Use of Permeable Pavement to Stormwater Harvesting and Reuse to irrigate oval at Morphett Vale Sport Complex, South Australia

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Permeable surfaces for roads and carparks have been used as a means of disposing stormwater in developed urban areas. Such surfaces provide an alternative to impermeable surface which would otherwise produce a rapid stormwater runoff, leading to possible flooding and degeneration of receiving water quality through uncontrolled discharge of polluted urban waters. The paper discusses the direct storage of stormwater in a permeable pavement and the reuse of it for irrigation. It allows developers to reduce stormwater runoff and reduce portable water demand. In addition, on many sites, above-ground rainwater tanks are too large, being unappealing or unfeasible due to space restrictions. As such, construction and reconstruction of pavements with underlying storage is a more viable solution. In Morphett Vale sporting club, a permeable pavement on a carpark with underlying storage of stormwater is used to irrigate the adjacent sporting field. Stormwater infiltrates through the permeable pavers and is stored within the voids in the aggregates underneath the permeable pavers. It is then is pumped to overhead tank where it is used to irrigate the oval. The water quality and the efficiency of the reuse stormwater system are monitored by water quality analysis, taking samples in regular intervals and quantity of the water reused for irrigation by water flow metering system. The City of Onkaparinga Council capital works program has focused on the incorporation of Water Sensitive Urban Design

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elements in the re-development of Morphett Vale carpark to implement in larger scale for future greenfield developments.

1. Introduction

South Australia has a long history in stormwater harvesting, with early investigations of harvesting potential dating back to at least 1978 (Read, 1978). Stormwater harvesting came of age in the mid-1990s when stormwater treatment wetlands were coupled with aquifer storage and recovery schemes to overcome the problem of storing treated stormwater over low water demand periods. Treated stormwater is not subjected to water use restrictions and so has increasingly become attractive as a source of alternative water. This is particularly the case for the local government who have been pressured by their communities to keep parks, ovals and open spaces green and useable. Pavements account for a large portion of the impervious area of urban catchments and are significant contributors to uncontrolled discharge of pollutants, and to urban stormwater runoff, leading to possible flooding. A range of stormwater treatment and harvesting techniques are applied in urban areas to reduce pollutant loads in stormwater and the reuse of harvesting schemes using permeable pavers. The small scale projects are playing significant roles in introducing Council policies in the emphasis on Water Sensitive Urban Design (WSUD) in new developments. Water quality testing on small scale WSUD projects are undertaken to demonstrate the importance of stormwater quality treatment devices including stormwater harvesting and reuse schemes to developers and the local community.

![Permeable Pavement and gap for infiltration](image)

Figure 1. Permeable Pavement and gap for infiltration

Permeable pavements for roads and footpaths, as shown in Figure-1, are an alternative to impermeable surfaces and allow for the infiltration of stormwater runoff to reduce both pollutant loads and the overall volume of runoff on site. The surface layer is composed of concrete blocks with small gaps in the short ends.
which allow rainwater to infiltrate into the pavement. Under the surface layer there are two aggregate layers called regulating course and sub-base, formed of clean limestone. Generally there is a geotextile between the regulating course layer and sub-base, in order to avoid the 5 mm bedding layer migrating into the spaces between the larger aggregates. The sub-base layer is the reservoir where infiltrated water is stored and available to be used for non-potable demands as irrigation of sporting field.

Permeable pavements are a viable alternative to storage tanks which are large, inconvenient, costly and unattractive as well as potentially requiring deep excavation to install below the ground. If a suitable sub-base to permeable paving is enclosed within an impermeable membrane and an appropriate surface lay over the top, a storage system may be established which is easy to construct without restricting development at the surface.

In Morphett Vale, where the City of Onkaparinga has developed a strategy of local water storage and re-use, it is used for the irrigation of a public sporting field. The subsurface storage system is under a public car park, as portrayed in Figure 2. This form of water storage has many advantages including inaccessibility to public for safety, no loss of land, lack of complex construction, financially effective in the long term, convenient access to pumping equipment, and prevention to vandalism being totally enclosed.

Figure 2. Permeable Pavement Carpark
As evident in Figure-3, the permeable car park pavement is not only collecting stormwater car park runoff, but also part of the roof water from the club rooms. The submersible pump is pumping the harvested stormwater to the existing above ground tank. The tank is also getting supplied by the mains water supply and the water in the tank is pumped to irrigate the football/cricket oval.

A. Stormwater Harvesting System

The typical section, as shown in Figure 4, comprises of permeable paving which is a surfacing material of a traditional paving type. Then, it comprises a geotextile filter layer in order to eliminate the particles of the run-off and then, a sub base where the storage takes place. It is a 20mm nominal diameter washed nominal dolomite aggregate of a minimum 700mm in depth as the pavement is mostly used by smaller
vehicles for parking. The whole construction is enclosed within a 2 mm thick high density impermeable polyethylene (HDPE) liner to provide a watertight storage system. Stormwater runoff from the car parking surface is being stored within it as described in Figure-4.

![Figure 4. Stormwater Harvesting System](image)

There are various possible methods for establishing required design storage volume, but can be simply assumed that potentially 14-days re-use water supply is desirable as an available volume in storage. The void ratio is the ratio of the volume of void space to the volume of solid substance in any material consisting of void space and solid material. Here, the void ratio is 0.4 and by consequent, the volume of water within the aggregates is 70 kL.

**B. Sump and Pump**

The sump and pump, as shown in Figure 5, is on a low level which constitutes a “sump”. In the submersible pump chamber, there are two perforated pipes for collecting the stored water from the sub-base pavement contained within the aggregates in the enclosure.

![Figure 5. Pump Chamber](image)

![Figure 6. Junction box of overflows](image)
The supply pump is activated by a drop of pressure in the supply line: it starts approximately at a level of 300mm in the sump and turns off at a level of 180mm and will only run when the above ground tank water level is lower than 2.1meters. It operates at 420 litre/min. and is maintained regularly to prevent any clogging.

Any excess of stormwater which overflows from the sub base pavement and stormwater runoff for a heavy storm event is collected in a grated inlet pit and is discharged through the pipe to the street. This will prevent any water upwelling which may cause water pooling in the car parking area and adjacent land.

Harvested water from the permeable pavement is pumped to an above ground tank. When there is not enough water from the re-use system, mains water will automatically start filling the tank. The above ground tank is connected to both recycled stormwater and mains water which eventually will be pumped from the adjacent pump house to irrigate the sporting oval. The above ground tank volume is about 20 kL. On the above ground tank, a rain gauge is also installed as shown in Figure-7.

![Figure 7. Rain gauge (Pluviometer) fixed on the above ground tank near the car park.](image)

C. Irrigation of the Sporting Oval

Irrigation of the sporting field takes place only during the night (when nobody is anticipated to be present on the sports oval). It is an automatically controlled irrigation program which occurs in a defined period (between Sunday and Thursday) in response to a defined value of evapotranspiration (ET): approximately 75 mm. This value is estimated by the Penman Monteith equation based on a rain gauge operated by the scheme designers, Agua Pty Ltd. Information is also collected from a nearby weather station which is measuring the temperature, solar radiation, wind speed and relative humidity. With such a system,
the irrigation is timed to occur in response to calculated ET level by a commonly utilised means of irrigating in response to the estimated soil water requirements.

The grass on the field is irrigated by sprinklers with gear driven rotors, the water passing through the sprinkler drives a gear train that traverses the stream in a circle or portion of a circle. The type of grass is kikuyu (Pennisetum clandestinum) which is cost effective and drought-tolerant.

![Figure 8. Sporting field being irrigated](image)

**D. Water Quality Analysis**

Stormwater quality varies considerably between rainfall events and catchments. Factors affecting water quality are physical, chemical and biological characteristics that may also affect the soil environment and, as a consequence, the users of the sport field in Morphett Vale. Roof water generally has lower levels of chemical contaminants and pathogens than urban stormwater, which collects contaminants during its passage over roads or other surfaces. Consequently, the health and environmental risks associated with stormwater surface runoff reuse are higher than those associated with roof water reuse.

Moreover, except for the filtration process occurring at the pavement surface and residence time under the pavement, there is no specific treatment in the Morphett Vale scheme. That is why the water quality should be analysed to check if the reuse water being used for irrigation is compliant with Australian Guidelines.

It was found by Pratt, C.J (1995) that the water quality for a harvesting sub base depends on the base course aggregate material used. In this case, the material is dolomite aggregate, which has the potential to affect the quality of stored water.
Once or twice a week, during a 5 week period, water samples were collected in the sump and pump chamber that reflect the quality of the water in the pavement storage. There were three bottles collected each time: one bottle was sent to a laboratory to measure and other two samples were used for measuring pH, conductivity and the concentration of Na\(^+\), Mg\(^{2+}\) and Ca\(^{2+}\). Measurement of concentration of total zinc, lead and copper in the reservoir model filled with dolomite aggregate were not carried out because dolomite aggregate can retain heavy metals from solution by adsorption and that the retention increased with residence time. However, biological parameters—pathogenic bacterium: Escherichia Coli were analysed.

**E. Salinity and risk of soil structure degradation**

Salinity, which is the presence of soluble salts in water, has to be monitored because high salinity levels in soil may result in reduction in plant productivity and may damage the field grass. Moreover, sodicity, which is the presence of a high proportion of sodium ions relative to calcium and magnesium ions in water, were monitored because it degrades soil structure.

**F. Materials and methods**

The pH of water has to be managed because the dissolution process of aggregate constituents in the storage system (dissolution of calcium and magnesium carbonate in the dolomite) can be affected by increasing the level. Similarly for electrical conductivity, EC\(_i\) (dS/m), it may pose a risk for the growth of plants and may also increase the salinity and the sodicity of the water.

The suitability of irrigation water salinity can be determined by calculating the average root zone salinity to see if the crop (in this case, field grass) is likely to be affected by the irrigation water salinity. LF is the average leaching fraction; i.e. the proportion of applied water that leaches below the root zone. For loam and light clay (considering the grass in Morphett Vale), the value is 0.33. (See reference: Australian and New Zealand Guidelines for fresh and Marine Water quality).

The EC\(_{\infty}\) value is compared with the values given in *Table 9.2.10 in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 3*, to assess the general level of crop tolerance to the irrigation water salinity. For Kikuyu grass (Pennisetum clandestinum), the salinity threshold EC\(_{\infty}\) is 3 dS/m.
However, to determine the risk of soil structure degradation caused by irrigation water sodicity, the Sodium Adsorption Ratio (SAR) should be calculated using the formula. It measures the relative concentration of Na\(^+\) to Ca\(^{2+}\) and Mg\(^{2+}\) (in mmol/L), and can be used with EC\(_i\) to predict soil structure stability in relation to irrigation water, using the graph SAR versus EC relationship in the Guideline by superimposing EC\(_i\) and SAR to see if it will affect soil structure.

To calculate this SAR, the concentration of Na\(^+\), Ca\(^{2+}\) and Mg\(^{2+}\) in each sample of water have to be measured. Ca\(^{2+}\) and Mg\(^{2+}\) are determined by EDTA titration, whereas Na\(^+\) is determined by atomic absorption.

**G. EDTA titration to determine Calcium and Magnesium:**

The purpose of EDTA titration is to determine the concentration of metal ions in a water sample. The most common positively charged metal ions in natural waters are Ca\(^{2+}\) and Mg\(^{2+}\). In this case, it was assumed that these are the only metal ions present in the stored water. Two sets of titrations and one set of titrations were used to determine the total concentration of Ca\(^{2+}\) and Mg\(^{2+}\) present in the water sample. After selectively precipitating the Mg\(^{2+}\) as Mg(OH)\(^\text{2}\), it was performed to a second set of titrations to determine the concentration of Ca\(^{2+}\) in the water. Method for determination of Sodium by atomic absorption:

**Table 1. pH values**

\[
\begin{array}{|c|c|c|c|}
\hline
\text{Results} & \text{Date} & \text{Time} & \text{pH} \\
\hline
1 & 2/07/2012 & 10h20 & 7.85 \\
2 & 5/07/2012 & 11h10 & 7.71 \\
3 & 12/07/2012 & 11h00 & 7.59 \\
4 & 20/07/2012 & 10h10 & 7.39 \\
5 & 25/07/2012 & 10h00 & 7.40 \\
6 & 2/08/2012 & 9h10 & 7.90 \\
\hline
\end{array}
\]

The pH has to be checked to limit corrosion and fouling of pumping, or irrigation systems. This value should be maintained between 6 and 8.5. The six samples have been analysed and the results show that the pH
of reuse water is within the limit during this last five weeks. The EC\textsubscript{se} is then monitored and the results are shown in Table 2.

Table 2. EC\textsubscript{se} values

<table>
<thead>
<tr>
<th>Sample</th>
<th>Date</th>
<th>Conductivity (µS/cm)</th>
<th>E\textsubscript{ci} (dS/m)</th>
<th>Salinity E\textsubscript{cse} (dS/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2/07/2012</td>
<td>254</td>
<td>0.254</td>
<td>0.35</td>
</tr>
<tr>
<td>2</td>
<td>5/07/2012</td>
<td>262</td>
<td>0.262</td>
<td>0.36</td>
</tr>
<tr>
<td>3</td>
<td>12/07/2012</td>
<td>245</td>
<td>0.245</td>
<td>0.34</td>
</tr>
<tr>
<td>4</td>
<td>20/07/2012</td>
<td>234</td>
<td>0.234</td>
<td>0.32</td>
</tr>
<tr>
<td>5</td>
<td>25/07/2012</td>
<td>272</td>
<td>0.272</td>
<td>0.37</td>
</tr>
<tr>
<td>6</td>
<td>2/08/2012</td>
<td>237</td>
<td>0.237</td>
<td>0.33</td>
</tr>
</tbody>
</table>

The salinity threshold for Kikuyu grass is 3dS/m. In Table-2, the EC\textsubscript{se} of the six samples are well below the threshold, with some variation between weeks. It can be concluded that the crop is unlikely to be affected by water salinity during these last weeks and that the water quality in terms of salinity was quite good at the time of the study.

The concentration of Na\textsuperscript{+} is determined by the straight calibration line equation. With these three concentrations SAR can be calculated and the risk of soil structure degradation can be determinate. The different results for the six samples are described in Table 3.

Table 3. SAR values

<table>
<thead>
<tr>
<th>Sample</th>
<th>Date</th>
<th>[Ca\textsuperscript{2+}] (mg/L)</th>
<th>[Ca\textsuperscript{2+}] (mmol/L)</th>
<th>[Mg\textsuperscript{2+}] (mg/L)</th>
<th>[Mg\textsuperscript{2+}] (mmol/L)</th>
<th>[Na\textsuperscript{+}] (mg/L)</th>
<th>[Na\textsuperscript{+}] (mmol/L)</th>
<th>SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2/07/2012</td>
<td>40.1</td>
<td>1.00</td>
<td>2.92</td>
<td>0.12</td>
<td>42.0</td>
<td>1.83</td>
<td>2.44</td>
</tr>
<tr>
<td>2</td>
<td>5/07/2012</td>
<td>36.1</td>
<td>0.90</td>
<td>7.78</td>
<td>0.32</td>
<td>32.3</td>
<td>1.40</td>
<td>1.80</td>
</tr>
<tr>
<td>3</td>
<td>12/07/2012</td>
<td>24.1</td>
<td>0.60</td>
<td>7.78</td>
<td>0.32</td>
<td>31.1</td>
<td>1.35</td>
<td>1.99</td>
</tr>
<tr>
<td>4</td>
<td>20/07/2012</td>
<td>25.7</td>
<td>0.64</td>
<td>10.69</td>
<td>0.44</td>
<td>25.0</td>
<td>1.09</td>
<td>1.48</td>
</tr>
<tr>
<td>5</td>
<td>25/07/2012</td>
<td>32.1</td>
<td>0.80</td>
<td>12.15</td>
<td>0.50</td>
<td>32.0</td>
<td>1.39</td>
<td>1.73</td>
</tr>
<tr>
<td>6</td>
<td>2/08/2012</td>
<td>24.9</td>
<td>0.62</td>
<td>7.78</td>
<td>0.32</td>
<td>38.9</td>
<td>1.69</td>
<td>2.47</td>
</tr>
</tbody>
</table>

These SAR values are used with E\textsubscript{ci} values on the graph, SAR vs EC and for each sample, soil structure stability is predicted.

With graphic reading, we noticed that water quality of sample 1 and sample 6 is on the left of the solid line, whereas the quality of the other samples (2, 3, 4 and 5) is between the lines. By consequent, the water quality at the beginning of July and at the beginning of August was likely to induce degradation of soil structure.
structure, the quality was not good and irrigation of the sporting field grass with reuse water shouldn’t be done. Moreover, the water quality during the month of July was marginal in terms of soil structure stability. The irrigation water sodicity must be monitored with caution in the future in order to minimise impacts on soil structure in the Morphett Vale sporting field.

H. E Coli

E.Coli is measured in water for specific microbiological material. After each sampling in Morphett Vale, we sent one bottle to Water Quality Centre in SA Water for pick up suitable for sampling E.Coli and results were received each week.

In the Australian Guidelines in regards to E.Coli levels for irrigation, considering that the irrigation is unrestricted, it can be concluded that if E.Coli levels are <10CFU/100mL, the water quality in terms of E.Coli is acceptable. The results for the last four 4 weeks are synthetized in Table 4.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Date</th>
<th>Counting of E.Coli (CFU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2/07/2012</td>
<td>1/100mL</td>
</tr>
<tr>
<td>2</td>
<td>9/07/2012</td>
<td>1/100mL</td>
</tr>
<tr>
<td>3</td>
<td>16/07/2012</td>
<td>2/100mL</td>
</tr>
<tr>
<td>4</td>
<td>24/07/2012</td>
<td>3/100mL</td>
</tr>
<tr>
<td>5</td>
<td>01/08/2012</td>
<td>1/100mL</td>
</tr>
<tr>
<td>6</td>
<td>10/08/2012</td>
<td>3/100mL</td>
</tr>
</tbody>
</table>

In Table-3 that during the last four weeks, the E.Coli count was<10 CFU/100mL and water quality in terms of E.Coli was acceptable. However, to make a complete monitoring, samples should be analysed at least every 3 months to justify the water quality in terms of E.Coli.
I. Water Balance Analysis

In order to assess and monitor the Morphett Vale water reuse scheme, a water balance analysis should be carried out. By monitoring the various flow data of the system, the system’s efficiency can be estimated. From the data available, how much reuse stormwater has been used and how much mains water is pumped to irrigate the sporting field can be estimated and consequently, the efficiency of the reuse stormwater scheme can be estimated. A key concern of this study was to estimate how much water can be harvested and how much water is really harvested using this scheme. From the flow data derived from sump to tank and sump water level, it is possible to monitor the quantity of harvested stormwater from the permeable pavement storage and to compare it with the total volume of water used for irrigation. The sump water level is determined via the depth of water in the pavement storage. The irrigation schedule is required to know how much, and in which frequency, water is used for the irrigation of the sporting field. Also, how much mains water is utilised for irrigation and come to the conclusion on using harvested volume in the sub base storage and the demand of irrigation usage.

J. Link between water level and pumping events:

To monitor this, the water level in the sump enclosure was measured from 2/07 to 2/08. These results are described in the table below

<table>
<thead>
<tr>
<th>Sample</th>
<th>Date</th>
<th>Time</th>
<th>Water level (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2/07/2012</td>
<td>10h20</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>5/07/2012</td>
<td>11h10</td>
<td>320</td>
</tr>
<tr>
<td>3</td>
<td>12/07/2012</td>
<td>11h00</td>
<td>335</td>
</tr>
<tr>
<td>4</td>
<td>20/07/2012</td>
<td>10h10</td>
<td>240</td>
</tr>
<tr>
<td>5</td>
<td>25/07/2012</td>
<td>10h00</td>
<td>260</td>
</tr>
<tr>
<td>6</td>
<td>2/08/2012</td>
<td>9h10</td>
<td>355</td>
</tr>
</tbody>
</table>
The variations in water level among the samples are linked to rainfall and water extraction from the storage tank. For example, between 5/07 and 12/07, there must have been rainfall because the level of water in the pavement storage increased, but it doesn’t exclude that some water must have been pumped. Similarly, between 12/07 and 20/07, water from the permeable pavement must have been pumped to the tank. These observations can be checked by using the rain gauge charts and the flow data on the Agua website. The rain gauge chart for the period of analysis is presented in Appendix 1. Flow from the pavement storage to the tank can also be recovered with Agua data. By selecting the flow rate since 1/07, it has been observed that when water from the permeable pavement is pumped. The flow rate and volume of water pumped are shown in Table 6.

**Table 6. Flow rates values and water volume pumped**

<table>
<thead>
<tr>
<th>Date and time</th>
<th>Flow rate (L/s)</th>
<th>Water volume pumped (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012-07-02 11:15:00</td>
<td>1.667</td>
<td>1500</td>
</tr>
<tr>
<td>2012-07-02 11:30:00</td>
<td>1.667</td>
<td>1500</td>
</tr>
<tr>
<td>2012-07-02 11:45:00</td>
<td>1.667</td>
<td>1500</td>
</tr>
<tr>
<td>2012-07-02 13:30:00</td>
<td>2.5</td>
<td>2250</td>
</tr>
<tr>
<td>2012-07-16 16:45:00</td>
<td>0.004</td>
<td>4</td>
</tr>
<tr>
<td>2012-07-16 17:00:00</td>
<td>0.003</td>
<td>3</td>
</tr>
<tr>
<td>2012-07-18 23:00:00</td>
<td>3.333</td>
<td>3000</td>
</tr>
<tr>
<td>2012-07-20 04:00:00</td>
<td>0.833</td>
<td>750</td>
</tr>
</tbody>
</table>

The water level has reduced into the permeable pavement from 335 to 240 mm, between 12/07 and 20/07. This pumping event matches with rainfall data because, during this period, water levels in the sump increased and activated the pumping.

**K. Relationship between rainfall depth and pavement volume:**

A link can be established to identify which water volume in the permeable pavement corresponds to rainfall (mm). Appendix 6 shows the rainfall and sump level chart and the different quantities (in mm) of water that fell during the studied period; we find 19.2 mm of rainfall. Graphically, this amount corresponds to an increase of 76 mm in the sump. By calculation, 1 mm of rainfall, therefore, corresponds to 3.96 mm of
water in the pavement storage, which is equal to 0.40 kL water in the pavement. Thus, 1 mm rainfall ≈ 400L of water storage in the pavement. The area that collects stormwater is approximately 850m². Theoretically, the water corresponding to 1mm of rainfall that should infiltrate in the storage pavement should be 0.80 kL.

The water that fall during the study period is 2.6mm. Theoretically, with the void ratio, the height of the water in the pavement should 10.3mm. But the sump chart shows an increase of 13mm. The deviation from the previous relationship is 26%, which is considered reasonable. This is due to the lack of precision on the different charts.

II. Conclusion

The project has demonstrated that storage of stormwater runoff using permeable pavement and reuse scheme is a cost effective solution compared with other stormwater harvesting and reuse schemes. The water quality is adequate to irrigate sporting fields and no additional treatment seems to be necessary since the salinity and the presence of pathogens are in compliance with the guidelines. However, we have seen that the risk of soil structure degradation is not excluded due to the SAR risk analysis tool and controls must be considered to ensure that the water quality does not have an impact on the soil structure of the sporting field.

The demand for irrigating open spaces should be compared with the storage capacity and rainfall events. The maintenance cost is minimal compared to water sensitive urban design method for stormwater harvesting and reuse schemes.
Appendix 1

Rainfall

Date
1/07/2012 15/07/2012 29/07/2012 12/08/2012 26/08/2012

Rainfall (mm)

Rainfall

Water level in the Sump

Date
20/6/12 30/6/12 10/7/12 20/7/12 30/7/12 9/8/12 19/8/12 29/8/12 8/9/12

Level

Level
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