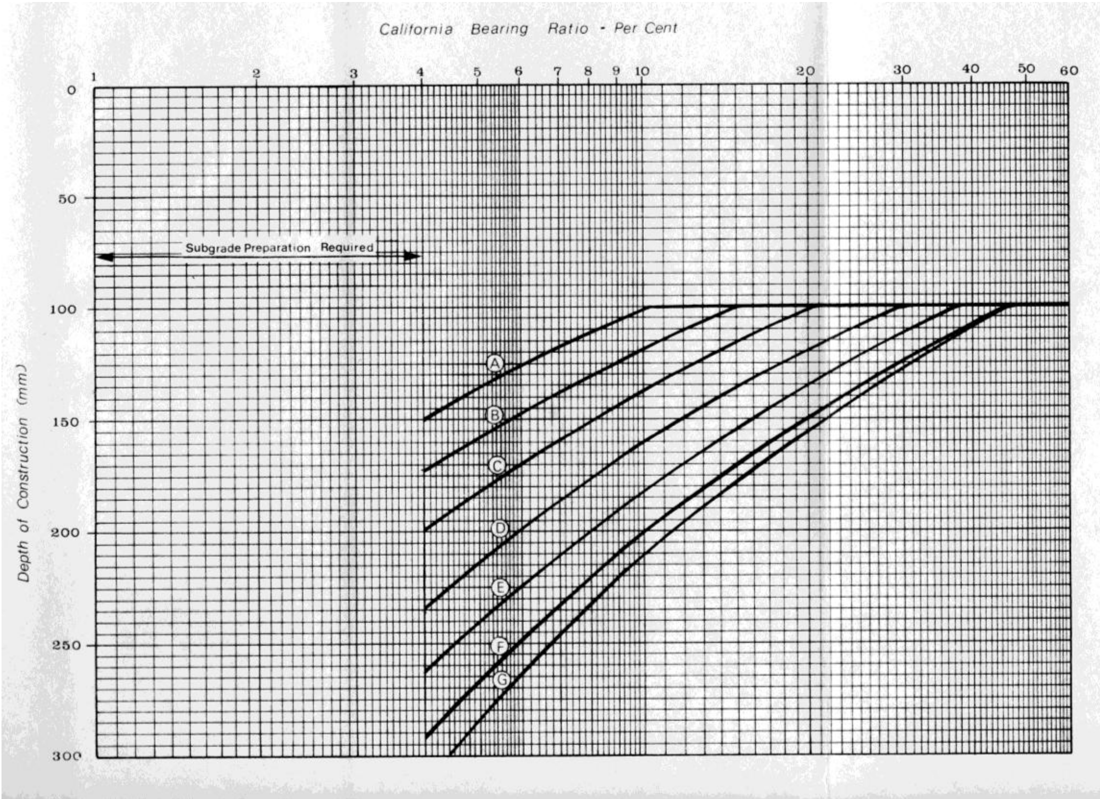


Figure 8.2 Ipswich City Council Full Depth Asphalt Design Curve, 1979

Slect (1979) makes two interesting comments about ICC practices. Firstly, lime stabilization of subgrades became practice in 1964, particularly in the city urban areas and secondly that ICC persisted with this practice due to observed improvements and limited costs compared to other treatment types. Observations of current practice and discussions with experienced technical staff prove this school of thought is still current for subgrade treatments. Whilst there appears to be interest and trials of various subgrade treatments there is a certain restraint against change.

One might ask how a subgrade treatment becomes part of pavement design process. As seen in Chapter 4, the extent of expansive soils around the city most certainly implies one will encounter a low CBR with a corresponding high liquid limit. Over time, design has come to incorporate a subgrade replacement or treatment as part of the course. Whilst this seems to be the case in ES it does not seem to be common practice nor encouraged as part of the Planning Scheme Policy, which outlines the requirements of developer-produced designs.

Design within ICC and the Planning Policy still relies heavily upon the manuals produced by AUSTROADS and the Department of Transport and Main Roads. Considerable thought has been paid to the introduction of the more modern CIRCLY methods, however, the cost of training and lack of experience in its use has been a deterrent. A small portion of staff still refer to old design manuals and personal experience for alternative designs. Typically, ICC pavement designs are flexible, unbound in nature. Recent years has seen considerably greater use of full-depth asphalt (deep-lift), particularly where traffic movements are difficult to manage. Most recently, ES have been trialing designs that incorporate geosynthetics such as biaxial and triaxial grids.

The current Planning Scheme Policy (Policy 3, Part 1, Division 2) outlines flexible pavement design considerations to be used in conjunction with the manuals previously mentioned for sub-arterial and arterial roads. Figure 8.3, a copy of Table 1.2.2 from the Policy, shows how the design ESA value is to be determined for use in the table reproduced in Figure 8.4. ES have experienced difficulties with this method of ESA determination and find that specific traffic counts and projections tend to produce much higher values, in extreme cases as much as 10 times more for arterial roads.

Description	Road Class	ESA's
Access Place	A (30 Lots Max.)	5×10^4
Access Street	A1(75 Lots Max.)	1.0×10^5
Collector	B (300 Lots Max.)	2.0×10^5
Trunk Collector	C (1000 lots Max.)	1.0×10^6
Sub-Arterial	D	2.0×10^6
Industrial	E	7.0×10^6
Arterial	F	DMR Design Standards

Figure 8.3 Design ESA's by Road Class, Table 1.2.2 from the Planning Scheme (Ipswich City Council 2006)

The policy also stipulates the minimum total pavement thickness according to the CBR of the subgrade and the road class/ESA's. Table 1.2.3 of the Policy, reproduced in figure 8.4, shows that minimum gravel course thicknesses are also given. This table is derived from an ARRB special report and the Department of Transport Pavement Design Manual (1990). A comparison of these values with Austroads has been conducted to determine if the Policy reflects Australian Standards, graphs seen in Figure 8.5.

Minimum Total Pavement Thickness (mm) (excluding AC Surfacing)							
CBR of Subgrade	**A**	**A1**	**B**	**C**	**D**	**E**	**F-Refer all Type F Roads to DMR**
1 and 2	Refer to section 1.2.4(1)(b)						
3	450	470	495	550	560	670	
4	375	395	420	465	520	620	
5	325	340	360	390	480	580	
6	290	310	325	350	450	550	
7	265	280	295	320	425	520	
8	240	255	265	295	400	500	
9	225	230	245	275	380	480	
10	225	225	225	255	365	465	
12	225	225	225	225	325	430	
14	225	225	225	225	305	400	
16	225	225	225	225	290	375	
18	225	225	225	225	275	355	
20	225	225	225	225	275	335	
Minimum Course Thickness							
Asphalt	25	25	25	50	50	50	
Base Course Type 2.1 (Min CBR80)	125	125	125	125	125	125	
Upper Sub Base Type 2.3 (Min CBR45)	100	100	100	100	150	150	
Lower Sub Base Type 2.5 (Min CBR15))	As required to obtain minimum thickness (100mm minimum layer thickness)						

Source: A, A1, B, C type ARRB Special Report No. 41 - Figure 7 / D, E, F type Queensland Department of Main Roads Pavement Design Chart 1.

Notes for Table 1.2.3—

(1) This table has been derived from ARRB Special Report No. 41, Figure 7 and Department of Transport Pavement Design Manual 1990, Design Chart 1.

(2) To cater for the difference in the mechanisms of pavement failure, Class A, A1, B and C road pavement designs are based on ARRB curves and Class D and E road pavement designs are based on Department of Transport curves.

(3) All Class F roads are to be designed to DMR standards.

(4) CBR is the 4 day soaked CBR value.

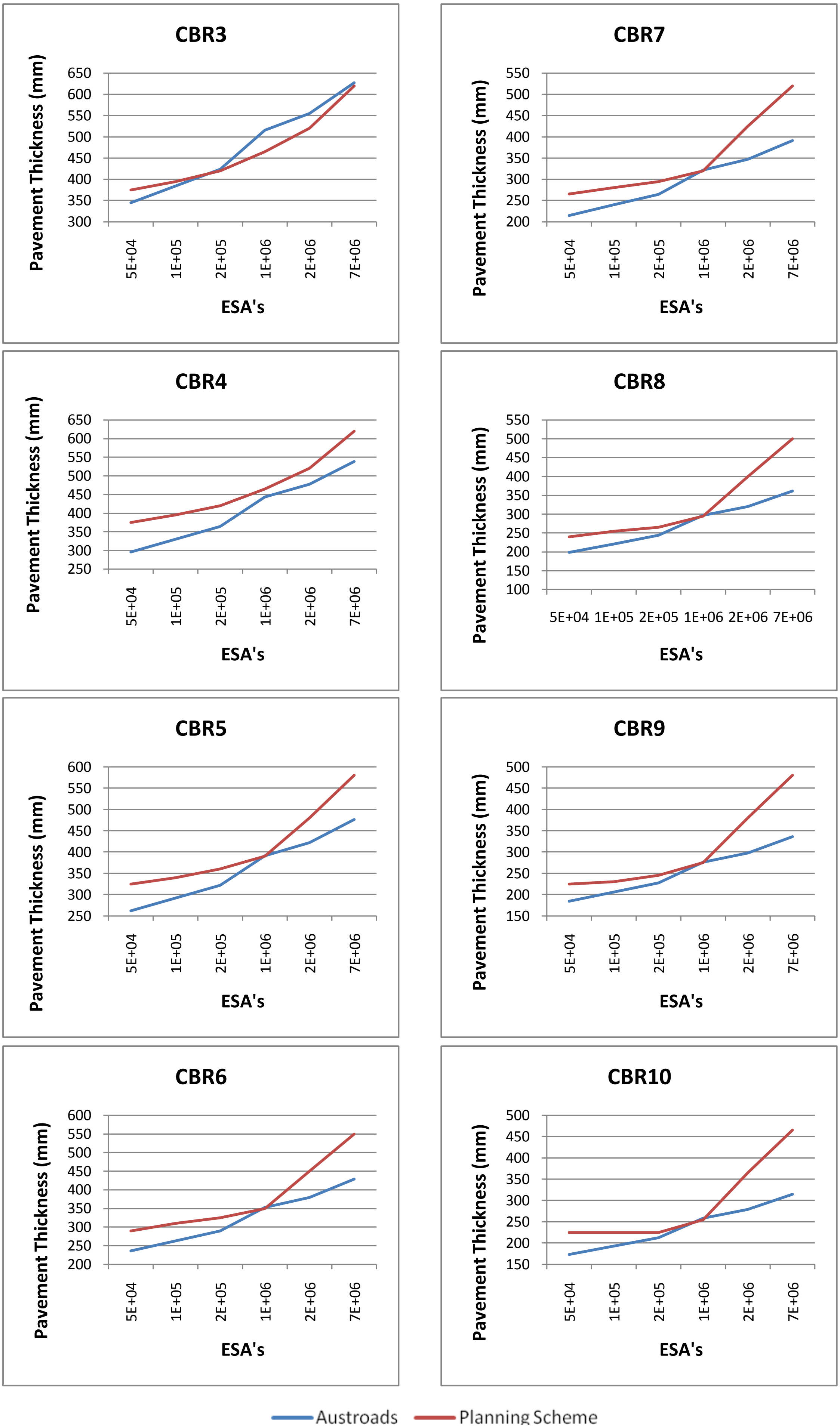
(5) If upper sub-base course minimum thickness cannot be achieved, then base course material is to be used for full pavement depth.

(6) Kerb and Channel shall be in accordance with section 1.1.11.

(7) The above pavement thickness are gravel thicknesses only.

(8) AC surfacing thickness is to be added to the gravel thickness to determine the total box depth.

Figure 8.4 Minimum Pavement Thickness - Table 1.2.3 from the Planning Scheme Policy (Ipswich City Council 2006)


CBR3
Pavement Thickness (mm)
650
600
550
500
450
400
350
300
5E+04
1E+05
2E+05
1E+06
2E+06
7E+06
ESA's
CBR7
Pavement Thickness (mm)
550
500
450
400
350
300
250
200
5E+04
1E+05
2E+05
1E+06
2E+06
7E+06
ESA's
CBR4
Pavement Thickness (mm)
650
600
550
500
450
400
350
300
250
5E+04
1E+05
2E+05
1E+06
2E+06
7E+06
ESA's
CBR8
Pavement Thickness (mm)
550
500
450
400
350
300
250
200
150
100
5E+04 1E+05 2E+05 1E+06 2E+06 7E+06
ESA's
CBR5
Pavement Thickness (mm)
600
550
500
450
400
350
300
250
5E+04
1E+05
2E+05
1E+06
2E+06
7E+06
ESA's
CBR9
Pavement Thickness (mm)
500
450
400
350
300
250
200
150
5E+04
1E+05
2E+05
1E+06
2E+06
7E+06
ESA's
CBR6
Pavement Thickness (mm)
600
550
500
450
400
350
300
250
200
5E+04
1E+05
2E+05
1E+06
2E+06
7E+06
ESA's
CBR10
Pavement Thickness (mm)
500
450
400
350
300
250
200
150
5E+04
1E+05
2E+05
1E+06
2E+06
7E+06
ESA's
Austroads
Planning Scheme

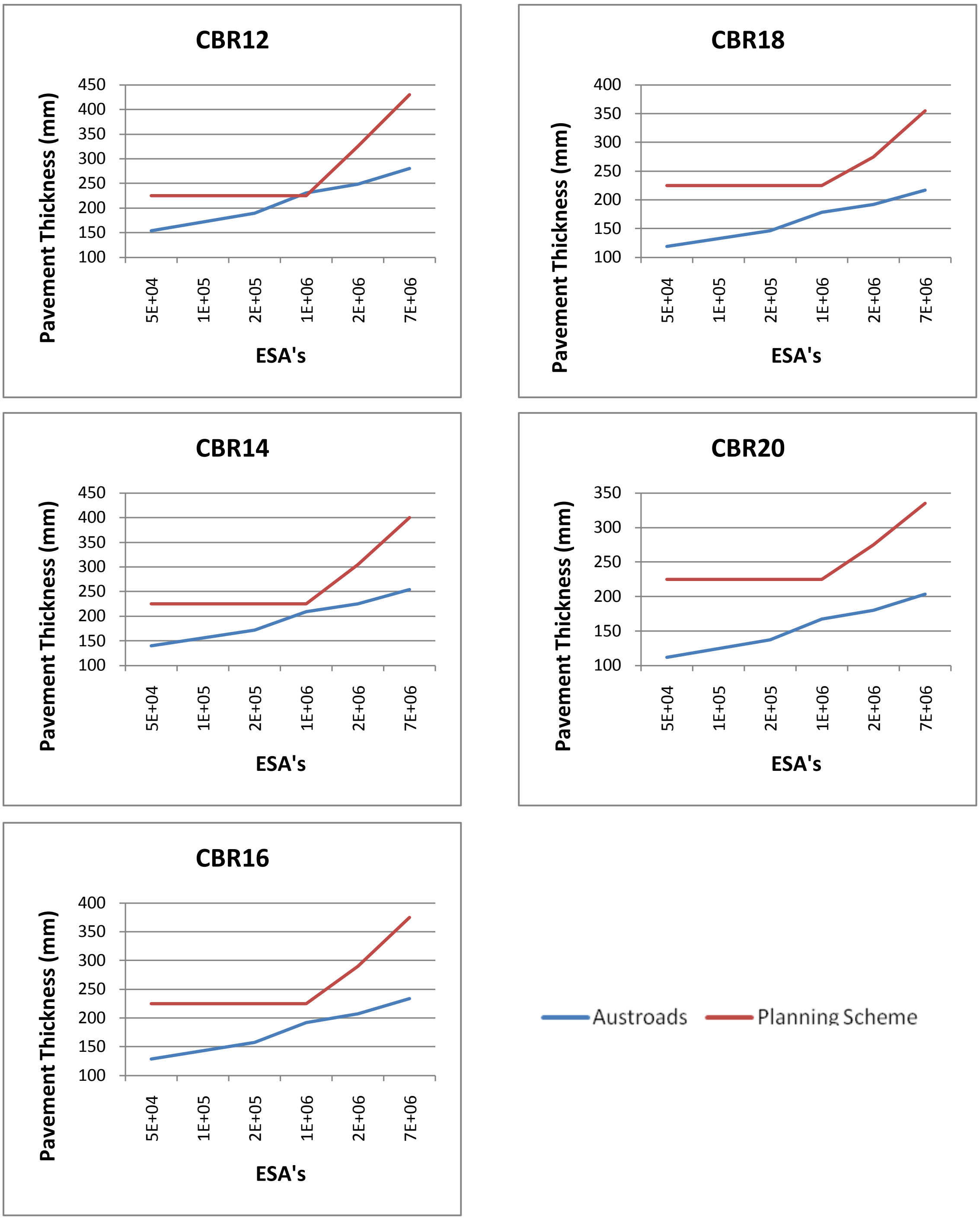


Figure 8.5 Comparison graphs of minimum thickness for flexible pavements between the Ipswich City Council Planning Scheme Policy 3 and the Austroads Guide to Pavement Technology

Comparisons show that the Planning Scheme underestimates the unbound minimum pavement thickness for CBR3; however, progressively over states the thickness as the CBR approaches 20.

With regard to subgrade, the policy stipulates that the Developers must determine the subgrade strength by testing the CBR. Where less than five samples are tested the lower value is to be assumed, else the tenth percentile value is to be used. The samples must be taken from the outer wheel paths and all results, together with pavement designs, are to be submitted for approval prior to a subgrade inspection.

The Policy explains the determination of a working platform as one which shows no visible signs of deformation under a proof-roll by a fully loaded water truck, to be jointly inspected by ICC. For subgrades exhibiting a CBR less than 3 with adequate strength for construction (i.e. suitable working platform), subgrade replacement depths are given. Should the subgrade CBR be less than 3 and prove inadequate to support construction machinery (this being the case for typical expansive soils), three options are given -:

- A replacement of a minimum of 300mm with CBR 15 material,
- Use of geofabric sheeting, or
- Cement or lime stabilization.

The following compaction and testing methods are stipulated by the Policy -:

- Subgrade/replacement - 100% by standard maximum dry density (MDD)
- Unbound courses – 95% by modified maximum dry density (MMDD)

The current Laboratory Manager believes that the modified testing does not provide a better outcome to standard testing and that Council should aim to achieve the Australian Standards (AS1289.0-2000), rather than Main Roads standards which are more laborious and seem to provide no benefit for the extra time and cost. Council is still required to achieve Main Roads standards for works that are carried out on state controlled roads.

8.2 Recent Trials of Alternative Pavement Designs

Following the paper presented by Crone (2009) and the subsequent recommendations for the use of alternative pavements, Council began to incorporate geogrids as a means of minimizing the pavement depth required over poor subgrades. Sections 8.2.1 and 8.2.2 give brief details of two recent trials conducted by the author of this dissertation over the past year.

8.2.1 Redbank Plains Rd, New Chum

During the construction and realignment of this arterial road problems were encountered with achieving the designed box depth. This was due to the natural material being a mix of very hard rock with pockets of weathered sandstone and shale. The rock caused extensive delays to construction and it was found that as the designed subgrade level neared, the desired levels could not be achieved without significant plucking of very large sandstone boulders/blocks. Soil testing proved the rock to have extremely varied CBR results, with the lowest around CBR 12. The original pavement design was for a CBR10 subgrade with a depth of 575mm, consisting of -:

50mm	DG14 asphalt
125mm	DG40 asphalt
125mm	Type 2.1 gravel
150mm	Type 2.2 gravel
125mm	Type 2.4 gravel

In order to avoid further delays the pavement design was revised to minimize the depth. It was ultimately found that the only way this could be done to maintain the structural integrity required for the future traffic counts, was by combining a Tensar Geogrid with a full-depth asphalt pavement. A program supplied by Geofabrics Australia, Tensar Pave, was used to determine the depth required. The new pavement design was reduced to 300mm -:

50mm	DG14 asphalt
85mm	DG28 asphalt

	Tensar ARG
85mm	DG28 asphalt
80mm	DG28 asphalt

Construction problems continued and the damage caused by plant to the subgrade/box (plucking of large sandstone rocks) required correction to provide a level working platform for the asphalt to be laid. The chosen Tensar ARG asphalt reinforcement grid (as seen in figure 8.6), consisting of a grid attached to a heat stabilized fabric, was incorporated within the asphalt layers. Due to the shape of the roundabout, the straight rolls of geogrid required many cuts and overlaps to round the corners. Construction staff found it extremely difficult to keep the grid in place whilst the asphalt paver maneuvered over the top. The grid was laid on a tack coat and pinned to the subbase layer of asphalt. However, as the paver moved forward on the grid it caused a ripple and the tack and pins could not hold the grid in place. After much frustration the asphalt was placed and the result was acceptable.

This section of road has been open to traffic since February 2010 and will be monitored for performance over the coming years. The need to cut and overlap the fabric may limit the effectiveness of the geofabric in resisting movement.

Figure 8.6 Rippling affect during placement of the Tensar ARG Asphalt Reinforcement Grid

8.2.2 Intersection of Edwards St/Whitehill Rd, Raceview

The area of Raceview and Flinders View is well known as one of the worst black soil areas in Ipswich (see Figure 8.7). The road in question has been rebuilt several times since opening and many older experienced staff had been involved in these works. During the design process for this Blackspot funded intersection upgrade, testing and previous experiences indicated that the subgrade would be poor (seen by current pavement performance) and consequently the pavement design was based on a CBR 1. Other construction issues were considered such as service locations and the expected increase in ESA's due to future development. This stage of construction was the first of two for the ultimate design. The future traffic alignment and potential rework requirements were taken into account.

Figure 8.7 Blacksoil on Whitehill Rd

Three different pavement types were chosen for various sections of the project and for various reasons. Design was based on AUSTROADS and the Tensar Pave program, the resulting pavements specified-:

Pavement 1 (current west bound lane that will ultimately become a service road on the southern side)

50mm	DG14 asphalt
140mm	Type 2.2 gravel
125mm	Type 2.4 gravel
125mm	Type 2.4 gravel
180mm	Type 2.5 gravel

Pavement 2 (east bound lane that will ultimately become the west bound lane on the northern side)

50mm	DG14 asphalt
140mm	Type 2.2 gravel
125mm	Type 2.4 gravel
125mm	Type 2.4 gravel
180mm	Type 2.5 gravel
	Tensar TriAx Geogrid

Pavement 3 (the intersection containing many shallow underground services including a high pressure gas main, optic fibre, water mains and sewerage)

50mm	DG14 asphalt
90mm	DG28 asphalt
90mm	DG28 asphalt
200mm	Type 2.5 gravel

During construction the subgrade was found to behave exactly as predicted, with proof rolls failing throughout the intersection area, as seen in Figures 8.8 and 8.9. A few days following the proof roll an unfortunate water main break on southern corner (near the pole seen in Figure 8.6) flooded the subgrade. This made it very difficult to control the moisture content of the soils and construction was limited due to the gas main, which was more shallow than expected.

Figure 8.8 Results of a proof roll on the southern side of the intersection of Edwards St and Whitehill Rd, Flindersview

Figure 8.9 Subgrade surface following a proof roll with a laden water truck

In order to provide a working platform for the pavement construction it was decided that a layer of Bidim geofabric would be placed under Pavement 3 on the subgrade, as seen in Figure 8.10. Compaction was achieved on the subbase layer of gravel, however, movement was still seen during rolling. Asphalt placement demonstrated little or no movement and pavement construction was completed with a certain degree of satisfaction. ICC have planned to construct stage 2 of these works over the coming 5-10 years, this will provide an opportunity to observe the performance of each pavement type and the particular geofabrics that have been used.

Figure 8.10 Placement of a geofabric on the clay subgrade to provide a working platform

8.3 Comparison to World Best Practice

In order to compare current ICC practice to world best practice it is necessary to first determine what the world best practice for pavement design is. This is clearly subjective and depends on the values that the designer or organization holds. For example, designers in developing countries aim to achieve the most economical pavement using local resources. Traffic volumes and vehicle types may be very different from those of developed countries and environmental conditions may govern subgrade behaviour. Given these differences, it has been decided that best practice in this sense will be determined by the success of pavement performance in countries that have the most similar soils, environmental conditions and traffic characteristics.

There are two areas of pavement design and construction within ICC that need to be considered, those done by ICC and those done by Developers in accordance with ICC Policy. Experience with roads, which have been designed and built by both parties, has made apparent two major differences. Developers tend to design and construct to the minimum standards which are imposed upon them, outlined in the Ipswich Planning Scheme. Council itself tends to design and construct based on a combination of Austroads or Main Roads charts and experience. Either way it is necessary to compare the materials and design methods that are employed to those which can be considered best practice.

8.3.1 Materials

The Ipswich Planning Scheme (Ipswich City Council 2006) Policy 3, Part 1, Division 1 outlines the design standards for arterial/sub-arterial roads as per Austroads/Main Roads and for all other local roads in accordance with Queensland Streets (recently re-titled 'Complete Streets: Guidelines for Urban Street Design' by IPWEAQ), which does not specify pavement design procedures. The Policy does not limit the choice of pavement, rigid or flexible, nor highlight the local geological properties of Ipswich subsoils. All research indicates that rigid pavements would crack due to subgrade heave and that some form of flexible pavement is the preferred option for expansive soils.

There is a long history of lime and cement stabilization in Ipswich for both subgrade and pavement materials. There is also a history of longitudinal cracking coincidental with changes in pavement materials from rigid to flexible. Cement and lime stabilization are still widely employed around the world, however, due to the issues discussed in previous sections alternative restraints are being developed and trialled. Over the past few years the Council has begun to trial these alternatives including new geosynthetics materials and alternative stabilization and base materials such as foamed bitumen. So far these have proved successful, though time will tell.

The common practice of designing unbound pavements within Council still exists, though there has been a move toward full-depth asphalt (deeplift), particularly in intersections, where services are shallow and when traffic movements are restricted. These too have performed well and do not appear to be requiring maintenance at this early stage (longer term performance requires monitoring).

Unbound pavements designed by Engineering Services within the Council, as per the Austroads and Main Roads charts, typically specify type 2 gravels. This has not always been the case, as seen in the testing conducted as part of the pavement survey. Various compositions of soil aggregates were common practice until Council began specifying the standards required. Gravel choice is limited to locally available basaltic origin which conforms to given Main Roads specifications. Quality varies between quarries and often there are concerns with low plasticity levels. Local quarries do not always produce all five type 2 gravels (i.e. 2.1, 2.2, 2.3, 2.4 and 2.5) so often next higher standard available is delivered.

Typical Council surfacing on urban roads varies from 40-50mm of DG14 asphalt and is rarely less than 40mm as per the guidelines for the charts used. The choice of asphalt type has become a topic of debate. Council rarely deviates from dense graded and only recently began using various sizes including DG 20 and DG28 for deep lift and DG10 as a corrector. Cold-mix asphalt is commonly used for pot-hole repairs though performance seems poor.

Of recent years Council has trialed recycling asphalt by way of reusing it as a lower subbase layer and by foam stabilizing the pulverized asphalt for reuse. Current research shows sustainability is becoming a major factor in the development of ‘new’ methods and material use. There is not enough data yet available on the performance of such methods though continued trialing provides the opportunity to learn of new ways to be sustainable.

8.3.2 Method of Design

There is clearly a lean toward the use of mechanistic design in developed countries where access to suitable strain determining programs is available. The ‘old’ empirical design charts leave no opportunity to use new or recycled materials as they specify particular granular materials for flexible pavement design. The empirical approach still plays a role in pavement design for standard unbound pavements with thin asphalt surfacing and provides a faster, easier choice of design.

The new Austroads (2010) manual appears to be representative of current world best practice for methodical pavement design. It takes into account a variety of materials and construction methods. In addition, the Main Roads (2009) manual extends on the Austroads basics to provide more specific data for Queensland conditions.

As has previously discussed, it is best to use traffic counts and projected growth to determine design ESA’s. Austroads (2010) suggest that for green field sites, actual counts from nearby roads of a similar nature, factored to account for the increase in traffic due to the development, should be used to determine the standard axle repetitions (SAR’s) or design equivalent standard axles (DESA’s). In the Austroads section on Lightly Trafficked Pavements, a similar table has been reproduced, however, the figures for some road types are higher than those given in the Ipswich Planning Scheme, e.g. Collector – Ipswich Planning Scheme gives $2x10^5$ and Austroads gives $1x10^5$ (no buses) and $8x10^5$ (buses).

SAR is determined from the load magnitude on the axle group, the standard load for the axle group and a load damage exponent for the damage type. The DESA's are determined from the ESA's, the cumulative number of heavy vehicle axle group (HVAG) and the design traffic (N_{DT}). Austroads (2010) warns that shear forces and load transfer are not accounted for in the design traffic section of the design manual. However, they suggest the effect of load transfer on roundabouts can be accounted for by increasing the anticipated vehicle loads by up to 30% in some cases.

Table 1.2.3 of the Ipswich Planning Scheme Policy 3 Part 1, provides the designer with a minimum pavement thickness for flexible pavements based on the design ESA's. The values in this table are higher than those given in the empirical design graph by Austroads (2010). The table refers users to a section on how to determine the pavement thickness for CBR 1 and 2 subgrades. It further outlines the requirements for those with 'sufficient' strength and those that cannot support a loaded water cart without deformation. Specified subgrade replacement thicknesses are given and a choice of three subgrade treatments. These stringent specifications do not give the designer the option to use a mechanistic approach where alternative treatments may be possible.

Austroads (2010), section on Lightly Trafficked Pavements, clearly states that there is a great risk of environmentally-induced distress prior to load-induced fatigue on pavements with DESA's 10^3 to 10^5. Given the reduced flexible pavement thickness specified in the empirical tables, upheaval is more likely than those pavements designed for greater DESA's. It is vital that the subgrade treatment and drainage are considered very important in these cases.

8.4 Potential Improvements to Practice

8.4.1 Subgrade Testing

- Consider the need to refine test practices such as the choice of Australian Standards or Main Roads test methods to suit Council requirements.
- Maintain a spreadsheet or database of soil test results to allow subgrade CBR to be pre-determined prior to actual test results becoming available.
- Use DCP testing to check worst case CBR in the field only, not for pavement design purposes unless a good correlation can be proven with both soaked and insitu CBR results.

8.4.2 Subgrade Design

- Develop a register of consistently medium to high plasticity soil suburbs and invoke a mandatory CBR3 for pre-construction design and planning with subgrade treatment a consideration.
- The incorporation of Geofabrics at subgrade level should be encouraged where a working platform is not adequate and services are shallow. Further trials of various geosynthetics should be conducted to determine best practice for Ipswich.
- The method for lime stabilisation should be refined and the environmental and health effects further studied.

8.4.3 Pavement Design

- Projected traffic counts should be utilised where possible rather than road classification based on potentially old information.
- The 'heaviest' pavement allowable should be chosen to resist heave, this generally corresponds with the deepest/thickest unbound pavement.
- Unbound pavements - the latest Austroads (2010) empirical charts should with the DTMR Queensland specific design information.
- Other pavements – key pavement design staff should be trained in the use of current pavement design software such as CIRCLY and Council

should trial or purchase software to enable the production a set of graphs through mechanistic methods specific to Ipswich conditions. These graphs could be implemented in an empirical fashion for 'common' pavement situations in Ipswich to be designed in a shorter time frame.

- Avoid the use of rigid pavement materials adjacent to flexible materials where possible. This may require road widening design to be wider than the minimum necessary for constructability.

8.4.4 Rehabilitation

- Review the pavement management system to ensure sealing maintenance needs are identified and carried out as required to minimise moisture ingress and failure.
- Use software such as CIRCLY to determine the most appropriate thicknesses for a variety of paving materials, particularly asphalt.
- Continue to trial new methods such as polymer modified binders, foamed bitumen and rubberized asphalt. Keep records of all trials and monitor performance.

8.4.5 Other

- All Council Departments should be working to the same standard and policies.
- Revise the Planning Scheme Policy to reflect current best practice and design manuals in collaboration with the Engineering Services Department.
- Enforce the need for traffic planning studies for all developments and pavement design done by external contractors.
- Further investigate methods to minimise the effects of movement adjacent to rigid structures such as kerb, e.g compressible sealant????

9 Suggested Ipswich City Council Planning Scheme Policy Alterations

9.1 General Comments

It has been identified that the current world best practice is reflected in the latest version of pavement design manuals produced by Austroads and Queensland Department of Main Roads. The following recommendations are made with respect to the Ipswich Planning Scheme Policy 3 – General Works, Part 1 – Standards for the Design of Roadworks.

9.2 Recommended Alterations

9.2.1 Division 1 – Site and Road Layout

Replace Note (4) with 'Design ESA's from actual traffic count projections are to be used for the classification of the road for pavement design. Where Council is unable to provide such data a traffic count is required to be undertaken (either on the road in question or on a similar street within the area).'

9.2.2 Division 2 – Flexible Pavement Design

Amend title to 'Pavement Design'
Delete Note 1.2A (1) and (2)
Add Note (1) The pavement design for all roads is to be in accordance with the latest versions of Austroads manuals and the Queensland Department of Main Roads pavement design manual (supplement to Austroads).
Add Note (2) This section provides Ipswich specific information which shall be taken into account.
Add Note (3) Due to the nature of Ipswich soils, rigid pavements should not be considered.

Delete sections 1.2.1 – 1.2.4
Add new section 1.2.1 Subgrade

Add (1) Typically Ipswich geology consists of sedimentary rocks that are prone to break down during construction to form expansive soils.

Add (2) 75% of soils tested in Ipswich are found to be of medium to high plasticity.

Add (3) Historical test results also indicate that there is often no correlation between in-situ CBR test results by DCP and estimated or soaked CBR results in Ipswich. DCP results must only be used for worst case scenario CBR.

Add (4) The following areas of Ipswich consistently produce very poor subgrade test results and a **minimum** design CBR of 3 is required -:

Ipswich Suburb	
• Bellbird Park	• Flinders View
• Blackstone	• Goodna
• Booval	• Leichhardt
• Brassall	• North Ipswich
• Bundamba	• Raceview
• Calvert	• Redbank Plains
• East Ipswich	• Riverview
• Eastern Heights	• Rosewood
• Ebbw Vale	

Table 9.1 Suburbs of Ipswich typically with CH soils

10 Conclusions

10.1 Introduction

Current Ipswich and world best practice pavement design and rehabilitation techniques were investigated. Ipswich geology was determined and soil data collected and analysed to determine the extent of expansive soils and the degree of correlation between the Atterberg Limits. A collection of existing pavements were surveyed and correlations drawn with regard to the pavement and subgrade materials and condition. As a result, alterations to the Ipswich Planning Scheme Policy for pavement design have been suggested. The following sections highlight findings that are considered important in the three areas of subgrade, pavement design and rehabilitation.

10.2 Subgrades

The majority of Ipswich consists of soils which display periodic subsurface waterlogging and can be classified within the range of CL to CH (plastic clays). For Ipswich soil testing, high liquid limits (LL) correlate well with very low estimated CBR results. However, DCP results show no correlation with either estimated or soaked CBR results. Current soil testing methods employed by Council Laboratory staff are in accordance with Australian Standards, and in some cases Main Roads, and are consistent with world best practice. Other test methods believed to be superior for determination of expansivity are onerous and require special equipment.

Subgrade replacement depths should be minimized and alternative options considered. In order to achieve a subgrade less likely to swell, compaction should be approximately 3% above OMC and achieved with lower compactive effort. Chemical stabilisation with lime is very popular, cheap and can be effective. The major concerns are determination of the correct percentage of lime to be used, using a suitable method for construction and potential for cracking. Geosythetics are proving effective with each type providing specific benefits such as reinforcement, drainage, separation and as a barrier.

10.3 Pavement Design

From the pavement survey it was found that existing pavements on expansive soils in Ipswich were not originally designed to deal with the traffic volumes that they are currently experiencing. Typically cracking occurred where the pavement materials and structure contained variable properties, for example where a rigid or semi-rigid material such as lean-mix concrete was adjacent to a flexible material such as gravel. Moisture variability was certainly a factor in areas that were adjacent to services and repairs. However, the subgrade was not considered to be the cause of failure in all cases.

Currently, the pavement design procedure used by Council, and that which is specified by Council for Developers, varies considerably. Practices seem to be outdated, however, the intent and will to progress is apparent. Rigid pavements are not constructed by ES, however, there is still a tendency to utilize cement treated bases and lean-mix is non-standard designs. Flexible pavements are most common and the incorporation of 'new' technologies is being trialed.

World best practice seems to be a blend of empirical and mechanistic design, evident in the latest Austroads and Main Roads manuals. Programs such as CIRCLY are being used extensively by Main Roads for the design of non-flexible pavements, particularly asphalt. Council staff are not trained in new mechanistic design and software purchasing is necessary. There appears to be an interest in modern pavement design methods, supported by management.

Sustainability has become increasingly important in future pavement design and Council needs to consider trialing new methods and materials to ensure long-term gains. Promising areas include the use of geosynthetics, recycled tyres/rubber, recycled pavement materials and modified bitumen and asphalt products. Given the extent of research and alignment with world best practice, the latest Austroads pavement manuals provide excellent resources for design and should be the crux of the Ipswich Planning Policy. This would allow Developers and Council to design pavements in a consistent manner to a given standard yet still have flexibility in the choice of structure and materials.

10.4 Rehabilitation

Though this paper did not focus on rehabilitation the following comments are worth restating.

It is essential that the root cause of pavement failure is accurately assessed to enable the best practice rehabilitation to be determined. The three main contributors to pavement failure in Ipswich appear to be inadequate pavement structure for traffic loads experienced (inadequate projection of traffic volumes), asphalt/bitumen fatigue and differential subgrade movement (due to highly plastic soils). These issues lead to symptoms such as cracking that allow moisture ingress and further degradation of the pavement.

With the large proportion of Ipswich surfaced by these plastic clays it is may be necessary for more frequent maintenance of surfacing to minimize failures. Software, such as CIRCLY, can be used to assess existing pavements for stresses and strains, providing important information regarding the desirable pavement composition or thickness that is required to deal with particular traffic volumes.

There needs to be continuity of elastic properties at material boundaries to decrease the likelihood of cracking at these locations. The use of rigid materials adjoining flexible materials rarely proves effective with standard sealed or asphalt surfacing and can increase the chance of crack creation. Rehabilitation offers a great opportunity to trial new products such as rubberized or polymer modified bitumen binders and asphalt to minimize reflective cracking.

10.5 General

The Austroads pavement manuals reflect world best practice and should be the primary document of reference for Ipswich City Council pavement design across Departments through the Planning Scheme Policy. Ipswich specific conditions should be clearly communicated to designers and availability of geotechnical and traffic data for efficient and best practice pavement design addressed.

10.6 Further Research and Recommendations

Continued practice improvement requires further research and investigation into areas that are still being developed and trialled around the World. This dissertation has brought to light several specific areas of further research or development that would benefit pavement design practice in Ipswich, these include -:

- ❖ The creation of a more complete subgrade map for Ipswich based on data collected through this dissertation, more recent data from the ICC Soil Laboratory and that from other Geotechnical companies
- ❖ Development of a traffic count register that is available to pavement designers/developers to determine appropriate ESA's
- ❖ Investigation of the current pavement maintenance program in Ipswich and development of a more current management system
- ❖ Effects of cement and lime stabilisation on the environment and residents
- ❖ Best practice lime stabilisation procedures for Ipswich soils, e.g. determination of the ideal percentage of lime for Ipswich soils, appropriate construction procedures, effective lifetime due to chemical change
- ❖ Alternative road formations for urban situations that limit or minimise moisture variation in the subgrade including pavement widths, subsoils drainage, kerb and channel location
- ❖ The use of recycled materials in pavements e.g. shredded or chipped tyres/rubber, sub-standard gravels for lower subbase courses, profiling materials (asphalt, bitumen seals) for subbase or base courses

- ❖ Trials of various geosynthetics in diverse situations

- ❖ Creation of empirical graphs/designs using the mechanistic approach (CIRCLY or similar software) for Ipswich conditions and materials

Specific recommendations to Council in the immediate future include -:

- ✓ Consider and implement the suggested Planning Scheme Policy amendments,
- ✓ Train staff in pavement design and particularly the mechanistic approach
- ✓ Purchase software such as CIRCLY to enable staff to use current best practice design methods and develop Ipswich specific graphs for design
- ✓ Continue to trial and monitor the use of recycled materials and new products and methods

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Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project

Project Specification

FOR: **CATHERINE CAUNCE**

TOPIC: Effective Road Pavement Design for Expansive Soils in Ipswich

SUPERVISOR: Prof. Ron Ayers

SPONSORSHIP: Ipswich City Council

PROJECT AIM: To develop effective road pavement design standards for expansive soil subgrades in the Ipswich area.

PROGRAMME: Issue A, 23 March 2010

1. Research current Australian and international information relating to road pavements on expansive soil subgrades, and in particular information regarding:
   a. Road pavement design;
   b. Subgrade treatment methods;
   c. Engineering test methods for expansive clays; and
   d. Rehabilitation methods employed for deformed pavements.

2. Research geological history of Ipswich and formation of expansive clay soil deposits.

3. Gather soil test information for expansive clays in Ipswich. Classify the clays of the Ipswich area based on their material properties e.g. liquid limit, plastic limit, shrinkage limit, activity, potential swell, etc.

4. Carry out a survey of pavement condition for road pavements on expansive clays throughout the Ipswich area.

5. Assess the effectiveness, in regard to world's best practice and actual performance, of current Ipswich City Council pavement design practices for both flexible and rigid pavements.

6. Propose and evaluate improvements to the Ipswich City Council current pavement design practices.

7. Present information, results and recommendations in the required written and oral formats.

As time permits:

8. Produce tables and/or graphs for pavement design in Ipswich

9. Develop a policy for pavement design for incorporation in the Ipswich City Council Planning Scheme

AGREED: _______________ (Student) _______________ (Supervisor)

Date: 23 / 3 /2010 Date: 26 / 3 /2010

Examiner/Co-Examiner: _______________

Appendix B – Rock Key

TERTIARY

Tb	Booval Group	*Claystone, basalt, magnesian limestone, sandstone*
Tf	Flinders Dolomite	*Magnesian limestone*
Ts		*Sandstone, conglomerate, shale, siltstone, mudstone*
Ty		*Basalt, agglomerate, rhyolite, trachyte*
Tx	Oxley Group	*Claystone, sandstone, shale, basalt, conglomerate, siltstone, limestone*

JURASSIC

Jbm	Marburg Formation	*Sandstone, siltstone, shale, conglomerate, coal, oolitic ironstone*
Je	Evergreen Formation	*Sandstone, siltstone, shale, mudstone, oolitic ironstone*
Jh	Hutton Sandstone	*Sandstone, conglomerate, siltstone, shale*
Jt	Tiaro Coal Measures	*Sandstone, siltstone, shale, coal, conglomerate, limestone, tuff, oolitic ironstone*
Jw	Walloon Coal Measures	*Shale, siltstone, sandstone, coal, mudstone, limestone*

TRIASSIC-JURASSIC

TRJb	Bundamba Group (undifferentiated)	*Sandstone, siltstone, shale, conglomerate*
TRJbh	Helidon Sandstone	*Sandstone, siltstone, shale, conglomerate*
TRJbw	Woogaroo Subgroup	*Sandstone, conglomerate, siltstone, shale, coal*

TRIASSIC

TRa	Aranbanga Beds	*Andesite, dacite, tuff, agglomerate*
TRb	Brisbane Tuff	*Rhyolitic tuff, ignimbrite, agglomerate, conglomerate, sandstone, shale*
TRc	Chillingham Volcanics	*Rhyolite, tuff, shale*
TRe	Keefton Formation Traveston Formation	*Sandstone, conglomerate, shale*
TRi	Ipswich Coal Measures	*Shale, conglomerate, sandstone, coal, siltstone, basalt, tuff*

Appendix C – Subgrade Data

Subgrade Classifications - Soil Testing Ipswich

Est. CBR = Estimated CBR from Victorian Country Roads Board Method

Insitu CBR = DCP

Unified Soil Classification System used

Suburb	Road Name	Class.	M.C. (%)	Insitu CBR	Est. CBR	Soaked CBR	LL %	PI %	LS %	Description
Bundamba	Aberdeen (Wade to Foxton)	CH	23	4						reddish brown clay
Bundamba	Aberdeen (Wade to Foxton)	CH	36	2	2		83	63	25	grey clay
Bundamba	Aberdeen (Wade to Foxton)	CH	38	2	2	3	79	58	24	green grey clay
Bundamba	Aberdeen (Wade to Foxton)	CH	34	2	2		87	68	24	light brown clay
Bundamba	Aberdeen (Wade to Foxton)	CH	23	8	4		53	38	18	brown grey clay
Bundamba	Aberdeen (Wade to Foxton)	CH	25	10	6		50	32	15	reddish loamy clay
Thagoona	Adelong Avenue	CH	26	7	2		72	58	20	mottled brown grey red clay
Thagoona	Adelong Avenue	CH	22	9	2		71	57	22	brown grey clay
Thagoona	Adelong Avenue	CL	15	12	9	**2**	32	21	8	brown grey silty clay
Thagoona	Adelong Avenue	CH	25	9	3		75	61	15	brown clay
Thagoona	Adelong Avenue	CH	35	6	2		81	67	15	black clay red specks
Thagoona	Adelong Avenue	CH	38	5	1		100	81	22	mottled grey brown clay red
Thagoona	Adelong Avenue	CH	34	4	2		83	63	20	grey clay
Thagoona	Adelong Avenue	CH	28	6	2		76	58	18	grey clay
Thagoona	Adelong Avenue	CH	29	8	2		71	56	19	mottled brown grey red clay
Churchill	Albert Street	CI	12	18	6		39	25	14	mottled orange sandy clay
Churchill	Albert Street	CI	17	5	10	1	37	25	11	mottled grey orange sandy clay
Churchill	Albert Street	ML	8	12	14		19		1	brown loam
Churchill	Albert Street	CL-ML	10	3	15		15	5	2	grey brown clayey sandy loam
Brassall	Albion Street (Hancock bridge to Chuwar)	CI	16	23	5		47	31	15	grey brown silty clay
Brassall	Albion Street (Hancock bridge to Chuwar)	CH	27	8	3		62	39	18	grey brown silty clay
Brassall	Albion Street (Hancock bridge to Chuwar)	CH	28	5	3	1	72	51	19	grey clay

Brassall	Albion Street (Hancock bridge to Chuwar)	ML	22	15	11		46	21	10	grey pebbly silt
Redbank Plain	Aldinga Street (Cedar to Keidges)	CH	45	3	2		93	60	24	black clay
Redbank Plain	Aldinga Street (Cedar to Keidges)	CH	21	9	4		62	37	17	brown clay
Redbank Plain	Aldinga Street (Cedar to Keidges)	CH	20	12	6		51	28	12	mottled pink grey silty clay
Redbank Plain	Aldinga Street (Cedar to Keidges)	CH	38	5	3		67	40	20	black clay
Redbank Plain	Aldinga Street (Cedar to Keidges)	CH	35	5	2	1	79	58	18	brown clay
Redbank Plain	Aldinga Street (Cedar to Keidges)	CH	38	4	2		81	53	23	black clay
Redbank Plain	Aldinga Street (Cedar to Keidges)	CH	34	6	2		93	63	24	black clay
Redbank Plain	Aldinga Street (Cedar to Keidges)	ML	15	30	19		39	10	5	rotten rock
Redbank Plain	Aldinga Street (Cedar to Keidges)	CI	15	14	11		43	18	9	rotten rock
Booval	Alexandra (Brisbane to	CH	37	5	6		56	28	15	dark brown black clay
Booval	Alexandra (Brisbane to	CH	38	4	3	2	63	39	19	brown black clay
Booval	Alexandra (Brisbane to	CH	23	23	3	2	63	39	19	brown black clay
Booval	Alexandra (Brisbane to	CH	29	9	3	2	63	39	19	dark brown clay
Booval	Alexandra (Brisbane to	CI	28	9	7		40	22	14	speckled light brown clay
Booval	Alexandra (Brisbane to	CH	21	8	3		59	42	19	light reddish brown clay
Booval	Alexandra (Brisbane to	CH	26	10	3		73	46	21	dark brown silty clay
Booval	Alexandra (Brisbane to	CH	26	13	5		53	30	16	Brown sandy silty clay
Goodna	Alice St (Bertha to Jo)	CL-CI	9	52	18		25	11	6	sandstone
Goodna	Alice St (Bertha to Jo)	CL	10	29	17		26	13	7	orange white silty sandstone
Goodna	Alice St (Bertha to Jo)	CI	14	7	7	2	45	31	13	silty clay
Goodna	Alice St (Bertha to Jo)	CL	18	5	9		31	21	11	mottled orange/grey/brown, silty clay
Goodna	Alice St (Bertha to Jo)	CL	11	17	23		22	10	4	brown sandy, silty, stony clay
Goodna	Alice St (Bertha to Jo)	CL	15	5	14	6	20	9	4	brown silty clay
Goodna	Alice St (Bertha to Jo)	ML-CL	9	34	13		17	7	3	brown, stony, silty clay

Goodna	Alice St (Bertha to Jo)	ML	8	10	14		16	6	2	brown silty, sandy clay with some stone
Goodna	Alice St (Bertha to Jo)	ML	9	20	14		16	6	2	brown silty, sandy clay with some stone
Goodna	Alice St (Bertha to Jo)	CI-CH	18	6	5		46	32	14	Brown clay
Karalee	Arunta Street	CL	5	12	12		25	12	7	light brown stony silty sand
Karalee	Arunta Street	CL	5	>60	15		24	12	6	light brown sand / sandstone
Karalee	Arunta Street	CL	6	26	13	13	29	15	7	light brown sand / sandstone
Karalee	Arunta Street	CL	17	17	6		45	26	12	brown silty clay
Karrabin	Badower Road (Butterfield to Clarks)	CL	4	34	15		19	8	4	red stony silt
Karrabin	Badower Road (Butterfield to Clarks)	CL-ML	3	> 60	12		17	7	3	bright red silt
Churchill	Balaclava Street	CL	11	7	10		24	11	4	light orange sandy clay
Churchill	Balaclava Street	CI	13	9	7		35	21	10	orange sandy clay
Churchill	Balaclava Street	CI	13	9	7	4	33	22	9	mottled orange / white sandy clay
Churchill	Balaclava Street	CL	13	7	9		25	14	5	Pale orange clay
Brassall	Barkell Street	CH	16	10	7		53	33	13	Mottled Grey Yellow sandy clay
Brassall	Barkell Street	CH	17	14	8		54	33	13	Mottled grey-yellow sandy clay
Brassall	Barkell Street	CI	18				50	26	9	Clayey coalstone soil aggregate
Brassall	Barkell Street	CH	16	25	3	1	62	41	18	Red Brown silty
Brassall	Barkell Street	CI	13	14	9		32	15	9	Brown silty clay
Brassall	Barkell Street	CI	11	20	10		41	21	11	Brown silty sand
Goodna	Barram Street (Albert to William)		6	13	16		17	1	1	Brown silty sand
Goodna	Barram Street (Albert to William)		6	34	16		17	1	1	Brown silty sand
Goodna	Barram Street (Albert to William)		10	10	10	7	27	15	7	brown sandy silty clay
Goodna	Barram Street (Albert to William)		23	5	10		25	12	4	grey silty clay
East Ipswich	Barrett Street	CH	25	4	5		56	33	18	dark brown pebbly clay
East Ipswich	Barrett Street	CH	40	4	2		82	54	24	Black clay
East Ipswich	Barrett Street	CH	23	25	3		64	34	21	dark brown clay
East Ipswich	Barrett Street	CH	26	25	3		64	33	19	Mottled brown decomposed rock
East Ipswich	Barrett Street	CI	20	27	6	6	48	21	14	brown clay
East Ipswich	Barrett Street	CI	21	25	6		46	27	14	brown black clay

East Ipswich	Barrett Street	CI	22	21	8		45	24	14	brownish black decomposing rock
East Ipswich	Barrett Street	CI	21	27	8		45	24	14	Brownish black decomposing rock
Goodna	Bertha St - Mill Street intersection	CH	19	10	5	3	58	41	17	dark brown clay
Goodna	Bertha St - Mill Street intersection	CI	14	9	12		39	22	10	orange stony sandy clay
Goodna	Bertha St - Mill Street intersection	CI	20	12	7		46	21	11	brown silty clay
Goodna	Bertha St - Mill Street intersection	CI	18	8	8		40	21	10	black silty clay
Goodna	Bertha St - Mill Street intersection	ML	5	> 60	17		16	4	3	light brown silt
Goodna	Bertha St - Mill Street intersection	CL	10	3	15		25	11	5	brown silty sandy clay
Eastern Heigh	Blackstone Road	CH	32	9						Black Clay
Eastern Heigh	Blackstone Road	CH	58	3						Black Clay
Eastern Heigh	Blackstone Road	CH	44	8						Black Clay
Eastern Heigh	Blackstone Road	CH	62	3						Black Clay
Eastern Heigh	Blackstone Road	CH	51	4						Black Clay
Eastern Heigh	Blackstone Road/Southstation Road	CH	30	22	5		62	34	16	Black sandy silty clay
Eastern Heigh	Blackstone Road/Southstation Road	CI	20	17	13		41	18	9	rotten rock
Eastern Heigh	Blackstone Road/Southstation Road	CI	13	21	14		38	16	8	brown silty sand
Eastern Heigh	Blackstone Road/Southstation Road	CI	26	18	8	11	43	24	14	brown sandy silty clay
Eastern Heigh	Blackstone Road/Southstation Road	CI	12	8			38	16	8	brown silty sand
Eastern Heigh	Blackstone Road/Southstation Road	CI	24	10	7		39	25	11	brown silty clay
Eastern Heigh	Blackstone Road/Southstation Road	CL	16	4	10		29	15	9	brown sandy silty clay
Bellbird Park	Boscowan	ML	6	8	14		18	5	1	black clay
Bellbird Park	Boscowan	CH	36	6	2		77	56	24	black clay
Bellbird Park	Boscowan	CH	35	10	2		77	56	24	red clay
Bellbird Park	Boscowan	CH	47	5	1		112	87	26	black clay
Bellbird Park	Boscowan Crescent	CH	32	11	3		72	47	20	mottled brown/orange/red sandy clay
Bellbird Park	Boscowan Crescent	CL	7	10	13		21	10	4	brown silty sand (stony)

Bellbird Park	Boscowan Crescent	CH	32	5	2		85	54	24	Mottled black/white/brown /grey clay with
Bellbird Park	Boscowan	CL	7	22	12		22	12	6	brown silty sand
Bellbird Park	Boscowan	CH	33	8	2	2	84	60	23	Black clay
North Ipswich	Bothwick Street	CH	19	25	3		65	45	16	brownish-red clay
North Ipswich	Bothwick Street	CH	9	44	10	10	23	14	5	brown-grey clay
North Ipswich	Bothwick Street	CH	27	2	4		61	43	13	dark brown clay
Brassall	Bottomely Street	CI	17	8	4		49	30	18	brown silty clay
Brassall	Bottomely Street	CI	16	8	7		35	19	11	dark brown silty clay
Brassall	Bottomely Street	CH	28	4	3		65	38	21	brown clay
Brassall	Bottomely Street	CH	27	4	3		66	42	21	brown clay
Bundamba	Boundary	ML	25	10	4		76	47	18	brown loamy silt
Bundamba	Boundary	CL	8	26	10		27	9	6	brown stony silty clay
Bundamba	Boundary	CI	14		16		37	15	9	grey yellow clayey sand
Churchill	Bremer Street	CI	11	8	7		32	19	10	yellow grey silty sand
Churchill	Bremer Street	ML	10	11	13	10	15	2	1	yellow orange grey clayey sand
Churchill	Bremer Street	CI	13	18	6		39	24	11	grey yellow silty sand
Churchill	Bremer Street	CL-ML	4		13		19	5	2	sandstone
Redbank Plain	Brennan Street	CL-CI	8	> 60			22	10	6	brownish grey stony silty sand
Redbank Plain	Brennan Street	CL	8	29			17	1	0	mottled grey clay
Redbank Plain	Brennan Street	CI	18	9			44	30	16	orange red grey mottled clay
Redbank Plain	Brennan Street	CH	16	18			54	37	18	light brown siltstone
Redbank Plain	Brennan Street	CH	17	20			64	45	17	reddish grey mottled clay
Flinders View	Briggs Road Depot	ML	6	21	14		21		0	orange white soft sandstone
Flinders View	Briggs Road Depot	CI	14	3	7	4	33	20	12	sandy clay
Flinders View	Briggs Road Depot	CL	8	20	9		27	14	7	Orange / white sandy clay
Flinders View	Briggs Road Depot	CL-ML	6	18	17		21	6	4	brown silt
Flinders View	Briggs Road Depot	CL	9	18	9		27	14	7	Orange clayey sandstone
Flinders View	Briggs Road Depot	ML	3	34	15		22		1	brown loam
Flinders View	Briggs Road Depot	ML	3	36	15		22		1	brown loam
Flinders View	Briggs Road Depot	CL	8	14	9		30	17	9	orange sandy clay
Flinders View	Briggs Road Depot	CL-ML	10	15	13		26	6	4	brown loam
Flinders View	Briggs Road Depot	CL-ML	9	12	11		21	5	4	brown loam
West Ipswich	Brisbane Street	ML	9	34	10		28	13	9	grey sandy pebbly clay
West Ipswich	Brisbane Street	CI	13	19	8		39	22	12	mottled light brown sandy clay
West Ipswich	Brisbane Street	CI	15	13	8	2	43	27	14	orange sandy clay

West Ipswich	Brisbane Street	CI	16	10	8		34	20	9	mottled orange/brown/grey silty clay
West Ipswich	Brisbane Street	CI	11	16	11		33	19	8	orange silty clay
West Ipswich	Brisbane Street	CL	11	14	11	6	22	12	6	pebbly brown silty clay
West Ipswich	Brisbane Street	CL	12	26	11		26	14	7	mottled grey/brown clay
West Ipswich	Brisbane Street	CL	17	5	11		27	13	8	greyish brown clay
West Ipswich	Brisbane Street	CI	19	7	7	8	40	27	13	light brown silty loam
Churchill	Brisbane Street	CL-ML	5	58	13		15	4	1	mottled greyish orange sandy clay
Churchill	Brisbane Street	CH	21	5	6		53	36	15	dark brown grey gravelly loam
Goodna	Brisbane Terrace	CI	20	10	6		40	25	14	grey gravelly clay loam
Goodna	Brisbane Terrace	CL	10	23	13		22	12	6	brown loamy clay
Goodna	Brisbane Terrace	CI	15	7	9		32	19	11	dark brown loamy clay
Goodna	Brisbane Terrace	CL	15	7	8	5	30	19	10	grey sand
Karalee	Brodzig's Road	SM	2	46	21	23	16		1	mottled grey orange yellow
Karalee	Brodzig's Road	CH	14	15	5		57	38	16	black clay
East Ipswich	Bunya Street	CH	27	17	3	3	60	40	19	Brown clayey decomposing rock ("rotten rock")
East Ipswich	Bunya Street	OL	18	17	11		37	9	6	orange clay
Woodend	Burnett Street	CH	21	6	4	1	56	39	15	pale brown sandy silt
Woodend	Burnett Street	ML	6	> 60	19		17	4	3	Mottled yellow - grey sandy clay
Woodend	Burnett Street	ML	16	6	8		38	23	11	Pale brown sandy silt (stony)
Woodend	Burnett Street	CL	6	38	21	23	19	4	3	mottled orange grey clay
Woodend	Burnett Street		19	7	5		60	42	15	white sandstone
Woodend	Burnett Street		3	> 60	18		15	4	1	light brown silty sand
Woodend	Burnett Street	CI	12	21	8		42	27	14	mottled orange grey clay
Woodend	Burnett Street		18	10	3	0	61	44	15	orange brown sandy soil
Woodend	Burnett Street	ML	3	34	19		20	5	1	brown silty loam
Karrabin	Butterfield Road	CL	7	48	12		18	6	2	mottled red brown silty clay
Karrabin	Butterfield Road	CH	10	52	5		52	28	16	reddish brown stony silt
Karrabin	Butterfield Road	CL	6	34	15		21	11	5	greyish brown clay
Thagoona	Caledonian Road		23	2	5	2	49	35	17	mottled greyish brown silty clay

Thagoona	Caledonian Road		21	4	8		37	24	13	mottled orange/grey silty
Thagoona	Caledonian Road		19	3	4		52	41	17	Loamy clay with some coalstone
Thagoona	Caledonian Road		14	5	16		28	14	8	light brown stony clay
Thagoona	Caledonian Road		17	3	5		46	31	16	brown silty clay
Walloon	Calvin Street	CI	19	7	6		39	21	13	brown clay
Walloon	Calvin Street	CI	22	4	5		49	31	17	brown silty clay
Walloon	Calvin Street	CI	15	15	8		34	18	11	brown clay
Walloon	Calvin Street	CI	17	6	5		43	27	15	black clay
Redbank Plain	Carol Street	CH	35	10	2	3	84	61	23	black clay
Redbank Plain	Carol Street	CH	35	10	2		89	64	23	brown clay
Redbank Plain	Carol Street	CH	35	10	3		67	44	20	rotten rock
Redbank Plain	Carol Street	CI	22	11	11		42	19	9	mottled orange grey sandy clay
Raceview	Caroline Street	CI	15	15	6		51	36	14	dark brown silty sand
Raceview	Caroline Street	CI	8	23	14		20	10	6	gravelly brown silty (lime odour)
Raceview	Cascade Street		23	> 60	18		49	17	8	black clay
Raceview	Cascade Street	CH	44	5	3	2	71	50	21	brown shale
Redbank Plain	Cedar Road		10	> 60			36	11	7	black clay
Redbank Plain	Cedar Road	CH	43	4	2	2	74	54	22	dark green loamy clay
Redbank Plain	Cedar Road	CH	27	11	6		44	23	13	black clay
Redbank Plain	Cedar Road	CH	62	11	6		44	23	13	black silty clay
	Cemetery	CH	26	7	5		53	34	16	black clay
	Cemetery	CH	29	5			78	55	20	black clay
	Cemetery	CH	46	7	3	2	78	55	20	black clay
Basin Pocket	Charlotte Street	CH								
East Ipswich	Chermside Road	CH	20	14	4		49	36	17	dark brown silty clay
East Ipswich	Chermside Road	CH	23	5	3		58	41	19	brown clay
East Ipswich	Chermside Road	CH	23	8	4	3	54	36	18	stony black clay
East Ipswich	Chermside Road	CH	29	6	3		54	36	19	loamy brown clay
East Ipswich	Chermside Road	CI	24	26	8		46	24	13	greyish black stony clay
East Ipswich	Chermside Road	CI	12	14	18	15	36	22	10	clayey gravel
One Mile	Chubb Street	CH	20	7	7		37	29	11	black silty clay with stone
One Mile	Chubb Street	CI	18	5	7		35	24	12	brown clay
One Mile	Chubb Street	CH	32	13	5		57	36	17	brown clay (possibly lime stabilised)
One Mile	Chubb Street	CH	31	6	3	3	59	41	19	brown silty clay
One Mile	Chubb Street	CH	36	3	2		96	77	22	grey-brown clay
One Mile	Chubb Street	CH	35	3	2		77	52	21	brown clay
One Mile	Chubb Street	CH	24	6	3		57	44	18	brown clay
Goodna	Church Street	CL-CI	16	14	10		30	15	8	brown silty clay
Goodna	Church Street	CI	21	5	9		37	21	11	black clay

Goodna	Church Street	CI	22	6	12		34	19	10	mottled grey-black clay
Churchill	Churchill Street	CI	9	15	7		34	21	10	Yellow Orange Grey clayey sand
Churchill	Churchill Street	CI	12	19	6		41	27	12	Yellow Orange Grey clayey sand
Churchill	Churchill Street	ML	7	>30	13		16	3	2	Grey Yellow Brown silty sand
Churchill	Churchill Street	CI-CH	17	5	5	5	48	33	14	Yellow Orange Grey sandy clay
Karrabin	Clarkes Road	CL-ML	2	22	14		19	4	1	light brown stony silt
Karrabin	Clarkes Road	CL-ML	6	14	14		27	17	8	orange red stony silty loam
Karrabin	Clarkes Road	CL-ML	7	25	10		24	10	7	dark red loamy silt
Carole Park	Cobalt Street	SC	5	36/46	17	76	20	2	1	grey sand
	Cole Street	CH	49	5	2		100	56	23	brown clay
	Cole Street	CH	41	5	2		74	56	21	brown silty clay
	Cole Street	CH	24	13	8		50	21	13	brown silty clay
	Cole Street	CH	24	7	6		57	40	17	brown silty stony clay
	Cole Street	CH	52	3	3		96	56	16	greyish black clay
	Cole Street	CH	48	4	3		100	60	17	dark brown clay
	Cole Street	CH	29	10	4	3	64	45	20	brown black clay
	Cole Street	CH	36	5	3		74	52	21	brown silty clay
	Cole Street	CI-CH	21	11	7		48	30	11	brown silty clay
	Cole Street	CH	28	10	4		71	47	21	brown silty clay with white streaks
Willowbank	Cooper's Road	CI-CH	13	40	18		40	12	9	brown decomposing
Willowbank	Cooper's Road	CH	22	7	3	3	62	41	20	grey clay
Willowbank	Cooper's Road	CH	22	27	4		62	39	19	stony brownish grey clay
Willowbank	Cooper's Road	CH	12	28	4		62	39	19	brown stony clay
East Ipswich	Countess Street	CH	42	2	2		91	70	19	grey clay
East Ipswich	Countess Street	CH	33	2	2		75	57	22	grey clay
East Ipswich	Countess Street	CH	35	3	2		76	59	24	grey clay
East Ipswich	Countess Street	CH	33	3	3	2	63	47	20	brown clay
Bundamba	Creek Street	CI	17	12	7		45	28	14	sandy silty clay
Bundamba	Creek Street	CH	23	5	3		70	49	22	dark brown clay
Bundamba	Creek Street	CI	15	11	11		31	18	9	brown sandy clay
Bundamba	Creek Street	CI	19	4	8		41	28	13	greyish brown sandy clay
Bundamba	Creek Street	CH	27	4	4		58	40	19	black clay
Bundamba	Creek Street	CH	25	7	3		63	44	21	dark brown clay
Bundamba	Creek Street	CI	14	5	10	5	37	24	12	brown silty sandy clay
Bundamba	Creek Street	CH	21	10	4		57	40	17	mottled orange-brown silty clay
Redbank Plain	Cudgee Street	CH	24	4	3		72	53	19	grey clay
Redbank Plain	Cudgee Street	CH	30	2	3	2	72	53	19	grey clay
Redbank Plain	Cudgee Street	CH	28	9	3		70	44	18	grey clayey silt

Redbank Plain	Cudgee Street	CH	24	6	3		62	45	21	brown clay
Redbank Plain	Cudgee Street	CI	20	7	7	2	41	28	14	brown stony silty clay
Redbank Plain	Cudgee Street	CL	6	13	11		21	11	6	brown silt
Redbank Plain	Cudgee Street	CH	22	10	4		50	34	16	brown silty clay
Redbank Plain	Cudgee Street	CH	25	7	3		64	48	20	grey brown clay
Redbank Plain	Cudgee Street	CH	24	7	4		57	38	17	grey brown clay tending silty
Redbank Plain	Cudgee Street	CH	21	4	3		52	38	20	grey brown clay
Brassall	Cushing Street	CI	14	22	12		35	17	8	Mottled orange brown sandy clay
Brassall	Cushing Street	CI	20	3	7		47	27	11	Mottled Grey Orange clay
Brassall	Cushing Street	CI	20	5	6	4	40	26	12	Mottled Grey Orange clay
Brassall	Cushing Street	CI	16	13	7		39	19	10	Brown silty clay
Camira	Dale Road	SM	14	16	16		24	8	5	pebbly pinkish brown clayey silt
Camira	Dale Road	CI	11	20	7		41	30	11	orange/brown silty clay
Camira	Dale Road	CL-ML	3	12						grey sand
Camira	Dale Road	CL-ML	8	18	15	24				grey sand
Ipswich	Darcy Doyle Place	CL-CH								
Basin Pocket	Davidson Street	CH	25	4	3		64	45	19	brown clay
Basin Pocket	Davidson Street	CI	27	3	4		46	31	16	brown silty clay
Basin Pocket	Davidson Street	CH	27	7	3		64	45	19	brown clay
Basin Pocket	Davidson Street	CH	25	9	2		70	50	21	brown clay
Basin Pocket	Deacon Street	CI	16	6	18		37	17	8	coalstone soil
Basin Pocket	Deacon Street	CH	32	3	2		83	56	23	brown clay
Basin Pocket	Deacon Street	CH	28	3	3		64	47	19	mottled orange/grey/brow n clay
Basin Pocket	Deacon Street	CH	33	2	2		77	52	24	blue-grey silty clay
Basin Pocket	Deacon Street	CH	3	3	1		74	54	19	blue-grey clay
Basin Pocket	Deacon Street	CH	32	3	2		78	57	20	grey clay
Yamanto	Deebing Creek Road	CI	14	6	9		32	21	10	mottled brown/grey/green sandy clay
Yamanto	Deebing Creek	CH	21	5	3		59	42	18	grey clay
Yamanto	Deebing Creek Road	CI	14	6	6		36	26	13	mottled light brown/grey sandy clay
Yamanto	Deebing Creek Road	CI	14	7	10	2	31	18	10	brown silty, sandy clay
Yamanto	Deebing Creek	ML	5	26	18		21	6		brown silty sand
Ebenezer	Ebenezer Road	CI	22	10	3		64	41	19	brown gravelly clay
Ebenezer	Ebenezer Road	CI	22	5	5	3	52	32	17	brown gravelly clay
Eastern Heigh	Edinburgh Street	CH	39	7	3		79	54	23	black clay
Eastern Heigh	Edinburgh Street	CH	29	7	5	3	63	43	19	black stony clay
Eastern Heigh	Edinburgh Street	CH	35	7	6		62	42	19	brown stony clay
Eastern Heigh	Edinburgh Street	CH	40	7	2		92	60	24	Red clay
Gailes	Edna Street	SC	8	.5/8.5/1	13	30	20	4	3	brown silty sand

Gailes	Edna Street	CH	17	5/7.0/8	5	2	51	34	15	yelllow brown clay
Gailes	Edna Street	SC	10	.5/16/2	14	58	19	3	2	stony brown sand
Gailes	Edna Street	SC	4	58	15	24	19	3	2	yellow-brownish sand
Gailes	Edna Street	SC	9	50	15		19	3	2	yellow - brownish sand
Flinders View	Edwards Street	CI	14	> 60	16		41	9	4	brown decomposing rock,
Flinders View	Edwards Street	CI	17	12	9		46	27	10	clayey coalstone soil
Flinders View	Edwards Street	CH	23	12	3	3	81	56	14	brown grey clay white flecks and pebbles
Flinders View	Edwards Street	CI	17	25	9		48	29	9	brown loamy clay
Flinders View	Edwards Street	CI		44	16		41	9	4	light brown decomposing rock
Flinders View	Edwards Street	CH	20	19	3		63	43	18	Brown clay
Flinders View	Edwards Street	CH	24	14			63	43	18	Brown clay
Flinders View	Edwards Street	CH	40		2		94	69	22	Black clay
Flinders View	Edwards Street	CH	32	6	4		61	39	18	Black clay, tinge green
Flinders View	Edwards Street	CH	24	19	3		66	44	20	brown clay
Flinders View	Edwards Street	CI	19	32	19		43	16	7	"rotten rock"
Flinders View	Edwards Street	CI	23	14	10		52	12	5	"rotten rock"
Flinders View	Edwards Street	CH	25	7	7		56	28	15	brown silty clay
Flinders View	Edwards Street	CH	34	8	3		82	50	17	brown clay
Flinders View	Edwards Street	CI	21	40	9	6	48	26	13	decomposing rock
Flinders View	Edwards Street	CI	21	15	9	6	48	26	13	Decomposing rock
Flinders View	Edwards Street	CH	44	2	2	2	93	69	22	Brown clay
Flinders View	Edwards Street	ML	17	20	16		43	10	8	decomposing rock
Flinders View	Edwards Street	ML	20	14	16		43	10	8	decomposing rock
Flinders View	Edwards Street	CH	29	5	8		55	30	16	Black clay
Flinders View	Edwards Street	CH	40	2	8		55	30	16	black clay
Flinders View	Edwards Street	CL	11		18	16	34	17	7	coalstone soil
Flinders View	Edwards Street	CH	27	4	8		53	29	16	black clay
Flinders View	Edwards Street	CI	21	9	9		49	24	15	dark brown clay
Bundamba	Elm Street	sandsto	5	> 60	19		30	14	6	sandstone
Bundamba	Elm Street	CH	22	11	3	2	63	44	16	orange clay
Bundamba	Elm Street	CH	14	32	7		44	23	13	brown shaly clay
Goodna	Enid Street	CI								
Leichhardt	Ernest Street	CH	25	9	3	2	73	48	17	brown clay
Leichhardt	Ernest Street	CH	25	11			73	48	17	brown clay
Leichhardt	Ernest Street	CH	22	10			73	48	17	brown clay
Barallen Point	First Avenue	sandsto	2	> 60	25		17	3	1	light grey sand
Barallen Point	First Avenue	sandsto	4	52	17	26	18	4	2	brown sand
Barallen Point	First Avenue	CH	20	8	3	3	64	46	16	brown clay
Ripley	Fischer Road	sandsto	4	too harc	18		19	4	1	stony sandy silt
Ripley	Fischer Road	sandsto	3	12	18	54	20	3	1	stony sandy silt
Ripley	Fischer Road	CI	11	34	9		44	27	13	orange/brown silt clay
Tivoli	Francis Street	CI	17	5	11		36	18	7	grey stony sandy clay

Tivoli	Francis Street	CL	14	4	21	7	24	8	3	dark grey brown sandy silty clay
Tivoli	Francis Street	CL/ML	5	17	19		21	7	4	sandstone
Sadliers Crossi	Francis Lane	CI	10	10	16	9	33	17	10	stony silty clay
Sadliers Crossi	Francis Lane	CL	9	17	26		21		0	grey silty sand (some stone)
Sadliers Crossi	Francis Lane	CL-ML	15	5	16		23	6	5	grey sandy clay
Sadliers Crossi	Francis Lane	CI	4	> 60	15		36	15	6	yellow sandstone
Sadliers Crossi	Francis Lane	CI	9	24	21		30	11	5	orange sandy silt (some stone)
Sadliers Crossi	Francis Lane	CI	13	10	12		37	20	10	rocky clayey fill
Eastern Heigh	Gilliver Street	CH	39	12	2		85	49	23	reddish brown stony clay
Eastern Heigh	Gilliver Street	CI	14	60	14		41	14	9	weathered basalt
Eastern Heigh	Gilliver Street	CI	11	7	19	4	37	22	9	Clayey coalstone
North Booval	Gledson Street	CH	41							black clay
North Booval	Gledson Street	CH	31	4	3		68	50	21	black clay
North Booval	Gledson Street	CH	12				34	17	9	brown clayey gravelly material
North Booval	Gledson Street	CH	32	3	5	2	56	40	18	black clay
North Booval	Gledson Street	CI	18		14		35	11	6	greenish black loamy gravel with clay lumps
North Booval	Gledson Street	CH	27	6	5	5	49	34	16	black clay
North Booval	Gledson Street	CH	46	2	1		99	77	27	grey brown clay
Redbank Plain	Glen Fairlie	CH	36	4	2		80	54	23	black clay
Redbank Plain	Glen Fairlie	CH	31	9	3		75	51	21	black clay
Redbank Plain	Glen Fairlie	CH	34	7	1	2	102	82	21	black clay
Redbank Plain	Glen Fairlie	CH	41	7	2		91	59	24	black clay
Redbank Plain	Glen Fairlie	CH	55	3	1		110	76	26	black clay
Redbank Plain	Glen Fairlie Avenue	MH-CH	19	38	8		51	17	11	decomposing rock to grey silty clay
Redbank Plain	Glen Noble	CH	37	3	1		100	80	25	grey clay
Redbank Plain	Glen Noble	CH	42	3	1		97	76	27	black clay
Redbank Plain	Glen Noble Avenue	CH	25	5	4	2	63	46	20	Mottled Brown Grey Orange sandy
Redbank Plain	Glen Noble Avenue	CL	14	8	11		32	20	10	Brown sandy silty clay
Redbank Plain	Glen Noble Avenue	CL	7	30	15		22	10	5	Light Brown silty sand
Redbank Plain	Goondoola Street	CH	37	3	1		106	73	25	brownish black clay
Redbank Plain	Goondoola Street	CH	54	1	0		143	119	30	brown clay with green tinge
Redbank Plain	Goondoola Street	CH	37	3	3	2	69	52	21	mottled grey-black-red-orange clay
Bellbird Park	Gramby Street	CH	32	11	3		68	40	20	brown clay
Bellbird Park	Gramby Street	CH	27	9	4		62	37	18	dark brown clay
Bellbird Park	Gramby Street	CI	17	27	9		36	12	6	"rotten rock"
Bellbird Park	Gramby Street	OH	9	15	13	10	42	13	9	"rotten rock"
Grandchester	Grandchester-MtMort Road	CL-CI	15	21	21		30	15	9	reddish brown silty clay

Grandchester	Grandchester-MtMort Road	CI	12	17	9		35	22	12	reddish brown silty clay
Grandchester	Grandchester-MtMort Road	CI	16	27	11		40	23	13	Orange/brown silty clay
Grandchester	Grandchester-MtMort Road	ML	6	> 60	18		23	3	4	pink decomposed sandstone
Grandchester	Grandchester-MtMort Road	ML	8	> 60	13		24	5	3	brown silty sand
Grandchester	Grandchester-MtMort Road	ML	9	54	12		28	14	8	Reddish orange-brown decomposed
Grandchester	Grandchester-MtMort Road	ML	2	> 60	16		18		0	white sandstone
Grandchester	Grandchester-MtMort Road	CI	13	> 60	9		33	18	9	black silty clay
Grandchester	Grandchester-MtMort Road	ML	7	> 60	13		23	7	5	Brown decomposed
Grandchester	Grandchester-MtMort Road	ML	6	> 60	14		21	6	2	brown decomposed
Grandchester	Grandchester-MtMort Road	CI	14	29	12		36	19	9	black silty clay
Ebbw Vale	Green Street	CL	8	48	9		31	17	6	grey silt
Ebbw Vale	Green Street	CL	7	22	14	14	34	21	8	clayey coalstone soil material
Ebbw Vale	Green Street	CH	23	9	2		65	49	21	brown clay
Karrabin	Haggartys Avenue	CL	4	25	19	29	21	7	5	Brown sandy clay
Karrabin	Haggartys Avenue	CI	15	25	5		49	31	16	Mottled reddish brown sandy clay
Karrabin	Haggartys Avenue	ML	6	23	18		26	7	6	Light brown gravelly powdery
Karrabin	Haggartys Avenue	ML	3	> 60	15		22	6	4	Brown gravelly
Karrabin	Haggartys Avenue	ML		> 60	13		17	3	1	Brownish grey sandy loam
Yamanto	Hall Street	CI-CH								
Redbank Plain	Halletts Road	CH	29	14	4	3	57	31	17	black clay
Redbank Plain	Halletts Road	ML	12	10	20		33	12	7	coalstone soil
Redbank Plain	Halletts Road	CH	39	5						black clay
Karrabin	Harwoods Road	CI	12	30	6		42	29	15	brown silty clay
Karrabin	Harwoods Road	ML	4	> 60	11		23	9	5	brown loam
Karrabin	Harwoods Road	CL	10	36	12		20	4	1	orange brown loamy clay
Karrabin	Harwoods Road	CL	10	36	12		20	4	1	Reddish brown mottled sandy clay
Karrabin	Harwoods Road	CL	7	26	8		29	16	9	brown loamy clay
Redbank Plain	Henty Drive	CH	59	2	1		118	89	21	black clay
Redbank Plain	Henty Drive	CH	53	2	1	2	104	77	25	black clay
Redbank Plain	Henty Drive	CH	68	1	1		129	99	28	black clay
Redbank Plain	Henty Drive	CH	36	4	4		56	36	17	black clay
Camira	Hosanna Place	ML								
Rosewood	Ipswich-Rosewood Road	CH	38	2	2		68	52	22	grey clay

Rosewood	Ipswich-Rosewood Road	CH	28	3	3		62	46	20	grey clay
Rosewood	Ipswich-Rosewood Road	CH	38	2	2	2	75	56	21	grey clay
Rosewood	Ipswich-Rosewood Road	CH	31	5	3		68	48	20	brown clay
Ironbark	Ironbark Road	CI-CH	3	> 60	18		33	19	10	white conglomerate
Ironbark	Ironbark Road	CL	7	> 60	11		26	14	7	greyish brown loamy clay
Ironbark	Ironbark Road	ML		> 60						sandstone
Ironbark	Ironbark Road	CI	19	12	10		45	28	15	red stony clay
Ironbark	Ironbark Road	CI	9	38	10		37	17	10	brown loamy clay
Camira	Ishmael Road	SC	4	44			17	1	1	brown silty sand
Camira	Ishmael Road	ML	7	17			18	1	1	grey/brown stony silt
Camira	Ishmael Road	CL	33	7			23	10	8	orange/grey silty clay
Camira	Ishmael Road	CL-ML	3	27	15		18		0	brown sand
Camira	Ishmael Road	CH	19	27	5		56	36	15	Mottled Orange Brown sandy clay
Camira	Ishmael Road	CL-ML	4	14	15		18		0	brown sand
Camira	Ishmael Road	CL-ML	3	11	15	23	19		1	brown sand
Camira	Ishmael Road	CL-ML	6	9	13		17	3	1	brown sand
Camira	Ishmael Road	CL-ML	8	7	13		17	3	1	brown sand
Bundamba	John Street	CH	18	19	2		72	54	20	brown clay
Bundamba	John Street	CH	17	21	4		56	37	16	brown clay
Bundamba	John Street	ML	3	21	16		21	4	2	Light Brown silty sand
Bundamba	John Street	CH	19	14	4	1	63	40	17	brown clay
Brassall	Johnson Street	CL	2	14	21		25	8	4	light brown sand
Brassall	Johnson Street	CL-ML	9	17	22		25	5	2	orange silty sand
Brassall	Johnson Street	CL	7	21	20		29	9	3	yellow / brown sand with some
Bellbird Park	Johnston Street	CH	25	6	5	3	65	41	18	mottled brown-white-grey clay
Bellbird Park	Johnston Street	CH	34	6	2		85	56	21	mottled brown-white-grey clay
Bellbird Park	Johnston Street	CH	30	32	2		88	58	20	grey silty clay
Bellbird Park	Johnston Street	CH	22	20	6		61	34	14	grey silty clay with small stone
Redbank Plain	Jones Road	CH	17	15	12		39	15	9	decomposing "rotten rock"
Redbank Plain	Jones Road	CH	27	45						black clay
Redbank Plain	Jones Road	CH	34	9	2	1	92	64	24	black clay
Redbank Plain	Jones Road	CH	41	2						black clay
Redbank Plain	Jones Road	CH	49	2	2		101	66	25	black clay
Redbank Plain	Jones Road	CH	45	5						black clay
Redbank Plain	Jones Road	CH	36	6						black clay
Redbank Plain	Jones Road	CH	19	7	28		35	16	10	black stony clay
Redbank Plain	Jones Road	ML	9	12	15	50	23	4	1	brown loam

Redbank Plain	Jones Road	CI-CH	22	2	5		48	32	15	Mottled orange-brown-grey clay
Redbank Plain	Jones Road	CL-ML	8	5	11		26	7	4	brown loam
Redbank Plain	Jones Road	CI	15	4	8	5	36	21	11	light brown loamy clay
Redbank Plain	Jones Road	CL	12	27	13		29	14	8	Brown loamy clay with some stone
Redbank Plain	Jones Road	CL	9	16	13		21	9	4	Orange brown sandy loam
Redbank Plain	Jones Road	CL-ML	12	4	15	23	23	6	2	brown loam
Redbank Plain	Jones Road	CH	23	20	4		53	37	16	brown clay
Redbank Plain	Jones Road	CL	19	3	10		23	11	5	brown clayey loam
Redbank Plain	Josey Street	CH	32	3	4	3	50	28	17	grey silty clay
Redbank Plain	Josey Street	CH	33	8	7		56	28	11	brown silty clay
Redbank Plain	Josey Street	CH	31	5	1		91	71	27	light brown clay
Redbank Plain	Josey Street	CH	32	2	1		91	71	27	light brown clay
East Ipswich	Joyce Street	CH	36	3	2		78	51	20	brown clay
Karalee	Junction Road (Lyndon Way)	sandstone	6	20	18		18	4	3	grey stony, silty sandstone
Karalee	Junction Road (Lyndon Way)	sandstone	13	36	8	2	51	27	14	orange/grey decomposing s'stone
Karalee	Junction Road (Lyndon Way)	sandstone	5	> 60	15		29	12	8	sandstone
Karalee	Junction Road (MtCrosby to Langlands Street)	sandstone	10	60	10		25	13	8	orange-white sandstone
Karalee	Junction Road (MtCrosby to Langlands Street)	sandstone	10	36	6		39	25	11	pinkish white clayey sandstone
Karalee	Junction Road (MtCrosby to Langlands Street)	sandstone	11	60	6		39	25	11	pinkish white clayey sandstone
Karalee	Junction Road (MtCrosby to Langlands Street)	sandstone	12	32	6		39	25	11	mottled orange-pink-white clayey sandstone
Karalee	Junction Road (MtCrosby to Langlands Street)	sandstone	20	5	7	1	54	35	14	orange-white decomposed s/stone
Karalee	Junction Road (MtCrosby to Langlands Street)	ML	5	13	16		17	3	2	brown loam
Redbank Plain	Kanangra Street	CH	50	2	1		120	79	24	black clay
Redbank Plain	Kanangra Street	CH	60	3	1	1	120	79	24	black clay
Redbank Plain	Kanangra Street	CH	41	3	2		84	56	19	grey clay
Redbank Plain	Kanangra Street	CH	21	5	2		84	56	19	grey clay
Gailes	Karina Street	CH								
Redbank Plain	Keidges Road	CI	26				36	16	11	Light pink sandy clay
Redbank Plain	Keidges Road	ML	17	60			36	18	9	Mottled red-white decomposed sandstone

Dinmore	King Street	CH	30	12	3	9	81	57	20	orange clay
Dinmore	King Street	CL	9	18	11		25	13	7	brownish orange silty clay
Dinmore	King Street	CI	22	11	4		69	50	17	red-orange-black tint pebbly clay
Dinmore	King Street	CL	25	6	16		39	21	11	mottled orange/white clay (some c'stone)
Coalfalls	Kingsmill Road	CI	14	26	5		45	28	15	mottled reddish - orange-grey silty clay
Coalfalls	Kingsmill Road	CI	17	7	10		31	14	11	grey-brown clay
Coalfalls	Kingsmill Road	CI	18	7	7		48	33	15	stony brown clay
Coalfalls	Kingsmill Road	CI	19	8	5		46	29	15	brown stony clay
Coalfalls	Kingsmill Road	CI	20	5	6	2	43	28	12	brown clay
Coalfalls	Kingsmill Road	CH	30	7	2		88	70	21	brown clay
Coalfalls	Kingsmill Road	CH	24	9	3		56	41	16	brown silty clay
Rosewood	Kingston Street	CH								
Redbank	Kruger Parade	CH	34	2	3		79	54	19	dark brown clay
Redbank	Kruger Parade	CH	33	6	2	1	74	61	20	black clay
Redbank	Kruger Parade	CH	29	3	3		64	45	18	mottled grey clay
Redbank	Kruger Parade	CH	26	4	3		64	45	18	mottled grey clay
Redbank	Kruger Parade	CI	15	12	20	7	43	22	12	reddish grey clayey shale
Redbank	Kruger Parade	CI	15	30	22		37	15	9	orange/red/grey clayey shale
Redbank	Kruger Parade	CI	14	9	9		40	25	13	reddish brown silty clay
Redbank	Kruger Parade	CH	21	8	3		64	42	17	greyish brown clay
Calvert	Kuss Road	CH	19	14	4		53	33	17	black clay
Calvert	Kuss Road	CI	14	29	7	5	35	21	11	brown silty clay
Camira	Lacey Street	CI								
Camira	Langley Road	ML	3	13	17		18	2	1	brown stony sand
Camira	Langley Road	CI	14	27	19		32	13	8	mottled grey-orange sandy, silty
Camira	Langley Road	ML	5	52	17		17	2	1	Brown sand
Camira	Langley Road	CI	14	22	18		35	14	10	mottled grey-orange sandy, silty
Camira	Langley Road	CL	17	17	16	9	28	13	7	mottled grey-orange sandy, silty
Camira	Langley Road	ML	5	32	14		21	4	1	Grey sand
Camira	Langley Road	CL	13	40	17		27	14	7	mottled grey-orange sandy, silty
Goodna	Layard Street	CL	15	8	11		25	13	7	Mottled red grey sandy silty clay
Goodna	Layard Street	SC	5	25	19		23	3	2	brown coarse sand
Goodna	Layard Street	CI	9	16						brown silty clay
Ipswich	Limestone Street	CH								
Churchill	Lobb Street - Perry Street Intersection	ML	16	14	10		21	8	5	orange brown clayey loam
Churchill	Lobb Street - Perry Street Intersection	CL	9	15	10	13	23	10	7	orange/yellow loamy clay

Churchill	Lobb Street - Perry Street Intersection	ML	7	32	14		21	3	1	orange brown loam
Karalee	Lyndon Way	ML	5	> 60	16		22	10	4	brown silty sand
Karalee	Lyndon Way	SC	8	16	18		24	13	6	mottled clay in coarse sand
Karalee	Lyndon Way	CH	22	4	4		76	52	21	mottled brown orange grey clay
Karalee	Lyndon Way	ML	5	56	18		16	5	2	light brown silty sand
Karalee	Lyndon Way	ML	4	> 60	20		17	5	3	light brown silty sand
Karalee	Lyndon Way	ML	7	48	19	21	19	6	3	brown silty sand
Karalee	Lyndon Way	ML	3	> 60	20		18	6	2	creamy light brown sand
Karalee	Lyndon Way	ML	5	30	20		19	4	2	light brown sand
Sadliers Crossi	Macfarlane Street	CH	15	25	5		53	37	15	mottled brown orange silty clay
Sadliers Crossi	Macfarlane Street	CL	6	24	15	28	17	5	2	brown silty sand
Sadliers Crossi	Macfarlane Street	CH	21	15	3		70	51	17	mottled red orange grey clay
Rosewood	Makepeace Street	CH	26	3	3		65	43	20	brown clay
Rosewood	Makepeace Street	CH	25	3	6	2	52	32	16	brown stony clay
Rosewood	Matthew Street	CH	20	16	3		59	44	19	dark brown silty clay
Rosewood	Matthew Street	CH	21	11	3		52	43	19	dark brown grey clay
Rosewood	Matthew Street	CH	25	6	3		63	47	20	dark brown silty clay
Rosewood	Matthew Street	CI-CH	19	10	4	3	50	37	17	dark grey brown silty clay
Rosewood	Matthew Street	CI-CH	23	9	4	3	50	37	17	dark grey brown silty clay
Rosewood	Matthew Street	CI-CH	19	9	4	3	50	37	17	dark grey brown silty clay
Rosewood	Matthew Street	CH	17	11	4		55	41	18	dark grey brown silty clay
Rosewood	Matthew Street	CH	29	6	4		55	41	18	dark grey brown silty clay
Redbank Plain	McLean Street	CI	11	17	13		42	22	10	Brown sandy silty clay
Redbank Plain	McLean Street	ML	8	30	12		28	14	6	brown silty sand
Redbank Plain	McLean Street	ML	9	22	13		24	10	4	sandstone
Camira	Meier Road	ML	6	50	18		27	11	5	sandstone
Camira	Meier Road	ML	3	60	21		15		0	light brown sandstone
Camira	Meier Road	ML	3	29	17		17	4	2	light brown sandstone
Camira	Meier Road	ML	9	60	14		33	18	8	orange brown sandstone
Camira	Meier Road	ML	2	50	19	30	21		1	brown sand
Carole Park	Mica Street	CH	23	10			53	33	14	red orange grey mottled clay

Carole Park	Mica Street	CL-CI	13	8			31	18	10	yellow grey mottled clay
Purga	Middle Road	CL-CI	17	15	11		31	18	10	reddish brown silty clay (some stone)
Purga	Middle Road	CL-CI	16	8	11		31	18	10	reddish brown silty clay
Purga	Middle Road	CI	20	7	6	5	40	24	13	brown silty clay
Purga	Middle Road	CI-CH	23	4	4		49	30	16	brown clay
Purga	Middle Road	CI	18	18	6		47	31	13	black silty clay
Purga	Middle Road	CI	18	25	5		49	35	14	reddish brown clay
Purga	Middle Road	ML	9	> 60	19	32	34	4	2	decomposing granite
Purga	Middle Road	CL	8	13	19		30	14	8	orange brown gravelly sandy clay
Purga	Middle Road	CL	14	10	11		24	12	5	brown sandy clay
Purga	Middle Road	CL-ML	17	14	12		21	5	3	Orange - grey - brown sandy clay
Purga	Middle Road	CI	12	13	12		31	17	10	brown silty, sandy clay with some gravel
Purga	Middle Road	CI	17	6	6		38	26	12	black clay
Brassall	MiHi Street	CH	20	7			60	43	19	black clay
Brassall	MiHi Street	CH	18	10			48	29	14	black clay
Rosewood	Mill Street	CH	30	8	2		77	51	21	dark brown clay
Rosewood	Mill Street	CH	31	7	3		67	44	20	black clay
Bellbird Park	Moonyean Street	ML	5	> 60			19	2	1	brown sand
Bellbird Park	Moonyean Street	ML	4	60			19	1	1	brown silty sand
Bellbird Park	Moonyean Street	CI	16	10			38	24	12	orange brown mottled clay
Bellbird Park	Morgan Street	CI	15	6			45	25	14	brown silty clay
Bellbird Park	Morgan Street	CH	23	6	4		54	34	18	brown clay
Bellbird Park	Morgan Street	CI	19	15			45	25	14	brown silty clay
Bellbird Park	Morgan Street	CI	17	15	5		48	25	15	mottled brown orange grey clay
Bellbird Park	Morgan Street	CI	17	9	5		45	25	14	brown silty clay
Bellbird Park	Morgan Street	CH	20	9			54	34	18	brown clay
Bellbird Park	Morgan Street	CI	17	16	7		44	22	12	brown silty clay
North Ipswich	Murray Streeet	CI	13	22	7		44	29	12	reddish brown clay
North Ipswich	Murray Streeet	CH	11	36	3	2	61	44	15	reddish brown clay
North Ipswich	Murray Streeet	CI	15	13	10		37	21	10	dark stony silty clay
Collingwood P	Namatjira Drive	CL	12	18	14		24	12	6	mottled red/pink/brown sandy clay (stony)
Collingwood P	Namatjira Drive	CI	8	18	10	8	29	17	8	reddish brown sandy clay
Collingwood P	Namatjira Drive	CI	13	12	7		32	22	11	mottled reddish grey clay
Calvert	Newcastle - Wilsom St	CI								
North Booval	North Station Road	CI	27	3	5		45	24	13	brown silty clay
North Booval	North Station Road	CH	21	10	5		45	24	13	brown silty clay
North Booval	North Station Road	CH	24	10	3		57	36	18	brown clay

North Booval	North Station Road	CI	20	20	5		44	28	15	brown silty clay
North Booval	North Station Road	CI	17	22	5	5	42	31	14	brown silty clay
Riverview	Old Ipswich Road	CI-CH	17	3	10		48	26	14	ironstone clay
Riverview	Old Ipswich Road	CH	28	4	3		76	47	19	rusty grey clay
Riverview	Old Ipswich Road	CI	14	42	7		44	28	13	red loamy clay, white specks
Riverview	Old Ipswich Road	CH	22	30	4		63	41	17	red loamy clay
Riverview	Old Ipswich Road	CH	15	29	12	9	51	31	13	mottled red brown clayey loam
Riverview	Old Ipswich Road	CI	12	27	10		34	19	9	grey brown loamy soil
Leichhardt	Old Logan Road	ML	6	34	30		16		0	light brown gravelly sand
Leichhardt	Old Logan Road	ML	4	44	16		16		0	light brown stony sand
Leichhardt	Old Logan Road	ML	3	40	15	34	18		0	light brown sand
Leichhardt	Old Logan Road	CL	6	25	16		21	9	3	orange silty clayey sand
Leichhardt	Old Logan Road	CI	9	> 60	19		37	15	5	yellow white orange sandstone
Leichhardt	Old Logan Road	CI	13	26	9		36	22	11	mottled pink/grey/orange decomposing sandstone
Leichhardt	Old Logan Road	CI	7	10	15		38	19	8	Yellow/white/orange silts sandstone
Leichhardt	Old Logan Road	CI-ML	5	34	13		19	6	1	orange/brown silty sand
Leichhardt	Old Logan Road	ML	6	10	14	44	17	1	0	light brown silty sand
Leichhardt	Old Logan Road	CI-ML	7	5	13		19	6	1	orange brown silty sand
Leichhardt	Old Logan Road	CL	6	> 60	11		21	10	3	orange brown silty sand
Leichhardt	Old Logan Road	CL	7	28	10		23	11	6	mottled orange/brown sandy clay
Leichhardt	Old Logan Road	CI	18	24	6		46	28	13	mottled orange/brown sandy clay
Leichhardt	Old Toowoomba Road	CH	34	23	2		84	61	23	grey brown clay
Leichhardt	Old Toowoomba Road	CH	27	7	2		73	56	23	black clay
Leichhardt	Old Toowoomba Road	CH	25		2		80	58	20	black clay
Leichhardt	Old Toowoomba Road	CH	23	7	4		56	41	18	brown clay
Leichhardt	Old Toowoomba Road	CH	34		1	2	90	59	26	grey black clay
Leichhardt	Old Toowoomba Road	CH	25		2	2	82	65	19	grey black clay

Leichhardt	Old Toowoomba Road	CH	12	25	16		22	9	6	orange brown loamy clay
Raceview	Oliver Street	CH	46	3	4		75	40	22	black clay
Raceview	Oliver Street	CH	56	3	1		110	68	27	brown clay
Raceview	Oliver Street	CH	51	4	3	2	73	51	21	black clay
Raceview	Oliver Street	CH	41	4	5		61	44	17	black clay
Redbank Plain	Orana Street	CH	46	2	1		109	75	30	brown clay
Redbank Plain	Orana Street	CH	22	9	4	2	51	38	18	brown clay
Redbank Plain	Orana Street	CH	22	10	3		67	49	20	brown clay
Raceview	Orchard Street	CH	18	28	5	2	58	39	18	black clay with some coal stone
Raceview	Orchard Street	CH	36	36	5	2	58	39	18	black clay with some coal stone
Raceview	Orchard Street	CH	23	12	5	2	58	39	18	clayey coalstone
Raceview	Orchard Street	CH	28	7	3		68	45	20	brown clay
Raceview	Orchard Street	CH	27	5	4		64	41	19	black gravelly clay
Raceview	Orchard Street	CH	25	13	4		61	42	18	brown silty clay
Ipswich	Outridge Street	CI	15	28	7		48	29	9	orange brown silty clay
Ipswich	Outridge Street	ML	3	>60	28		27	12	7	white sandstone
Ipswich	Outridge Street	ML	9	>60	11		31	16	9	brown silty sand
Ipswich	Outridge Street	ML	8	42	10		29	15	8	brown silty sand
Ipswich	Outridge Street	ML	10	>60	23		43	16	11	pink sandstone
Ipswich	Park Street	ML	4	32	15		15	4	1	light brown sand
Ipswich	Park Street	ML	5	20	15	42	15	2	1	brown stony sand
Ipswich	Park Street	ML	6	24	18		19	4	1	brown stony sand
Raceview	Petaine Street	CH	43	6	6		89	59	23	clayey coalstone
Raceview	Petaine Street	CL	5				22	8	3	dark brown clay
Raceview	Petaine Street	CH	37	11	2		79	59	20	brown clay
Raceview	Petaine Street	CH	31	7	7	2	73	52	21	dark brown clay
Raceview	Petaine Street	CH	41	3	6		80	61	23	grey brown clay
Redbank Plain	Philip Street	CH	28	14	2		73	47	21	brown clay
Redbank Plain	Philip Street	CH	35	6	5	1	51	29	15	brown clay
Redbank Plain	Philip Street	CH	47	4	1		87	59	25	black clay
Redbank Plain	Philip Street	CH	37	9	1		87	59	25	black clay
Redbank Plain	Philip Street	CH	35	8	2		81	56	24	brown clay
Redbank Plain	Philip Street	ML	8	>60	14		35	7	3	rotten rock
Brassall	Pine Mountain	MH	19	56	10	15	51	17	8	rotten rock
Brassall	Pine Mountain	CH	44	4	2		88	58	23	brown clay
Brassall	Pine Mountain Road	CH	38	10	3		75	42	20	Brown sandy silty clay
Brassall	Pine Mountain	CH	23	18	6		53	27	14	brown silty clay
Pine Mountai	Pine Mountain Road	OL	10	> 60	25		36	11	6	light brown loamy sandston
Pine Mountai	Pine Mountain	OL	13	48	19		39	12	8	gravelly fill
Pine Mountai	Pine Mountain Road	OL	15	> 60	23	29	40	10	7	greyish brown loamy sandstone
Pine Mountai	Pine Mountain Road	OL	11	25	18		40	15	10	light brown ridge gravel
Pine Mountai	Pine Mountain	ML	4	> 60	22		18	2	2	reddish gravelly silt
Pine Mountai	Pine Mountain Road	ML	6	> 60	16		23	9	6	orange white sandstone

Pine Mountai	Pine Mountain Road	ML	4	22	17	30	19		0	orange white sandstone
Pine Mountai	Pine Mountain Road	CI	11	27	9		32	18	9	mottled orange grey sandy clay
Pine Mountai	Pine Mountain Road	CI-CH	24	13	12		48	18	12	brown clayey gravel fill
Pine Mountai	Pine Mountain	CI	16	52	21	10	40	12	7	brown silty clay
Pine Mountai	Pine Mountain Road	CI	9	50	17		36	11	8	light sandy brown silty clay
Pine Mountai	Pine Mountain Road	CI	14	36	16	9	39	15	9	brown gravelly silty clay
Pine Mountai	Pine Mountain	CI	16	> 60	14		43	9	4	brown silty clay
North Ipswich	Pine Street	GC	8				32	16	8	basalt soil
North Ipswich	Pine Street	GC	9				32	15	8	basalt soil
North Ipswich	Pine Street	GC	8				32	16	8	basalt soil
North Ipswich	Pine Street	CH	20	17	3	2	52	32	15	red brown mottled clay
North Ipswich	Pine Street	ML	6	13	19		16	2	1	brown sand
North Ipswich	Pine Street	ML	9	38	15		26	11	6	decomposed sandstone
Churchill	Pitt Street	CL-ML	8	23	12		18	7	2	light brown silty sand
Churchill	Pitt Street	CI	16	13	6		41	28	12	mottled orange sandy clay
Brassall	Pommer Street	CL-CI	10	21	18	2	16	5	4	brown silty sand
Brassall	Pommer Street	ML	5	17	16		19	7	5	yellow brown gravelly silt
Brassall	Pommer Street	ML	9	26	16		19	7	5	yellow brown gravelly silt
Carole Park	Poplar Street	ML								
North Ipswich	Power Street	ML	13	18	9		35	16	10	pink brown silt
North Ipswich	Power Street	ML	7		22		38	14	8	coalstone
Camira	Preece Lane	ML-CL	3	25	16		20	7	4	grey stony loam
Camira	Preece Lane	ML	4	> 60	24		26	10	6	brown gravelly fill
Camira	Preece Lane	ML	3	50	15		19	7	2	light orange stony loamy sand
Churchill	Princess Street	CI-CH	14	42	6		45	32	13	mottled brown orange sandy clay
Churchill	Princess Street	CL-ML	12	14	11		21	7	4	brown silty loam
Churchill	Princess Street	CL	8	17	10	20	23	11	5	brown loam
Churchill	Princess Street	CI	18	5	5		40	28	13	mottled orange brown sandy clay
Blackstone	Queen Street	ML	17	36	9		45	23	11	pink brown silty shale
Blackstone	Queen Street	CH	21	6	3		62	45	15	mottled orange grey clay
Blackstone	Queen Street	ML	13	11	7	2	43	32	14	mottled orange grey decomposed sandstone
Blackstone	Queen Street	ML	7	30	18		23	4	1	orange grey sandy silt

Goodna	Queen Street	CL	11	50	12		27	12	8	silty sandy brown clay
Goodna	Queen Street	CL	18	24	12		27	12	8	silty sandy brown clay
Goodna	Queen Street	CL	15	7	14		27	11	6	light brown silty clay
Goodna	Queen Street	CL	13	18	20		21	3	4	grey brown gravelly sandy silt
Goodna	Queen Street	CH	22	8	4		58	37	15	mottled orange brown yellow silty clay
Goodna	Queen Street	CH	27	3	5		61	38	13	grey brown silty clay
Raceview	Raceview Street	CH	42	6	1		101	74	22	black clay
Raceview	Raceview Street	CH	42	11	2		94	68	21	black clay
Raceview	Raceview Street	CH	41	9	2	2	89	66	22.5	black clay
Raceview	Raceview Street	CH	38	8	2		95	67	23	black clay
Raceview	Raceview Street	CH	27	5	2		95	67	23	black clay
Raceview	Raceview Street	CH	40	10	2		95	67	23	black clay
Raceview	Raceview Street	CH	24	14	13		50	33	16	black clay
Rosewood	Railway Street	CH	16	18	8		40	23	12	dark brown loamy clay
Rosewood	Railway Street	CH	26	8	3		67	51	19	black clay
Rosewood	Railway Street	CH	29	5	3		67	51	19	black clay
Rosewood	Railway Street	CH	28	4	4	2	54	40	16	dark brown clay
Rosewood	Railway Street	CH	26	4	2		65	52	20	black clay
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	ML	17	45	11		43	18	11	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	ML	12	> 60	22	24	38	10	5	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	ML	11	54	30	16	47	18	10	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	CH	30	12	2		81	46	25	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	ML	14		26	28	44	15	9	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	CH		11	4		58	32	19	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	ML	20	11	15	24	46	16	10	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	CI	17	12	8		38	21	11	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	CH	42	6	2		93	61	25	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	ML	12	> 60	25	40	38	10	4	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	CH	20	8	8	6	53	30	14	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	CH	37	11	2		102	60	25	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	CH	37	40	3		65	39	20	

Bellbird Park	Redbank Plains Rd (Jones to Shirley)	CI	19	8	11		40	20	10	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	CI	14	16	10	18	40	18	11	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	CH	32	4	2	4	73	43	22	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	ML	15	> 60	25	30	35	7	4	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	ML	15	48	18		41	13	6	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	ML	16	27	13	24	42	16	9	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	CH	34				75	45	23	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	ML	5	> 60	15		22	5	3	
Bellbird Park	Redbank Plains Rd (Jones to Shirley)	ML	4	> 60	15		20	3	2	
Blackstone	Redbank Plains Rd (Mary to Cunningham Hwy)	CL	13	9	11		32	16	9	Brownish grey silty sandy clay with stone
Blackstone	Redbank Plains Rd (Mary to Cunningham Hwy)	CI	13	11	10		36	19	11	brown sandy clay
Blackstone	Redbank Plains Rd (Mary to Cunningham Hwy)	CI	14	10	10	4	38	22	10	mottled orange-brown-white clay
Blackstone	Redbank Plains Rd (Mary to Cunningham Hwy)	CL	11	16	11		34	18	11	Stony mottled orange-brown-grey sandy clay
Blackstone	Redbank Plains Rd (Mary to Cunningham Hwy)	CL	15	6	15		35	15	10	grey stony sandy clay
Blackstone	Redbank Plains Rd (Mary to Cunningham Hwy)	CI	21	4	9	2	37	21	9	reddish brown clay
Blackstone	Redbank Plains Rd (Mary to Cunningham Hwy)	CI	21	6	6		46	25	13	mottled orange - brown sandy clay
Blackstone	Redbank Plains Rd (Mary to Cunningham Hwy)	CI	17	5	8		39	20	12	orange brown stony clay
Blackstone	Redbank Plains Rd (Mary to Cunningham Hwy)	CI	16	5	9		36	18	11	grey stony silty clay
Blackstone	Redbank Plains Rd (Mary to Cunningham Hwy)	CL	16	5	12		33	18	10	brown silty sandy clay
New Chum	Redbank Plains Rd	CL, CI	10	28	15		31	16	10	brown stony silty clay
New Chum	Redbank Plains Rd	CI			11	7	42	23	13	grey shaly
New Chum	Redbank Plains Rd	CI		9	6		48	24	12	reddish brown clay

New Chum	Redbank Plains Rd	CI		9	6		46	23	13	reddish brown clay
New Chum	Redbank Plains Rd	CI		6	6		44	22	12	reddish brown clay
New Chum	Redbank Plains Rd	CH		6	3		64	36	17	reddish orange clay
New Chum	Redbank Plains Rd	CH			3	3	72	43	18	orange clay
New Chum	Redbank Plains Rd	MH			4	2	66	36	18	shaly mudstone with seams of clay
New Chum	Redbank Plains Rd	CI-CH			7	6	49	30	15	light brown siltstone
New Chum	Redbank Plains Rd	MH		32	2		76	46	21	reddish orange clay
New Chum	Redbank Plains Rd	CI			17	44	34	15	5	orange white sandstone
New Chum	Redbank Plains Rd	CL-CI			10	23	30	14	8	siltstone and reddish soil
New Chum	Redbank Plains Rd	ML		10	7		42	22	12	orange clay
New Chum	Redbank Plains Rd	CI			9	15	35	15	9	sandstone
New Chum	Redbank Plains Rd	CI		17	14		31	11	8	grey silty clay
New Chum	Redbank Plains Rd	CI		3	11	8	31	15	9	mottled orange sandy clay
New Chum	Redbank Plains Rd	CL	9	29	12	19	21	10	5	broen silty clay
New Chum	Redbank Plains Rd	CH		13	3		64	38	17	orange red clay
New Chum	Redbank Plains Rd	CI			6	3	44	25	13	orange clay
New Chum	Redbank Plains Rd	CH		22	5		55	31	14	creamy brown clay
New Chum	Redbank Plains Rd	CI			26	11	45	22	11	Coalstone material
New Chum	Redbank Plains Rd	CH			5		52	29	14	Greenish grey clay
New Chum	Redbank Plains Rd	CH			5		54	35	15	Mottled orange-red clay
New Chum	Redbank Plains Rd	CI		11	6		46	24	13	Mottled orange-red clay
Redbank Plain	Redbank Plains Rd	CL	5	> 60	15		23	7	5	red sandy silty decomposing sandstone
Redbank Plain	Redbank Plains Rd	CH	46	7	2		78	59	22	black clay
Redbank Plain	Redbank Plains Rd	CI-CH	14	16	11		50	14	6	Brown sandy silty clay
Redbank Plain	Redbank Plains Rd	CI	19	9	7		47	29	12	rotten rock
Redbank Plain	Redbank Plains Rd	CH	43	4	10		71	43	19	green black sandy silty clay
Redbank Plain	Redbank Plains Rd	CH	45	4	1		119	91	25	black clay
Redbank Plain	Redbank Plains Rd	CH	59	4	1		119	91	25	black clay
Redbank Plain	Redbank Plains Rd	CI	14	>60	12		39	18	9	light grey white silt powder
Redbank Plain	Redbank Plains Rd	MH	30	12	3		69	47	19	brown black clay with white specks
Redbank Plain	Redbank Plains Rd	CI	19	46	7		47	29	12	rotten rock
Redbank Plain	Redbank Plains Rd	CI	20	29	19	19	46	14	6	light brown sandy silty clay
Redbank Plain	Redbank Plains Rd	CI	14	8	12		35	16	9	brown silty sandy clay
Redbank Plain	Redbank Plains Rd	CH	30	8	12		63	36	18	brown silty clay
Redbank Plain	Redbank Plains Rd	CH	26	16	5		68	45	20	dolomote clay
Redbank Plain	Redbank Plains Rd	CH	70	2	1	1	110	75	28	black clay
Redbank Plain	Redbank Plains Rd	CH	40	22		1	110	75	28	black clay

Redbank Plain	Redbank Plains Rd	CH	52	3		1	110	75	28	black clay
Redbank Plain	Redbank Plains Rd	CH	38	11		1	110	75	28	black 'greasy back' clay
Redbank Plain	Redbank Plains Rd	CH	36	22		1	110	75	28	black 'greasy back' clay
Redbank Plain	Redbank Plains Rd	CH	36	15	2		92	58	24	brown clay
Redbank Plain	Redbank Plains Rd	MH	40	11		1	110	75	28	black 'greasy back' clay
Redbank Plain	Redbank Plains Rd	CI	11	> 60	16	36	36	9	7	rotten rock
Redbank Plain	Redbank Plains Rd	ML	23	15	6		48	26	13	grey silt clay
Redbank Plain	Redbank Plains Rd	CI	14	16	9	7	41	23	12	clayey rotten rock
Redbank Plain	Redbank Plains Rd	CH	42	6	3	3	66	43	20	black silty clay
Redbank Plain	Redbank Plains Rd	CH	48	4	3	3	66	43	20	black silty clay
Redbank Plain	Redbank Plains Rd	CH	33	4	3	3	66	43	20	black silty clay
Redbank Plain	Redbank Plains Rd	ML	10	60	15		26	10	5	brown decomposing
Redbank Plain	Redbank Plains Rd	ML	7	60	24		27	10	6	pinkish white sandstone
Redbank Plain	Redbank Plains Rd	ML	7	27	11	15	28	12	8	brown silt
Redbank Plain	Redbank Plains Rd	CI	10	22	13	7	35	17	10	orange brown silty clay
Redbank Plain	Redbank Plains Rd	ML	8	22	18		30	13	7	brown silt
Redbank Plain	Redbank Plains Rd	ML	3	60	20		21	7	3	pink white sandstone
Bellbird Park	Redbank Plains Rd	CH	39	5	2		100	67	23	mottled orange brown clay
Bellbird Park	Redbank Plains Rd	CH	37	4	2		92	62	23	brown grey clay
Mt.Walker	Rielly's Road	CH	22	9	3		61	39	21	light brown clay
Mt.Walker	Rielly's Road	CH	23	10	3		60	29	20	dark brown clay
Mt.Walker	Rielly's Road	CH	21	23	3		68	35	21	brown clay
Mt.Walker	Rielly's Road	CI-CH	18	19	11		50	28	17	loamy brown clay
Mt.Walker	Rielly's Road	CH	25	11	2		67	40	21	brown clay
Mt.Walker	Rielly's Road	MH	19	16	4		58	37	20	brown clay
Flinders View	Ripley Road	MH	21	60	15		59	28	16	reddish brown rotten rock
Flinders View	Ripley Road	MH	29	12	15		59	28	16	decomposing rock
Flinders View	Ripley Road	ML	8	10	13		26	10	7	brown loam
Flinders View	Ripley Road	CH	24	25	4	3	59	43	19	brown silty clay
Flinders View	Ripley Road	CH	48	4	1		120	83	27	black clay
Flinders View	Ripley Road	CH	43	9	1		120	83	27	black clay
Flinders View	Ripley Road	CI	19	12	7		43	25	14	brown silty clay
Flinders View	Ripley Road	CI	12	22	19		31	17	8	dark brown black clay
Flinders View	Ripley Road	SC	9	27	12		26	11	6	light brown silty sand
Flinders View	Ripley Road	SC	16	17	13	13	38	13	7	brown silty sand
Flinders View	Ripley Road	SC	9	26	16		31	14	8	light brown silty sand
Ripley	Ripley Road	CI	17	11	13		40	16	9	brown silty clay
Ripley	Ripley Road	CL	6	15	16	7	25	7	3	sandy
Ripley	Ripley Road	CL	4	> 60	19		33	10	6	sandstone

Ripley	Ripley Road	ML	3	> 60	19	8	20		1	reddish orange sandy
Ripley	Ripley Road	CI	10	34	16		31	13	9	decomposing clayey sandstone
Ripley	Ripley Road	ML	3	60	16	36	21		1	sandy silt
Ripley	Ripley Road	ML	9	6	16		22	4	3	decomposing sandstone
Ripley	Ripley Road	ML	4	18	17		22	2	1	silty sand
Ripley	Ripley Road	CL	9	42	11	5	32	15	7	decomposing clayey sandstone
Ripley	Ripley Road	CL	9	22	10		32	14	8	orange brown silty clay
Ripley	Ripley Road	ML	4	14	16	28	22	3	1	orange silty sand decomposing sandstone
Ripley	Ripley Road	CI	8	48	9		33	19	10	brown clay
Ripley	Ripley Road	CL	11	6	10		28	13	8	grey clay
Ripley	Ripley Road	ML	8	7	14	22	22	4	2	brown clayey sand
Ripley	Ripley Road	CI	9	28	22		36	14	8	sandy loamy shale
Ripley	Ripley Road	CI	11	25	13		33	11	7	brown decomposing
Ripley	Ripley Road	CI	10	19	12	13	34	14	7	brown orange loamy clay shale sandstone
Ripley	Ripley Road	CI	9	56	11		31	10	7	brown decomposing
Ripley	Ripley Road	CI	9	21	12	15	32	13	5	brown sandy silt
Ripley	Ripley Road	CL	6	> 60	14		28	4	5	sandstone
Ripley	Ripley Road	CL-CI	10	30	10	5	30	14	7	brown silty sandy clay
Dinmore	River Road	ML	7	27	14		17	4	2	grey silt
Dinmore	River Road	ML	5	52	14		21		1	brown silty sand
Dinmore	River Road	CH	22	6	4	3	56	34	17	mottled red grey clay
Dinmore	River Road	ML	4	>60	N		20	6	3	sandstone
Dinmore	River Road	CH	19	19	5		56	34	14	orange silty clay
Karalee	Riverside Avenue	ML	4	29	14		22	8	5	grey silty sand
Karalee	Riverside Avenue	SM	9	38	12	9	23	9	6	brown sandy silt
Karalee	Riverside Avenue	CI	22	4	7		36	18	10	dark brown loamy clay
Karalee	Riverside Avenue	CI	20	11	7		36	18	10	dark brown loamy clay
Karalee	Riverside Avenue	CI	24	7	5	3	42	24	14	black loamy clay
Karalee	Riverside Avenue	CI	24	7	7		36	18	10	dark brown laomy clay
Riverview	Riverview Depot	CH	27	2	4	0	60	41	17	mottled orange pink maroon clay
Riverview	Riverview Depot	CI	18	5	7		38	24	12	dark brown clay
Riverview	Riverview Depot	CH	21	4	4	0	60	41	17	mottled orange pink maroon clay
Riverview	Riverview Depot	CI	14	4	9		28	18	9	mottled grey orange brown clay

Riverview	Riverview Depot	CI	24	2	7		41	27	12	dark brown loamy stony clay
Riverview	Riverview Depot	CH	24	2	4	0	60	41	17	mottled orange pink maroon clay
Riverview	Riverview Depot	CH	23	2	4	0	60	41	17	mottled orange pink maroon clay
Riverview	Riverview Depot	CH	22	3	5		57	38	15	mottled brown pink grey maroon
Riverview	Riverview Depot	CI	15	4	12		37	24	9	Brown/grey/pinkish sandy stony clay
Riverview	Riverview Depot	CI	20	3	6		44	28	14	dark grey-black
Riverview	Riverview Depot	CH	21	4	4		55	37	17	mottle dorange brown clay
North Ipswich	Robert's Street	CH	24	10	4		55	31	14	orange white mottled clay
North Ipswich	Robert's Street	CI	14	22	13		35	16	10	orange brown shaly clay
North Ipswich	Robert's Street	CH	18	10	4		55	31	14	orange white mottled clay
North Ipswich	Robert's Street	CH	26	3	4	15	55	31	14	orange white mottled clay
Raceview	Robertson Road	CI-CH	62	2	1		110	70	26	black clay
Raceview	Robertson Road	CI-CH	28	5	5		52	29	16	speckled black clay
Raceview	Robertson Road	CH	24	6	6		51	35	14	black clay
Raceview	Robertson Road	CH	55	10	1		124	81	30	black clay
Raceview	Robertson Road	CH	39	3	2	1	91	71	24	black clay
Ipswich	Roderick Street	CI	8	44	13	12	32	16	9	light brown silty clay
Ipswich	Roderick Street	CI	8	30	9		36	21	11	light greyish brown silty clay
Ipswich	Roderick Street	CI	12	9	13	12	32	16	9	light brown silty clay
Ipswich	Roderick Street	CL	16	9	8		42	23	13	orange brown silty clay
Ipswich	Roderick Street	CL	16	10	12		27	14	8	orange brown sandy clay
Ipswich	Roderick Street	CL-CI	13	17	11		30	17	10	yellow brown silty clay
Ipswich	Roderick Street	CL	12	13	11		29	15	8	mottled orange brown grey silty clay
North Booval	Roma Street	CL	6				29	11	5	coalstone soil
North Booval	Roma Street	CH	28	10	3		76	57	19	dark brown clay
North Booval	Roma Street	CI	51	7	3		81	62	19	coalstone soil clayey
North Booval	Roma Street	CH	51	3	3		81	62	19	greyish black clay
Woodend	Roseberry Parade/Elizabeth Street intersection	OL	9	17	12		34	12	7	brown silt
Woodend	Roseberry Parade/Elizabeth Street intersection	CL-ML	9	>60	17		24	6	6	grey shale

Redbank Plain	Rosemary Street	CL-CI	38	2	5		48	27	13	dark brown clay
Redbank Plain	Rosemary Street	CH	20	8	3		71	53	19	brown silty clay
Redbank Plain	Rosemary Street	CH	20	9	2		78	59	20	orange reddish clay
Redbank Plain	Rosemary Street	ML	5	36	17		14	1	1	light brown silty sand
Redbank Plain	Rosemary Street	CH	21	10	3		69	50	18	mottled grey sandy clay
Rosewood	Rosewood-Laidley Road	CI								
Rosewood	Rosewood-Thagoona Road	CH	16	13	4		50	37	17	greyish brown clay
Rosewood	Rosewood-Thagoona Road	CI	15	25		4	43	28	12	coalstone soil
Rosewood	Rosewood-Thagoona Road	CI	16		10	7	43	28	12	coalstone soil
Rosewood	Rosewood-Thagoona Road	CH	24	4	3	4	50	34	17	dark brown clay
Rosewood	Rosewood-Thagoona Road	CI	17	18		4	43	28	12	coalstone soil
Rosewood	Rosewood-Thagoona Road	CI	18	9		4	43	28	12	coalstone soil
Rosewood	Rosewood-Thagoona Road	CH	22	8	3		56	40	18	brown clay
Rosewood	Rosewood-Thagoona Road	CI	15	34		4	43	28	12	coalstone soil
Rosewood	Rosewood-Thagoona Road	CH	19	15	7		64	46	18	greyish brown clay
Rosewood	Rosewood-Thagoona Road	CI	10	11		4	43	28	12	coalstone soil
Rosewood	Rosewood-Thagoona Road	CH	33	2	5		66	49	20	light brown clay
Rosewood	Rosewood-Thagoona Road	CL-CI	8	36			30	15	7	grey brown soil aggregate
Rosewood	Rosewood-Thagoona Road	CH	**24**	5	5		66	49	20	grey brown clay
Rosewood	Rosewood-WarrillView Road	CI-CH								
Ebbw Vale	Ross Street	CI	14	13	7		37	23	12	brown silty clay
Ebbw Vale	Ross Street	CH	19	7	5	3	52	37	15	reddish brown clay
Ebbw Vale	Ross Street	CH	23	6	5	3	52	37	15	mottled reddish brown silty clay
Raceview	Rumsey Drive	CL/ML	17	10	31	23	34	6	5	rotten rock
Raceview	Rumsey Drive	CL/ML	10	50	31	23	34	6	5	rotten rock
Redbank Plain	Russell Drive	CI	21	30	10		46	29	12	rotten rock and dolomite
Redbank Plain	Russell Drive	CH	32	10	5	6	60	41	20	stony black grey clay
Redbank Plain	Russell Drive	CI-CH	24	10	7		51	29	13	dolomite clay
Redbank Plain	Russell Drive	CH	42	5	2		93	71	20	black clay
Redbank Plain	Russell Drive	CH	43	4	2		93	71	20	black clay
Redbank Plain	Russell Drive	CH	43	3	2		93	71	20	black clay
Redbank Plain	Russell Drive	CH	44	2	2		103	83	18	black clay

Redbank Plain	Russell Drive	CH	52	3	2		103	83	18	black clay
Redbank Plain	Russell Drive	CH	29	5	4	2	62	40	19	stony black clay
Redbank Plain	Russell Drive	ML	12	26	23		35	11	6	brown rotten rock
Redbank Plain	Russell Drive	CH	41	3	2		77	56	21	black clay
Redbank Plain	Russell Drive	ML	14	27	23		35	11	6	brown rotten rock
Redbnk	Riverview-Redbank	SC	3	> 60	13		21	3	1	orange red silty sand
Redbnk	Riverview-Redbank	ML				7	14	17	9	decomposed sandstone
Redbnk	Riverview-Redbank	CL				5-5.5	20	32	13	red clay
Redbnk	Riverview-Redbank	ML				5	18	14	9	decomposing sandstone
Redbnk	Riverview-Redbank	ML				15	15	15	6	sandstone and shale
Redbnk	Riverview-Redbank	ML				11	17	14	8	shaly material
Redbnk	Riverview-Redbank	CL				5	15	15	9	clayey shale
Redbnk	Riverview-Redbank	CH	21	4			70	48	20	dark brown loamy clay
Redbnk	Riverview-Redbank	CH	24	9			73	49	12	dark brown loamy clay
Redbnk	Riverview-Redbank	CI	15		6		48	33	7	orange brown mottled clay
Redbnk	Riverview-Redbank	ML	6	9	11		23	12	6	brown loam
Redbnk	Riverview-Redbank Connection Road	ML	7	44	8	6	41	26	13	orange decomposing sandstone
Redbnk	Riverview-Redbank	CI	11	60	14		33	19	9	red orange clay
Redbnk	Riverview-Redbank	CI	7	60	23		39	21	6	brown clayey shale
Redbnk	Riverview-Redbank	CI	11	29	14		33	19	9	red sandy clay
Redbnk	Riverview-Redbank	CI	8	> 60			37	24	10	brown shaly soil
Redbnk	Riverview-Redbank	CI	10	29	10		37	20	11	brown loamy soil
Redbnk	Riverview-Redbank	CI	9	28	11	10	27	14	7	brown sandy loamy clay
Redbnk	Riverview-Redbank	CI	14	15	10		33	19	4	dark grey laomy clay
Redbnk	Riverview-Redbank	CH	16	48	4		64	47	16	mottled greyish red clay
Eastern Heigh	Salisbury Road	ML	14	48	14		41	8	7	brown decomposed
Eastern Heigh	Salisbury Road	ML	16	50	14		41	8	7	brown decomposed
Eastern Heigh	Salisbury Road	CH	20	18	5	2	55	30	16	dark brown silty clay

Eastern Heigh	Salisbury Road	CH	24	12	4		53	27	18	red clay with white pebbles
Leichhardt	Samford Road	CI	10	46;36	13		38	24	14	orange silty clay
Leichhardt	Samford Road	CI	20	15	6		46	30	14	orange silty clay
Leichhardt	Samford Road	CH	25	8.5;7.5	3		67	43	20	orange clay
Leichhardt	Samford Road	ML	8	27;41;44	16		17	5	3	brown stony silt
Leichhardt	Samford Road	CI	20	7	6	11	46	30	14	orange silty clay
Ironbark	Schultz's Road	CL-CH	13	48						brown silt
Ironbark	Schultz's Road	CL-CH	13	28						brown silt
Ironbark	Schultz's Road	CL-CH	18	30						reddish brown pebbly clay
Ironbark	Schultz's Road	CL-CH	22	20						reddish brown pebbly clay
Ironbark	Schultz's Road	CL-CH	13	26						brown silty clay
Ironbark	Schultz's Road	CL-CH	19	26						reddish brown clay
Ironbark	Schultz's Road	CL-CH	15	28						chocolate brown clay
Ironbark	Schultz's Road	CL-CH	17	21						chocolate brown clay
Marburg	Seminary Road	CL-CH								
Redbank Plain	Shanahan Parade	ML-CH	38	7	1		107	73	26	black silty clay
Redbank Plain	Shanahan Parade	ML-CH	43	7	1		107	73	26	black silty clay
Redbank Plain	Shanahan Parade	ML	19	10	20		42	7	6	light brown decomposed rock
Redbank Plain	Shanahan Parade	CH	34	9	3		66	40	19	dark brown clayey decomposed rock
Redbank Plain	Shanahan Parade	ML	26	12	9	7	47	14	10	reddish brown decomposed rock
Redbank Plain	Shanahan Parade	ML	12	60	22		34	9	5	decomposed rock
Redbank Plain	Shannon Street	CH	33	7	3		74	52	20	brownish black clay
Redbank Plain	Shannon Street	CH	37	5	2		88	64	20	black clay
Redbank Plain	Shannon Street	CH	38	6	2	2	81	56	22	black clay
Redbank Plain	Shannon Street	CH	36	6	2	2	81	56	22	black clay
Redbank Plain	Shannon Street	CI	21	20	12		45	18	8	light brown rotten rock
Redbank Plain	Shannon Street	OL	12	> 60	13	11	36	8	6	rotten rock
Redbank Plain	Shannon Street	CI	15	46	12		39	10	6	light brown rotten rock greenish tinge
Redbank Plain	Shannon Street	CH	37	3	3		70	47	20	black clay
Redbank Plain	Shannon Street	CH	36	3	2		90	66	23	greyish black clay
Churchill	Short Street	CI	14	22	8		31	18	8	mottled orange yellow sandy clay
Churchill	Short Street	CH	12	25	5		64	47	18	mottled orange yellow sandy clay
Redbank Plain	Siedofsky Street	CH	47	6	2	2	84	55	25	black clay
Redbank Plain	Siedofsky Street	CH	34	13	2	2	84	55	25	black clay
Redbank Plain	Siedofsky Street	CH	31	18	2	2	84	55	25	black clay
Redbank Plain	Siedofsky Street	CH	32	14	3		78	44	21	brown clay
Redbank Plain	Siedofsky Street	CI	24	14	8		48	18	9	brown silty clay
Leichhardt	Siemon Street	CH	30	4	2		85	62	19	brown clay
Leichhardt	Siemon Street	CI	21	9	5	3	41	26	17	brown loamy clay
Leichhardt	Siemon Street	CH	30	19	2		84	58	17	dark brown clay

Riverview	Slone Street	CI	15	18	8		36	11	8	brown loamy clay
Riverview	Slone Street	CI	15	40	8		36	11	8	Brown loamy clay
Riverview	Slone Street	CH	20	27	4		63	41	17	Reddish brown stony clay
Riverview	Slone Street	CI	18	15	8	10	36	11	8	brown loamy clay
Riverview	Slone Street	CH	24	11	2		66	44	15	red clay
Goodna	Smith's Road (Richardson & Stuart)	CL	9	23	15		21	8	4	brown silty clay
Goodna	Smith's Road (Richardson & Stuart)	CH	22	10	4		64	44	15	Reddish brown clay
Goodna	Smith's Road (Richardson & Stuart)	CL	7	38	14		22	8	5	red sandy silt
Goodna	Smith's Road (Richardson & Stuart)	CH	19	21	4		64	44	15	reddish brown clay
Goodna	Smith's Road (Richardson & Stuart)	CL	20	4	11		26	10	8	greyish brown clay
Goodna	Smith's Road (Richardson & Stuart)	CL	10	16	18		20	3	1	Dark grey sandy silt
Goodna	Smith's Road (Richardson & Stuart)	CL	13	21	12	29	19	6	3	grey silty clay
Goodna	Smith's Road (Richardson & Stuart)	CH	18	20	5		51	33	14	light brown clay
Goodna	Smith's Road (Richardson & Stuart)	CL	17	30	8		34	20	10	brown sandy clay
Goodna	Smith's Road (Richardson & Stuart)	CH	20	34	5		50	32	13	Red/brown mottled clay
Goodna	Smith's Road (Queen to William)	CI	16	10	10		32	21	11	brown gravelly clay
Goodna	Smith's Road (Queen to William)	CI	21	5	6	2	44	31	12	brown black clay
Goodna	Smith's Road (Queen to William)	CL	10	10	19		24	13	4	brown black gravelly silty clay
Goodna	Smith's Road (Queen to William)	CI	20	7	8		40	20	9	mottled brown orange clay
Goodna	Smith's Road (Queen to William)	CL	9	34	14		23	13	6	brown silty sandy clay
Goodna	Smith's Road (Queen to William)	CI	26	6	5		48	31	14	black silty clay
Goodna	Smith's Road (Queen to William)	CI	14	12	15		31	13	6	orange brown clay coarse sand
Goodna	Smith's Road (Queen to William)	CL	14	10	19		24	13	4	grey gravelly silty clay

Goodna	Smith's Road (Queen to William)	CI	14	11	8	3	33	22	11	grey silty sandy clay
Goodna	Smith's Road - Albert Street Intersection	CH	20	20	4		66	46	18	red silty clay
Goodna	Smith's Road - Albert Street Intersection	CI	15	36	7		49	31	13	orange red silt
Goodna	Smith's Road - Albert Street Intersection	CI	14	11	8		39	24	11	reddish silt
Goodna	Smith's Road - Albert Street Intersection	CI	11	> 60	9		47	29	12	orange grey brown silty clay with some sandstone
Booval	South Station Road (Auld to Morris)	CH	30	5	4		66	47	20	black clay
Booval	South Station Road (Auld to Morris)	CH	34	5	2		86	61	25	black clay
Booval	South Station Road (Auld to Morris)	CH	34	5	2	2	86	62	23	black clay
Booval	South Station Road (Auld to Morris)	CH	21	8	7		45	24	14	brown silty sandy clay
Silkstone	South Station Road (Rodney to Robertson)	CH	9	11	14	19	39	25	10	orange red silty clay
Silkstone	South Station Road (Rodney to Robertson)	CH	22	11	6		67	43	18	black clay with coalstone
Silkstone	South Station Road (Rodney to Robertson)	CH	48	5	1		110	76	23	black clay
Silkstone	South Station Road (Rodney to Robertson)	CI	9	12	14	19	39	25	10	orange red silty sand
Silkstone	South Station Road (Rodney to Robertson)	CI	9	18	14	19	39	25	10	orange red silty sand
Silkstone	South Station Road (Rodney to Robertson)	CI	14	18	11		46	29	14	Clayey coalstone
Silkstone	South Station Road (Rodney to Robertson)	CI	10	22	14	19	39	25	10	orange red silty sand
Silkstone	South Station Road (Rodney to Robertson)	CI	10	15	14	19	39	25	10	orange red silty sand
Silkstone	South Station Road (Rodney to Robertson)	CH	47	3	1		110	76	23	black clay
Silkstone	South Station Road (Rodney to Robertson)	CI	10	7	14	19	39	25	10	orange red silty sand

Silkstone	South Station Road (Rodney to Robertson)	CH	53	7	2		109	75	23	black clay
Silkstone	South Station Road (Rodney to Robertson)	CH	53	2	2		109	75	23	black clay
Booval	South Station Road (Brisbane to Sloman)	CH	42	4	2		93	68	20	black clay
Booval	South Station Road (Brisbane to Sloman)	CH	43	4	2		89	62	17	black clay
Booval	South Station Road (Brisbane to Sloman)	CH	35	4	2		80	56	23	black clay
Booval	South Station Road (Brisbane to Sloman)	CH	38	5	2		86	60	24	dark brown clay
Booval	South Station Road (Brisbane to Sloman)	CH	23	3	6	3	52	35	17	brown clay some stone
Raceview	South Station Road (south of	CI	19	8	7		42	28	14	brown silty clay with stone
Raceview	South Station Road (south of	CL	13				21	4	2	dark brown sandy clayey gravelly soil
Raceview	South Station Road (south of	CI	43	4	4		78	53	22	brown black clay
Raceview	South Station Road (south of	CL	29	3	7	4	55	37	18	dark brown black stony clay
Raceview	South Station Road (south of	CI	47	3	7	4	55	37	18	dark brown black stony clay
Raceview	South Station Road (south of	CL	17	24	12		49	17	9	yellow brown decomposed rock
Raceview	South Station Road (south of	CI	32	24	12		49	17	9	yellow brown decomposed rock
Booval	South Station Road (Sloman to Clifton)	CH	53	4	1		92	68	25	black clay
Booval	South Station Road (Sloman to Clifton)	CH	49	3	2	2	87	64	24	grey clay
Booval	South Station Road (Sloman to Clifton)	CH	44	4	4		83	61	23	grey brown clay
East Ipswich	Spengler Street	CH	30	7	2		75	51	23	dark brown clay
East Ipswich	Spengler Street	CH	35	6	2		72	47	23	dark brown clay
East Ipswich	Spengler Street	CH	41	5	2	2	87	57	25	dark grey clay
East Ipswich	Spengler Street	CH	43	5	1		93	62	25	dark grey silty clay
East Ipswich	Spengler Street	CI	27	13	9		48	21	13	light brown silty clay
Booval	Stafford Road	CI	17	11	4		47	33	17	brown clay
Booval	Stafford Road	CH	29	4	3	2	63	44	20	brown clay
Yamanto	Suffield Drive	CH	31	5	2		82	57	19	brown clay
Yamanto	Suffield Drive	CH	37	3	2	1	78	55	19	brown clay
Yamanto	Suffield Drive	CH	36	2	2		90	56	20	grey brown clay

Yamanto	Suffield Drive	CH	37	2	3		75	49	17	grey clay
Yamanto	Suffield Drive	CH	32	3	2		79	59	22	dark grey clay
Brassall	Swan Street	CH	16	19			75	51	21	brown clay
Brassall	Swan Street	CI	13	60			40	23	13	brown silt clay
Brassall	Swan Street	CI	19	32			40	23	13	brown silt clay
Brassall	Swan Street	CH	26	16			75	51	21	brown clay
Brassall	Sydney Street (Ross to Vogel)	CH	25	5	4		55	37	18	grey brown clay
Brassall	Sydney Street (Ross to Vogel)	CH	29	4	4		53	34	17	brown clay
Brassall	Sydney Street (Ross to Vogel)	CI	17	12	8	2	31	18	11	brown loamy clay
Brassall	Sydney Street (Ross to Vogel)	CH	24	6	4		53	34	17	brown clay
Brassall	Sydney Street (Ross to Vogel)	CI	11	14	8	2	31	18	11	brown clayey loam
Brassall	Sydney Street (Ross to Vogel)	CH	22	6	4		53	34	17	brown clay
Brassall	Sydney Street (Ross to Vogel)	CH	15	22	4		55	37	18	grey/brown loamy clay
Brassall	Sydney Street (Ross to Vogel)	CH	15	16	4		55	37	18	Grey/brown loamy clay
Brassall	Sydney Street (Ross to Vogel)	CH	25	7	4		53	34	17	Brown clay
Brassall	Sydney Street (Ross to Vogel)	CH	16	19	8	2	31	18	11	brown loamy clay
Brassall	Sydney Street (Ross to Vogel)	CH		23	4		53	34	17	brown clay
Brassall	Sydney Street (Ross to Vogel)	CH	30	9	4		53	34	17	brown clay
Brassall	Sydney Street (Ross to Vogel)	CI	18	9	8	2	31	18	11	brown loamy clay
Brassall	Sydney Street (Ross to Vogel)	CH	19	8	4		50	33	17	brown loamy clay
Tallegalla	Tallegalla Cemetery	CI	17	10	8		45	24	14	brown silty sandy clay
Tallegalla	Tallegalla Cemetery	CH	18	18	3		61	38	20	dark brown silty clay
Tallegalla	Tallegalla Cemetery	CH	18	21	3		61	38	20	dark brown silty clay
Tallegalla	Tallegalla Cemetery	CH	27	13	3		61	38	20	dark brown silty clay
Tallegalla	Tallegalla Cemetery	CH	20	15	3		71	47	21	orange brown silty clay
Tallegalla	Tallegalla Cemetery	CH	29	4	3		71	47	21	orange brown silty clay
Tallegalla	Tallegalla Cemetery	CH	26	6	3		71	47	21	orange brown silty clay
Tallegalla	Tallegalla Cemetery	CH	25	6	3		71	47	21	orange brown silty clay

Tallegalla	Tallegalla Cemetery	CH	27	8	3		68	43	21	orange stony silty clay ironstone pebbles
Tallegalla	Tallegalla Road	CH	25	6	3		61	45	19	mottled orange grey clay
Tallegalla	Tallegalla Road	CH	24	6	2		66	48	19	mottled pale orange clay
Tallegalla	Tallegalla Road	CH	23	8	6		55	41	17	grey green clay
Tallegalla	Tallegalla Road	CH	23	8	3		57	41	17	Bluish black clay
Tallegalla	Tallegalla Road	CH	23	10	3		57	41	17	Bluish black clay
Tallegalla	Tallegalla Road	CI	15	10	7	4	46	32	14	pale pinkish brown clay (slightly sandy)
Tallegalla	Tallegalla Road	CH	23	7	2		66	50	20	brown clay
Tallegalla	Tallegalla Road	CI	19	14	5		48	31	15	mottled pale pink/brown clay, small stones
Tallegalla	Tallegalla Road	CI	15	14	5		48	31	16	Pale yellow loamy clay
Tallegalla	Tallegalla Road	CI	15	34	5		48	31	16	Pale yellow loamy clay
Tallegalla	Tallegalla Road	CH	26	8	2		74	54	20	mottled red/pink/brown
Tallegalla	Tallegalla Road	CH	23	8	2		66	45	21	Light brown clay
Tallegalla	Tallegalla Road	CH	30	4	2		82	56	22	reddish brown clay
Tallegalla	Tallegalla Road	CH	27	7	5	2	62	43	19	mottled multi coloured clay
Tallegalla	Tallegalla Road	CI	17	12	5	3	47	29	15	brown clay
Tallegalla	Tallegalla Road	CI	9	18	9		31	14	8	brown silty clay
Tallegalla	Tallegalla Road	CI	12	29	6		36	19	13	brown silty clay
Tallegalla	Tallegalla Road	CI	16	17	6		42	22	14	brown clay
Tallegalla	Tallegalla Road	CI	14	16	12		44	23	13	light brown silty clay stony
Tallegalla	Tallegalla Road	CL	7	34	14		26	10	5	brown silt
Tallegalla	Tallegalla Road	CH	22	5.0/9.0	4		60	39	18	brown silty clay
Tallegalla	Tallegalla Two Tree Hill Road	CH	13	60	6		50	37	15	mottled brown white clay
Tallegalla	Tallegalla Two Tree Hill Road	CH	13	46	6		50	37	15	mottled brown white clay
Tallegalla	Tallegalla Two Tree Hill Road	CI	20	20						black clay highly plastic
Tallegalla	Tallegalla Two Tree Hill Road	CI	8	> 60	7		41	22	11	light brown clay white flecks
Tallegalla	Tallegalla Two Tree Hill Road	CH	12	36	5		51	31	17	grey brown loamy clay
Tallegalla	Tallegalla Two Tree Hill Road	CH	28	28	6		60	31	17	grey brown clay
Tallegalla	Tallegalla Two Tree Hill Road	CH	25	21	4		65	27	18	grey brown loamy clay
Tallegalla	Tallegalla Two Tree Hill Road	CH	19	16	7		53	22	14	light brown loamy silty clay
Sadliers Cross	Tallon Street	CH	15	15	5		63	43	17	mottled orange grey sandy clay

Sadliers Cross	Tallon Street	CH	21	8	5		53	37	15	mottled reddish grey sandy clay
Sadliers Cross	Tallon Street	CH	18	12	5		53	37	15	mottled reddish grey sandy clay
Sadliers Cross	Tallon Street	CH	25	7	3		65	42	18	mottled reddish grey sandy clay
Sadliers Cross	Tallon Street	CI	13	10	10	9	30	16	9	Brown sandy silty clay
Sadliers Cross	Tallon Street	CL	8	25	9		28	14	6	brown silt
Riverview	Tessman Street (Nile to Old	CI	9	24	19	32	32	12	4	mottled orange grey sandy silt
Riverview	Tessman Street (Nile to Old	CI	19	17	12		41	18	9	mottled orange grey sandy silty
Riverview	Tessman Street (Nile to Old	CI	23	15	9		46	20	10	brown silty clay
Riverview	Tessman Street (Nile to Old	CH	17	23	5		57	36	15	Grey black clay
Riverview	Tessman Street (Nile to Old	CH	21	23	4		67	44	19	Grey brown silty clay
Thagoona	Thagoona - Haigslea Road	CI	20	11	7		46	26	14	dark brown clay
Thagoona	Thagoona - Haigslea Road	CH	29	5	4		58	36	17	rusty black clay
Thagoona	Thagoona - Haigslea Road	CI	17	23	15	9	49	24	12	black clay and coalstone
Thagoona	Thagoona - Haigslea Road	CI	30	10	7		46	26	14	dark brown clay
Thagoona	Thagoona - Haigslea Road	CH	29	6	4		58	36	17	rusty black clay
Thagoona	Thagoona - Haigslea Road	CI	29	6	7		46	26	14	dark brown clay
Thagoona	Thagoona - Haigslea Road	CH	30	9	3		70	46	22	black clay
Thagoona	Thagoona - Haigslea Road	CH	33	6	3		70	46	22	black clay
Thagoona	Thagoona - Haigslea Road	CH	23	18	4		63	43	19	brown black clay with coalstone
Thagoona	Thagoona - Haigslea Road	CH	27	5	3	2	63	46	21	dark brown clay
Thagoona	Thagoona - Haigslea Road	CH	24	6	4		59	39	18	brownish black stony clay (some coalstone)
Thagoona	Thagoona - Haigslea Road	CH	31	3	4		63	43	19	Brownish black clay with coalstone traces
Silkstone	Thompson Street	CH	40	7	2		96	68	21	grey clay
Silkstone	Thompson Street	CI	25	8	6		47	28	15	dark brown pebbly clay
Silkstone	Thompson Street	CH	40	7	3		84	50	18	reddish brown clay
Ipswich	Thorn Street Depot	CH	26	7			62	39	18	Mottled brown,yellow,grey silty clay

Ipswich	Thorn Street Depot	CH	23	8			58	32	17	brown black silty clay
Ipswich	Thorn Street	CI	11	50			39	19	11	Coalstone soil
Ipswich	Thorn Street	CI	11	13			39	19	11	Coalstone soil
Ipswich	Thorn Street	CI	11	20			39	19	11	Coalstone soil
Ipswich	Thorn Street Depot	CI	16	20			41	23	12	Brownish black silty clay
Ipswich	Thorn Street Depot	CI	16	14			41	23	12	Brownish black silty clay
Raceview	Thornton Street	CH	47	4						black clay with coalstone
Raceview	Thornton Street	CH	47	3						black clay with coalstone
Raceview	Thornton Street	CH	54	3						black clay
Raceview	Thornton Street	CH	34	4						black/grey clay wth coalstone
Raceview	Thornton Street	CH	41	4						Pebbly grey clay
Raceview	Thornton Street	CH	41	3						Pebbly grey clay
Raceview	Thornton Street	CH	43	3						Pebbly grey clay
Raceview	Thornton Street	CH	43	7						Pebbly grey clay
Raceview	Thornton Street	CH	30	7						Pale yellow dolomite clay
East Ipswich	Tongue Street	CH	41	5	1		97	63	31	black clay white flecks
East Ipswich	Tongue Street	CH	42	3	2		91	55	24	black clay
East Ipswich	Tongue Street	CH	53	3	2		91	55	24	black clay
East Ipswich	Tongue Street	CH	31	8	3	2	66	41	20	brown black clay
East Ipswich	Tongue Street	CH	32	10	2		72	41	24	black clay
East Ipswich	Tongue Street	CH	29	10	3		68	38	21	brown black clay
Leichhardt	Toongarra Road (Old Toowoomba to Samford)	CH	20	13	4		67	43	21	mottled orange red clay
Leichhardt	Toongarra Road (Old Toowoomba to Samford)	CI	14	8	5		47	33	16	orange brown clay
Leichhardt	Toongarra Road (Old Toowoomba to Samford)	CH	16	7	4	2	52	39	17	brown clay
Leichhardt	Toongarra Road (Old Toowoomba to Samford)	CH	21	6	5		51	35	13	light yellow brown clay
Leichhardt	Toongarra Road (Old Toowoomba to Samford)	ML	6	> 60	12		22	5	4	reddish decomposed sandstone
Leichhardt	Toongarra Road (Old Toowoomba to Samford)	ML	6	22	17		17	3	2	brown stony silt
Leichhardt	Toongarra Road (Old Toowoomba to Samford)	CI	19	5	6		39	23	11	reddish white sandy clay

Leichhardt	Toongarra Road - Samford Road intersection	CL	12	10	11		23	13	6	brown sandy silty clay
Leichhardt	Toongarra Road - Samford Road intersection	SC	7	42	13		18	7	2	brown silty sand
Leichhardt	Toongarra Road - Samford Road intersection	SC	7	10	13		18	7	2	brown silty sand
Leichhardt	Toongarra Road - Samford Road intersection	CI	14	6	6		39	27	15	brown silty clay
Leichhardt	Toongarra Road - Samford Road intersection	CH	22	7	4		56	36	16	mottled yellow brown clay
Leichhardt	Toongarra Road - Samford Road intersection	CI	20	11	5		46	30	13	mottled orange grey clay
Leichhardt	Toongarra Road - Samford Road intersection	SC	10	13	11		25	11	4	red silty sand
Leichhardt	Toongarra Road - Samford Road intersection	SC	7	32	11		25	11	4	red silty sand
Leichhardt	Toongarra Road - Samford Road intersection	SC	6	21	16		22	4	1	red silty sand
Leichhardt	Toongarra Road - Samford Road intersection	CI	19	7	6	9	48	26	15	mottled orange grey silty clay
Wulkaraka	Toongarra Road	CI	13	16	7	4	35	22	11	light brown loamy clay
Wulkaraka	Toongarra Road	CL	13	11	10	8	28	16	7	brown loamy clay
Bundamba	Vale Street	CH	18	27	3		62	42	18	brown clay
Bundamba	Vale Street	CI	16	8	8		33	15	9	brown silty clay
Bundamba	Vale Street	CI	23	2	7	3	39	23	11	brown grey clay
Bundamba	Vale Street	CI	29	2	7		39	19	11	grey clay
Bundamba	Vale Street	CI	18	21	5		49	27	15	brown clay
Rosewood	Waight Street (John to Creedy)	CH	27	4	3		63	47	20	brown clay
Rosewood	Waight Street (John to Creedy)	CH	26	4	3	3	64	49	18	grey brown clay
Rosewood	Waight Street (John to Creedy)	CH	30	3	3		67	52	20	brown clay
Booval	Walker's Lane	CH	33	5	2		72	39	22	black clay
Booval	Walker's Lane	CH	28	19	3	2	63	43	18	brown clay
Booval	Walker's Lane	OL	18	38	10		43	13	5	brown rotten rock
Booval	Walker's Lane	CH	39	4	3		64	34	18	brown black clay
Booval	Walker's Lane	OL	25	24	10		43	13	5	brown rotten rock
Booval	Walker's Lane	CH	40	5	2		72	39	22	black clay
Booval	Walker's Lane	CH	42	5	2		72	39	22	black clay
Eastern Heigh	Warrawong Street	CH	59	3	1		128	94	25	black clay

Eastern Heigh	Warrawong Street	CH	48	3	2	1	84	63	22	black clay
Eastern Heigh	Warrawong Street	CH	50	3	1		114	88	25	black clay
Calvert	Waters Road (Lanes to Cuss)	CH	19	21	4		52	31	17	black silty clay
Calvert	Waters Road (Lanes to Cuss)	CH	26	12	4		52	31	17	black silty clay
Calvert	Waters Road (Lanes to Cuss)	CI	14	29	5	3	44	27	15	dark brown silty clay
Calvert	Waters Road (Lanes to Cuss)	CI	12	42	5	3	44	27	15	brown silty clay
Calvert	Waters Road (Lanes to Cuss)	CI	13	32	5	3	44	27	15	dark brown silty clay
Calvert	Waters Road (Lanes to Cuss)	CI	13	42	4		44	29	16	dark brown silty clay
Calvert	Waters Road (Lanes to Cuss)	CI	16	36	5	3	44	27	15	brown clay
Calvert	Waters Road (Lanes to Cuss)	CI	10	54	7		38	23	13	brown silty clay
Calvert	Waters Road (Lanes to Cuss)	CI	10	46	7	5	34	20	11	brown clay
Calvert	Waters Road (Lanes to Cuss)	CL	12	32	7	5	34	20	11	brown silty clay
Calvert	Waters Road (Lanes to Cuss)	CI	21	26	4		53	34	17	brown silty clay
North Ipswich	Waterworks Road		10	> 60						orange red clay
North Ipswich	Waterworks Road		15	33						orange red clay
Riverview	Webb Street	CL	12	6	15		22	10	5	dark brown sandy loam
Riverview	Webb Street	CH	16	20	6	5	54	34	14	mottled yellow orange grey sandy clay
Riverview	Webb Street	CH	12	22	6		54	34	14	mottled yellow grey sandy clay
Riverview	Webb Street	CH	12	36	6		54	34	14	Mottled yellow/grey sandy
Riverview	Webb Street	CH	12	56	6		54	34	14	Mottled yellow/grey sandy
Riverview	Webb Street	CH	12	> 60	6		54	34	14	Mottled yellow/grey sandy
Riverview	Webb Street	CI	10	> 60	16		31	9	9	Light orange clayey sandstone
Flinders View	Whitehill Road (Cowley to Reif)	CH	23	7	6	3	52	34	17	brown clay white flecks
Flinders View	Whitehill Road (Cowley to Reif)	CH	25	15	5		56	38	18	mottled grey brown clay
Flinders View	Whitehill Road (Cowley to Reif)	CH	21	6	5		60	43	17	mottled white/yellow/brow n clay
Flinders View	Whitehill Road (Cowley to Reif)	CH	26	6	5		60	43	17	Mottled white/yellow/brow n clay with

Flinders View	Whitehill Road (Cowley to Reif)	CH	26	2	5		60	43	17	Mottled white/yellow/brow n clay with
Flinders View	Whitehill Road (Cowley to Reif)	CI	12	14	9		33	17	6	light brown silty clay
Flinders View	Whitehill Road (Cowley to Reif)	CI	17	7	5		48	29	17	mottled red brown clay
Flinders View	Whitehill Road (Cowley to Reif)	sandsto ne		> 60						hard sandstone?
Flinders View	Whitehill Road (Cowley to Reif)	CI	18	9	6		46	28	14	mottled grey sandy clay
Flinders View	Whitehill Road (Cowley to Reif)	sandsto ne	10	60						orange sandstone
Flinders View	Whitehill Road (Cowley to Reif)	CI	18	8	7		39	26	12	mottled red orange grey clay
Flinders View	Whitehill Road (Cowley to Reif)	CL	10	> 60	13		25	12	5	grey green silty loam
Flinders View	Whitehill Road (Cowley to Reif)	CI	12	32	14		32	19	9	grey gravelly clay
Flinders View	Whitehill Road (Cowley to Reif)	CI	12	10	14		32	19	9	Grey gravelly clay
Flinders View	Whitehill Road (Cowley to Reif)	ML	16	10	13		23	9	3	Black clay lumps in brown silty sand
Raceview	Whitehill Road (no.227 to	CH	45	3	2		91	58	24	black clay
Raceview	Whitehill Road (no.227 to	CH	44	3	2		89	56	23	black clay
Raceview	Whitehill Road (no.227 to	CH	42	5	1		99	65	24	black clay
Raceview	Whitehill Road (no.227 to	CH	46	2	2		99	63	24	black clay
Raceview	Whitehill Road (no.227 to	CH	38	2	2	3	91	60	23	black clay
Raceview	Whitehill Road (no.227 to	CH	37	6	2		89	56	21	black clay
Raceview	Whitehill Road (no.227 to	CH	33	6	2	3	86	55	22	brown clay
Raceview	Whitehill Road (no.227 to	CH	39	5	2		93	55	26	brown clay
Harrisville	Weinholt Road	CH	25	8	4		56	31	17	brown loamy clay
Harrisville	Weinholt Road	CH	36	9	2		89	57	24	black clay
Raceview	Wildey Street	ML	24	7	11	10	37	7	5	light brown silty clay
Raceview	Wildey Street	CH	39	7	3		61	33	19	brown clay
Raceview	Wildey Street	ML	16	15	13		35	10	5	brown silt
Raceview	Wildey Street	ML	26	12	11	10	37	7	5	brown silty clay
Raceview	Wildey Street	CI	22	8	6		42	18	12	light brown silty clay
Raceview	Wildey Street	CH	30	8	3		61	33	19	brown clay
Raceview	Wildey Street	ML	9	56	12		37	9	6	brown silty
Raceview	Wildey Street	ML	15	9	13		37	8	5	brown silty

Redbank Plain	Willow Road West (School to Wilkie)	CH	32	6	3		61	44	18	black clay
Redbank Plain	Willow Road West (School to Wilkie)	CI	16	34	12		38	14	9	brown clayey rotten rock
Redbank Plain	Willow Road West (School to Wilkie)	CI	16	15	12		38	14	9	brown clayey rotten rock
Redbank Plain	Willow Road West (School to Wilkie)	CH	31	6	3	3	61	42	19	dark brown clay
Camira	Woodlands Avenue	sandstone		> 60						sandstone (too hard to test)
Camira	Woodlands Avenue	sandstone		22						sandstone (too hard to test)
Camira	Woodlands Avenue	sandstone		> 50						sandstone (too hard to test)
Camira	Woodlands Avenue	CI	14	56	14	17	39	19	10	reddish brown shale sandy clay
Camira	Woodlands Avenue	sandstone		60						sandstone (too hard to test)
Camira	Woodlands	CL	7	50	14		25	11	6	yellow silty sand
Camira	Woodlands Avenue	sandstone		22						sandstone (too hard to test)
Camira	Woodlands Avenue	sandstone		60						sandstone (too hard to test)
Camira	Woodlands Avenue	sandstone	9	60						yellow brown sandstone
Goodna	Woogaroo Street - Church Street Intersection	CI	18	7			37	19	11	black silty clay
Goodna	Woogaroo Street - Church Street Intersection	CI	13	9			32	15	8	coalstone soil
Goodna	Woogaroo Street - Layard Street	CL	10	10	21		25	10	5	brown gravelly silty sand
Goodna	Woogaroo Street - Layard Street	CI	14	12	10		33	20	8	brown sandy silty clay
Goodna	Woogaroo Street - Layard Street	CI	14	8	10		33	20	8	brown sandy silty clay
Goodna	Woogaroo Street - Layard Street	CI	28	8	5		48	31	12	brown clay
Goodna	Woogaroo Street - Layard Street	CI	28	5	5		48	31	12	brown clay
Goodna	Woogaroo Street - Layard Street	CI	21	9	6		42	27	12	brown silty clay
Goodna	Woogaroo Street - Layard Street	CI	21	6	6		42	27	12	brown silty clay
Goodna	Woogaroo Street - Layard Street	CI	25	9	5		48	30	12	brown clay
Goodna	Woogaroo Street (opp. RSL)	CH	26	9	3		57	39	17	black silty clay
Brassall	Wyman Street	CH	20	5	8	6	51	31	12	mottled orange grey clay
Brassall	Wyman Street	CI	17	20	7		48	29	14	firm orange clay

Brassall	Wyman Street	CI	19	14	7		48	29	14	orange clay
Rosewood	Yarrow Road	CH	20	15	9		53	28	13	coalstone soil
Rosewood	Yarrow Road	CI	20	11	5		46	26	14	brown clayey silt
Rosewood	Yarrow Road	CH	21	14	4		53	36	17	brown silty clay
Rosewood	Yarrow Road	CH	21	10	4		53	36	17	brown clay
Rosewood	Yarrow Road	CI	16	19	6		37	21	13	brown silty clay
Rosewood	Yarrow Road	CH	19	6	4		51	35	17	brown silty clay