Hydrologic Regions for sizing Stormwater Treatment Measures in Victoria

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Abstract
Designing stormwater treatment measures generally requires a continuous simulation modelling approach using a small time step to properly consider the influence of a range of local storm characteristics and hydrologic conditions. This can be a complex and costly exercise and requires both technical expertise and the availability of a suitably long period of rainfall data. This paper describes the development of a simple but rigorous procedure to transpose known performance data from one geographic location to another within the state of Victoria in Australia. The procedure is based on continuous modelling of the performance of a number of stormwater treatment measures using 6 minute rainfall recorded over a suitably long period for 45 sites across Victoria. The size of the treatment measures required to attain prescribed water quality outcomes for each of the sites investigated is determined from application of the model. These data are then normalised and correlated to geographic and meteorological characteristics of the individual sites to enable regional relationships to be derived. Five hydrologic regions within Victoria and a further four regions for the metropolitan region in Melbourne were delineated. Their corresponding regional formulae are applicable for all sites within Victoria.

Keywords
Stormwater Treatment, Performance Assessment, Hydrologic Design Regions

INTRODUCTION
Water Sensitive Urban Design (WSUD) as a framework for a holistic management of the urban water cycle and its integration into urban design is now widely accepted in Australia. In the state of Victoria, reference to adoption of WSUD is now incorporated into state planning provisions (Department of Sustainability and Environment, 2005a) and in Melbourne 2030, the strategic planning policy for the metropolitan area of Melbourne (Department of Sustainability and Environment, 2005b). Guidelines for treatment objectives for stormwater quality have been defined in many states in Australia, to represent achievable targets using best practice. The guiding principles of WSUD are centred on achieving integrated water cycle management by addressing the three water streams in terms of potable water conservation, wastewater minimisation and stormwater management. In Victoria, treatment objectives for stormwater are expressed in mean annual reductions of pollutant loads from typical urban areas with no stormwater treatments installed. The objectives are 80% reduction in TSS, 45% reduction in TP and 45% reduction in TN (Victorian Stormwater Committee, 1998).

A range of stormwater treatment measures are capable of removing pollutants from urban stormwater to meet the treatment objectives stated. The design of stormwater treatment measures generally requires a continuous simulation approach to properly consider the influence of antecedent conditions of the treatment measure during the occurrence of a storm event and the wide range of storm characteristics and hydraulic conditions that the individual treatment measures are to operate in. Computer models such as the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) developed by the Cooperative Research Centre for Catchment Hydrology (2005) have been developed to enable continuous simulations of complex stormwater management treatment trains to aid in the development of stormwater management strategies and the design (sizing) of stormwater treatment measures.
Using models such as MUSIC can be a complex and requires both technical expertise and the availability of a suitably long period of rainfall data at 6 minute time intervals. With the implementation of stormwater quality treatment required in all urban development in Victoria, it was considered essential that an alternative method be developed to allow consistent sizing of a number of commonly utilised stormwater treatment measures. This paper describes the development of a simple but rigorous procedure to transpose known performance data from one geographic location to another within the state of Victoria in Australia, thus removing the need for complex modelling for small projects and allow a level of consistent application of a procedure based on continuous modelling to be applied at every site irrespective of the availability of suitable historical rainfall record.

METHODS

A total of forty five rainfall pluviographic stations were selected for analysis and derivation of regional equations for sizing stormwater treatments measures in Victoria. Fifteen of these are concentrated around the Melbourne/Geelong Metropolitan Region. Figures 1 and 2 show the spatial locations of the selected stations according to their longitude and latitude bearings. The additional stations around Melbourne were considered important because of the expected development activity. Furthermore, there is more available data for this region which enables a finer representation of the climatic factors. The mean annual rainfall for the sites selected ranged from 290 mm to 1900 mm, covering the wide range of rainfall conditions experienced across the state.

Rainfall data sets were checked to ensure that there were no significant gaps and that the mean annual rainfall for the data set was within 10% of the long term average for the site (from www.bom.gov.au). Where possible, the rainfall data set used was from 1980 to 2000, however sometimes data gaps meant a different time period was used.

The required area to achieve a specified treatment objective was selected as the measure for representing the effectiveness of various sized treatment devices. In most cases, a 45% removal of TN was used as the specified treatment objective, although this was reduced in the case of vegetated swale systems to 25% TN removal (swales cannot generally achieve a 45% TN reduction). MUSIC was used to simulate the performance of wetlands, bioretention systems, vegetated swales and ponds to size these systems to meet the specified objective. A typical result from the modelling for constructed wetlands in Melbourne is shown in Figure 3.
It can be seen that for urban areas in Melbourne, a wetland must be approximately 2.4% of the impervious catchment area to meet the TN reduction target. The sizes of treatment measures derived from MUSIC modelling for all sites were normalised against the sizes derived for a reference site in Melbourne and expressed as the ratio of the size of the treatment area for the reference location in Melbourne (i.e. the Australian Bureau of Meteorology Melbourne regional office site). This ratio is referred to as the adjustment factor; a practitioner wanting to design stormwater treatment measure at any location in Victoria could refer to the design requirements developed for the reference site (i.e. Melbourne regional office site) and apply an adjustment factor to that size to determine the appropriate dimensions of the treatment measure for their particular site. For example, it was found that a wetland in Bright needed to be 3.8% of the impervious catchment area to meet the TN reduction objective. The wetland adjustment factor for Bright is therefore 3.8/2.4 = 1.57.

The adjustment factors derived were analysed for their spatial grouping and trends and correlations with various climatic characteristics to enable regional equations relating the adjustment factors with key climatic variables to be derived.

RESULTS AND DISCUSSION

Hydrologic Regions and Regional Equations

The adjustment factors determined for each of the pluviographic stations and four stormwater treatment measures are listed in Table 1.

It was considered important that any information on site characteristics to be included in the regression analysis with the derived adjustment factors needed to be readily available from the Bureau of Meteorology. As such, the set of possible influencing factors that were investigated were limited to those that can be obtained from the Bureau of Meteorology website (www.bom.gov.au). The following climatic characteristics were used:

- mean annual rainfall;
- mean annual raindays;
- site elevation;
- the ratio of mean summer raindays to mean winter raindays (as a measure of rainday seasonality); and
- ratio between mean summer rainfall to mean winter rainfall (as a measure of rainfall seasonality).

Following extensive testing and statistical analysis of the significance of the above possible influencing factors, it was found that Victoria could be divided into nine regions for which there are good correlations between the size of treatment element required and the mean annual rainfall. The inclusion of climatic characteristics other than mean annual rainfall provided minimal improvement in predictive reliability of the regional procedures devised. The nine hydrologic regions developed hold for all four stormwater treatment elements used in the analysis.

Figures 4 to 7 show plots of adjustment factor versus mean annual rainfall for each of the four treatment elements for Greater Victoria (i.e. excluding the Melbourne/Geelong region). The relationship between the adjustment factor and mean annual rainfall have been represented by linear lines of best fit for each region. The equations of these lines form the empirical relationship for sizing treatment elements within each region (refer Table 2). Similar plots and corresponding regression equations were derived from data for the Melbourne/Geelong region (Table 3).

The boundaries of the hydrologic regions for Greater Victoria and the Melbourne/Geelong Region are shown in Figures 8 and 9. Region boundaries were determined to represent the results of the analysis and be aligned such that they do not dissect major urban areas in Victoria or are aligned with municipal boundaries, as much as possible, in the Melbourne/Geelong Metropolitan area. The exceptions to this are in the Cities of Wyndham and Casey where the Hydrologic Regions are bounded by Skeleton Creek and Monash Freeway respectively.

<table>
<thead>
<tr>
<th>Table 1 Adjustment Factors</th>
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<tbody>
<tr>
<td>Wetland</td>
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<tr>
<td>Wetland</td>
</tr>
<tr>
<td>Melbourne Airport</td>
</tr>
<tr>
<td>Melton</td>
</tr>
<tr>
<td>Essendon</td>
</tr>
<tr>
<td>Bundoora</td>
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<td>Laveron</td>
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<td>Koo Wee Rup</td>
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<tr>
<td>Carrum Downs</td>
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<td>Dandenong</td>
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<tr>
<td>Croydon</td>
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<tr>
<td>Upwey</td>
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<tr>
<td>Narre Warren North</td>
</tr>
<tr>
<td>Werribee</td>
</tr>
<tr>
<td>Little River</td>
</tr>
<tr>
<td>Geelong North</td>
</tr>
<tr>
<td>Casterton</td>
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<td>Weepanton</td>
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<tr>
<td>Wyealonga</td>
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<tr>
<td>East Tarwin</td>
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<tr>
<td>Noojee</td>
</tr>
<tr>
<td>Yallourn</td>
</tr>
<tr>
<td>Mortlake</td>
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<tr>
<td>Horsham</td>
</tr>
</tbody>
</table>
Hydrologic Regions for sizing Stormwater Treatment Measures in Victoria

Great Dividing Range
\[ y = 0.881x + 0.520 \]
\[ R^2 = 0.757 \]

South Coast
\[ y = 0.670x + 0.389 \]
\[ R^2 = 0.924 \]

Northern
\[ y = 0.757x + 0.683 \]
\[ R^2 = 0.608 \]

Western Plains
\[ y = 0.716x + 0.439 \]
\[ R^2 = 0.844 \]

Gippsland
\[ y = 1.62x + 0.248 \]
\[ R^2 = 0.916 \]

**Figure 4** Adjustment factor versus mean annual rainfall for wetlands in Greater Victoria

Northern
\[ y = 0.348x + 0.843 \]
\[ R^2 = 0.496 \]

Western Plains
\[ y = 0.0540x + 0.835 \]
\[ R^2 = 0.357 \]

South Coast
\[ y = 0.130x + 0.654 \]
\[ R^2 = 0.434 \]

Great Diving Range
\[ y = 0.287x + 0.696 \]
\[ R^2 = 0.8163 \]

Gippsland
\[ y = 0.294x + 0.858 \]
\[ R^2 = 0.770 \]

**Figure 5** Adjustment factor versus mean annual rainfall for bioretention in Greater Victoria

Northern
\[ y = 0.320x + 0.869 \]
\[ R^2 = 0.501 \]

Western Plains
\[ y = 0.490x + 0.565 \]
\[ R^2 = 0.903 \]

South Coast
\[ y = 1.67x - 0.145 \]
\[ R^2 = 0.944 \]

Great Dividing Range
\[ y = 2.00x - 0.309 \]
\[ R^2 = 0.983 \]

Gippsland
\[ y = 2.07x - 0.206 \]
\[ R^2 = 0.886 \]

**Figure 6** Adjustment factor versus mean annual rainfall for swales in Greater Victoria

Shepparton
Geelong
Melbourne
Wodonga
Sale
Mallacoota
Bright
Benalla
Ouyen
Warrnambool
Casterton
Hamilton
Wonthaggi
Omeo
Healsville
Echuca
Ballarat
Bendigo
Warragul
Morwell
Bairnsdale
Lakes Entrance
Orbost
Seymour
Horsham
Mildura
Nhill
Kerang
Healsville
NORTHERN
SOUTH COAST
GREAT DIVIDING RANGE
GIPPSLAND
WESTERN
Figure 8 Hydrologic Regions for Greater Victoria

**Table 2** Greater Victoria Empirical Adjustment Factor Equations (MAR = Mean Annual Rainfall [m])

<table>
<thead>
<tr>
<th>Region</th>
<th>Wetland</th>
<th>Bioretention</th>
<th>Swale</th>
<th>Pond</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern</td>
<td>0.757 x MAR + 0.683</td>
<td>0.348 x MAR + 0.843</td>
<td>0.320 x MAR + 0.869</td>
<td>1.68 x MAR + 0.137</td>
</tr>
<tr>
<td>Western Plains</td>
<td>0.716 x MAR + 0.439</td>
<td>0.054 x MAR + 0.835</td>
<td>0.490 x MAR + 0.565</td>
<td>1.74 x MAR - 0.0953</td>
</tr>
<tr>
<td>South Coast</td>
<td>0.670 x MAR + 0.389</td>
<td>0.130 x MAR + 0.654</td>
<td>0.138 x MAR + 0.698</td>
<td>1.67 x MAR - 0.145</td>
</tr>
<tr>
<td>Great Dividing Range</td>
<td>0.881 x MAR + 0.520</td>
<td>0.287 x MAR + 0.696</td>
<td>0.304 x MAR + 0.739</td>
<td>2.00 x MAR - 0.309</td>
</tr>
<tr>
<td>Gippsland</td>
<td>1.62 x MAR + 0.248</td>
<td>0.294 x MAR + 0.858</td>
<td>0.680 x MAR + 0.609</td>
<td>2.07 x MAR - 0.206</td>
</tr>
</tbody>
</table>

**Figure 9** Hydrologic Regions for Melbourne & Geelong Metropolitan area
Table 3 Melbourne/Geelong Metropolitan Region Adjustment Factors (MAR = Mean Annual Rainfall [m])

<table>
<thead>
<tr>
<th>Region</th>
<th>Wetland</th>
<th>Bioretention</th>
<th>Swale</th>
<th>Pond</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central and North West Metropolitan Area</td>
<td>-0.421 x MAR + 1.29</td>
<td>-0.235 x MAR + 1.13</td>
<td>-0.131 x MAR + 1.07</td>
<td>1.38 x MAR + 0.106</td>
</tr>
<tr>
<td>South West Metropolitan Area</td>
<td>0.94</td>
<td>0.84</td>
<td>0.9</td>
<td>0.86</td>
</tr>
<tr>
<td>East Metropolitan Area</td>
<td>1.1</td>
<td>0.96</td>
<td>0.97</td>
<td>1.44</td>
</tr>
<tr>
<td>South East Metropolitan Area</td>
<td>0.9</td>
<td>0.81</td>
<td>0.85</td>
<td>1.15</td>
</tr>
</tbody>
</table>

Validating the Regional Equations

The adjustment factors predicted by the empirical equations for Greater Victoria (from Table 2) have been plotted against the adjustment factors derived from MUSIC modelling. Figures 10 to 13 show that the observed adjustment factor is generally within 10% of the predicted adjustment factor. Similarly the predicted adjustment factors for the Melbourne/Geelong Metropolitan area (from Table 3) all fit within 10% of the adjustment factors obtained from MUSIC modelling (refer Figures 14 to 17).
DISCUSSION
The plots comparing the predicted adjustment factors to those determined from MUSIC modelling indicate that the regional equations and constants derived for the five state-wide hydrologic regions and four regions for the Melbourne/Geelong Metropolitan region fall within a ±10% band. It was thus reasonable to adopt an adjustment factor that is 1.1 times (i.e. +10%) that predicted by these equations and constants in Table 2 to ensure that the predicted size of stormwater treatment measures using this method will not be an under-estimation of what is required. This preserves the opportunity (and incentive) for practitioners to adopt a more rigorous approach (e.g. MUSIC modelling using local rainfall data) to further refine and reduce the size of treatment measures being considered if they so desire. The recommended equations and constants (including +10% adjustment) for computing the appropriate adjustment factors for Victoria, including the Melbourne/Geelong Metropolitan region, have now been adopted for application in Victoria.

The regional equations and constants for computing adjustment factors are the result of pooling modelling results for relevant reference pluviographic stations within each hydrologic region. To ensure a systematic application of the procedure, it was recommended in the WSUD Engineering Procedures Stormwater Manual that computation of adjustment factors should exclusively use the regional equations or constants provided instead of individually derived adjustment factor values, irrespective of the proximity of the site in question to a reference pluviographic station. This avoids situations where practitioners can between the adjustment factor computed from the regional
approach and that derived for the reference pluviographic station of close proximity to the site in question.

If however practitioners are given the option to use adjustment factors derived for individual reference pluviographic stations, a consistent approach to define the areal extent of applicability of adjustment factors derived for individual pluviographic station will need to be developed. This areal extent of applicability for individual reference pluviographic station may vary depending on its proximity to other pluviographic stations and will more than likely be determined in an ad-hoc manner.

CONCLUSION
A simple procedure for sizing stormwater treatment measures to meet current best practice environmental management objectives for stormwater has been developed and adopted for application across all sites within the state of Victoria. This procedure is based on defining nine hydrologic regions within Victoria (four of which are in the Melbourne/Geelong Metropolitan area). Empirical methods for determining an adjustment factor for sites within these regions have been derived for the design of constructed wetlands, bioretention systems, swales and ponds.

Melbourne was selected as the reference site in this procedure. Detailed simulations of a wide range of treatment measures with different configurations for this reference site have been undertaken to provide a comprehensive set of performance curves (Melbourne Water, 2005). These curves can then be adapted for use in different sites across Victoria by use of adjustment factors. The relevant value of an adjustment factor for any particular site can be computed from the relevant equations for the hydrologic region and this is then used to adjust the area of the treatment measure found suitable for Melbourne.

ACKNOWLEDGEMENTS
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REFERENCES
Department of Sustainability and Environment (2005a), State Planning Provisions