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The Sustainability of Permeable Road Pavements – The North Shore Experience

Yung, C.Y.S. Kodippily,S. Henning T.F.P. Fassman, E.

The University of Auckland
Department of Civil and Environmental Engineering The University of Auckland Private Bag 92019 Auckland Mail Centre Auckland, 1142 NEW ZEALAND Phone: +64-9-3737599 (ext. 88181) Mobile: +64-27 5788 662 Fax: +64-9-373 7462 Email: t.henning@Auckland.ac.nz

YUNG, C.Y.S. KODIPPILY,S. HENNING T.F.P. FASSMAN, E.

ABSTRACT

Road Infrastructure is the backbone of a country's socio-economic sustainability. Often though, roads would also be one of the major hurdles of the environmental and cultural sustainability. During road construction and maintenance, finite geological resources are being consumed and borrow pits could be seriously detrimental to the aesthetic values of some areas. In addition to that, the road corridor significantly influences the natural flow and treatment of runoff water. In an attempt to address some of these environmental sustainability issues engineers have developed permeable pavements.

A major design consideration of classical road pavements is to keep it water-tight and dry at all times. Unlike this, the permeable pavement captures water into the pavement layers, thus not only reducing the runoff but also treating the water through the natural filtration process. Fassman et al (2007) reported that the North Shore permeable pavement experiment was successful in delaying the runoff by 2.4 hours and reduce the peak flow by 83%. In addition to that there was a significant improvement on the water quality when compared to the adjacent asphalt pavement. The question remains though, how well does the permeable pavements perform both physically and according to life-cycle considerations.

This paper reports on the results obtained from the North Shore permeable pavement experiment. It details the finding of the structural integrity and long-term performance of these pavements. It also discusses the pavement design principles and evaluates the economic sustainability of these pavements. Ultimately the paper recommends viable application areas for these pavements in order to assist in the establishment of a long-term socio-economical and environmental sustainable solution.

INTRODUCTION

Challenges related to sustainability and the environment became global issues and many countries are actively pursuing solutions within all sectors in order to address it. The New Zealand (NZ) central government has taken a holistic approach in addressing the specific challenges in NZ within the context of globalisation issues. Central and local government departments are encouraged to address sustainability and environmental issues through legislation and through incentive schemes. The transportation sector in NZ faces similar regulations to other allied sectors, namely, social, environmental, cultural, and economic. The onus of leading changes within the transportation sector was largely encouraged driven through legislation such as the Local Government Act 2002 (LGA,2002).

The only manner in which sustainability and environmental issues could be address satisfactory is by having multi-disciplinary team tackling technical challenges together. In the past engineering designs and solutions were far removed from the objectives of environmentalist. In order to progress on the objectives of sustainability these disciplines needs to gain a better understanding of drivers within the respective fields. This will allow for tangible solutions that will be sustainable according to socio-economic, the environment and life cycle cost principles.

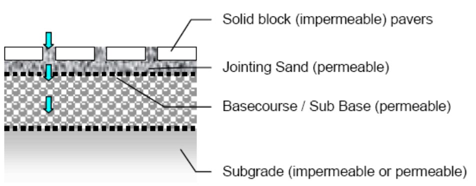
This paper discusses the permeable pavement options as one of the solutions that will address the above issues for the transportation and stormwater sectors. There are many benefits associated with using this pavement system; they include runoff reduction, ground water recharge, pollutant removal, and provides for efficient land use (Scholz and Grabowiecki, 2007, Smith, 2003a, Tennis et al., 2004). Stormwater resulting from developed urban areas has a significant cost implication for authorities due to high reticulation and treatment cost. Run-off from pavements and surfaced areas are a main contributor to this impact from urban development. By eliminating some of the needs to transport and treat the water resulting from these areas, significant savings are prominent. However, solutions such as permeable pavements seem to be expensive. This paper investigates permeable pavements from a performance and life cycle cost perspective in order to establish the cost-effectiveness by considering it from the greater objectives of sustainability.

BACKGROUND OF PERMEABLE PAVEMENTS

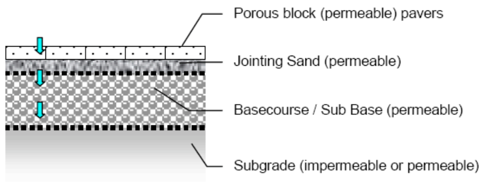
Definition of Permeable Pavement

Permeable pavement systems are a structural best management practice (Burak, 2004a) that is designed to allow for the collection, treatment and infiltration of stormwater through its pavement structure (Bean et al., 2004). Furthermore, it also provides a surface to support vehicular traffic and pedestrians (Smith, 2003b).

Porous pavers and permeable surfaces (Figure 1) are the two main types of permeable pavement systems. A porous pavement allows the stormwater to infiltrate through the pores on the individual surface and into the pavement structure. In comparison, in a permeable surface, stormwater enters the pavement structure via the gaps between the impermeable layer (Diyagama et al., 2004a).



Solid Block (Permeable Surface) Pavers



Porous Block Pavers

FIGURE 1: TYPES OF PERMEABLE PAVEMENT SYSTEMS

Applications

Permeable pavement system can be used for a variety of applications, some examples include car parks, residential driveways, land irrigation, container yards, and low-traffic use roads (Diyagama et al., 2004a, Scholz and Grabowiecki, 2006). Figure 2 illustrates some typical example of permeable pavement applications. It is noticeable that all applications are in areas with a low speed environment and in most cases with low traffic volumes. There is a potential misconception that these pavement can only be applied in low wheel loading areas since the New Jersey container yard shown in Figure 2 would be a typical example of heavy duty pavements that caters for extreme high pavement loadings.

Permeable Pavement on Public Space at Olympic Park, Sydney

Permeable Carriageway in New South Wales

Permeable Bus Terminal in Germany

Permeable Container Yard in New Jersey

FIGURE 2: EXAMPLE OF TYPICAL PERMEABLE PAVEMENT APPLICATIONS

Construction

Permeable pavement is generally built on a open-graded, crushed stone base (Burak, 2004a). The upper layer of the permeable pavement structure comprises of impermeable layers. These layers are specifically designed and arranged so that gaps are created between each paver to allow the stormwater to seep through (Beecham and Myers, 2007a). Research done by Shackel and Pearson in 1996 has concluded that shaped permeable layer performs better than rectangular permeable pavers. As specified in the NZ Permeable Pavement Design Guidelines (Diyagama et al., 2004a), the minimum thickness of the permeable paver should be no less than 80mm. The joint material that is filled in between the gaps of the pavers shall be between 2mm and 5mm. Sand is not a desirable joint material as it is susceptible to clogging and also it has low infiltration rate (Borgwardt's, 2007, Beecham and Myers, 2007a).

The bedding layer follows directly below the impermeable paver layer. This layer acts as an additional layer for infiltration. The next layer is the base layer which is made up of crushed aggregates with grading between 9.5mm to 65mm (Diyagama et al., 2004b). This base layer provides structural support to the pavement system, as well as a temporary storage system for the stormwater. In addition, it also acts as an infiltration mechanism (Beecham and Myers, 2007a).

A geotextile layer, which is located in between the base and sub-grade layer provides an additional filtration layer (Beecham and Myers, 2007a). Furthermore, this optional geotextile layer can reduce the amount of rutting and rate of block breakages (Scholz and Grabowiecki, 2007).

ENVIRONMENTAL SUSTAINABILITY – STORMWATER OUTCOMES

Test Methodology

The North Shore Permeable Pavement experimental section is depicted in Figure 3. It shows the 35m sections for half the carriageway. Note that the section was constructed at the entrance of a school. High volume accesses are normally subjected to high pavement stresses due to traffic turning movements. The figure also indicates the catchments used for both the permeable pavement and the asphalt surface (the control for the experiment).

FIGURE 3: PERMEABLE PAVEMENT EXPERIMENTAL SECTION ON BIRKDALE ROAD

Understanding the outcome of the permeable pavement in terms of the stormwater reduction consisted of three test areas including hydrologic assessment, runoff quality tests and surface infiltration tests. These tests methods are described in detail by (Fassman and Blackbourn). In summary the objectives for each of these tests are:

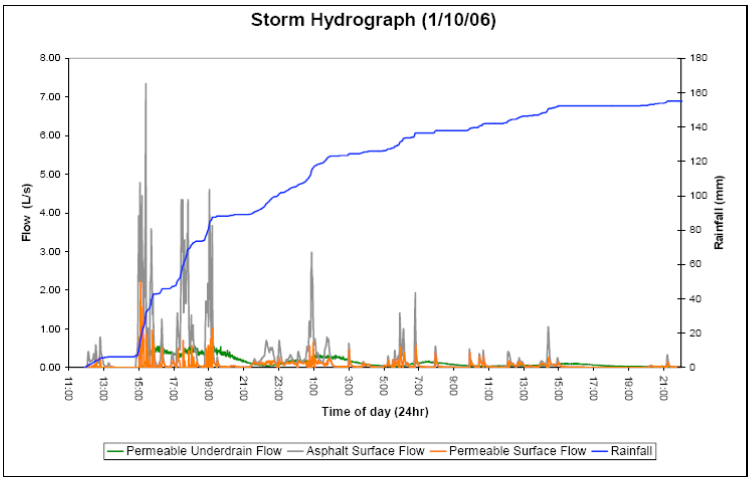
- The hydrologic measurements were undertaken to determine the run-off from each surface, and discharge from the basecourse of the permeable pavement. This was achieved through flow measurements directly after the catchment;
- Run-off water quality tests were undertaken on water samples taken from the asphalt surface and the permeable pavement discharge. These samples were then subjected to analysis for pH, total suspended solids (TSS), total recoverable and dissolved zinc (Zn) and copper (Cu);

- Lastly, surface infiltration test were undertaken to monitor the surface permeability characteristics over time.

These test had excellent outcomes as presented in the following section.

Main Outcomes

Figure 4 illustrates the comparison of the run-off for the respected surfaces. This example indicates the outcome for a 1 in 10-yr storm event or 152.3 mm precipitation. Note that normal road drainage structures are design for 1 in 5-yr storms. The figure shows a significant reduction in runoff rate for the permeable pavement. The permeable surface had a flow of 2 L/s during peak compared to the 7.4 L/s on the asphalt surface. On average for all storms measured, the peak flow reduction for the permeable pavement was 83% (Fassman et al, 2007).



Ten year storm event. Total precipitation = 152.3 mm (10-yr storm).

FIGURE 4: COMPARING RUN-OFF FOR RESPECTIVE SURFACES (FASSMAN ET AL, 2007)

The system was also efficient in removing the pollutants from the water with the following results reported in terms of the mass removal efficiency in percentage:

- TSS – 58 (±15)%;
- Cu - 58(±10)%;
- Zn – 86 (±8)%.

The permeability of the Birkdale sections is well above the design specifications for permeable pavements. The worse section result had a permeability of 523 mm/hr is still above the 120 mm/hr design requirement for the area.

It can therefore be concluded that the North Shore permeable pavement had an excellent outcome in terms of the storm-water outcomes. Monitoring continues in 2008.

DESIGN OPTIONS AND EXPERIENCE

There are three main types of permeable paving system, these includes, grass pavers (lattice)/ open cell pavers (left hand plot - Figure 5) surfacing or interlocking blocks (right hand plot- Figure 5) and porous surfaces (Diyagama et al., 2004b, Burak, 2004b).

	
GRASS PAVER	**INTERLOCKING BLOCK**

FIGURE 5: PERMEABLE PAVEMENT SYSTEMS

Grass paver contains open void space in which vegetation is planted or aggregates are placed in it. They are generally constructed from plastic, concrete or gravel. Vegetation within each void provides an aesthetic quality to the environment. Grass paver is typically applied in temporary roadways and parking lot (Diyagama et al., 2004b).

Interlocking block pavers are constructed from impermeable pavers that are specifically arranged to create gaps between each paver to allow for the seepage of water into its pavement structure (Burak, 2004b). Regular maintenance is required as they are susceptible to clogging. This type of permeable paving can be use for parking lots, driveways, sidewalks, boat ramps, and pedestrian areas (Burak, 2004b, Diyagama et al., 2004b).

When designing for a permeable pavement system, a number of site characteristics are required to be considered. As discussed in the NZ permeable pavement design guideline (Diyagama et al 2004), these site characteristics includes land topography (slope), traffic volume, sub-grade, land-use, stability, and the discharge type.

Based on this guideline, the site limitations are described below:

- Slope: A permeable pavement system is not recommended to be constructed on a slope which is greater than 3 degrees. This is because if the slope is too steep, water tends to seep out onto the surface of the pavement.
- Traffic Volume: It is recommended that the permeable pavement system be designed for a life span of 20 years. Depending on the type of application this permeable pavement system is used for, the amount of traffic volume can be determine from Table 1.
- Sub-grade: There should be no excess deformation in this layer when supporting the traffic loading.
- Land-use: It is recommended that the permeable pavement system be use in area when there is light vehicular loading. In addition, in site where sedimentation generation is high, the use of permeable pavement should be avoided.
- Stability: If the site contains soil which is susceptible to instability, the construction of permeable pavement in that area should be avoided. The reason is because the water that flows into the soil via the surface of the pavement can increase the instability of the soil.

Table 1: Permeable Pavement Types for Different Traffic Classes (Diyagama et al, 2004)

Design Traffic				
Road Category/ Class	Function/Description	Minimum Road Reserve Width	Daily Traffic Volume	Cumulative Design Traffic (Typical)
Residential Driveway	Access place or Cul-de-Sac with: < 50 Household-Unit Catchment (HUC) & <100m length, excluding the turning head	12m	< 300 vpd	2,000 ESA*
Residential Road (Local Living)	< 150 HUC and not a public bus route	17m	< 1,000 vpd	10,000 ESA*
Residential Road (Neighbourhood: Collector)	> 150 HUC, providing access to properties	20m	< 3,000 vpd	20000 ESA*

* Equivalent Standard Axle - A Standard Axle with 550 kPa has been assumed for the guideline.

North Shore Permeable Pavement Design

The North Shore permeable pavement system is constructed on an active carriageway and bus lane in North Shore (Fassman and Blackbourn). The length and width of this system is 35m and 6m respectively. The cross section of this pavement is shown in Figure 6. It shows a base course thickness of 150mm plus sub-base of 230mm respectively. It can therefore be expected that the design would be suitable for the traffic loading of an arterial urban road.

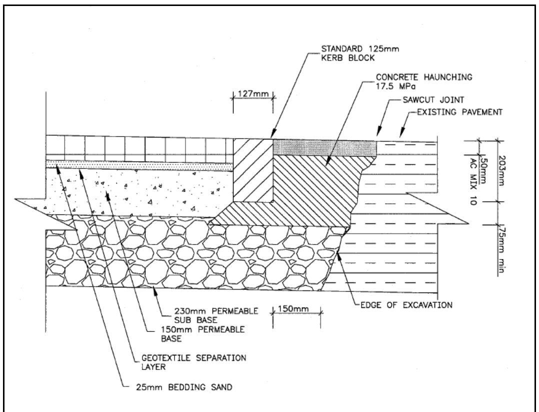


FIGURE 6: NORTH SHORE PERMEABLE PAVEMENT (GHD, 2004)

PERFORMANCE AND ECONOMIC SUSTAINABILITY

International Experience

Studies have been conducted in Australia, South Africa, Europe and North America over the last 30 years investigating the structural capacity of permeable pavements. These studies included the influence of paver blocks on pavement performance, strength properties of pavement materials and developing new materials for pavement base courses (Beecham and Myers, 2007b, Shackel, 1979).

Australian research carried out on the structural behaviour of permeable pavements concluded that permeable pavements perform satisfactorily for structural defect of rutting compared to asphalt pavements (Shackel, 1990). A test pavement at a port in Australia recorded rut depths of between 20 mm – 25 mm under axle loads of 90 tonnes, which is significantly higher than the loads experienced normally (Shackel, 1990). In the Netherlands, an acceptable rut level of 35 mm is set as the structural limit. This structural behaviour is however, observed to vary between different paver block materials as well as the block shape (Pearson and Shackel, 1996).

The joints between the paver blocks reduce the progression of cracks. As a result, the pavement is able to withstand much higher deflections compared to conventional asphalt pavements (Shackel, 1994). Shackel's (1994) research observed some permeable block pavements having deflections of 2 mm and more without showing any signs of failure.

The sustainability of permeable pavements has been assessed using Leadership in Energy and Environmental Design (LEED) and Life Cycle Analysis (LCA) rating systems. Both LEED and LCA analyses have concluded that permeable pavements rated higher compared to conventional asphalt and concrete pavements (Anderson et al., 2004). Within the LEED system, permeable pavements are able to contribute 14 points under the Sustainable Sites (SS), Material and Resources (MR) and Innovative and Design Process (ID) credits (Burak, 2006).

North Shore Results

Rut measurements obtained from the North Shore permeable pavement since its construction in 2006 were analysed in order to determine its performance. The results are shown in Figure 7.

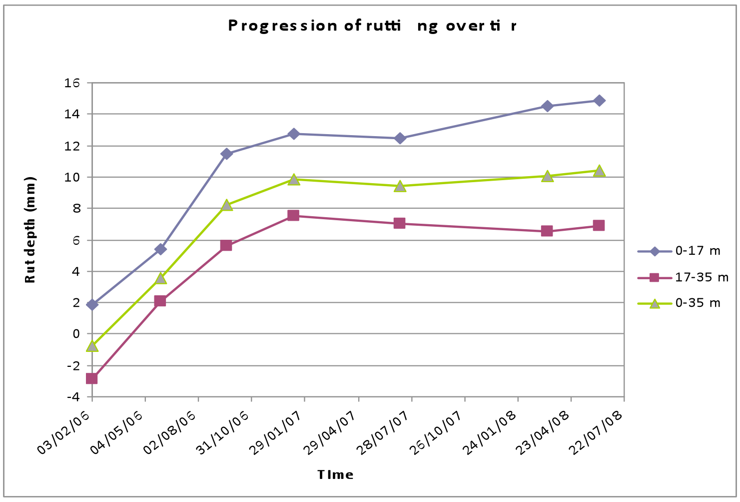


Figure 7. Rut progression on the North Shore permeable pavement

The change in rut depths on the North Shore permeable pavement was large initially following construction. This change has decreased overtime and currently the permeable pavement is at a stable rut phase. This behavior is similar to the rut progression in unbound granular pavements, where the pavement had an initial densification phase followed by a gradual deterioration phase (Henning et al., 2007).

Both permeable pavements and unbound granular pavements have similar pavement structures and therefore, a similar trend for rutting. As a result of this similarity, the permeable pavement can be predicted to reach a failure point which will initiate rapid deterioration of the pavement.

The rut rate for the North Shore permeable pavement was found to be 0.4 mm/yr. This rut rate lies between the rates in chip seal (0.6 mm/year) and asphalt concrete pavements (0.3 mm/year) (Henning et al., 2007). This rut rate of 0.4 mm/yr can be used as a preliminary design parameter for permeable pavements in New Zealand.

Analysis of the average rut depth on the pavement suggested that the progression of rutting follows a similar pattern to the conventional asphalt pavement systems, although rutting on asphalt pavements are significantly lower. There is a large increase in rutting at the early stages of the pavement life. This increase however, minimised as the pavement aged, reaching a stable level at current time. Figure 7 shows the progression of rutting on the permeable pavement surface. As can be seen on Figure 7, the progression of rutting differed slightly between the upper (0 – 17 m) section and the lower (17 – 35 m) section, which contains a geogrid within the pavement structure. From these observations, it can be concluded that the use of a geogrid significantly reduces rutting on the surface.

In conventional asphalt pavements rut depths of between 15 mm and 20 mm are seen as the maximum allowable. As the rut depths increase, the risk of ponding also increases. However, in permeable pavements, ponding is unlikely to be an issue as most surface water is able to infiltrate into the pavement structure. Therefore, these pavements should be able to withstand higher rut depths than asphalt pavements. A rut depth of approximately 25 mm can be used as the limit for serviceability for permeable pavements, and a rut depth of 35 mm can be used as the structural limit.

Figure 8 illustrates deflection measurements over time. As expected, the deflection significantly decreases during the initial stages after pavement construction, thereafter it stabilises. This is likely a result of densification of pavement layers under traffic loading. The change in deflections between tests has decreased as the pavement aged, reaching a steady state at the current date. This behaviour indicates that the pavement strength has increased over time, which is also similar to that found by (Shackel, 1990).

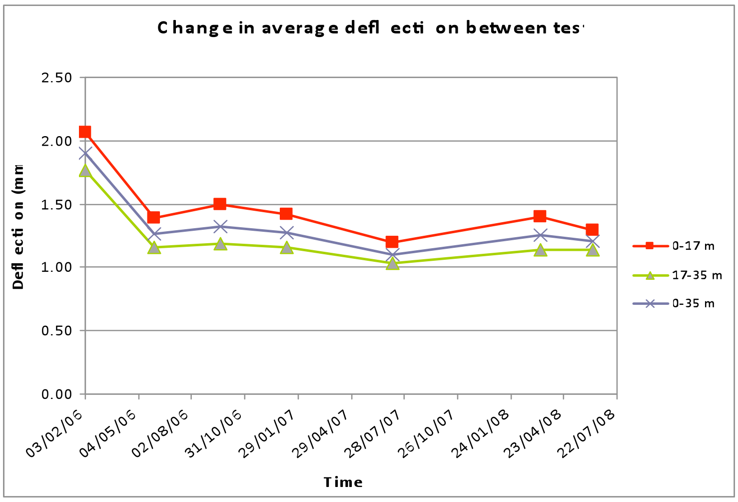


Figure 8. Average deflections on the North Shore permeable pavement

The permeable pavement section in North Shore has to date performed satisfactorily for structural defects such as rutting and deflections under a reasonably busy environment (468 Equivalent Standard Axles-ESA per day). The pavement is able to withstand higher rut depths compared to standard asphalt pavements as well as increase in its strength over time. Course extrapolations of the current performance data suggest that the design life of 15 to 20 years should be easily achievable.

Therefore, it can be concluded that permeable pavements are an innovative and viable option in place of conventional asphalt pavements in reasonably high traffic areas.

Life Cycle Cost Analysis

The present value of life cycle costs associated with a permeable pavement and an asphalt concrete pavement are shown in Figure 9. These costs were calculated for a one-kilometer pavement length, consisting of two 3.4 m wide traffic lanes and 0.5 m wide shoulders. The permeable pavement costs were calculated for a pavement consisting 20% permeable surface and 80% asphalt concrete surface. As the test pavement was on a high-traffic road, it was assumed that 20% permeable surface is sufficient for the one-kilometer length. The cost for the asphalt pavement was calculated for 100% asphalt concrete surface.

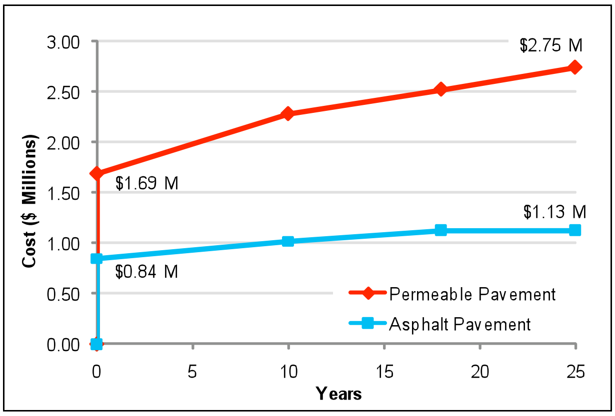


Figure 9: Life-cycle cost comparison between a permeable pavement and an asphalt concrete pavement

The present value of the construction and maintenance cost of the permeable pavement was found to be $2.75 million/km. This value seems considerably high compared to the cost of a standard asphalt surface of the same length ($1.13 million/km). However, it is expected that the environmental and economic benefits received from the use of permeable pavements will far exceed this cost. The life cycle cost of $2.75 million/km can be used as an initial estimate for future permeable pavement constructions in New Zealand.

Without any doubt, permeable pavements are significantly more expensive compared to conventional options. It is estimated that this options could be more than twice the cost of conventional options. Under conventional cost benefits analysis, these pavements would simply not be cost effective. However, benefits promised by the permeable pavement are not incorporated into the current life-cycle analysis. These benefits include but are not limited to:

- Savings due to less pressure on storm water reticulation systems;
- Reduced environmental impacts, including hydrologic and water quality (pollution) impacts etc.

To date limited work has been completed in quantifying these significant benefits, which may well have a very positive outcome for a true Life cycle cost and benefit calculation.

SUMMARY AND RECOMMENDATIONS

Road infrastructure is the backbone of a country's socio-economic sustainability. Often though, roads would also be one of the major hurdles of the environmental and cultural sustainability. The road corridor especially has a significant influence on the natural flow and treatment of runoff water. In an attempt to address some of these environmental sustainability issues engineers have developed permeable pavements. In order to investigate the economic and environmental sustainability, a permeable test section has been constructed in North Shore City. Results from this experiment have indicated an excellent outcome in terms of run-off outcomes. Fassman et al (2007) reported that the North Shore permeable pavement experiment was successful in delaying the runoff by 2.4 hours and reduce the peak flow by 83%. In addition to that there was a significant improvement on the water quality when compared to the adjacent asphalt pavement.

In terms of the pavement performance, the experiment had an equally promising results and intuitive projection are that this section will exceed its design life of 20 years. However, life-cycle costing has indicated these pavements to be significantly more expensive compared to conventional pavement options. However, with the environmental benefits offered by this technology, calculating the true benefits for these pavements may result in significant life-cycle savings which are not currently considered for road projects.

Therefore, in order to make permeable pavements attractive for authorities, true benefits associated with these options have to be quantifiable. It is recommended that research in NZ to aim at quantifying benefits for environmental impact savings.

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