3. Results

3.1 Site Infiltration Rates

The average site and location infiltration rates before and after the trial clean were calculated and are provided below in Table 2. Further site test details are provided Appendix A.

Table 2. Infiltration Rates

		Pre-Clean		Post-Clean	
Site #	**Location**	**Site average infiltration rate (mm/hr)**	**Location average Infiltration Rate (mm/hr)**	**Site average infiltration rate (mm/hr)**	**Location average Infiltration Rate (mm/hr)**
1	Collins St	1,053	525	13,242	16,028
2	Collins St	557		20,542	
3	Collins St	122		13,278	
4	Collins St	367		17,048	
5*	Eades Place	204	203	8,452	5,714
6*	Eades Place	330		3,374	
7*	Eades Place	76		5,316	
8**	Harris St	0.001	0.001	4,584	5,566
9**	Harris St	0.001		N/A	
10**	Harris St	0.001		N/A	
11**	Harris St	0.001		6,548	
12**	Abbotsford St	0.001	0.001	3,526	2,489
13**	Abbotsford St	0.001		1,859	
14**	Abbotsford St	0.001		2,083	

(*) - Equivalent sites were selected for post-cleaning tests at Eades Place (see Figure 23).

- Site 5 was re-tested with site 16
- Site 6 was re-tested with site 15
- Site 7 was re-tested with site 17

(**) - Negligible or no infiltration observed after 10mins or more for pre-cleaning tests.

N/A - Test was unable to be completed due to obstructions.

3.2 MUSIC Modelling

A MUSIC model was created to model the amount of water (ML/year) the selected systems would typically receive and how much would be infiltrated in a pre-cleaned and post-cleaned state. Table 2 below lists these results. Each of the table's headings is described below:

- Flow in: Typical amount of water (ML/year) that each complete permeable pavement system receives from direct rainfall and its local catchment (adjacent road or footpath).
- Infiltrated: Typical amount of water (ML/year) that each complete permeable pavement asset captures and infiltrates with discharge to underground drainage presumed to occur.
- Not infiltrated: Typical amount of water (ML/year) that each complete permeable pavement asset is unable to capture and remains as surface runoff.

Table 3. MUSIC pre-clean and post-clean modelling infiltration

		Pre-Clean			Post-Clean		
Location	**Flow in (ML/yr)**	**Infiltrated (ML/year)**	**Not infiltrated (ML/year)**	**Not infiltrated (%)**	**Infiltrated (ML/year)**	**Not infiltrated (ML/year)**	**Not infiltrated (%)**
Collins St	1.05	1.01	0.04	4%	1.05	0	0%
Eades Place	0.82	0.82	0	0%	0.82	0	0%
Harris St	0.38	0.03	0.36	95%	0.38	0	0%
Abbotsford St	1.19	0.04	1.15	97%	1.19	0	0%

The results suggest that even though they are significantly clogged, Collins St and Eades place still provide significant levels of functionality. It is likely that the actual performance is poorer than the modelling suggests as some parts of the systems may be quite significantly compromised while others may be in better functional condition depending on variable catchment conditions.

4. Discussion & Recommendations

4.1 Pre-cleaning tests

The SIT test method was used in preference to the ASTM test method prior to cleaning as it has been demonstrated to be more robust and representative of typical infiltration conditions due to its larger testing footprint (Winston et. al., 2016). This is backed up by prior E2Designlab testing using infiltrometers similar to the ASTM test method systems where we have found results to be highly variable due to the small size of the test rigs and issues like lateral flows. For the pre-cleaning tests, issues were encountered across the test locations with some ASTM tests exceeding 25 mins to infiltrate 3.6 litres completely.

The SIT test provides a broader test area with greater variability and is likely to be more representative of conditions across the permeable pavement. Generally the infiltration rates for these were higher than the ASTM tests pre-cleaning. This suggests that over the larger area there is typically some parts that are less clogged that infiltrate more freely while an ASTM site has a higher probability of solely comprising a fairly clogged area.

The Collins St modular bluestone paving recorded the highest average infiltration rate (525 mm/hr) across the four locations tested. The permeable asphalt at Harris St and Abbotsford St recorded no observable infiltration within 10 mins of recording and were concluded to be largely clogged and non-functioning. After 30 minutes, a reduction in levels of a few millimetres indicated very slow infiltration at Abbotsford St while no change at all was observed at Harris St. An average infiltration rate of 0.001 mm/hr was assumed as a default estimate for these locations to enable comparative calculations.

4.2 Post-cleaning tests

The water jetting cleaning technique produced a prominent change in infiltration rates across all the locations. The average infiltration rates across all the locations exceeded approximately 2,500 mm/hr after cleaning with Collins St recording the highest result again at 16,028 mm/hr. Due to the significance of this unanimous result it can be comfortably concluded that all the permeable systems were clogged by surface debris. This clogging reduced the functionality of the tested systems to varying degrees due to the system designs and their unique environments.

Due to the high infiltration rates achieved, the SIT test method was not suitable to re-conduct the infiltration tests as the results were too largely dependent on the rate of application of water rather than the infiltration rate of the media. To reduce this error the ASTM test method was mainly used to conduct the infiltration tests post-cleaning for all the locations as it is more effective with the high infiltration rates. This means that strictly speaking the test results are not directly comparable. However the large differences in results before and after cleaning substantially outweigh any differences that may arise between the testing methods.

Although care was taken, small volumes of aggregate from the permeable asphalt assets and infill media (sand and quarter minus (2-5 mm) crushed rock) between the modular bluestone paving was dislodged during the cleaning process. Where practical, released sediments and these volumes of material were collected. It was found that sediment volumes released were quite insignificant at this scale. For larger scale cleaning it is recommended that wash-off waters are collected using vacuum collection.

4.3 Site test results

The average site and location infiltration rates in Table 2. Infiltration Rates are produced from combining the results from both the ASTM and SIT methods and the pre-wetting tests. These results can thus only be viewed as high-level performance indicators for each of the sites and locations. The results were combined as the SIT method could not readily be replicated for the post-cleaning tests due to an increased level of error (see heading 4.2).

4.4 MUSIC results

A MUSIC model was prepared for each of the locations to represent the combined effect of each permeable pavement asset taking into account the full catchment and treatment areas at the location.

The results suggest that even with the impaired infiltration rates at Eades Place and Collins St, the permeable pavements should still be able to infiltrate most of the mean annual runoff volume while the Abbotsford and Harris St sites predictably provided little infiltration. This suggests that infiltration rates do not need to be close to the post-cleaned rates observed to be functionally effective and that it may be possible to wait until a reasonably significant amount of clogging has occurred before cleaning becomes necessary. Conversely, it has been noted in the literature that preventative cleaning to remove clogging material is preferable to corrective cleaning so a reasonable maintenance frequency should be maintained.

There are some limitations to modelling these systems in MUSIC. The chosen treatment node, media filtration is intended to represent sand filters, but adequately represents permeable pavements as some of the underlying datasets were for gravel systems similar to the permeable pavements being assessed here. The level of water quality treatment predicted is considered to be highly uncertain, particularly for nitrogen and should be used with great caution. Here we have only considered quantitative results.

A further limitation is that the permeable pavements are intended to facilitate passive irrigation of surrounding trees. This is not readily represented by MUSIC and the media filtration node used as the closest approximation of permeable pavements does not simulate evapotranspiration. The closest approximation of this behaviour may be to use a bioretention node to represent a tree pit with a submerged zone provided and scaled up to represent the adjacent structural soil which acts as a soil moisture store.

4.5 Discussion and recommendations

Overall the infiltration testing undertaken has clearly demonstrated that:

- All of the assets tested are significantly clogged, have resulting low infiltration rates and are performing poorly or at a reduced level relative to their design intent
- Cleaning (using spray) is effective in restoring infiltrative capacity of the assets

Given these outcomes, it is apparent that there is potential for wider implementation of permeable pavements within the City to be undertaken with confidence, provided that an effective asset audit and maintenance regime is put in place to ensure that the assets are regularly maintained.

It is noted that while very high infiltration rates were recorded immediately after cleaning, these will most likely drop dramatically during the first few following rainfall events (1-2 months of operation at best) and it is probably more realistic to aspire to maintaining infiltration rates in the order of 500-2,000 mm/hour on an ongoing basis. This is more than sufficient to enable effective operation of the systems and will allow cleaning to be scheduled at something in the range of once every 6 months out to possibly once every 2-3 years depending on the behaviour and catchment conditions of the various systems.

The following recommendations are made for further investigations, maintenance works and future designs

1. Clean all Council permeable pavement systems to remove or reduce surface clogging. It is suggested that the Abbotsford St and Harris St systems should be a priority due to their very low level of functionality.
   - Surface cleaning is to be carried out with pressure washing
   - All discharged material and washed-off water from permeable pavement cleaning is to be collected using vacuum or other suitable method and appropriately disposed of during the cleaning process as it may contain elevated levels of heavy metals and hydrocarbons. It is not recommended to dispose of discharge down street drainage pits.
2. Council should immediately replace the infill media (quarter minus (2-5 mm) crushed rock) between the modular bluestone at site's 1-4 at Collins St that was removed during cleaning ***as this presents a trip hazard that needs to be rectified as a priority***.

3. Trial sweeping and vacuuming as potential stand-alone permeable pavement cleaning methods. Also trial different water jetting pressures to confirm an appropriate pressure for different permeable pavement systems.

4. Future infiltration maintenance tests should commence with the ASTM method and then proceed to the SIT method if expected infiltration times are exceeded.

5. It would be beneficial to undertake infiltration testing at selected sites across assets immediately following cleaning to firstly ensure the cleaning was effective broadly across the assets and secondly to establish a baseline for comparison. This would ideally be followed up with infiltration testing at regular intervals (say 6, 12 and 24 months) to determine how quickly the permeable pavements clog and establish what an appropriate maintenance frequency would be. While this would ideally occur

for all sites to account for differences of catchment and system, the repeated testing of at least one site combined with observations of condition or less frequent testing at others would provide valuable insights to inform the maintenance frequency and program.

6. Prepare an infiltration and clogging model to predict the change in infiltration rates over time and infer appropriate times for cleaning intervention. This could be calibrated based on the data collected (and ideally updated following subsequent cleans and testing) and would allow Council to develop a more robust asset management model to support ongoing management of permeable pavement systems.

5. References

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