# Firth EcoPave®

## Pervious Paving


The Firth EcoPave® range will assist in the management of rain and stormwater runoff.

Firth FlowPave

Firth FlowPave Set

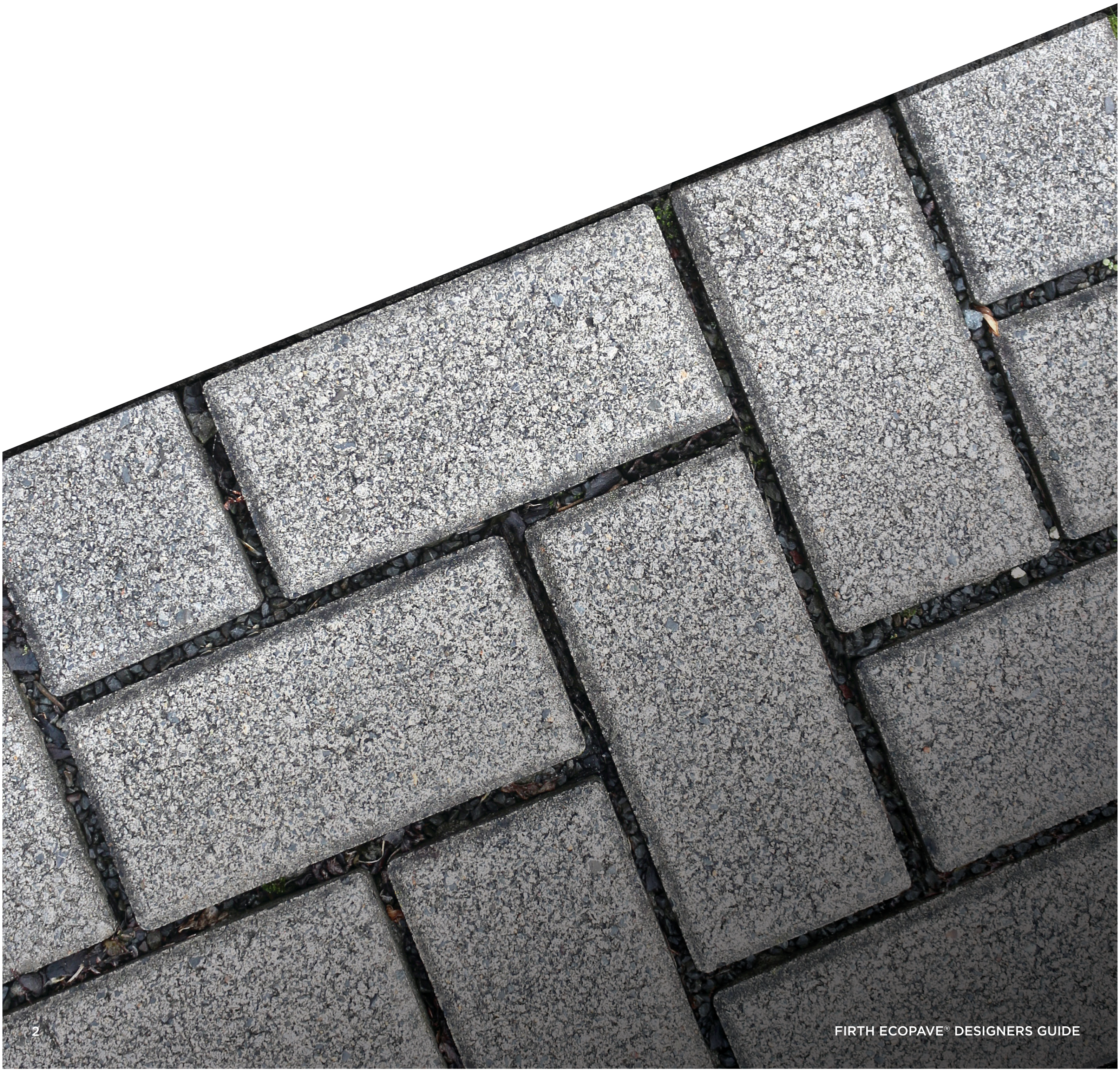
Firth PorousPave®

Firth Gobi® Block

Firth Grass Paver

CONTENTS





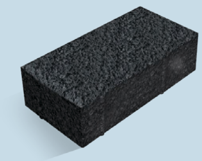
# 1 INTRODUCTION

THIS DOCUMENT IS TO PRESENT DESIGN GUIDANCE FOR THE INSTALLATION OF THE FIRTH ECOPAVE® RANGE OF PERMEABLE CONCRETE PAVING SYSTEMS UP TO 1,000M² IN AREA. PAVEMENT AREAS GREATER THAN 1,000M² REQUIRE SITE SPECIFIC DESIGN BY A QUALIFIED ENGINEER. THIS GUIDE SHOULD BE READ IN CONJUNCTION WITH THE FIRTH INSTALLATION GUIDE WHICH HAS A FOCUS ON THE CONSTRUCTION MATERIALS, INSTALLATION AND MAINTENANCE PLAN FOR THE DIFFERENT TYPES OF PERMEABLE PAVING SYSTEMS. THIS DESIGN GUIDE IS APPLICABLE TO THE FOLLOWING FOUR TYPES OF SYSTEMS:

1

**Firth FlowPave 80mm** – water travels through the gaps between impervious concrete pavers (200mm long, 100mm wide and 80mm depth) into the underlying components.

2



**Firth PorousPave® 80mm** – where water travels through pervious concrete pavers (200mm long, 100mm wide and 80mm depth, made from nO-fines concrete) into the underlying components

3

**Firth Grass Paver 80mm** – where water travels through the soil/gravel infill in the 50mm x 50mm void spaces of the impervious concrete matrix in paver sizes of 400mm x 400mm by 80mm depth.

4

**Firth Gobi® Block 100mm** - where water travels through the soil/gravel infill in the ???? void spaces of the impervious concrete matrix in paver sizes of 200mm x 200mm by 100mm.

This guide should be used in consultation with an engineer, architect or landscape architect in order to ensure compliance with council requirements and project conditions. Pavements should be designed in consultation with a qualified civil engineer and within the guidelines of NZS 3116:2002 with due consideration of the likely moisture sensitivity of the subgrade and the need for filter fabrics. Normal gap types of aggregate are not suitable as basecourse material and will lead to pavement failure if used.

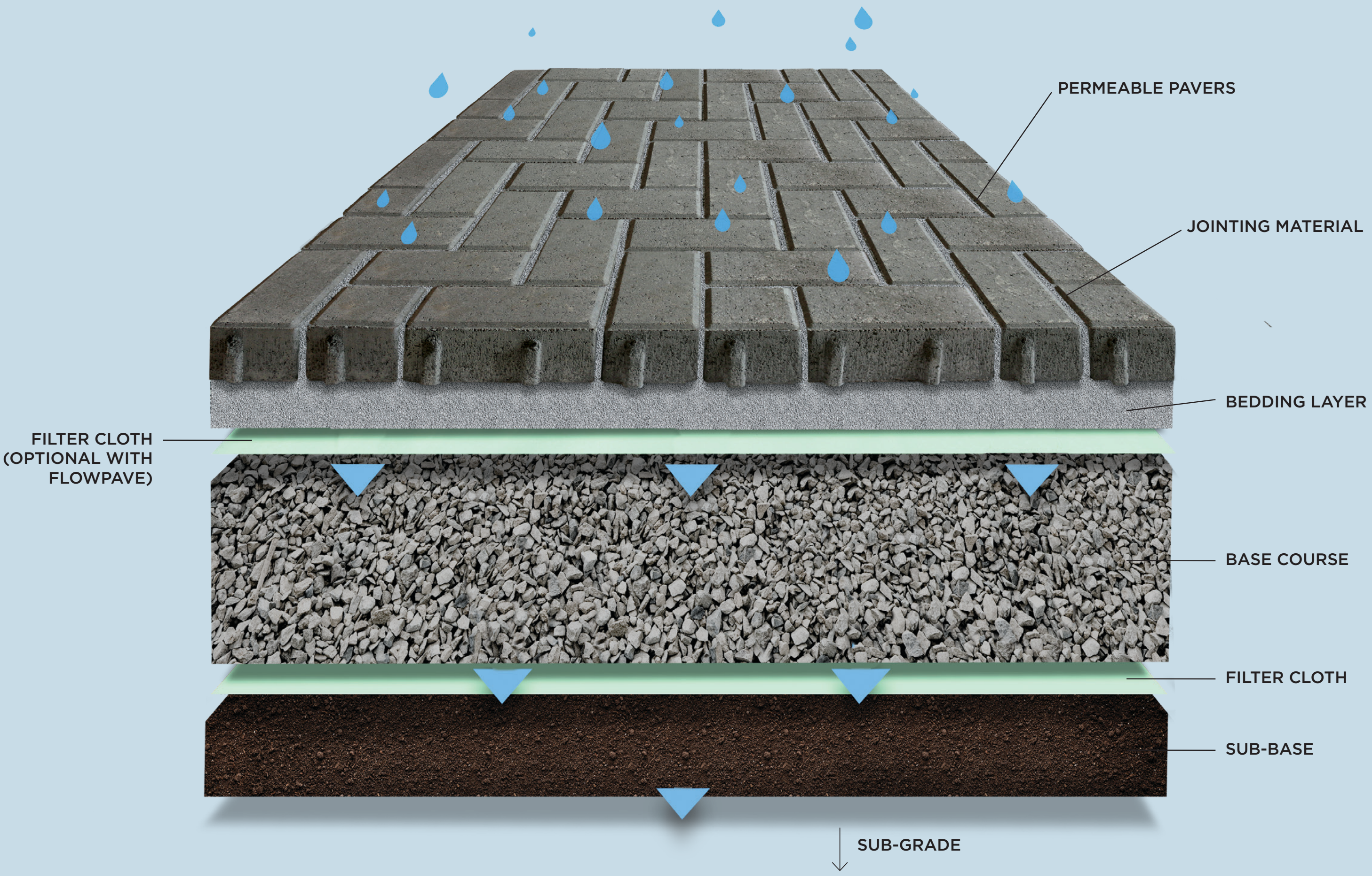
FOR CONSISTENCY WITH AUCKLAND COUNCIL PERVIOUS PAVING DOCUMENTS THE FOLLOWING TERMS ARE DEFINED AS:

**Pervious paving** – the general term used to describe a constructed hard surface which allows water to pass through to the underlying components.

**Porous paving** – where water travels through the surface paver into the underlying components. This is the Firth PorousPave® system.

**Permeable paving** – where water travels through the gaps between impervious blocks into the underlying components. This is the Firth FlowPave system.

HOW THE PERMEABLE SYSTEM WORKS



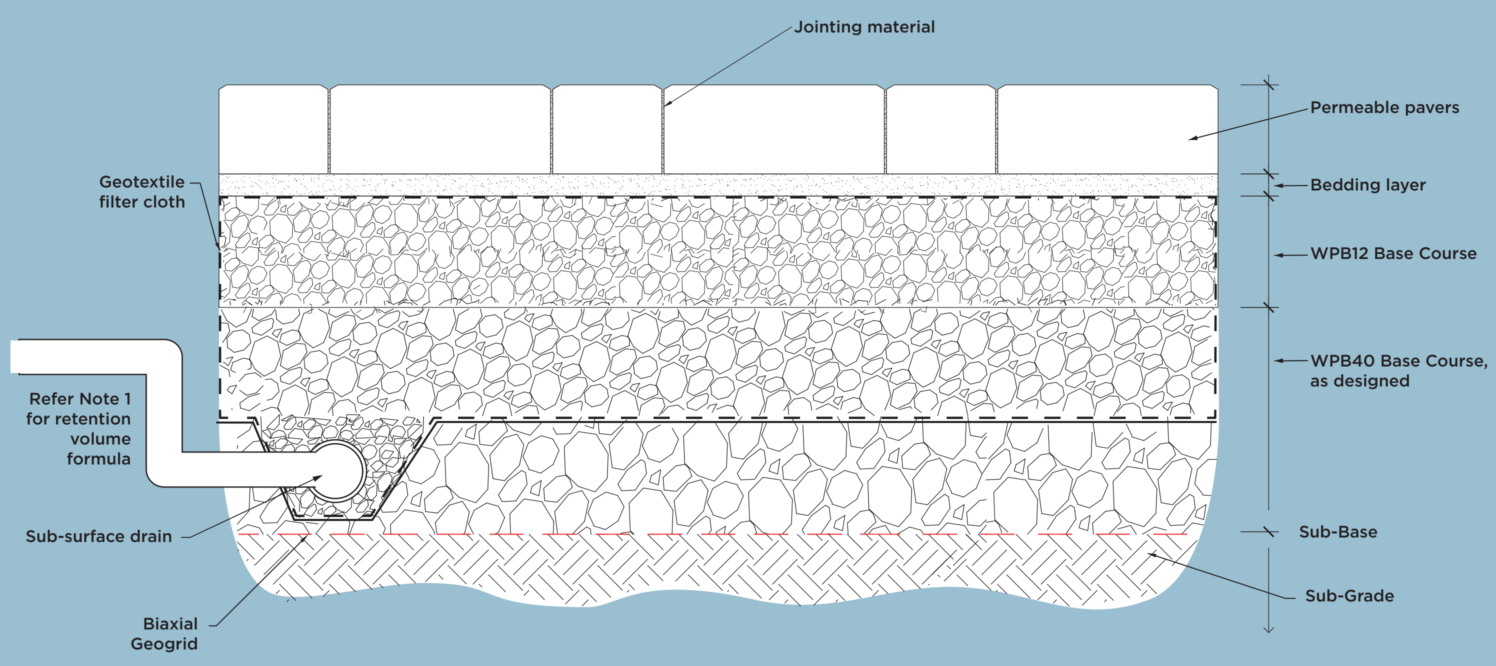

## COUNCIL RECOGNISED

**Proven permeability 5500mm/hr as installed**

Councils now require steps to be taken to reduce the effects that property development has on waterways from stormwater runoff. Firth's EcoPave® is a council recognised paving system that will help to maintain the natural water balance of a property and reduces the need for retention structures.

## 1.1 TERMINOLOGY

Cross section of typical permeable pavement




**Note 1:** retention volume formula = a x h x 0.3
a = area of paving m2 h = height between bottom of overflow outlet and base of form base course 0.3 = porosity of perm base course

**Bedding Layer** – Permeable pavers are bedded on a 20mm layer of either sand or chip depending on the type of permeable paver used.

**Base course/Water Storage Medium** – The structural drainage layer underneath the bedding layer, which can be either drainage aggregate or a no-fines concrete. This layer is also referred to as "storage medium" as it acts as a storage tank once the storm water runoff has dissipated into it. The base course layer can be made up of two layers:

- Top layer of WPB7 - maximum thicknes of 150mm
- Bottom layer of WPB40 if additional thickness is

**Sub-Base** – GAP40 or GAP65 to create a stable base in low CBR. Generally not considered to provide any water storage.

**Biaxial Geogrid** – For low CBR subgrades.

**Sub-grade** – The undisturbed soil at the bottom of the pavement system. The strength of this influences the thickness of structural support layer of the base course.

**Sub-surface drain** – A drainage system which allows water to enter it so it can be directed out of the base course. Assists with removing water in impermeable clay sub-grades and can be designed to reduce the stormwater peak flow.

**Filter cloth** – Normally a non-woven geotextile which is a polypropylene fabric which allows water to pass through it and prevents the bedding sand from migrating into the sub-base drainage aggregates. Also assists in stopping contamination of the sub base drainage aggregates when surrounded by clay soil.

**WPB40** – A layer of aggregate which may be required as per design (check your requirements), which allows a higher amount of storage water.

## 1.2 DESIGN GUIDANCE

**This document gives design guidance on the following topics:**

1. Auckland Unitary Plan SMAF1 and SMAF2 areas – these Stormwater Management Areas for Flow (SMAF) have additional design requirements to protect stream health through the stormwater management of the 90th and 95th percentile detention volume for the SMAF2 and SMAF1 areas respectively
2. Stormwater management of the 1 in 10-year and 1 in 100-year rainfall events
3. Pervious Paving vs Grass Surface
4. Structural Design
5. Water Quality

## 2 AUCKLAND UNITARY PLAN SMAF1 AND SMAF2 AREAS

The Auckland Unitary Plan maps identify Stormwater management area controls – Flow 1 (SMAF1) and Flow 2 (SMAF2). Stormwater management within these areas seek to protect and enhance Auckland's rivers, streams and aquatic biodiversity in urban areas. The SMAF1 and SMAF2 areas identify rivers and streams (and their contributing catchments) that are particularly susceptible to the effects of development or have relatively high values. The SMAF controls are greater in SMAF1 areas than SMAF2 areas as these catchments discharge to sensitive or high stream health value streams that have relatively low levels of existing impervious areas. The less strict SMAF2 requirements are for catchments discharging to streams with moderate to high values and sensitivity to stormwater, but generally with higher levels of existing impervious area within the catchment.

The following design guidance in SMAF areas is based on 'Section C2.2.3.5 Summary of pervious pavement design process', Stormwater Management Devices in the Auckland Region, Auckland Council guideline document, GD2017/001 Version 1.

**Step 0 – Determine if "passive" or "active" system**

- Passive systems only captures water directly falling on the pervious paving
- Active systems receive water from adjacent impervious surfaces in addition to rain which falls on the pervious paving area

This distinction is important as there are no sizing specifications for the management of "passive" SMAF systems. This is because it is assumed that the SMAF detention and retention volumes will not produce runoff from the surface provided it meets general site and paving design considerations/specifications.

**For "Passive Systems"**

- No specific sizing required provided it meets general site and paving design considerations/specifications
- Ensure design meets (Table 40: Site Considerations, Auckland Council GD2017/001 – see attached Appendix A) and paving design considerations and specifications (Table 41: Pervious paving design considerations and specifications, Auckland Council GD2017/001 – see Appendix B) including long-term infiltration requirements
- Ensure structural and loading specifications from traffic loading are met (refer Section 5 for some general guideline structural basecourse depths)
- If pervious paving is being used in a high contaminant generating car park, Auckland Council must review and approve the device to ensure it treats to the required level. Passive systems will generally meet this requirement.

**For "Active Systems"**

For Active Systems see the following steps.

Step 1 – Design basecourse storage to meet detention requirements (C2.2.3.1, Auckland Council GD2017/001)

**Basecourse storage is calculated as:**

$$V_{(tot)} = A \times d_{(basecourse)} \times Ø$$

*Where:* $V_{(tot)}$ = *Total storage volume in basecourse* ($m^3$)

*A = Pervious surface area* ($m^2$)

$d_{(basecourse)}$ = *Depth of basecourse layer (m)*

*Ø = Void space of basecourse layer (%)*

The required detention volume depends on the relevant 90th (SMAF2) and 95th (SMAF1) percentile rain depths calculated using the methodology as described in Section B, Auckland Council GD2017/001. Typical rain depths are between 24mm to 30mm for SMAF2 areas and 32mm to 40mm for SMAF 1 areas (refer Figure 5 – 90th percentile and Figure 6 – 95th percentile, Section B, Auckland Council GD2017/001, pages 46 and 47 respectively).

Figure 1 shows the required base course depth vs the design rainfall event for a typical permeable paving installation with an underdrain spacing of 10mm.

FIGURE 1

SMAF BASECOURSE DEPTH VS 24-HR RAINFALL EVENT FOR PASSIVE AND ACTIVE SYSTEMS

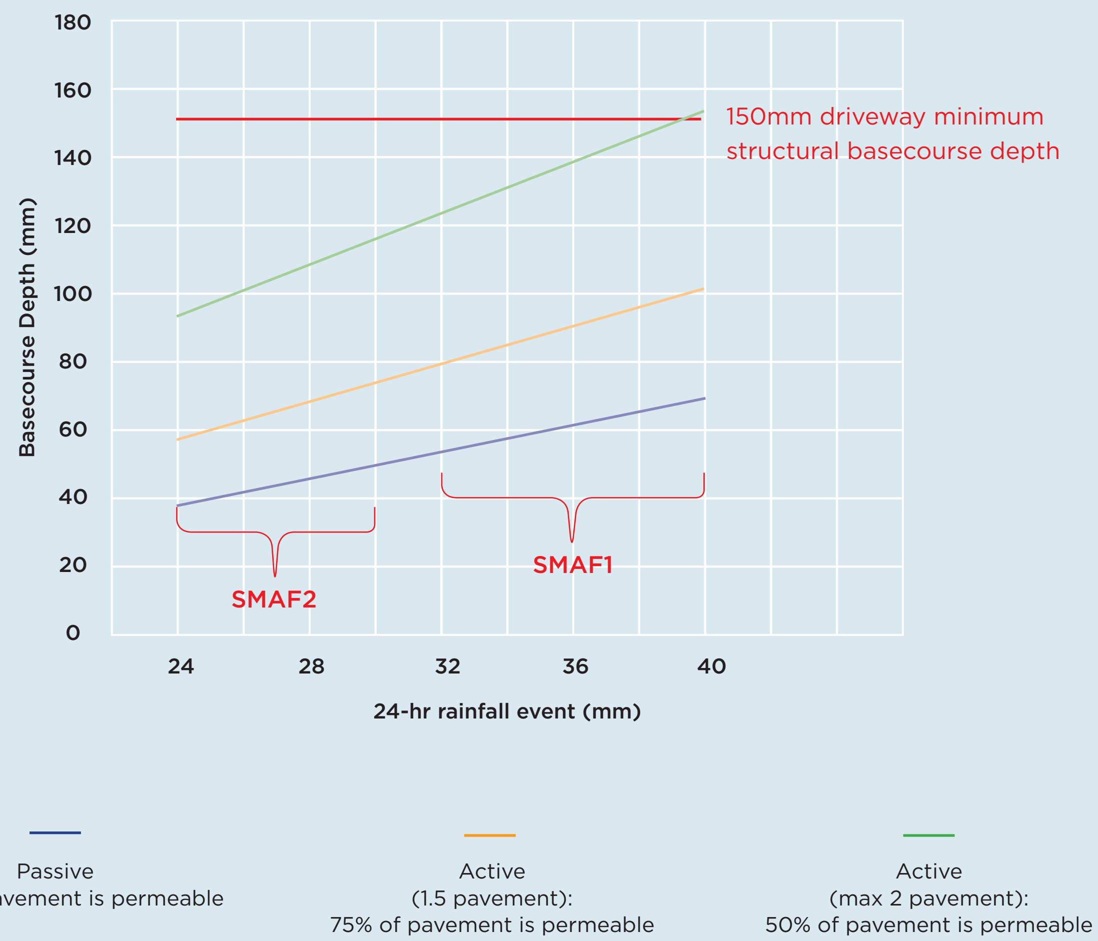



**FIGURE 1: BASECOURSE DEPTH VERSUS 24-HR RAINFALL EVENT**

**To use Figure 1:**

1. Enter the graph on the x-axis with the value of the 24-hr rainfall event (mm) from Figure 5 – 90th percentile and Figure 6 – 95th percentile, Section B, Auckland Council GD2017/001. Refer to Appendix D.
2. Determine "Active" System ratio. Maximum allowed Active System ratio is 2 pavement: 1 pervious paving. Interpolate between Figure 1 ratios of 1:1, 1.5:1 and 2:1 for your specific pavement : pervious paving ratio.
3. Determine Basecourse Depth. From the intersection point of the 24-hr rainfall event and the "Active" System Ratio, read off the required basecourse depth on the y-axis. For example, a 24-hr rainfall event of 36mm, for an "Active" System Ratio of 1.5, gives a basecourse depth of 90mm.

**Note** that Figure 1 shows that the required SMAF basecourse depth (up to the rainfall depth of 40mm) is less than the minimum recommended driveway structural basecourse depth of 150mm.

**Step 2 – Infiltration systems to meet retention requirement (C2.2.3.2, Auckland Council GD2017/001)**

To protect and enhance Auckland's rivers, streams and aquatic biodiversity in urban areas it is also a requirement to manage stormwater runoff volumes. For this, both SMAF1 and SMAF2 areas need to provide retention (volume reduction) of at least 5mm runoff depth for the impervious area for which the hydrology mitigation is required.

**Section C2.2.3.2, Auckland Council GD2017/001 states that:**

*'Passive unlined pervious paving systems, with or without a drain, will be able to achieve this retention requirement through infiltration losses into the underlying soils. Pervious paving should not be used where expansive soils with low infiltration rates are present.*

*Active systems will have to infiltrate up to 10mm (5mm retention depth x 2 areas) in the underlying soils, based on the maximum ratio for active systems of 2:1 to meet the retention requirements. Therefore, permeability testing of the underlying soils is required where active systems are proposed to prove that the infiltration rates will be sufficient.*

*There are three different options (Table 42):*

### TABLE 1: INFILTRATION SYSTEMS (TABLE 42, AUCKLAND COUNCIL GD2017/001, P 124)

| Infiltration System | Description | Underdrain | Performance specification |
|---|---|---|---|
| Full infiltration system | Subsoil infiltration rates are sufficiently high so that all runoff from the design event (detention and retention volume) will infiltrate within 72 hours. | No | To be used only if the storage volume can be infiltrated within 72 hours. |
| Partial infiltration system | Subsoil infiltration rates are too low to fully infiltrate the detention volume within 72 hours. The paving will still be able to provide the full retention volume. | Yes | Underdrains must be designed to empty base course in 72 hours. |
| No infiltration system | The system is lined and no infiltration to underlying subgrade will occur. | Yes | Underdrains must be designed to empty base course in 24 hours. |

**Note:** The full infiltration system is only likely to be possible for subgrade soil particle sizes greater than Auckland's typical alluvium and sandy soil types in Auckland. The majority of the SMAF areas are located in fine grained soils and are therefore likely to need underdrains.

### STEP 3 – UNDERDRAIN LAYOUT (C2.2.3.3, AUCKLAND COUNCIL GD2017/001)

The purpose of the underdrain is to discharge the total volume of runoff that is collected by the pervious paving within the required timeframe (24 to 72 hours, refer performance specification Table 1 above). The flow rate can be calculated as (Auckland Council GD2017/001, equation 3, p 124):

$$Q_{(under)} = \frac{\text{rainfall depth (mm) x contributing area (m}^2\text{)}}{60 \times 60 \times 24}$$

*Where* $Q_{(under)}$ *= underdrain design flow rate (L/s)*

For pavement areas up to 1,000m$^2$, the underdrain calculated flow rate for the maximum likely SMAF 24-hr rainfall depth of 40mm equates to approximately 0.4 L/s. This is significantly less than the peak flow of 1.8 L/s for the minimum size 100mm drain coil. This means that for paving areas up to 1,000m$^2$, the minimum 100mm diameter drain coil will meet the underdrain flow requirements.

Underdrains are to be laid at a minimum fall of 0.5% and provide maintenance access at the upstream end of the pipes.

## 3 STORMWATER MANAGEMENT OF THE 1 IN 10-YEAR AND 1 IN 100-YEAR RAINFALL EVENTS

The performance of pervious paving in the larger 1 in 10-year and 1 in 100-year rainfall events requires specific stormwater calculations and modelling. For this design guide, these calculations have been carried out using the Interlocking Concrete Pavement Institute's Permeable Paving Design Pro Software (Ver 2). A detailed outline of the Design Pro Software is presented in Appendix C. This section gives a summary of the hydraulic performance for typical pervious paving installations up to 1,000m$^2$ in area.

**The hydraulic performance of the pervious paving system is a function of:**

1. **Pavement geometry** – area (length x width) and the runoff from contributing adjacent areas (area, curve number, roughness coefficient, average slope and maximum length of overland flow)
2. **Subgrade Layer** – porosity and permeability
3. **Granular Layer** – porosity and permeability (based on gradation or actual test value)
4. **Paving Layer** – Surface infiltration rate
5. **Design** 24-hr rainfall events
6. **Underdrain spacing**

**For this design guide the following typical parameters have been used:**

**Pavement Geometry:**

- Area of pavement up to a maximum of 1,000m$^2$.
- Area of contributing adjacent impervious area up to a maximum of ratio of 2 pavement : 1 pervious

**Subgrade Layer:**

- Silty-clay, medium plasticity, void space (porosity) 0.41, permeability 1.3 x 10$^{-9}$m/s

**Granular Layer:**

- WAPP12, void space (porosity) 0.30, permeability 6 x 10$^{-3}$m/s (Firth test results gave a porosity (void space) of 0.33 and a permeability of 5 x 10$^{-3}$m/s.

**Paving Layer:**

- Infiltration rate of 250mm/hr (taken as approximately twice the design infiltration rate of 120mm/hr

**Design 24 hour rainfall events (typical events for North Shore, adjusted for 2 degrees climate change)**

- 1 in 2-yr – 85mm
- 1 in 10-yr – 160mm
- 1 in 100-yr – 255mm

**Underdrain Spacing**

- Underdrain spacing of 3, 5, 10, 20m

**Figure 2 presents a summary of the required basecourse depths for:**

- Varying contributing area (50% Pervious Paving, that is, ratio of 2 pavement : 1 pervious and 100% Pervious Paving, that is, ratio of 1 pavement : 1 pervious
- Varying underdrain spacing of 3, 5, 10, and 20m
- Varying 2-yr, 10-yr and 100-yr rainfall events

The required basecourse depth is taken at a maximum allowable water depth in the granular layer of 85% of the depth of the granular layer.

FIGURE 2

WAPP12

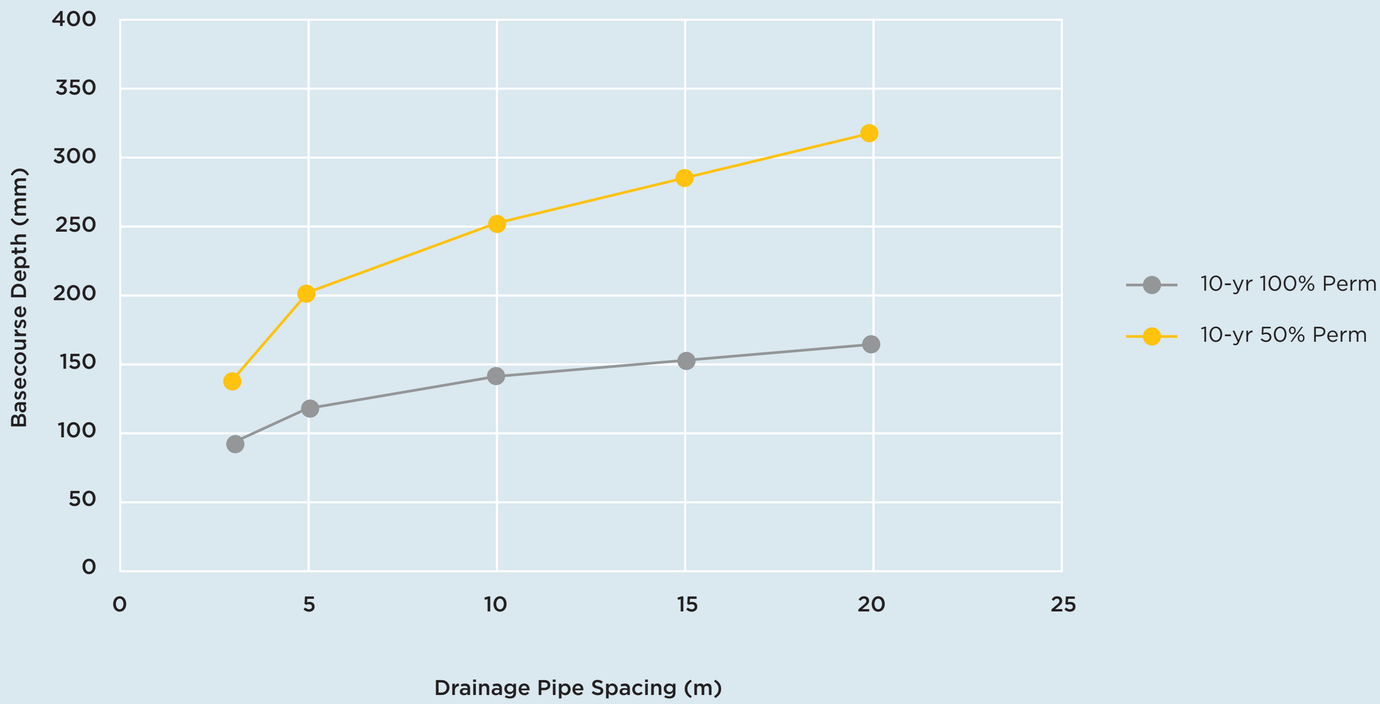



FIGURE 2: BASECOURSE DEPTH VERSUS STORM EVENT AND UNDERDRAIN SPACING

Figure 2 shows the increasing basecourse depth with increased underdrain spacing, increasing storm events and increased additional impervious contributing area. For example, for the 1 in 10-yr rainfall event:

- For a passive system (catching only rain that falls on the pervious paving itself, that is, 100% pervious paving) the required depth of basecourse varies from 140mm for 10m underdrain spacing up to 165mm for a 20m underdrain spacing
- For an active system (catching runoff from an adjacent equal area of 500m$^2$ of additional impervious surface, that is, 50% pervious paving) the required depth of basecourse varies from 250mm for 10m underdrain spacing up to 320mm for a 20m underdrain spacing

Figure 2 shows that a "passive" system (100% pervious paving), can manage the 1 in 100-yr rainfall event with a depth of 150mm of basecourse (the minimum recommended basecourse depth for a driveway) with 10m underdrain spacing.

## 4 PERVIOUS PAVING VS GRASS SURFACE

Multiple sources indicate that pervious paving has similar runoff characteristics as a grass surface. For catchment modelling it is suggested that the “Runoff Curve Numbers” or “Runoff Coefficients” of grass cover be used to model pervious paving surfaces. That is a runoff curve number of 74 and a runoff coefficient of 0.35.

**Information sources include:**

**International literature** - The Interlocking Concrete Pavement Institute (ICPI) 2008 guidelines gives representative ranges of curve numbers of between 45 and 80 (similar to the Auckland Council TP108 curve numbers of 70 to 74 for bush and pasture respectively) and runoff coefficients of between 0.0 to 0.3 (less than the 0.4 for heavy clay soils in the New Zealand Building Code).

The Permeable Paving Fact Sheet adapted from the Massachusetts Low Impact Development Toolkit (Massachusetts Nonpoint Source Pollution Management, n.d.) gives a runoff coefficient of 0.3.

**Pervious Paving Trial site, Birkdale Road, North Shore, Auckland** - The Masters Thesis on the water quantity and quality characteristics of a trial section of pervious paving on Birkdale Rd, Auckland measured the peak flows from the 35m section of pervious paving versus an adjacent section of asphalt (Blackbourn, 2007). A 50% to 99% reduction in peak flows was measured between the pervious section versus the impermeable asphalt surface, during rainfall intensities up to a 1 in 10-yr event.

**The Interlocking Concrete Pavement Institute (ICPI) Permeable Paving Design Pro Software** – Modelling of pervious paving using the ICPI Design Pro Software gives a percent reduction of peak flow rates and runoff volumes from that of an impervious surface similar to that of a grass surface to an impervious surface calculated using Auckland Council’s Technical Publication TP108 (Auckland Council, 1999). That is, a reduction of 50 to 60% for the 2-yr, 30 to 40% for the 10-year and 20 to 30% for the 100-year events.

**Note:** because even in the smaller rainfall events there is still surface runoff from the pervious paving surface the design and construction of surface runoff collection systems are still required for pervious paving surfaces.

## 5 STRUCTURAL DESIGN

The structural design parameters for this design guide have been taken from the “Permeable Pavement Design Guidelines, Prepared for North Shore City, EcoWater Solutions and Rodney District, September 2004, Section 7 – Structural Design” prepared by Sinclair Knight Merz Limited’s structural engineer (URS New Zealand Limited, Maunsell Limited, & Sinclair Knight Merz Limited, 2004).

The structural depth of basecourse for subgrade CBR values of 3% and 5% for three road categories are presented in Table 2. These depths are a guide only and site specific conditions must be taken into account by a suitably qualified road pavement engineer.

### TABLE 2: STRUCTURAL BASECOURSE DEPTH PER ROADING CATEGORY

| Road Category/Class | Residential Driveway | Residential Road (Local Living) | Residential Road (Neighbourhood Collector) |
|---|---|---|---|
| Function / Description | Access place or cul-de-sac with: < 50 Household-Unit Catchment (HUC) and < 100m length, excluding the turning head | < 150 HUC and not a public bus route | > 150 HUC, providing access to properties |
| Daily Traffic Volume | <300 vehicles per day | < 1,000 vehicles per day | < 3,000 vehicles per day |
| Cumulative Design Traffic (Typical) ESA | 2,000 ESA | 10,000 ESA | 20,000 ESA |
| | | **SUBGRADE CBR OF 3%** | |
| Basecourse Depth | 200mm | 225mm | 250mm |
| | | **SUBGRADE CBR OF 5%** | |
| Basecourse Depth | 150mm | 200mm | 225mm |

**NOTES:**
ESA – Equivalent Standard Axle, a standard axle with 550kPa for a 20-year design life.
Subgrade CBR - Saturated value due to likelihood of prolonged ponding of water in the subbase.
Subgrades weaker than CBR of 3% require specific design.
For construction materials refer Firth’s Installation Guide (Firth Industries, 2018).

## 6 WATER QUALITY

Site specific water quality treatment options needs to be considered for heavy commercial or industrial areas where high contaminant loads may be present. For light commercial and residential areas the pervious pavement is considered to provide adequate water quality treatment. See following sources of contaminant removal characteristics.

**Sources of water quality contaminant removal characteristics of permeable paving:**

- Permeable pavements, Permeable pavements task committee American Society of Chartered Engineers (ASCE) 2015, removal efficiencies based on concentration (EMC)
- Interlocking Concrete Pavement Institute's (ICPI) 2008 Guideline document
- A pervious paving trial site on Birkdale Road, Auckland, carried out as a Masters Thesis
- Auckland Council Contaminant Load Model, Technical Report TR 2010/003.

TABLE 3: CONTAMINANT REMOVAL CHARACTERISTICS

| **Contaminant** | | **Pervious Paving** | | |
|---|---|---|---|---|
| | **ASCE 2015** | **ICPI 2008 Guideline** | **Birkdale Rd Trial** | **Auckland Council Contaminant Load Model** |
| **Total Suspended Solids (TSS)** | Mean 81%<br>Max 96%<br>Min 32% | 60 to 90% | 58% +/- 15% (included fines from subbase/ subgrade) | 50% |
| **Copper** | Mean 67%<br>Max 100%<br>Min 33% | 50 to 89% | 57% +/- 11% | 40% |
| **Zinc** | Mean 72%<br>Max 97%<br>Min 36% | 62 to 88% | 91% +/- 5% | 30% |

## 7 WORKED EXAMPLE

**Example site parameters are:**

- 600m$^2$ parking area (assumed <1,000 vehicles per day). Less than the 1,000m$^2$ maximum pavement area for the use of this design guide
- Parking area located in a light commercial area. No additional water quality treatment required
- Located in a SMAF1 area, 95th percentile 24hr rainfall event of 35mm
- Partial infiltration system – subsoil infiltration rates are too low to fully infiltrate the detention volume within 72 hours. The paving will still be able to provide the full 5mm retention volume. Therefore requires underdrains.
- WAPP12 basecourse with minimum void space of 30%
- 1 in 10-yr 24hr rainfall event of 160mm
- Soaked CBR of subgrade of 5%

**Three examples:**

1. Passive system (only captures water directly falling on the pervious paving)
2. Active System at maximum ratio of 2 pavement : 1 pervious (receives water from adjacent impervious surface in addition to rain which falls on the pervious paving area)
3. Downstream piping restriction of no increase in 1 in 10-year rainfall event

### 1. Passive System

No sizing specifications for the management of passive SMAF systems provided that:

- Design meets (Table 40: Site Considerations, Auckland Council GD2017/001 – see attached Appendix A) and paving design considerations and specifications (Table 41: Pervious paving design considerations and specifications, Auckland Council GD2017/001 – see attached Appendix B) including long-term infiltration requirements
- Minimum structural basecourse depth for Daily Traffic Volume < 1,000 vehicles per day, with a subgrade CBR of 5% is 200mm (Table 2, p 10)
- Pervious paving is being used in a light commercial area so no further water quality treatment is required

**Conclusion – minimum basecourse depth of 200mm.**

### 2. Active System

Check that design meets (Table 40: Site Considerations, Auckland Council GD2017/001 – see attached Appendix A) and paving design considerations and specifications (Table 41: Pervious paving design considerations and specifications, Auckland Council GD2017/001 – see attached Appendix B) including long-term infiltration requirements

**Step 1** – Design basecourse storage to meet detention requirements

Use Figure 1 (p. 4) with an x-axis value of 35mm (95th percentile 24-hr rainfall event), and an Active System Ratio of 2, that is ratio of 2 pavement : 1 pervious to give a SMAF1 area basecourse depth (y-axis) of 135mm.

**Step 2** – Infiltration system to meet retention requirement

Subsoil infiltration rates are too low to fully infiltrate the detention volume within 72 hours, therefore underdrains are required.

**Step 3** – Underdrain layout

For pavement areas < 1,000m$^2$ the peak flows are less than the maximum 100mm drain coil. Use heavy duty 100mm drain coil.

**Step 4** – Check structural basecourse depth (Section 5)

Daily traffic < 1,000 vehicles per day and a CBR of 5% gives a minimum structural basecourse depth of 200mm.

**Conclusion – minimum basecourse depth of 200mm.**

### 3. Downstream piping restriction of no increase in 1 in 10-year rainfall event

For 1 in 10-year 24 hour rainfall event of 160mm, refer ***Figure 2*** with the following input information:

- 50% Pervious Paving, that is, ratio of 2 pavement : 1 pervious
- 10-yr 50% perm (yellow) graph

This gives a range of basecourse depth versus underdrain spacing of:

| Underdrain Spacing | Required Basecourse Depth |
|---|---|
| 5m | 200mm |
| 10m | 250mm |
| 20m | 320mm |

## 8 REFERENCES


Auckland Council. (1999). *Guidelines for stormwater runoff modelling in the Auckland Region, Technical Publication TP108.*

Blackbourn, S. D. (2007). *PERMEABLE PAVEMENT PERFORMANCE FOR USE IN ACTIVE ROADWAYS IN AUCKLAND, NEW ZEALAND.*

Firth Industries. (2018). *Firth EcoPave Permeable Paving Installation Guide.*

Massachusetts Nonpoint Source Pollution Management. (n.d.). *Permeable Paving.*

URS New Zealand Limited, Maunsell Limited, & Sinclair Knight Merz Limited. (2004). *Permeable Pavement Design Guidelines. Prepared for North Shore City, EcoWater Solutions and Rodney District Council.*


# APPENDIX A

SOURCE: TABLE 40: SITE CONSIDERATIONS, AUCKLAND COUNCIL GD2017/001, P 120

| Item | Description |
|---|---|
| **Catchment size and location** | • Small/medium catchment. At source, upper catchment locations.<br>• The total pavement catchment area for active designs should be less than two times the area of pervious paving (maximum 2:1 ratio).<br>• Adjacent pervious surfaces should drain away from the pervious paving design. Drainage is required to manage flows from larger events. |
| **Groundwater** | • Full or partial exfiltration systems should be used only if the seasonal high water table is more than 0.6 m from the invert of the pervious pavement system.<br>• Groundwater mounding analysis should be undertaken. An impermeable liner may be used in some instances. |
| **Slope** | • Less than 3° (5%) for active designs and less than 7° (12%) for passive designs. Should not be used in areas of instability.<br>• Greater than 15 m from slopes of more than 9° (15%). ? |
| **Subsoils** | • Subsoil characteristics (infiltration rates, void space compaction etc.) need to be understood, especially for active designs where sub-design erosion? might occur.<br>• Where subsoils have limited permeability, a perforated underdrain at the base may be needed to drain the design volume within 24 hours. Drains via gravity to the public network. |
| **Soils requiring structural support** | • Geotextiles, impermeable layers or liners are required for both structural support and to prevent media migration. Can become clogged if the device is poorly maintained. May also be needed if pervious paving is designed for detention only. Follow the manufacturer's specifications. |
| **Soils with poor drainage** | • Infiltration from the base of pervious paving into the subgrade should not be allowed where soils are susceptible to instability. |
| **Pre-treatment** | • Pervious paving should receive flows after pre-treatment for sediment reduction/removal. Regular maintenance to remove particulate deposits is needed.<br>• Pervious paving should not be located downstream of areas expected to have a high sediment load. |
| **Private connection** | • Pervious pavements on private land must meet the connection requirements of Auckland Council and remain pervious so as not to trigger consenting requirements. |
| **Contaminated land** | • Must be fully lined with an impervious layer if contaminated land is present.<br>• The impervious liner should be a minimum 0.25 mm thick polypropylene. |
| **Setback** | • Should have a lined vertical surface if within 5 m of structures.<br>• Pavement within 3 m of a structure or 6 m upstream of a structure or within 1:1 slope offset from the bottom foundations should be fully lined with no exfiltration. |
| **Traffic** | • Design traffic loading should be less than 3,000 vehicles per day (private roads).<br>• Auckland Transport does not allow pervious paving to be used on roadways, only on car parking bays. Specific attention should be paid to the loading criteria. A road pavement engineer should be involved to ensure structural integrity. |

# APPENDIX B

SOURCE: TABLE 41: PERVIOUS PAVING DESIGN CONSIDERATIONS & SPECIFICATIONS, AUCKLAND COUNCIL GD2017/001, P 121

| Item | Description |
|---|---|
| **Infiltration rate** | • 120 mm/hour over life-time of device, with a minimum initial rate of 1,200 mm/hr (factor of 10 times to account for potential clogging of the surface).<br>• Alternatively, surfacing should be designed with projections to keep the pavers apart and these gaps filled with appropriate jointing aggregate to ensure the infiltration rate. |
| **Active system catchment area** | • The total pavement catchment area for active systems should be less than two times the area of pervious paving (maximum 2:1 ratio).<br>• The infiltration rate must be adjusted accordingly, e.g. with a 2:1 ration the subsequent minimum infiltration rate will be (120 mm/hr x 2 areas) 240 mm/hr (over the life span of the device). |
| **Subgrade** | • Soaked CBR (California Bearing Ratio) or Equilibrium Moisture Content CBR must be more than 3%. |
| **Slope** | • Active systems should have a maximum slope of 3° (5%).<br>• Passive systems should have a maximum slope 7° (12%).<br>• Slopes greater than 3° (5%) require paving to have cut-off barriers at intervals to prevent upwelling down slope. |
| **Overflow drainage** | • All pervious paving systems should be designed with surface collection and conveyance drains, in case of surface blockage or rainfall events which exceed the capacity of the system.<br>• All designs must comply with the New Zealand Building Code for overflow drainage. |
| **Edge restraints** | • Edge restraints should be provided around all edges of the pervious paving to prevent pavers from getting displaced and to prevent splitting and cracking around the edges. |
| **Bedding layer** | • For porous paving, use Standards New Zealand Concrete Segmental and Flagstone Paving (NZS3116:2002) Sand Category (<5 mm diameter grain size). For permeable paving, use 2-7 mm diameter chips. |
| **Jointing material** | • The same material as for the bedding layer must be used. For porous paving, use NZS3116:2002 Sand Category (<5 mm diameter grain size). For permeable paving, use 2-7 mm diameter chips. |
| **Base course** | • Use coarse-graded, clean, durable aggregate with high void space.<br>• Alternatives, such as plastic void formers, may also be used for this layer.<br>• If plastic void formers are used, loading and cover requirements must be checked to ensure they are fit for the proposed use. |
| **Underdrain** | • Required in soils with low infiltration or where impermeable liner is used (in which case the device does not provide retention).<br>• Where retention is designed for, underdrain must be positioned such that the storage below the invert will retain the 5mm design storm volume (i.e. 15mm depth where aggregate has 30% void space).<br>• Underdrain layout must be designed to drain the design volume within 24 hours (detention only) or 72 hours (retention and detention).<br>• Heavy duty 100 mm drain coil must be used as the underdrain pipe. |
| **Geotextile** | • Geotextile may be used to prevent migration of aggregate layers; geotextile must be secured at edges of paving area and all joins overlapped.<br>• Note that geotextile layers can clog and reduce permeability. |
| **Impervious liner** | • Pervious paving placed adjacent to roadways should have an impervious liner placed on the vertical side adjacent to the roadway or around the adjacent road sub-drain. This is to prevent impounded water flowing into road foundation layers, or short-circuiting retention by entering road subsoil drainage.<br>• The impervious liner should be a minimum 0.25 mm thick polypropylene. |

For this design guide, the hydraulic performance of the pervious paving under the larger 1 in 10-year and 1 in 100-year rainfall events have been calculated using the Interlocking Concrete Pavement Institute's Permeable Paving Design Pro Software (Ver 2).

**The hydraulic performance of the pervious paving system is a function of:**

- Pavement geometry – area (length x width) and the runoff from contributing adjacent areas (area, curve number, roughness coefficient, average slope and maximum length of overland flow)
- Subgrade Layer – porosity and permeability
- Granular Layer Configuration – porosity and permeability (based on gradation or actual test value)
- Paving Layer – Surface infiltration rate

**The Permeable Paving Design Pro Software input parameters are:**

- Precipitation – storm pattern (Auckland Council TP108 24hr storm), rainfall (for different rainfall return periods from 1 in 2-yr to 1 in 100-yr rain fall events), volume (based on contributing area and rainfall)
- Analysis Settings – maximum allowable depth in granular layer (taken as 85% of granular layer thickness), underdrain pipes (distance to pipe, drainage area per pipe, pipe diameter, height of outflow pipe above the underdrain, pipe slope and roughness coefficient)

**The Permeable Paving Design Pro Software analysis outputs are:**

- Intervals of 0.1 to 1hr; for a period of up to 7 days; rainfall events of 1 in 2-yr, 1 in 5-yr, 1 in 10-yr, 1 in 25-yr, 1 in 50-yr, 1 in 100-yr.
- Precipitation (mm/hr); volume ($m^3$/hr); surface water depth on pavement mm; depth of water in the granular layer base (mm); underdrain pipe drainage ($m^3$/hr); catchment area surface runoff ($m^3$/hr) and subgrade infiltration ($m^3$/hr)

**For this design guide, the following typical input parameters have been kept constant:**

- Area of Paving - 500m2 of pervious paving
- Subgrade - Silty-Clay, medium plasticity, void space (porosity) 0.41, permeability 1.3 x $10^{-9}$m/s
- Granular Layer - WAPP12, void space (porosity) 0.30, permeability 6 x $10^{-3}$m/s (Firth test results gave a porosity (void space) of 33% and a permeability of 5 x $10^{-3}$m/s )
- Paving Layer – infiltration rate 250mm/hr (taken as twice the design infiltration rate of 120mm/hr, refer Section XXX)

**The following typical input parameters were varied:**

- Area of contributing adjacent areas varied from the pavement being 100% pervious paving down to 50% of the pavement in pervious paving)
- Design 24 hour rainfall events of 1 in 2-yr (85mm), 1 in 10-yr (160mm) and 1 in 100-yr (255mm) return periods (adjusted for 2deg rise climate change for North Shore)
- Underdrain spacing of 5, 10, 15, 20 and 25m

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