Implementing Water Sensitive Urban Design in Stormwater Management Plans

Goyder Institute for Water Research

Technical Report Series No. 16/7

www.goyderinstitute.org

Goyder Institute for Water Research Technical Report Series ISSN: 1839-2725

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia. The Institute will enhance the South Australian Government's capacity to develop and deliver science-based policy solutions in water management. It brings together the best scientists and researchers across Australia to provide expert and independent scientific advice to inform good government water policy and identify future threats and opportunities to water security.

The following Associate organisations contributed to this report:

Enquires should be addressed to: Goyder Institute for Water Research
Level 4, 33 King William Street
Adelaide, SA, 5000
tel: 08-8236 5200
e-mail: enquiries@goyderinstitute.org

Citation

Myers, B., Cook, S., Pezzaniti, D., Kemp, D., Newland, P., 2015, Implementing Water Sensitive Urban Design in Stormwater Management Plans, Goyder Institute for Water Research Technical Report Series No. 16/x, Adelaide, South Australia.

Copyright

Disclaimer

Contents

Figures

Tables

Abbreviations

ARQ	Australian Runoff Quality
ACWQIP	*Adelaide Coastal Water Quality Improvement Plan*
ACWS	*Adelaide Coastal Water Study*
DCIA	Directly connected impervious area
DEWNR	Department for Environment, Water and Natural Resources (South Australia)
EIA	Effective impervious area
EPA SA	Environment Protection Authority South Australia
EPWQP	Environment Protection (Water Quality) Policy 2003 (South Australia)
GPT	Gross Pollutant Trap
NorBE	Neutral or Beneficial Effect
SMA	Stormwater Management Authority
SMP	Stormwater Management Plan
TIA	Total impervious area
WSUD	Water Sensitive Urban Design

Executive summary

This report provides a technical assessment of Water Sensitive Urban Design (WSUD) at the catchment scale in South Australia. The report contributes to a growing body of research that is informing the uptake of WSUD in South Australia, and is complementary to a related report that investigated approaches for incorporating WSUD in the South Australian planning and development process. The following activities were undertaken to inform the findings in this report:

- Review of existing stormwater management plans in South Australia, and in particular evaluating how WSUD approaches had been considered and applied;
- Evaluation of the implications of antecedent conditions on the performance of WSUD storage devices;
- Assessment of the MUSIC software model for planning and designing WSUD approaches in the South Australian context; and
- Analysis of how frequent flows should be considered in planning stormwater management approaches in South Australia.

The review of existing stormwater management plans in South Australia demonstrated that they were based on rigorous and comprehensive analyses, which considered WSUD as an approach to managing stormwater quantity and quality. However, the review identified a number of limitations and inconsistencies in the way in which WSUD was proposed, analysed and reported. Melbourne, Victoria, has been identified as a leader in the adoption of WSUD in Australia, which in part was due to mandating targets for nitrogen reduction in Port Phillip Bay. While water quality objectives vary among catchments in South Australia based on environmental values, this study suggests there is sufficient evidence on the environmental values of receiving waters to set minimum water quality objectives for the largest area in South Australia (Adelaide). Incorporating these targets in SMPs would need to be supported by changes in the planning policy framework and also detailed technical guidance to ensure a transparent and rigorous approach to evaluating how WSUD approaches can be applied to achieve the targets at the development scale.

In the SMPs reviewed the approaches used to assess water quality treatment measures varied, and in some case the underlying assumptions used in modelling WSUD performance were not clearly documented. This highlights the need for the development of MUSIC modelling guidelines that are specific to the South Australian context. In most cases the SMPs did not consider the impact of WSUD measures on runoff flow rate from ongoing development in the catchment, and in no case was the flow regime of receiving waters considered. The potential impact of infill development on runoff rates has been demonstrated in recent studies in South Australia. There may be a need for a greater focus in SMPs on the use of WSUD to maintain pre-development flow regime, particularly for frequent flows. Other inconsistencies were found in the means by which WSUD and other stormwater measures were prioritised and costed. It is recommended that the approach noted in the existing guideline is promoted for future SMPs to provide a consistent series of SMP outcomes across the state.

The hydrological assessment of storage based WSUD systems for quantity management demonstrated that the design of WSUD systems for flow and runoff volume management is influenced by antecedent conditions. This can limit the effectiveness of using design storm events for sizing WSUD retention and detention systems. On average it was found that the antecedent rainfall in the two hours prior to a design storm contained rainfall depths greater than the initial loss value of Australian urban catchments (1 mm). This indicates that for typical events with a 20% or 50% AEP, the initial loss values in an event based simulation may be considered to be consumed and should not be adopted. This also indicates the importance of selecting an analysis method that takes into account antecedent conditions when assessing the potential effectiveness of WSUD retention and detention devices on maintain pre-development flow regime. Current literature has also produced similar findings, with potential alternative analysis methods noted to include continuous simulation and Monte Carlo Frameworks to account for the spatial and temporal variability of runoff events. While no guideline currently exists with appropriate information in the Australian context, it is understood that the revised *Australian Rainfall and Runoff* guideline will include consideration of an approach, which should be referenced in any revision of the current SMP guidelines.

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is commonly applied in South Australia to estimate stormwater runoff volume, pollutant loads and the effectiveness of WSUD approaches in reducing them. There are no guidelines for the use of MUSIC that are specific to the South Australian context. This project, based on a literature review and modelling, developed recommendations for the use of MUSIC in the South Australian context. This included identifying where the application of MUSIC could be improved by applying South Australian specific data or analysis. Recommendations were made regarding appropriate climate data, soil parameters, run-off pollutant generation data and routing parameters. Priorities for research to improve the performance of MUSIC in South Australian conditions included monitoring, simulation and calibration of WSUD measures operating South Australian conditions to improve simulation performance, particularly with respect to removal of pollutants by locally available plants and soils; an assessment of South Australian catchments to develop indicative values of imperviousness; monitoring and assessment of water quality with respect to land use and calibration of MUSIC to catchments with varying size and slope to identify a suitable runoff routing parameters set.

In the context of the role and application WSUD measures in the development of stormwater management plans a review of frequent flow management approaches for maintaining natural (pre urbanisation) stream habitat and geomorphology was conducted. Case studies and approaches were investigated and a set of recommendations were developed. This included the need to adopt a minimum flow frequency threshold for maintaining aquatic habitat and the two year recurrence interval flow rate for managing stream geomorphology to prevent increased erosion, sediment transport and downstream deposition. Guidance on the type of WSUD functions that mimic the natural flow regimes have been provided.

Part I Introduction and Background

1 Introduction and Background

1.1 Introduction

This report outlines the results of a project contributing to a growing body of water sensitive urban design (WSUD) focussed studies which have been conducted by the Goyder Institute for Water Research. It presents the findings of Task 2 of the Goyder Institute's *Water Sensitive Urban Design Project – Phase 2*. The overall goal of this research project was:

1. To investigate the pathways for incorporating WSUD into the South Australian development planning processes; and
2. To investigate the technical knowledge needed to incorporate WSUD strategies into stormwater management plans.

This report focuses on the second goal of the research. The remainder of Part 1 describes the background to technical assessment of WSUD at the catchment scale in South Australia. Part 2 contains a review of existing stormwater management plans in South Australia and highlights their approaches and limitations to considering WSUD. It also provides some comment on how stormwater management planning guidelines might provide better guidance on WSUD assessment. In Part 3, the importance of considering antecedent conditions in the analysis of how WSUD will affect stormwater runoff volumes and flow rates is considered. In part 4, a review of recommendations for the use of the MUSIC model in Australia was undertaken and recommendations for applying the model in SA are made. These recommendations were based on the review of interstate guidelines and simulation scenarios for SA. Commentary on the consideration of frequent flows in South Australia is provided in Part 5, with a suggested approach where frequent flows in streams may be considered. Finally, Part 6 includes a brief discussion of findings and concluding remarks.

1.2 Background

The Goyder Institute's *Water Sensitive Urban Design Impediments and Potential: Contributions to the SA Urban Water Blueprint* project (or Goyder WSUD Project - Phase 1) was completed in 2014. The research focused on three main areas: the current implementation of WSUD in SA, and its effectiveness (Tjandraatmadja et al., 2014), the acceptance of WSUD by stakeholders affected by different types of structural WSUD measures (Leonard et al., 2014) and the effectiveness of WSUD for increasing drainage capacity (Myers et al., 2014b). The outcomes of the project identified several impediments to WSUD implementation in South Australia, and opportunities to overcome them. At the end of 2014, the research team conducted a review of these opportunities to overcome impediments. A series of proposed research projects were developed and these were presented to the then project steering committee. This steering committee consisted of stormwater management practitioners from across SA government and local corporations.

The committee were asked to rank the projects in order of importance. The project titles and their ranking are shown in Table 1-1. Following this process, the research goals were refined to achieve the highest priority project.

Table 1-1 – Research activities proposed for the *Goyder Institute WSUD project – Phase 2* as ranked by practitioners

Rank	Project / Task
1	Local government stormwater management plans - WSUD guidelines for developers/consultants and assessment tools for local government
2	Quantifying the impact of infill development on flooding, runoff yields and water quality
3	The economic benefits of WSUD
4	WUSD management and maintenance models
5	Review of urban runoff quality data
6	GIS map of catchment areas managed by WSUD measures – quantifying catchment areas
7	Evidence based performance and benefits of rainwater tanks in Adelaide

The highest ranked project related strongly to the outcomes of the Goyder Institute WSUD Project Phase 1 report *Post Implementation Assessment and Impediments to WSUD* (Tjandraatmadja et al., 2014). The report found that there were a number of common strategies which could help address impediments to mainstream WSUD implementation in South Australia. These strategies included the following:

1. A consistent and coordinated application of WSUD in planning frameworks and development approvals processes.
2. Further development of local government capacity of WSUD implementation.
3. Enabling WSUD adoption through state-level targets and policy.
4. Developing the knowledge base for WSUD in the South Australian context.
5. Improved understanding of how small-scale distributed WSUD systems can address catchment level objectives.

The current project contributes to several of these strategies. To assist with strategies 1 and 3, a review of WSUD policy was undertaken and presented in Report 1 of this project, *Pathways for Implementation of Water Sensitive Urban Design Policy in South Australia* (Cook et al., 2016). It described the current consideration of WSUD in planning policies for South Australia and identified several pathways for the implementation of WSUD within this framework. It also indicated that the current drivers for WSUD implementation in South Australia were targets which have been set as part of the *Planning Strategy for South Australia* such as the *30 Year Plan for Greater Adelaide* (South Australian Department of Planning and Local Government (SA DPLG), 2010) which broadly support the recommendations of the *Adelaide Coastal Water Quality Improvement Plan* (McDowell & Pfennig, 2013) in the case of Adelaide. Conflicting requirements for WSUD policy implementation were highlighted in the discussion of findings: on one hand, there is a demand for simple, consistent WSUD requirements for developers that can be applied uniformly and efficiently across urban areas of SA. However, there is also a need to consider catchment specific objectives. For example, the consideration of a frequent flow requirement to protect natural waterways may not be necessary in catchments with engineered drainage channels. Conversely, a catchment which drains to an environmental asset may warrant special water quality, runoff volume and wastewater management requirements. A means of making an assessment of catchment specific WSUD needs is therefore required.

A state government supported mechanism for catchment specific assessment of stormwater management requirements, including WSUD, already exists in the form of stormwater management plans (SMPs). SMPs are prepared in accordance with the *Stormwater Management Planning Guidelines* (Stormwater Management Authority, 2007). The background to these is described in Section 2.1 with a review of WSUD in existing plans.

At present, the way in which WSUD assessments have been conducted have varied. The *Post Implementation Assessment and Impediments to WSUD* (Tjandraatmadja et al., 2014) report indicated that the level of understanding of WSUD, it's assessment and implementation varied amongst practitioners including local government, consultants and construction personnel.

The remainder of this report contributes to strategies 1, 3, 4 and 5 above by providing further analysis and guidance on the assessment of WSUD strategies.

1.3 References

Cook, S, Myers, B, Newland, P, Pezzaniti, D & Kemp, D 2016, *Pathways for Implementation of Water Sensitive Urban Design Policy in South Australia*, Goyder Institute for Water Research, Adelaide, SA, Australia.

Leonard, R, Walton, A, Koth, B, Green, M, Spinks, A, Myers, B, Malkin, S, Mankad, A, Chacko, P, Sharma, A & Pezzaniti, D 2014, *Community Acceptance of Water Sensitive Urban Design: Six Case Studies*, Goyder Institute for Water Research, Adelaide, South Australia.

McDowell, LM & Pfennig, P 2013, *Adelaide Coastal Water Quality Improvement Plan (ACWQIP)*, Environment Protection Authority, South Australia, Adelaide, SA.

Myers, B, Pezzaniti, D, Kemp, D, Chavoshi, S, Montazeri, M, Sharma, A, Chacko, P, Hewa, GA, Tjandraatmadja, G & Cook, S 2014b, *Water Sensitive Urban Design Impediments and Potential: Contributions to the Urban Water Blueprint (Phase 1) Task 3: The Potential Role of*

WSUD in Urban Service Provision, Goyder Institute for Water Research, Adelaide, South Australia.

South Australian Department of Planning and Local Government (SA DPLG) 2010, *The 30 year plan for greater Adelaide: A volume of the South Australian planning strategy*, South Australian Department of Planning and Local Government, Adelaide, SA, Australia.

Stormwater Management Authority 2007, *Stormwater management planning guidelines*, Natural Resources Management Council, Adelaide, SA, Australia.

Tjandraatmadja, G, Cook, S, Chacko, P, Myers, B, Sharma, AK & Pezzaniti, D 2014, *Water Sensitive Urban Design Impediments and Potential: Contributions to the SA Urban Water Blueprint - Post-implementation assessment and impediments to WSUD*, Goyder Institute for Water Research, Adelaide, SA.

Part II Review of Stormwater Management Plans

2 Review of Stormwater Management Plans

2.1 Background

Stormwater Management Plans (SMPs) are developed:

'*to ensure that stormwater management is addressed on a total catchment basis with the relevant NRM board, various local government authorities and state government agencies responsible for the catchment working together to develop, implement and fund a coordinated and multi-objective approach to management of stormwater for the area for specific catchment areas within or across council boundaries'* (Stormwater Management Authority, 2007).

SMPs are generally prepared by or on behalf of local government authorities in consultation with state government entities. Since 2007, SMPs have been prepared in accordance with the Stormwater Management Authority's *Stormwater Management Planning Guidelines* (Stormwater Management Authority, 2007). These guidelines provide '*a concise framework for the preparation of Stormwater Management Plans for urban areas*' and they consist of a '*description of the required content of plans*' and a '*description of the techniques to be used for preparing some specific aspects of the plan content*'. The *Stormwater Management Planning Guidelines* are a legal requirement of the Stormwater Management Authority as part of the *Local Government (Stormwater Management) Amendment Act 2007*. The Act requires that a SMP comply with the guidelines and be prepared in consultation with the relevant regional NRM Board. A completed SMP is approved by the SMA with consultation from the relevant NRM Board and enables local government to apply for funding from the Stormwater Management Fund to undertake works in the plan.

According to the guidelines, a SMP should:

- Set out clearly the objectives for managing stormwater in the catchment
- Identify actions (both structural and non-structural) required to manage stormwater to achieve beneficial outcomes and meet the specified objectives;
- Provide a justification for any proposed catchment studies, works, measures or actions;
- Estimate capital and recurrent costs and assign priorities and timeframes to each of the actions; and,
- Define the obligations of the relevant parties in funding, implementing and communicating the plan.

The guidelines provide further details to support each of these broad goals, including the requirement that aspects of water sensitive urban design (WSUD) be included in the scope and objectives of a SMP. For example, consideration of runoff water quality, the impact of water quality on receiving waters, desirable end state values and opportunities for beneficial reuse of water should be considered in the setting of objectives, as well as strategies to achieve these objectives. As a result, most SMPs include consideration of these aspects of WSUD. The *Stormwater Management Planning Guidelines* do not however provide strong guidance on the extent to which these aspects of WSUD should be considered. For example, there is little guidance on the required extent of objectives, nor how proposed structural or non-structural solutions should be determined and assessed against those objectives. Since the publication of the guidelines, there have been further developments in WSUD research and implementation, including the development of South Australian guidelines for WSUD (South Australian Department of Planning and Local Government, 2010) and a South Australian WSUD policy (SA Department of Envrionment Water and Natural Resources (DEWNR), 2013).

With a growing number of SMPs becoming available since the publication of the guidelines, it was proposed that there be a review of how WSUD is considered by SMPs to determine how objectives are set and how strategies and solutions are being recommended against those objectives. The review was undertaken to identify consistencies and inconsistencies in the way the guidelines are being applied with a view to making recommendations on any changes or additions to the guidelines that will ultimately lead to improved WSUD implementation.

2.2 Methodology

SMPs given consideration in this report were those which were completed at the time of the review, prepared in accordance with the South Australian *Stormwater Management Planning Guidelines* and approved by the Stormwater Management Authority (SMA).

Table 2-1 shows a list of SMPs which had been approved by the SMA as of February 2015. It should be noted that the Port Road Rejuvenation SMP was excluded from the review because it was prepared in accordance with previous guidelines. The Brown Hill Keswick Creek Stormwater Project SMP was included with a focus on the aspects of the plan completed since 2012, however consideration was given to works already undertaken. In addition, the Laura SMP was not available for review. There were a number of SMPs that were in progress and these are listed as background information in Table 2-2. The North Arm East SMP has been included in this review because a final draft was made available during the review progress. However, the remainder of these have been listed for information only and have not been considered in the remainder of this research.

Table 2-1 - List of Stormwater Management Plans approved by the Stormwater Management Authority

	Plan	Local government(s)	SMA Approval
1	Port Road (Rejuvenation) SMP	City of Charles Sturt and City of Port Adelaide Enfield	September 2007
2	Brown Hill Keswick Creek Stormwater Project SMP 2012	Adelaide City Council, Cities of Burnside, Mitcham, Unley and West Torrens	February 2008, partly superseded by 2012 Plan
3	Truro SMP	Mid Murray Council	August 2010
4	Streaky Bay SMP	District Council of Streaky Bay	April 2011
5	Wasleys SMP	Light Regional Council	April 2011
6	Laura SMP	Northern Area Council	April 2011
7	Brown Hill Creek and Keswick Creek SMP	Adelaide City Council, Cities of Burnside, Mitcham, Unley and West Torrens	February 2013
8	Port Lincoln SMP	City of Port Lincoln	February 2014
9	Moonta, Moonta Bay, Port Hughes SMP	District Council of the Copper Coast	May 2014
10	Hallett Cove Creeks SMP	City of Marion	July 2014
11	Coastal Catchments Between Glenelg and Marino SMP	City of Marion and Holdfast Bay	July 2014

Table 2-2 – Stormwater management plans currently being produced for approval by the stormwater management authority

	Plan	Local government(s)
1	Port Pirie SMP	Port Pirie Regional Council
2	North Arm East Catchment SMP	City of Port Adelaide Enfield
3	Torrens Road Catchment SMP	City of Charles Sturt / City of Port Adelaide Enfield
4	Pedler Creek Catchment SMP	City of Onkaparinga
5	Beach Road SMP	City of Onkaparinga
6	Port Elliot SMP	Alexandrina Council
7	Yankalilla, Normanville and Carrickalinga SMP	District Council of Yankalilla
8	Eastern region Urban SMP	Campbelltown City Council / City of Norwood, Payneham and St Peters / City of Burnside / Adelaide City Council
9	Cobbler Creek SMP	City of Salisbury / City of Tea Tree Gully
10	Salisbury Escarpment SMP	City of Salsibury
11	Silver Sands Catchment SMP	City of Onkaparinga
12	Smith Creek Floodplain and Flood Hazard Study*	City of Salisbury / City of Playford / Town of Gawler
13	Seven Townships SMP	Clare & Gilbert Valleys Council
14	Gawler and Surrounds SMP	Town of Gawler / Light Regional Council / The Barossa Council
15	Mt Barker SMP	District Council of Mt Barker
16	Freeling, Greenock and Kapunda SMPs	Light Regional Council
17	North Arm East Catchment SMP	City of Port Adelaide Enfield
18	Adams Creek, Helps Road Catchment, and St. Kilda Catchment Floodplain mapping and Damage Assessment*	City of Salisbury / City of Playford
19	Burra SMP	Regional Council of Goyder
20	Lower Sturt SMP	City of Mitcham / City of Unley / City of Marion / City of West Torrens / City of Holdfast Bay
21	Kadina SMP	District Council of the Copper Coast
22	Lefevre Peninsula SMP	City of Port Adelaide Enfield
23	Salisbury Escarpment SMP	City of Salisbury
24	Auburn SMP	Clare and Gilbert Valleys Council
25	Old Port Road SMP	City of Charles Sturt
26	Two Wells SMP	District Council of Mallala
27	Nuriootpa Flood Mapping*	Barossa Council
28	Little Para*	City of Salisbury
29	Dry Creek*	City of Salisbury / City of Tea Tree Gully

* These studies are not formally noted as a SMP at the present time

The review of approved SMPs evaluated how WSUD has been considered and incorporated in these plans to date. WSUD was considered in a broad manner by this review. The stormwater management planning guidelines do not provide an explicit definition of WSUD, however there are several references which indicate a need to consider, for example, ‘desirable end state values for watercourses and riparian ecosystems’, ‘stormwater use opportunities’ and ‘adverse impacts on watercourses and receiving waters’. As such, all SMPs vary in their definition of WSUD and a flexible approach to reviewing guidelines was taken.

It should be noted that this review was not intended to rate, rank or indicate the adequacy of SMPs, nor their authors. The preparation of SMPs is unique for each catchment and the primary focus is unique for each plan. Furthermore, the extent to which WSUD should be considered may be interpreted broadly in the current SMP guidelines. Variation in the consideration of WSUD may be assumed to be related to the needs of the catchment as defined by the local authority and/or those working on their behalf.

To ensure that SMPs were compared in a consistent manner, the comparison was undertaken by examining each plan and identifying a response to the following questions. These were developed in reference to the *Stormwater Management Planning Guidelines* (Stormwater Management Authority, 2007). The questions were interpreted consistently for each plan, despite the varying assumptions of WSUD. For example, the inclusion of WSUD to address Question 2 ranged from a recommendation for rainwater tanks through to larger WSUD systems and policy recommendations. Similarly, analysis or simulation in Question 3 included consideration of modelling ranging from simple spreadsheet tools to more complex modelling approaches.

1. Did the SMP consider WSUD as part of the suite of options developed for the catchment?
2. Did the SMP recommend WSUD in its outcomes?
3. Did the SMP conduct analysis or simulation to support WSUD recommendations?
4. Did the SMP propose several WSUD alternatives with a decision?
5. Were WSUD recommendations prioritised (ranked in order of importance)?
6. Did the plan estimate costing of WSUD solutions?
7. Were WSUD options complimentary to other scheduled drainage works?
8. Were there policy recommendations with respect to WSUD?
9. Was WSUD considered with respect to harvesting?
10. Was WSUD considered with respect to runoff quantity management?
11. Was WSUD considered with respect to water quality management?
12. Were WSUD or water quality objectives stated by the SMP?
13. If the answer was yes, what was the basis of these objectives?
14. Were qualitative or quantitative targets used to support the implementation of WSUD options?
15. If so, what was the basis of these targets?
16. Was the hydrological (flow volume) impact of WSUD assessed?
17. Was the hydraulic (flow rate) impact of WSUD assessed?
18. Was the impact of WSUD on water demand assessed?

19. Were the potential demand source(s) for proposed harvesting systems identified?
20. Was the water quality impact of WSUD assessed?
21. Were the following WSUD features considered in the SMP:
    a. Wetlands
    b. Bioretention
    c. Permeable paving
    d. Rainwater tanks
    e. Swales
    f. GPT
    g. Kerb breaks and/or protuberances
    h. Detention

The complete review of SMPs is provided in Appendix A. Section 2.3 provides a summary of the findings from all SMPs and Section 2.4 discusses these findings and makes recommendations which may contribute to overcoming any problems that may be identified.

2.3 Synopsis of Review Findings

The following key findings provide a summary of the response to each of the questions proposed based on a review of all plans.

1. **Did the SMP consider WSUD as part of the suite of options developed for the catchment?**
    a. WSUD was considered to a varying degree by all of the SMPs reviewed.
2. **Did the SMP recommend WSUD in its outcomes?**
    a. WSUD was included in the list of SMP recommendations in all of the SMPs reviewed.
    b. There was variation in the extent to which WSUD was included in SMP recommendations. In most cases, WSUD works were presented with other infrastructure or planning recommendations. However there were cases where WSUD was presented separately (e.g. Moonta).
3. **Did the SMP conduct analysis or simulation to support WSUD recommendations?**
    a. Seven of nine plans included some simulation to support WSUD.
    b. The nature of this simulation tended to vary. Further commentary is provided in the summary response of questions 16 to 20 below.
4. **Did the SMP propose several WSUD alternatives with a decision?**
    a. SMPs all proposed individual WSUD measures in a prescriptive manner. Where assessment was undertaken, these measures were compared to a ‘do nothing’ approach. There were no apparent cases where several options for a site or catchment were presented and the optimal WSUD measure was

ultimately determined. This may or may not be indicative of the approach used - such processes may have been undertaken to determine the recommended WSUD measures and not reported in the final plan.

5. **Were WSUD recommendations prioritised (ranked in order of importance)?**
    a. Seven of the nine SMPs provided a prioritisation of WSUD recommendations.
    b. Similar to flood mitigation works, there was not a uniform way in which ranking was undertaken. Prioritisation included a numbered list or projects being grouped into a high- medium- or low-priority timeframe.
    c. In some cases, the features were recommended as a separate list, but in others presented within or as part of a single list of works.
6. **Did the plan estimate costing of WSUD solutions?**
    a. All SMPs provided costing for the recommended WSUD options
    b. The costing approach provided by SMPs was not consistent. Costs were presented as either capital cost only (Streaky Bay, Marion), or as capital and recurring costs (other SMPs). This may have been an arrangement between the affected council(s) and those authorised to conduct the SMP.
7. **Were WSUD options complimentary to other scheduled drainage works?**
    a. All SMPs recognise in some way that WSUD solutions should complement other works suggested for the catchment. There were several circumstances where individual WSUD solutions were proposed which were complementary to other drainage works, however WSUD works were also suggested in isolation.
    b. In general, larger WSUD options such as wetlands were complimentary, whereas smaller, allotment and street scale systems were recommended where there was no formal drainage works.
8. **Were there policy recommendations with respect to WSUD?**
    a. Eight of the nine SMPs provided policy guidance with respect to the control of water demand, runoff volume, runoff flow rate or water quality.
    b. This was generally regarding onsite WSUD measures, such as rainwater tanks sizing.
9. **Was WSUD considered with respect to harvesting?**
    a. Harvesting was considered in all SMPs reviewed. It was generally considered in a separate section of each SMP, reflecting the *Stormwater Management Planning Guidelines* requirement to consider harvesting across the catchment being considered.
    b. The consideration of harvesting was broad
10. **Was WSUD considered with respect to runoff quantity management?**
    a. Runoff quantity management through WSUD was considered by all plans either directly or indirectly.
    b. Seven on nine plans made specific reference to runoff quantity management, but in the remaining two, runoff quantity management was to some extent quantified as a benefit of WSUD measures including harvesting.
11. **Was WSUD considered with respect to water quality management?**

a. Opportunities to improve water quality through application of WSUD were considered in all SMPs to a varying extent.
b. Unlike harvesting, where specific sites and harvest volumes tended to be described when potential was considered, even when not recommended, SMPs tended to provide only a brief qualitative consideration of water quality outcomes. Studies which involved simulation of WSUD for water quality investigation (see Question 20) provided pre- and post-mitigation results, while others did not.

12. Were WSUD or water quality objectives stated by the SMP?

a. WSUD based objectives were present all SMPs reviewed.
b. In all cases, there were water quality objectives, but the basis and degree/level of protection varied.

13. If the answer was yes, what was the basis of these objectives?

a. The basis of WSUD objectives was not uniform throughout SMPs.
b. Sources for WSUD objectives included the findings of the *Adelaide Coastal Waters Study* (Fox et al., 2007), the *Adelaide Coastal Water Quality Improvement Plan* (McDowell & Pfennig, 2013), the former Department for Water's *WSUD consultation statement* (Department for Water, 2011), the *South Australian Environment Protection (Water Quality) Policy* and a general application of the neutral or beneficial effect concept (although not cited in these terms).
c. None of the reviewed SMPs cited the most recent WSUD objectives from the (SA Department of Envrionment Water and Natural Resources (DEWNR), 2013). However, this may be because the group of completed and approved SMPs all started prior to the release date of this document in October 2013.

14. Were qualitative or quantitative targets used to support the implementation of WSUD options?

a. Both quantitative and qualitative targets were stipulated to support assessment of WSUD infrastructure options.
b. In the absence of quantitative targets, assessment was undertaken to identify the impact of WSUD opportunities.

15. If so, what was the basis of these targets?

a. Where quantitative targets were implemented, SMPs cited *Australian Runoff Quality* (Wong, 2005), the then Department for Water's *WSUD Consultation statement* (Department for Water, 2011) and the A*delaide Coastal Water Quality Improvement Plan* (McDowell & Pfennig, 2013).
b. None of the reviewed SMPs cited the most recent WSUD targets from the (SA Department of Envrionment Water and Natural Resources (DEWNR), 2013). However, this may be because the group of completed and approved SMPs all started prior to the release date of this document in October 2013.

16. Was the hydrological (flow volume) impact of WSUD assessed?

a. Flow volume impacts were quantified in seven of the nine reviewed SMPs and the information was referred to when considering WSUD options.

b. In some cases, runoff volume reduction for a catchment was not explicitly determined, however a volume was identified in terms of the harvest potential of a proposed harvesting project (i.e. not explicitly stated as a runoff volume reduction).
c. In some cases the harvest potential of a proposed scheme was identified, however there was no methodology or reference reported to support the volume estimate.

17. Was the hydraulic (flow rate) impact of WSUD assessed?

a. There was only one example of an assessment of the impact of WSUD being conducted on peak flow rates in a catchment.
b. There were no examples of frequent flow management being considered.

18. Was the impact of WSUD on water demand assessed?

a. Five of the nine SMPs reviewed included an assessment of the impact of WSUD on water demand. This was determined through identification of the potential harvest volume for water reuse schemes, and the identification of demand sources (including their annual water use).

19. Were the potential demand source(s) for proposed harvesting systems identified?

a. The potential demand sources for water harvesting systems were identified in six of nine SMPs reviewed.
b. Identification varied from a single demand source to others which identified multiple potential sources.

20. Was the water quality impact of WSUD assessed?

a. The water quality impact of WSUD was assessed in seven of the nine SMPs.
b. In some cases, simulation was limited to an estimation of pollutant loads in runoff from the catchment being considered, with no analysis of measures to reduce it. In others, WSUD options were proposed and the reduction in pollutant loads compared to a 'do nothing' scenario was determined.
c. Where water quality improvement was simulated, the design of treatment options (size and other assumptions) to support water quality treatment was generally limited. While pollutant source parameters were generally identified as default concentrations, the performance of gross pollutant trap systems (for which a user must manually enter a treatment relationship into MUSIC) was not defined, nor were the assumed properties and modelling parameters of other systems which were simulated for water quality improvement. This information may have been provided as supplementary information to the report (e.g. as a model input file) which was not available with the publically available review, however it was never noted.

Table 2-3: Summary of how WSUD has been incorporated in existing Stormwater Management Plans

#	Question	Truro SMP	Streaky Bay SMP	Wasleys SMP	Port Lincoln SMP	Moonta, Moonta Bay, Port Hughes SMP	Hallett Cove Creeks SMP	Coastal Catchments Between Glenelg and Marino SMP	North Arm East Catchment SMP	Brown Hill Keswick Creek Stormwater Project SMP
1	Did the SMP consider WSUD as part of the suite of options developed for the catchment?	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
2	Did the SMP recommend WSUD in its outcomes?	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
3	Did the SMP conduct analysis or simulation to support WSUD recommendations?	*Y*	*N*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*N*
4	Did the SMP propose several WSUD alternatives with a decision?	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*
5	Were WSUD recommendations prioritised (ranked in order of importance)?	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*N*	*N*
6	Did the plan estimate costing of WSUD solutions?	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*N*
7	Were WSUD options complimentary to other scheduled drainage works?	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
8	Were there policy recommendations with respect to WSUD?	*N*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
9	Was WSUD considered with respect to harvesting?	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
10	Was WSUD considered with respect to runoff quantity management?	*Y*	*Y*	*N*	*Y*	*Y*	*Y*	*Y*	*Y*	*N*
11	Was WSUD considered with respect to water quality management?	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*N*
12	Were WSUD or water quality objectives stated by the SMP?	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
13	If the answer was yes, what was the basis of these objectives?	*Consult*	*Not stated*	*Consult*	*Review of sources*	*DEWNR Consultation statement (2011)*	*DEWNR/ Council*	*Review of sources*	*NorBE*	*ACWQIP*
14	Were qualitative or quantitative targets used to support the implementation of WSUD options?	*Y*	*N*	*N*	*N*	*Y*	*Y*	*Y*	*N*	*N*
15	If so, what was the basis of these targets?	*EP WQP*	*N/A*	*N/A*	*ARQ*	*DEWNR*	*DEWNR*	*ACWQIP*	*N/A*	*N/A*
16	Was the hydrological (flow volume) impact of WSUD assessed?	*Y*	*Y*	*Y*	*Y*	*N*	*Y*	*Y*	*Y*	*N*
17	Was the hydraulic (flow rate) impact of WSUD assessed?	*N*	*N*	*N*	*N*	*N*	*N*	*Y*	*N*	*N*

18	Was the impact of WSUD on water demand assessed?	N	N	Y	Y	Y	Y	N	Y	N
19	Were the potential demand source(s) for proposed harvesting systems identified	N/A	Y	Y	Y	Y	Y	N	Y	N
20	Was the water quality impact of WSUD assessed?	Y	N	Y	Y	Y	Y	Y	Y	N
21	Were the following WSUD features considered in the SMP:									
	(a) Wetlands	N	Y	N	Y	Y	Y	Y	Y	Y
	(b) Bioretention	Y	N	N	Y	Y	Y	Y	N	N
	(c) Permeable paving	Y	N	N	N	N	N	Y	N	N
	(d) Rainwater tanks	N	N	Y	Y	Y	Y	Y	Y	N
	(e) Swales	N	Y	Y	Y	Y	Y	N	Y	N
	(f) GPT	Y	N	N	Y	Y	Y	Y	Y	N
	(g) Kerb breaks/protuberances	Y	N	N	N	N	N	N	N	N
	(h) Detention	N	N	N	Y	Y	Y	Y	Y	Y

Legend

Y	Yes
N	No
N/A	Not applicable or no information

2.4 Discussion of Review Findings

The SMPs reviewed for this study were comprehensive and all considered aspects of WSUD in their analysis. However, the review found that there were several limitations and inconsistencies in the way in which WSUD was proposed, analysed and reported. Generally speaking, these inconsistencies and limitations included the following:

1. Inconsistencies in the basis for setting objectives and targets for WSUD.
2. Variation in the approach to water quality and volume assessment.
3. Limited consideration of stormwater runoff peak flow rate management, and no consideration of stream flow frequency.
4. Limited attention to policy based WSUD measures which might support implementation of WSUD or stormwater management in general.
5. Variation in the methodology and reporting of cost and priority for WSUD and other drainage measures.
6. Limitations on the ability to implement SMP outcomes

These inconsistencies and limitations are explained more fully in the following sections.

2.4.1 Setting WSUD Objectives

There was a lack of consistency in the adoption of water quality objectives and targets. This is understandable, because downstream environmental values may vary, particularly for coastal and inland catchments with varying requirements for receiving water qualities. However, even in the coastal catchments of Greater Adelaide, there was little consistency. For example, the Hallett Cove SMP has the following objective for water conservation:

Harvest and reuse stormwater to assist in achieving best practice irrigation management of open spaces where viable (supports Council Strategic Objective 2.1d)

By comparison, the Marion Holdfast SMP has several objectives for this same goal as follows:

Objective 3.1

Maximise the reuse of stormwater for beneficial purposes.

Objective 3.1

To the extent that it is technically possible and financially viable, the road and drainage network should be progressively retrofitted with WSUD devices that strive to capture road runoff to replenish soil moisture for maintenance of street trees and plantings. (Note also Strategy 2.1).

Objective 3.2

Encourage on-site use of stormwater by rainwater tanks, detention and retention systems. (Note also Objective 1.7).

Objective 3.3

Where feasible, implement stormwater reuse for watering of community or private open spaces.

Objective 3.4

Sufficient water shall be allocated for environmental flows to maintain water dependent ecosystems.

Likewise, quantity-based targets are proposed for water quality improvement in the Hallett Cove SMP. However, the water quality objectives and strategies of the Marion Holdfast Bay SMP are that '*Stormwater discharged to the marine environment should meet targets that are set by the Adelaide Coastal Waters Study and other relevant state and regional plans within Council's control and responsibility.*'

None of the reviewed plans directly linked their objectives to a current South Australian planning strategy such as *The 30 Year Plan for Greater Adelaide* (South Australian Department of Planning and Local Government (SA DPLG), 2010) or the more recent WSUD policy (SA Department of Envrionment Water and Natural Resources (DEWNR), 2013). This may be due to a lack of an explicit definition of WSUD, nor any explicit guidance on what a local government should use as a basis for setting objectives within the *Stormwater*

Management Planning Guidelines (Stormwater Management Authority, 2007). In addition, most of the approved SMPs would have been in progress when the current WSUD policy became available in October 2013.

For future SMPs, it is recommended that additional guidance from the *South Australian Planning Strategy* be provided or referenced in the SMP guidelines to ensure that there is a consistent baseline on which local objectives can be developed (whilst acknowledging local government planning targets may be superior). It is also important that this is revised whenever there are changes to the *South Australian Planning Strategy* and other relevant state planning measures.

Despite a reasonable argument for local government to set objectives to suit local needs, there is data available to support a minimum WSUD standard in the SMP guidelines for the largest urban area in South Australia (Adelaide). Roy et al. (2008) identified that the WSUD policy of the Melbourne region in Victoria, being perceived as a leader in WSUD in Australia, had its genesis in the Port Phillip Bay Environmental Study. This study specified a target for reducing nitrogen loads to Port Phillip Bay, including the component from stormwater, to maintain the ecological health of the Bay. This target was the primary motivator for setting of guidelines for stormwater pollution reduction targets. Recommendations for a South Australian policy on water use, quality and quantity were presented in a previous Goyder Institute for Water Research study (Myers et al., 2011a). In addition to this, baseline targets were proposed for receiving waters in the *Adelaide Coastal Waters Study* (Fox et al., 2007) and more recently the *Adelaide Coastal Water Quality Improvement Plan* (McDowell & Pfennig, 2013). These included:

"Nitrogen in stormwater to be reduced by 67%. This balances the load reduction in percentage terms equally between stormwater, industry and wastewater effluent and suspended solids to be reduced by 50%."

The findings of these have been considered in the development of the South Australian Government WSUD Policy (SA Department of Envrionment Water and Natural Resources (DEWNR), 2013) which provides water quality, volume and stream flow management targets. It is therefore recommended that SMP guidelines acknowledge the SA WSUD policy as a primary source to consider when setting WSUD objectives. It is also recommended that they allow for adjustments based on local need. Roy et al. (2008) identified some limitations of WSUD targets. In particular, there can be disconnect between maximum pollutant concentrations and ecological indicators for the health of receiving waters. It was recommended that more integrated WSUD performance targets are developed that address both water quality and flows, which are based on the desired ecological outcome.

2.4.2 Assessing Water Quality and Volume Management by WSUD

There was a varying approach to the assessment of water quality treatment measures in SMPs. Where water quality assessment was undertaken, SMPs adopted MUSIC modelling to examine the impact of current development on the load of pollutants generated by a catchment. However the underlying assumptions of this modelling, such as model parameters and pollutant loadings, were not well reported in all SMPs. Perhaps the best example of water quality simulation in the reviewed SMPs was produced for the Moonta SMP, where underlying catchment assumptions and pollutant generation parameters for a variety of sub-catchments were outlined exceptionally well. However, when the plan proposed WSUD measures to reduce pollutant loads from the developing catchment, there was little to no detail on the size of the treatment systems, the assumed parameters of soil for infiltration or filtration, nor for any storage volumes, all of which would impact on treatment. This information may be held by the local government in the form of a model run file, but it does not allow for consideration of outcomes by other parties.

To overcome this it is recommended that MUSIC modelling for SMPs is conducted in a standardised manner with reference to modelling guidelines, preferably specific to South Australian conditions. Since these guidelines do not currently exist for SA conditions, as an interim measure guidelines from interstate may be suitable for some modelling components to ensure that the structure and assumed input of models were consistent for all SMPs. Any variation from these procedures should then be highlighted. In the longer term, it is recommended that guidelines on the use of MUSIC in South Australia are produced. The development of guidelines has already been proposed as a priority project by Water Sensitive SA, and are understood to be in consideration for 2016/2017. Initial recommendations for the use of MUSIC in South Australia have also been produced in Section 4 of this report.

A further issue in water quality modelling was that few studies determined the impact of constructed WSUD measures for water quality treatment in a post construction scenario (having determined current catchment pollutant loads only), and of these fewer still compared the findings with respect to a quantitative target. For example, one SMP estimated the total pollutant load from the catchment, and, without reference to any target or supporting literature, indicated the loading was acceptable. While the estimation of a pollutant load can be useful, in the absence of targets such an estimate should not be used to make judgement and should be treated as purely informative. This problem may be overcome by the setting of standardised performance targets, such as the SA WSUD policy, as described in Section 2.4.1.

2.4.3 Limited Assessment of Stormwater Peak Flow Management and Stream Flows

Only one of the SMPs that were reviewed included an assessment of the impact of WSUD measures on the runoff flow rate within or resulting from ongoing development in a catchment. This is despite several plans identifying the occurrence of infill development within the catchment boundaries now an in the future. The potential impact of infill development has been recently demonstrated for smaller urban catchments (Myers et al., 2014b) in South Australia. This is not unique to South Australian practice. Burns et al. (2012) identified that stormwater management objectives have broadly been focussed on the reduction of pollutant loads and peak flows, but that there has been minimal application of runoff volume reduction targets in practice.

It may be beneficial that a revision of SMP guidelines provide an approach to undertake an examination of the impact of WSUD on peak flows for consideration in drainage modelling, particularly in catchments experiencing infill development. Some considerations for modelling approaches have been explored in Section 3 of this report. Furthermore, it is argued that stormwater management should not just focus on pollutant load reduction and mitigating peak flows but should also be extended to consider restoring the pre-development flow regime. Considerations for assessing flow regime management are presented in Section 5.

2.4.4 Limited Attention to Policy Based Measures

Few SMPs recommended local government development control or planning approval measures that would support implementation of WSUD or drainage measures to achieve water quantity or quality targets. This is unusual, because the SMP process is an ideal opportunity to develop technical support and recommendations for adopting catchment specific requirements for stormwater management in a local government development plan or other policy. Such recommendations may include requirements which could prevent the need for a drainage system upgrade in areas forecast to be troublesome in future. This should not be seen as a criticism of SMPs currently in place, rather as an opportunity to highlight the potential role of SMPs in supporting the development of local government planning policies that apply WSUD approaches to address local drainage needs, or achieve a water quality objective for runoff to receiving waters. The current SMP Guidelines from the SMA already allow for the development of strategies to achieve objectives. However it is recommended that a revision of SMP Guidelines place some emphasis on the option to include structural and non-structural WSUD measures.

2.4.5 Costing and Prioritisation

There were inconsistencies in the manner in which WSUD and other drainage related recommendations were costed and prioritised in SMPs. Most SMPs provided costs in the form of capital and recurring costs, but some only provided capital costs. This is important in the recommendation of a WSUD system as it perpetuates the issue of WSUD as a single upfront cost with little consideration of the ongoing costs of operation and maintenance of WSUD assets. The fact that ongoing costs of WSUD are often not planned for was highlighted in previous research as an impediment to the greater mainstream adoption of WSUD in SA (Myers et al., 2014a). In this previous research a review of existing developments with WSUD features in SA found that capital costs for WSUD were often the recipient of grants and other one-off funding opportunities, while operating costs had to be funded through the annual budgeting process. The lack of planning for ongoing WSUD costs may also produce inequity when assessing the merit of projects which seek SMA funding, because the underlying assumptions for costings are not directly comparable.

In addition to costing, the means by which WSUD and other drainage projects were prioritised differed among the reviewed SMPs. Some plans adopt three categories (Low-Medium-High), while others provide a list ranging from works of most importance to least importance. Further still, some SMPs separated WSUD from other projects, presenting two lists ranked in order of importance. While the superiority of any approach is beyond the scope of this report, this again may lead to difficulties for the SMA or other funding bodies who seek to use the priority of a proposed project as a means of assessing its merit for funding assistance. The lack of a consistent ranking system is also unusual because the SMA's *Stormwater Management Planning Guidelines* (Stormwater Management Authority, 2007) provide a template to determine relative priorities in a SMP which few of the completed SMPs have so far adopted. The Guidelines recommend that highest priority be allocated to projects that reduce flood hazard and protect life and property. The template provided determines work priorities by the following:

- Capital and annual recurrent costs;
- Flood mitigation benefit, which is quantified in terms of reduced annual average damage and properties affected;
- Volume of water harvested;
- Water quality benefit, which can be rated as high, medium or low; and,
- Any other qualitative benefit that can be described.

A simple means of overcoming this inconsistency in the application of a priority listing is to ensure that the template is adopted by all subsequent SMPs.

More broadly, inconsistency in assessment of WSUD in SMPs may also be a function of the capacity of South Australian practitioners to assess WSUD options in general. This may improve over time with the ongoing activity of the South Australian WSUD capacity Building program, Water Sensitive SA, and it is recommended that any changes to WSUD assessment in SMP guidelines are conducted in consultation with Water Sensitive SA with a view to ongoing training which may be required. A further reason which may have contributed to inconsistent assessment of WSUD is the lack of a mandatory approach in existing state policy. Practitioners and local governments have differed in their implementation of WSUD (Cook et al., 2015) which may be reflected in the approach to WSUD in SMPs.

2.4.6 Ability to Implement SMP Outcomes

There is some concern over the ability of SMP recommendations to be effectively implemented based on current planning policy. Discussion of these review findings with state government representatives indicated that the implementation of the South Australian *Residential Code* to an urban area restricts the ability of a local government to implement policy in that area. The background to the residential code is given in Report 1 of this research project (Cook et al., 2016). This work noted that while the *Residential Code* effectively over-rides local government planning policy in affected urban areas, neither the information regarding the *Residential Code* (SA Department of Planning Transport and Infrastructure (DPTI), 2012b), nor the checklist for a complying development (SA Department of Planning Transport and Infrastructure (DPTI), 2012a) consider WSUD approaches, except for the mandatory 1 kL rainwater tank.

2.5 Summary

This study has reviewed the consideration of water sensitive urban design by 10 of the 11 stormwater management plans currently approved by the South Australian Stormwater Management Authority. The review identified several limitations and inconsistencies in the way in which WSUD was analysed and proposed. Broadly, they included:

1. Inconsistencies in the basis for setting objectives and targets for WSUD.
2. Variation in the approach to water quality and volume assessment.
3. Limited consideration of stormwater runoff peak flow rate management, and no consideration of stream flow frequency.
4. Limited attention to policy based WSUD measures which might support implementation of WSUD or stormwater management in general.
5. Variation in the methodology and reporting of cost and priority for WSUD and other drainage measures.

Several recommendations have been made to overcome these. These are as follows:

- To overcome inconsistency in WSUD targets and objectives, a baseline source of WSUD objectives should provided in SMP Guidelines. The SA WSUD Policy would be the most current source, with updates in future as appropriate. It was also recommended that there be some flexibility to suit local need.
- Additional guidance on the assessment of WSUD measures should be provided. Since MUSIC was a popular tool for WSUD performance assessment in SMPs, South Australian guidelines for MUSIC modelling should be developed. This report provides recommendations for these guidelines in Section 4.
- Additional guidance on the assessment of WSUD for peak flow management and flow frequency in natural streams should be provided. Further recommendations have been provided in Sections 3 and 5 of this report.
- Existing SMP guidelines allow for the development of non-structural measures such as policy to support WSUD, however it is recommended that additional emphasis is placed on this as a means of addressing WSUD objectives.
- Existing SMP guidelines provide a template for the prioritisation and costing of projects. It is recommended that additional emphasis is placed on the adoption of this as a template for SMPs to allow for comparison of SMP related projects among plans.

2.6 References

Burns, MJ, Fletcher, TD, Walsh, CJ, Ladson, AR & Hatt, BE 2012, 'Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform', *Landscape and Urban Planning,* vol. 105, no. 3, 4/15/, pp. 230-240.

Cook, S, Myers, B, Newland, P, Pezzaniti, D & Kemp, D 2015, *Pathways for Implementation of Water Sensitive Urban Design Policy in South Australia (Report in progress)*, Goyder Institute for Water Research, Adelaide, Australia.

Cook, S, Myers, B, Newland, P, Pezzaniti, D & Kemp, D 2016, *Pathways for Implementation of Water Sensitive Urban Design Policy in South Australia*, Goyder Institute for Water Research, Adelaide, SA, Australia.

Department for Water 2011, *Water sensitive urban design - Consultation statement*, Department for Water, Adelaide, SA.

Fox, DR, Batley, GE, Blackburn, D, Bone, Y, Bryars, S, Cheshire, A, Collings, G, Ellis, D, Fairweather, P, Fallowfield, H, Harris, G, Henderson, B, Kämpf, J, Nayar, S, Pattiaratchi, C, Petrusevics, P, Townsend, M, Westphalen, G & Wilkinson, J 2007, *The Adelaide coastal waters study - Final report, Volume 1 - Summary of study findings*, CSIRO, Glen Osmond, Australia. <http://www.clw.csiro.au/acws/>.

McDowell, LM & Pfennig, P 2013, *Adelaide Coastal Water Quality Improvement Plan (ACWQIP)*, Environment Protection Authority, South Australia, Adelaide, SA.

Myers, B, Cook, S, Maheepala, S, Pezzaniti, D, Beecham, S, Tjandraatmadja, G, Sharma, A, Hewa, G & Neumann, L 2011a, *Interim Water Sensitive Urban Design Targets for Greater Adelaide*, Goyder Institute for Water Research, Adelaide, SA, Australia.

Myers, B, Chacko, P, Pezzaniti, D, Sharma, AK, Cook, S & Tjandraatmadja, G 2014a, 'Implementation of WSUD Infrastructure in Greater Adelaide – A Review', *3rd National Conference on Urban Water Management (Stormwater 2014)*.

Myers, B, Pezzaniti, D, Kemp, D, Chavoshi, S, Montazeri, M, Sharma, A, Chacko, P, Hewa, GA, Tjandraatmadja, G & Cook, S 2014b, *Water Sensitive Urban Design Impediments and Potential: Contributions to the Urban Water Blueprint (Phase 1) Task 3: The Potential Role of WSUD in Urban Service Provision*, Goyder Institute for Water Research, Adelaide, South Australia.

Roy, AH, Wenger, SJ, Fletcher, TD, Walsh, CJ, Ladson, AR, Shuster, WD, Thurston, HW & Brown, RR 2008, 'Impediments and Solutions to Sustainable, Watershed-Scale Urban Stormwater Management: Lessons from Australia and the United States', *Environmental Management,* vol. 42, no. 2, 2008/08/01, pp. 344-359.

SA Department of Envrionment Water and Natural Resources (DEWNR) 2013, *Water sensitive urban design - creating more liveable and water sensitive cities for South Australia*, Government of South Australia, Adelaide, SA, Australia. viewed October 2013,

SA Department of Planning Transport and Infrastructure (DPTI) 2012a, *Residential Code Checklist (New Dwellings and Additions to Existing Dwellings) Regulations – 1 August 2012, Version 1.2*, DPTI, Adelaide, SA, Australia.

SA Department of Planning Transport and Infrastructure (DPTI) 2012b, *Streamlining Planning Assessment - Guide to complying development, (Residential Code), exempt development and development requiring building consent only*, DPTI, Adelaide, SA, Australia.

South Australian Department of Planning and Local Government 2010, *Water sensitive urban design technical manual - Greater Adelaide region*, Department of Planning and Local Government, South Australia, Adelaide, SA, Australia.
<http://www.planning.sa.gov.au/go/wsud>.

South Australian Department of Planning and Local Government (SA DPLG) 2010, *The 30 year plan for greater Adelaide: A volume of the South Australian planning strategy*, South Australian Department of Planning and Local Government, Adelaide, SA, Australia.

Stormwater Management Authority 2007, *Stormwater management planning guidelines*, Natural Resources Management Council, Adelaide, SA, Australia.

Wong, THF (ed.) 2005, *Australian Runoff Quality*, Institution of Engineers Australia, Sydney.

Part III Hydrological Assessment of Storage Based WSUD Systems for Quantity Management

3 Hydrological Assessment of Storage Based WSUD Systems for Quantity Management

3.1 Introduction

Many structural WSUD measures consist of a storage volume that is used to intercept and store rainfall runoff. The volume intercepted is then either temporarily held and released to the drainage system during and after the stormwater event, or permanently held for reused and/or infiltration. The storage can significantly affect the magnitude of stormwater runoff volumes and flow rates. The proportion of a storage that is available prior to a storm event occurring can vary and is largely dependent on preceding rainfall events. Understanding the available storage characteristics for WSUD measures is important when examining their impact on critical stormwater flood events. This Section of the report aims to explore the characteristics of available storage for WSUD measures, and explores suitable way to simulate WSUD measures which have a storage component where they are aimed at reducing runoff or flow rates.

3.2 Background

The design of stormwater drainage systems in Australia tends to be undertaken based on *Australian Rainfall and Runoff* (*AR&R*) (Pilgrim, 1999), a guideline for flood and flow estimation for Australian conditions. The procedures in *AR&R* and Australian design practice tend to be based on 'design storms'. Full procedures for the determination of an appropriate design storm for a particular location in Australia are described in *AR&R*. Regardless of where one is located, however, all design storms consist of a single rainfall event which with a duration from 5 minutes up to 72 hours. Applied in isolation, a designer must assume the conditions of a catchment prior to the design event occurring. Among these factors are the antecedent rainfall and/or antecedent conditions of the catchment.

Antecedent rainfall is a term used to refer to rainfall which occurs prior to a particular rainfall event of interest (e.g. Voyde et al., 2010). This may also be referred to in literature by a similar opposing term, the antecedent dry weather period (ADWP) (e.g. Stovin et al., 2012). Some researchers also refer to antecedent conditions, which refer to the quantity of water stored in a catchment prior to an event of interest. This would include, for example, soil moisture and evaporation conditions prior to an event (e.g. Pathiraja et al., 2012) or the level of available storage(s) which may affect catchment outflow characteristics (e.g. Fassman & Blackbourn, 2010).

There have been numerous studies which have identified a correlation between the impact of antecedent rainfall and the performance of WSUD systems for retaining flow volume. The ADWP, and by association antecedent rainfall, is shown to be a significant variable in studies of the source control (retention) performance of green roofs (Stovin et al., 2012; Voyde et al., 2010), bioretention systems (Davis et al., 2012; Hatt et al., 2009), permeable pavement structures (Brattebo & Booth, 2003; Fassman & Blackbourn, 2010) and rainwater tanks (Vaes & Berlamont, 2001).

Despite this, the assessment of storage based WSUD systems for the management of runoff peak flow rates is generally undertaken using a design storm event approach (e.g. Tonkin Consulting, 2012; Villarreal et al., 2004). It is widely documented that WSUD features should be assessed on a continuous basis to estimate their performance for water quality or harvest potential (e.g. Melbourne Water, 2010b; Water by Design, 2010) however there is little advice on the assessment of WSUD features for managing peak flows or runoff volume. In this section of the report, the need for an alternative approach for considering peak flow and runoff quantity assessment of WSUD measure performance for South Australian stormwater management plans has been examined. The examination was conducted by exploring the occurrence of rainfall events which correspond to *AR&R* based 'design storm' events in a real, observed rainfall record in Adelaide, South Australia. The antecedent rainfall prior to these events was then characterised. Finally, the impact of considering these antecedent conditions on the simulated performance of common storage based WSUD measures was then examined for allotment and street scale catchments.

3.3 Methodology

The impact of antecedent conditions on the results of an assessment of WSUD effectiveness was explored by identifying the presence of storm events equivalent to *AR&R* derived design events of selected magnitudes in the rainfall records for Adelaide (Kent Town). The impact of using *AR&R* derived design storms and the equivalent observed storms for estimating the peak flow and runoff volume of two design scenarios with WSUD features was then evaluated. The effect of including an antecedent period on the simulated peak flow and runoff volume was then explored. The procedures used to identify design storm events in the selected rainfall record are detailed in Section 3.3.1. The procedure used to evaluate the impact of using *AR&R* derived design storms or equivalent observed storms is described in Section 3.3.2. The procedure used to evaluate the impact of increasing antecedent rainfall periods on the simulated peak flow and runoff volume, and the performance of WSUD measures to manage peak flows and/or runoff volume, is also described in Section 3.3.2.

3.3.1 Identification of Design Storm Events

The examination of antecedent conditions was undertaken for the Kent Town rainfall gauge using a long (38 year) rainfall data set from the Bureau of Meteorology (BOM) (BOM gauge

023090). To begin, intensity frequency duration (IFD) data from the BOM[1] were sourced for the Adelaide (Kent Town) rain gauge location (-34.9211° S, 138.6216 E). The IFD data is recommended for the production of design storm events which may be used in accordance with *AR&R* guidelines. A rainfall depth equal to the 20% annual exceedance potential (AEP) and 50% AEP design storm events with a 12 minute, 30 minute, 1 hour or 2 hour duration were identified. The 20% AEP and 50% AEP were selected because they represent events with approximately a 5 Year Average Recurrence Interval (ARI) and 2 Year ARI, respectively. The 5 Year ARI has been generally adopted as a design standard for minor drainage systems by local government authorities for residential areas in South Australia. The 50% AEP is a lower design threshold which represents the current capacity of many existing drainage systems in Adelaide (e.g. Myers et al., 2014b; Tonkin Consulting, 2013c). Durations between 12 minutes and 2 hours were selected to represent catchments ranging from what may be expected to be a few allotments up to larger areas.

Rainfall data for Adelaide (Kent Town) was acquired from the BOM at a six minute time step[2] from February 1977 to April 2015 (over 38 years). This data was analysed to identify periods in the time series which included rainfall depths with a 20% AEP or a 50% AEP over a 12 minute, 30 minute, 1 hour and/or 2 hour duration. To identify these periods, the six minute data was used to produce a corresponding series of rainfall depth over 12 minute, 30 minute, 1 hour or 2 hour periods, at a six minute time step. For example, the 1 hour data was a time series of rainfall depths summing the depth of the preceding hour's rainfall every six minutes.

Events with a 20% AEP or 50% AEP rainfall depth at the selected durations were identified where the observed rainfall depth was ±10% of the corresponding design IFD rainfall depth value. The following criteria and assumptions were made in the identification of design storm event periods:

- A storm event was defined as a continuous period of rainfall separated by at least 12 hours of dry weather.
- A single storm event as defined above may include several storm 'bursts' which correspond to the target AEP and durations. For example, when accumulating the rainfall depth of a single event, segments of the rainfall may represent a 12 minute, 30 minute and 90 minute storm event. For example, based on the definition above, there was a storm event isolated on 02/03/1983. This was one storm event, but it contained storm bursts with a 50% AEP corresponding to the 12 minute, 30 minute and 60 minute duration, all of which were counted.

[1] http://www.bom.gov.au/water/designRainfalls/ifd/

[2] Five minute data was sourced but a complete record was not available at this time step.

- For this analysis, only one burst of any given duration was selected from an event. For example, while multiple bursts of different durations were identified from the event of 02/03/1983, only one burst of each duration was selected.
- Where multiple rainfall bursts were identified in a single event which corresponded with the same AEP and duration, the highest value of summed rainfall for the corresponding duration was selected. If there were several points of identical maximum values, the first point was selected (i.e. it may not represent the worst case event).
- If a storm event contained summed data which satisfied the selected AEP and duration criteria, but was at some point exceeded by an accumulated rainfall depth 10% greater than the design AEP rainfall depth, the event was ignored and assumed to be an event of less frequent AEP.
- The original rainfall records from the BOM for Adelaide (Kent Town) contained quality coding to identify missed, summed and interpolated data. Only data which was quality coded as ‘Good’ (denoted by a code of ‘0’) was accepted in the analysis. Events with other quality codes were not used.
- In addition to quality code data from the BOM, each event which satisfied the requirements for an AEP and duration was investigated to identify suspicious records. This identified two events which consisted of over 1 hour of rain data of constant intensity, with no surrounding rainfall data (e.g. on 9/06/1983 and 31/12/1983). These events were also excluded.

Following the selection of storm events equivalent to the 50% AEP and 20% AEP, antecedent rainfall conditions for each event burst were calculated. Antecedent rainfall was calculated for periods ranging from 30 minutes up to 30 days. It should be noted that the antecedent rainfall depth was determined based on the time leading up to the event, and did not include the rainfall depth of the event itself. As such, for a 30 minute duration event, the 30 minute antecedent rainfall was calculated as the sum or rainfall in the 30 minutes leading up to the start of the 30 minute event period.

3.3.2 Evaluating Peak Flow and Runoff Volume Estimation Using Design Storms and Equivalent Observed Storms with Antecedent Conditions

The effects of using design storm events and equivalent, real storm events in the estimation of peak flow and runoff volume from a catchment fitted with WSUD features was conducted using two case study catchments. The same catchments were then used to explore the impact of assuming different levels of antecedent conditions on the performance of WSUD systems for peak flow and runoff volume management. The case study catchments in this evaluation were a redeveloped allotment scenario fitted with retention or detention storages, and a redeveloped street scale catchment scenario with rain garden features. In each case, there were several design configurations explored to identify the impact of selecting a design storm, an observed storm corresponding to the design storm, and the observed storm with varying periods of antecedent conditions.

Allotment Scale Catchment with Retention or Detention Tank

The allotment scale catchment scenario was derived based on the layout of a typical 760 m^2 single home allotment that was redeveloped to contain two new homes. The original allotment and the redeveloped allotment are illustrated in Figure 3-1. The allotment, which originally has a connected impervious area of 45% was redeveloped to have a connected impervious area of 80%. The WSUD assumed to be installed on the redeveloped allotment was either retention or detention tanks fitted to each new home.

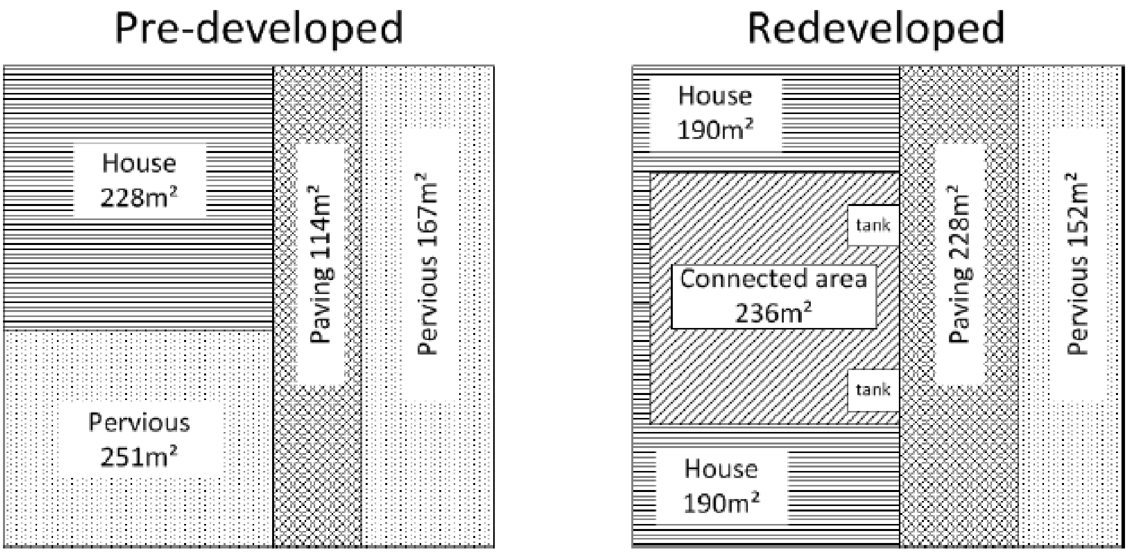

Figure 3-1 - Layout of the Allotment scale catchment

Key assumptions of the allotment scale catchment were as follows:

- It was assumed that redevelopment consisted of the removal of one home and the construction of two new homes.
- It was assumed that each new home will have a single WSUD connection in the form of a roof connected retention (i.e. rainwater) tank or a roof connected detention tank. As such, in the redeveloped case, there were two retention or two detention tanks assumed.
- Retention tanks were examined with a volume of either 1 kL or 5 kL. The tank demand was assumed to be indoor use at 100 L/day, which is approximately equal to an estimated daily household demand for toilet flushing or laundry cold water in South Australia (Myers et al., 2011b). Larger tank sizes were not applied based on the findings of previous work by the Goyder Institute for Water Research (Myers et al., 2014b) which indicated that the benefits of rainwater and detention tak use are not increased beyond a capacity of 5 to 10 kL.

- Detention tanks were examined with a volume of either 1 kL or 5 kL. The tank orifice was assumed to be 20 mm.
- The impervious area connected to the WSUD systems was assumed to be equal to the new impervious area generated by the redevelopment.

Street Scale Catchment Scenario with Rain Garden

The street scale catchment scenario was adopted based on a 200 m length of street derived from the calibrated Frederick Street catchment model which was documented in previous research (Myers et al., 2014b). The original catchment contained 10 homes, and was adapted slightly for this study to represent a pre-development site consisting of 10 homes in the pre-developed layout proposed in Figure 3-1. In addition to the 10 homes (comprising 0.76 Ha total), the existing street and verge areas were also included to produce a total catchment area of 0.92 Ha (note that driveway space was accounted for in the allotment scenario and did not need to be factored in for the street scale). The road and verge was assumed not to change throughout redevelopment, but the homes were assumed to be fully redeveloped, where each home was removed and replaced with two new homes (producing 20 homes on the 10 existing allotments) with the same impervious/pervious area ratio as those used in the post-development allotment scenario described above. The streetscape scenario is illustrated in Figure 3-2. The WSUD assumed to be installed at the street scale were rain gardens.

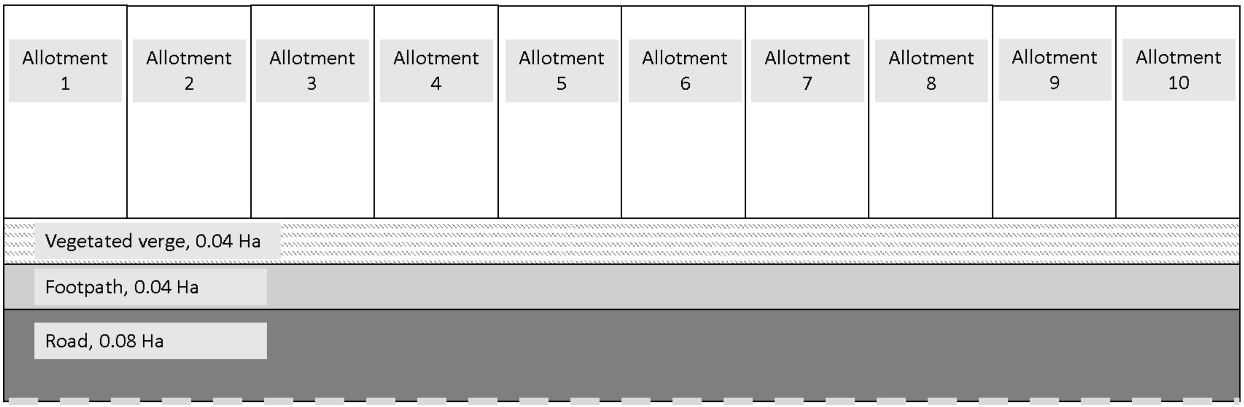

Figure 3-2 - Layout of the street scale catchment

The following assumptions were made in the simulation:

- The street scale rain gardens were placed at 100 m intervals - as such there were two in the street catchment scenario. This was based on the observed frequency of rain gardens currently constructed in Mile End, South Australia.
- Each rain garden was assumed to have properties equivalent to those outlined in Section 5 of the preceding Goyder Institute research (Myers et al., 2014b), which was based on the rain gardens currently implemented in Mile End, Adelaide. The properties of the gardens are provided in Table 3-1. Note that these properties produce raingardens with a surface storage of 7.9 m^3 each.

Table 3-1 – Properties of rain gardens adopted in the street scale scenario

Model Parameter	Value
Surface storage properties	
Surface area (m^2)	45
Filter area (m^2)	5.1
Storage depth (mm)	175
Vegetation volume	0
Soil storage properties	
Thickness (mm)^	850
Porosity (volume fraction) *	0.44
Field capacity (volume fraction) *	0.062
Wilting point (volume fraction) *	0.024
Conductivity (mm/hr) *	150
Conductivity slope*	5
Suction head*	1.93
Underground storage properties	
Height (mm) ~	250
Void ratio#	0.1
Conductivity (of soil at base, mm/hr)	0
Underdrain properties	
Drain coefficient (mm/hr)	18.5
Drain exponent	0.51
Drain offset (mm)	50

* Based on the typical values for a sandy soil as provided by Rossman (2010)
\# Void ratio is based on the void ratio of combined gravel and drainage pipe volume
^ Thickness refers to the depth of the filter media
~ Underground storage height is the depth of storage beneath the filter media – equivalent to the 'Depth below filter media' value in the eWater MUSIC model.

Allotment and Street Scale Runoff Simulations

To examine the impact of assuming a design storm or an observed storm with equivalent rainfall depth, the simulated peak flow and runoff volume values were compared based on the allotment and street scale catchment with several rainfall input scenarios. The rainfall input consisted of the *AR&R* derived 20% AEP design storm with a 30 minute, 1 hour and 2 hour duration and an extract of the equivalent observed storm from the observed time series of the Adelaide (Kent Town) gauge. It should be noted that the observed rainfall data was extracted and there were no antecedent conditions, nor rainfall included following the 30 minute, 1 hour or 2 hour duration of the storm at this point.

To examine the impact of antecedent conditions on the estimated effectiveness of WSUD, the peak flow and runoff volume values were determined, as above, from both the allotment and street scale catchment with varying rainfall input and varying WSUD measures. The rainfall input to the model consisted of a 20% AEP rainfall extract from the observed rainfall time series at Adelaide (Kent Town) with either a 30 minute, 1 hour or 2 hour duration. Following this, the same events were modelled, *but with the inclusion* of the preceding rainfall data for periods of 1 hour, 1 day, 10 days or 30 days (producing 12 rainfall scenarios). In addition, each rainfall scenario was simulated with 1 kL retention, 5 kL retention, 1 kL detention or 5 kL detention tanks installed on the homes in the redeveloped allotment. Additional information on the assumptions for these WSUD scenarios were identical to those described for the allotment scenarios above.

Determination of Peak Flow and Event Runoff Volume

The runoff peak flow for all modelling scenarios was calculated by identifying the maximum flow rate (L/s) which occurred in the simulated runoff time series of the existing and redeveloped catchments after the commencement of the storm event of interest. The selected peak flow excluded flow rates during antecedent rainfall periods.

The runoff volume for all scenarios was calculated by identifying the volume of flows which occurred in the simulated runoff time series after the commencement of the storm event of interest and for a period of up to six hours. The calculation did not include the runoff volume during antecedent rainfall periods.

3.4 Results

3.4.1 Identification of Design Storm Events in the Adelaide (Kent Town) rainfall record

The analysis of the data from the Adelaide (Kent Town) rain gauge revealed multiple events in the observed record equivalent to the 50% AEP and 20% AEP for the selected durations. Table 3-2 summarises the target rainfall depths for each AEP and event duration to identify events in the rainfall time series. A summary of the results is shown in Table 3-3, including the number of events of each target AEP and duration and the average depth of antecedent rainfall ranging from 30 minutes up to 30 days. A full list with these details for each individual event is provided in Appendix B.

Table 3-2 - Summary of the target rain depths used to identify events of the target AEP and duration in the observed rainfall record of Adelaide (Kent Town)

AEP	Duration	Rain depth (mm)	Rain depth - 10% (mm)	Rain depth + 10% (mm)
50%	12	7.5	6.8	8.3
	30	11.1	10.0	12.2
	60	14.3	12.9	15.7
	90	16.5	14.9	18.2
	120	18.2	16.4	20.0
20%	12	10.8	9.7	11.9
	30	15.9	14.3	17.5
	60	20.4	18.4	22.4
	90	23.4	21.1	25.7
	120	25.7	23.1	28.3

Table 3-3 - Summary of 20% AEP and 50% AEP events in the Adelaide (Kent Town) rain gauge record, and mean preceding rainfall

AEP	Duration	Number of Events	Target rainfall depth (mm)	Average depth of rainfall preceding the event (mm)								
				30 min	60 min	90 min	120 min	12 hr	24 hr	72 hr	10 day	30 day
50%	12	7	8.6	3.1	4.4	5.1	5.5	10.4	13.4	19.3	21.7	41.4
	30	14	10.9	2.3	2.7	3.4	4.3	6.4	8.5	12.1	17.9	27.8
	60	16	13.2	2.2	3.3	3.8	4.6	6.1	6.2	8.6	12.1	27.3
	90	16	16.3	1.3	2.2	2.9	3.6	7.4	9.5	12.5	14.9	27.7
	120	15	18.0	1.2	2.2	2.8	3.3	10.8	11.9	17.7	18.6	27.4
20%	12	4	10.5	5.6	7.8	8.2	8.8	10.8	16.3	17.4	18.2	45.3
	30	5	15.4	0.3	0.5	0.6	1.2	4.0	9.8	15.3	17.4	39.4
	60	6	19.7	0.7	0.9	1.4	2.4	6.0	11.3	21.8	32.2	55.5
	90	6	21.8	0.6	0.9	2.2	2.9	4.8	6.6	18.1	27.9	39.3
	120	2	24.3	0.3	1.0	2.6	4.5	6.1	9.5	17.8	22.5	40.9

As would be anticipated, there were fewer events with a 20% AEP compared to events with a 50% AEP. Of more interest is that almost all of the events identified, regardless of AEP, occurred with rainfall in the preceding 30 minutes. In fact, of all the events identified, only one did not show rainfall in the preceding 24 hours. This has implications in the simulation and performance assessment of WSUD systems for flow and runoff volume management using design storms because they may be affected by rainfall in the lead up to a storm event of interest. To put the antecedent rainfall depths into perspective, it is noted that even shorter periods of antecedent conditions of up to two hours contained, on average, rainfall depths larger than the initial loss value of Australian urban catchments. (Phillips et al., 2014) undertook an analysis of gauged urban catchments across Australia and found that the initial loss of the effective impervious area in the catchments varied from 1 mm to 5 mm. The South Australian site examined by (Phillips et al., 2014) was the Para Hills drain data, which showed an initial loss of 1 mm. The average antecedent rainfall in the two hours leading up to design events was almost always greater than 1 mm in the results of the current study. This indicates that for typical events with a 20% or 50% AEP, the initial loss values in an event based simulation may be considered to be diminished to zero by the time an storm event of interest for flood management occurs, and thus an initial loss should not be adopted.

Perhaps more importantly, however, it also indicates the importance of considering the impact of antecedent conditions on the effectiveness of any retention or detention based systems for flow rate or runoff volume management. The implications of these findings for retention and detention systems are explored further in Section 3.4.3.

3.4.2 Comparison of a Design Storm or an Equivalent Observed Storm to Predict Catchment Peak Flow and Runoff Volume

The effect of selecting a design storm event or equivalent observed storm event periods from the Adelaide (Kent Town) rainfall gauge was conducted by comparing the simulated peak flow and runoff volume from the *AR&R* derived design storm event with that of an equivalent event extracted from the observed rainfall record. The observed event was the 20% AEP event which occurred on 08/06/1991 from which a 30 minute, 1 hour and 2 hour duration event was extracted. The antecedent conditions of this event are shown in Table 3-4. A comparison of the design storm event hyetograph and the corresponding observed hyetograph at each duration is shown in Figure 3-3.

Table 3-4 – Antecedent conditions of the 30 minute, 1 hour and 2 hour 20% AEP rainfall event on 08/06/1991

Date	Event rain (mm)	Rainfall preceding event (mm)								
		30 min	60 min	90 min	120 min	12 Hr	24Hr	72 Hr	10 day	30 day
8/06/1991	14.6	0.9	1.9	2.4	5.0	8.0	14.8	23.9	33.8	69.7

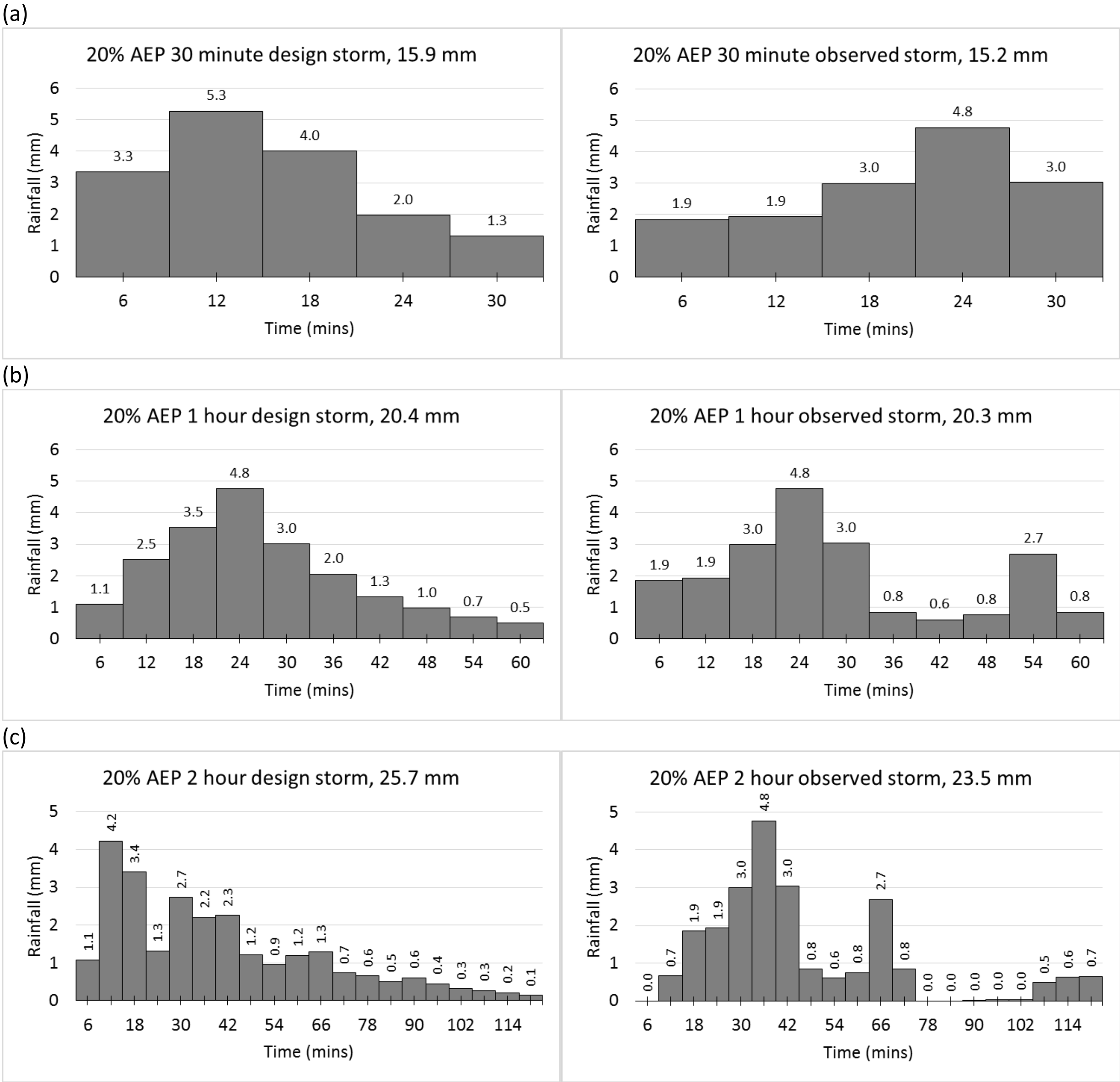

Figure 3-3 – Comparison of the 20%AEP design storm and observed equivalent 20%AEP storm event at Adelaide (Kent Town) showing the (a) 30 minute storm (b) 1 hour storm and (c) 2 hour storm

There were differences between the design events and the equivalent observed extracted rainfall event. The 30 minute observed storm has a different skew, with the highest intensity occurring toward the end of the event compared to the design storm. The one hour design storm more closely resembles the equivalent observed rainfall event. The two hour design storm event also resembles the observed equivalent, however there is a period of near zero rainfall in the observed event which is not present in the design, and the observed storm has a slightly higher peak rainfall intensity.

The simulated peak flow discharging from the redeveloped allotment scenario using these events is shown in Figure 3-4 and the resulting runoff volume is shown in Figure 3-5.

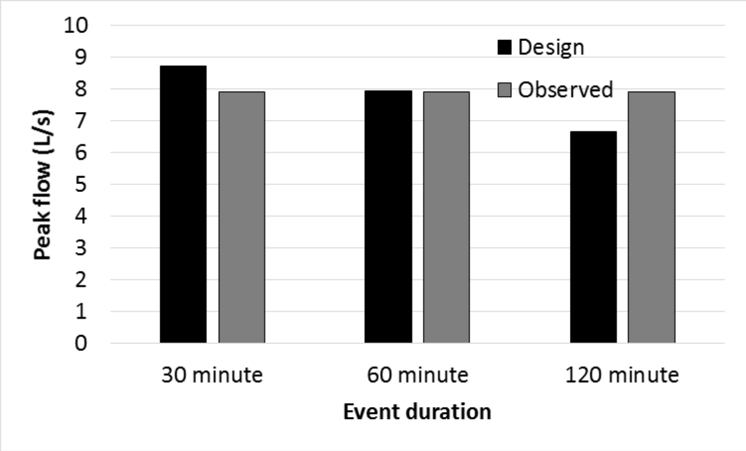

Figure 3-4 – A comparison of the simulated peak flow from the redeveloped allotment when selecting a 20% AEP design storm or an equivalent observed storm based on rainfall data from Adelaide (Kent Town)

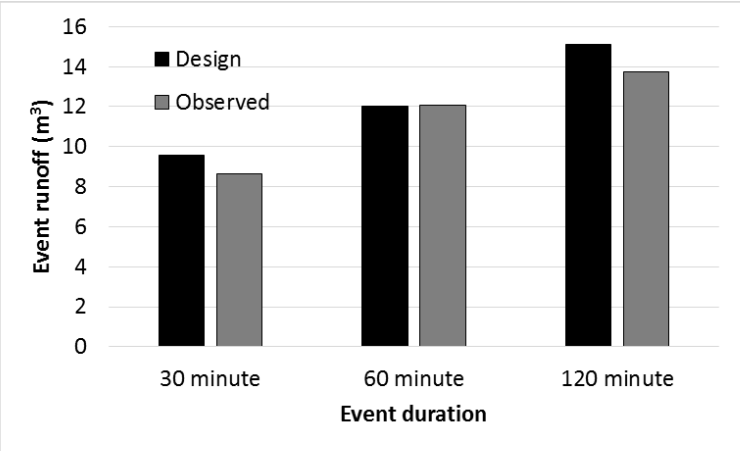

Figure 3-5 - A comparison of the total runoff volume from the redeveloped allotment when selecting a 20% AEP design storm or an equivalent observed storm based on rainfall data from Adelaide (Kent Town)

The results indicate that there was some difference between the predicted peak flow and runoff volume from a design storm event compared to an equivalent extract from the observed rainfall record. The peak flow predicted using the observed storm was 9% lower than the design storm at the half hour duration. This is attributable to the slightly higher peak rainfall intensity in the design storm. Peak flow was almost identical for the 1 hour duration event, reflecting the almost identical peak rainfall intensity. For the two hour duration, the peak flow from the observed storm was 19% higher than the design storm, again reflecting the higher intensity of the observed 2 hour duration event. For total runoff volume, the runoff from the observed event was 9% lower than the design event runoff volume at the 30 minute and two hour duration, reflecting differences in rainfall volume. However the runoff volume was very similar at the one hour duration. Similar results were also found when the post development scenario of the street scale catchment were examined (see Appendix C).

The differences in peak flow and runoff volume were relatively small. The design storm temporal patterns in *AR&R* were intended to be a representative 'average' rainfall pattern, and variation from observed storm events may be expected. The comparison of several observed storms over the entire length of the record may produce a better analysis of the fitness of the temporal pattern produced by *AR&R*. These results demonstrate that the peak flow rate produced by adopting equivalent observed storm events and design storm events may vary, and the variation may be a function of the selected duration or the nature of the observed storm event. In Section 3.4.3 the results of the investigation into the impact of antecedent conditions on the predicted performance of WSUD systems for peak flow and runoff volume management are presented.

3.4.3 Evaluating the Effect of Antecedent Conditions on WSUD system performance

The effect of antecedent conditions on WSUD system performance was examined by simulating the peak flow rate and runoff volume from both the allotment and street scale catchment scenarios for an observed event equivalent to a design storm with gradually increasing antecedent periods. The equivalent observed storm was the 20% AEP event on 08/06/1991 in the Adelaide (Kent Town) rainfall time series. The results of selecting zero, one hour, one day, ten days or 30 days of antecedent conditions for the observed 30 minute storm event from the Adelaide (Kent Town) rainfall time series on the peak flow rate of runoff from the allotment scenario are shown in Figure 3-6 (for retention) and Figure 3-7 (for detention, based on a 20 mm orifice size).

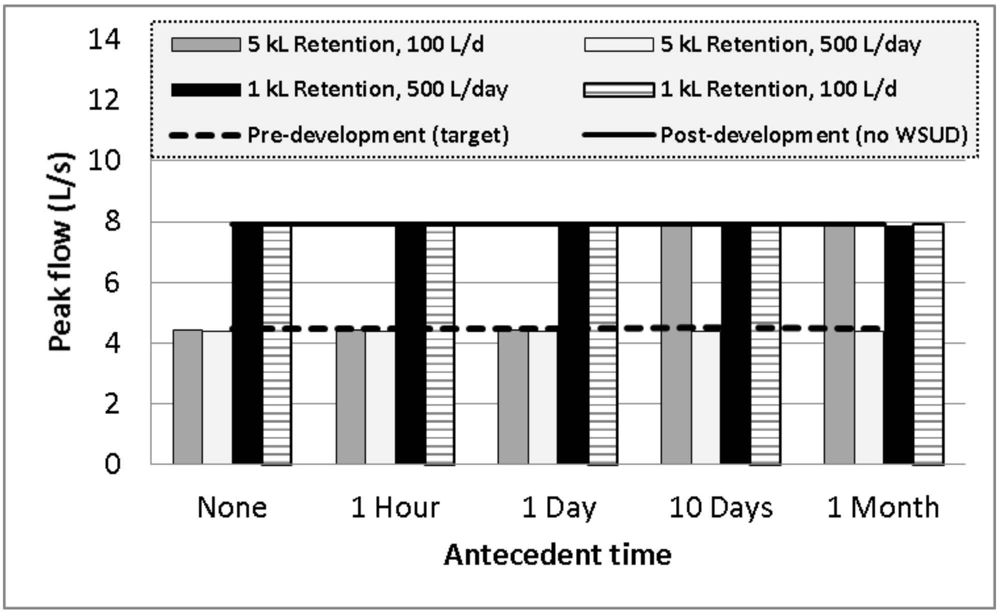

Figure 3-6 - The effect of antecedent conditions on the performance of retention based WSUD for improving peak flows of runoff from the selected observed 20% AEP event on the allotment scale catchment with a 30 minute duration

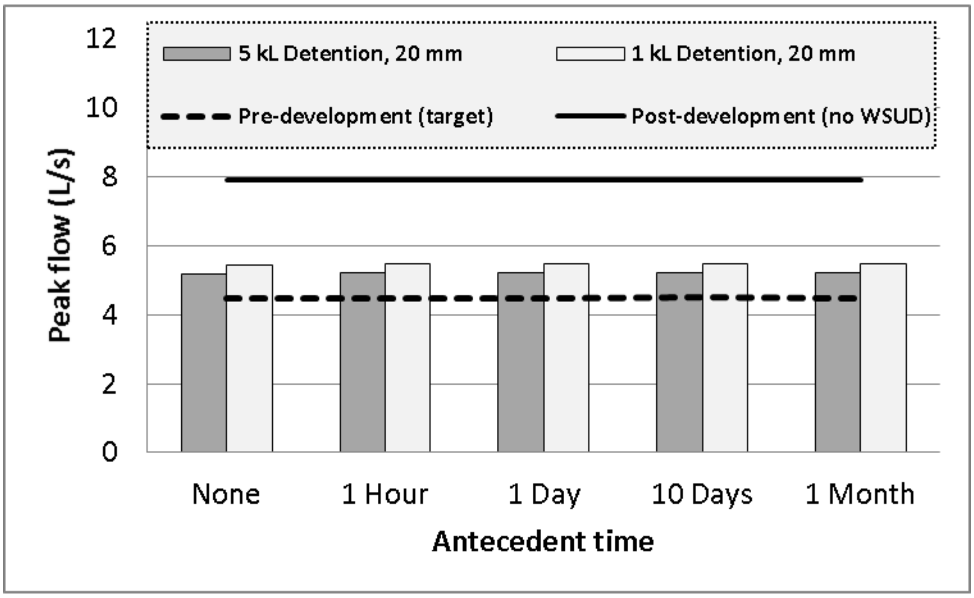

Figure 3-7 - The effect of antecedent conditions on the performance of detention based WSUD for improving peak flows of runoff from the selected observed 20% AEP event on the allotment scale catchment with a 30 minute duration

The results indicate that at the allotment scale, the selection of antecedent conditions has an impact on the performance of WSUD measures with storage volume. For example, the 5 kL retention tanks were the most effective on-site measure for reducing the peak flow of runoff from the redeveloped allotment, regardless of reuse. Considering the antecedent rainfall volume up to one day prior to the selected event did not affect the performance of this measure. However, when 10 days or more of observed antecedent rainfall was included in the analysis, the 5 kL retention tanks with only 100 L/d of disposal had no impact because the retention tank was filled by antecedent rainfall. Only the 5 kL tank with a 500 L/day usage remained effective. In all cases, the 1 kL retention tanks were ineffective because they filled during the beginning of the rainfall event.

The detention based WSUD measures were generally not affected by the inclusion of antecedent conditions in the case of this storm. This is because the emptying time of the detention tanks, as noted previously, was less than one hour. The peak flow from redeveloped allotments fitted detention systems was slightly higher than corresponding retention cases because the detention tank outflow was present during the storm event.

The results of selecting antecedent conditions for the observed 30 minute storm event on the runoff volume from the allotment scenario are shown in Figure 3-8 (for retention) and Figure 3-9 (for detention, based on a 20 mm orifice size).

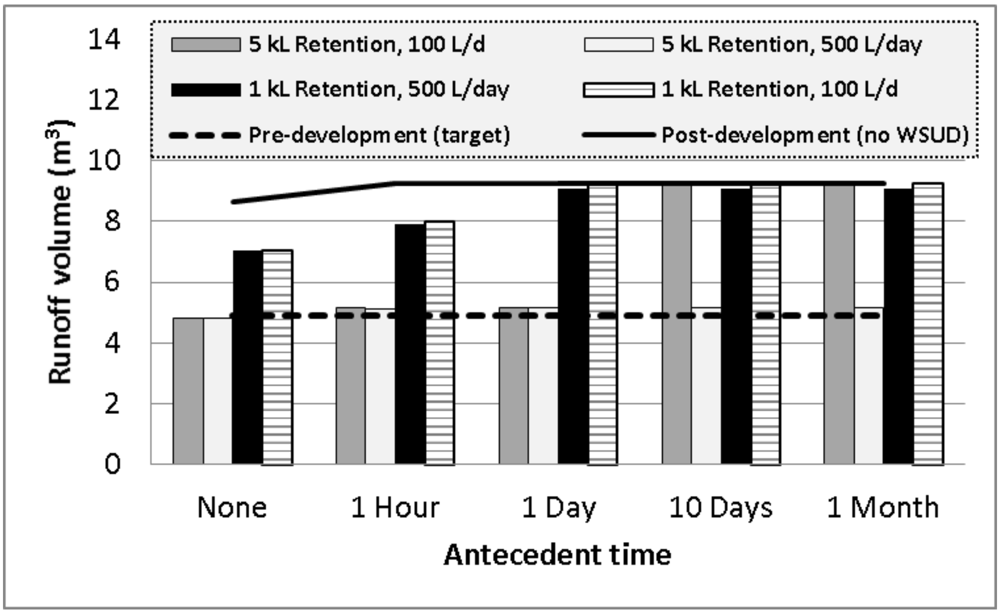

Figure 3-8 - The effect of antecedent conditions on the performance of retention based WSUD for improving runoff volume from the selected observed 20% AEP event on the allotment scale catchment with a 30 minute duration

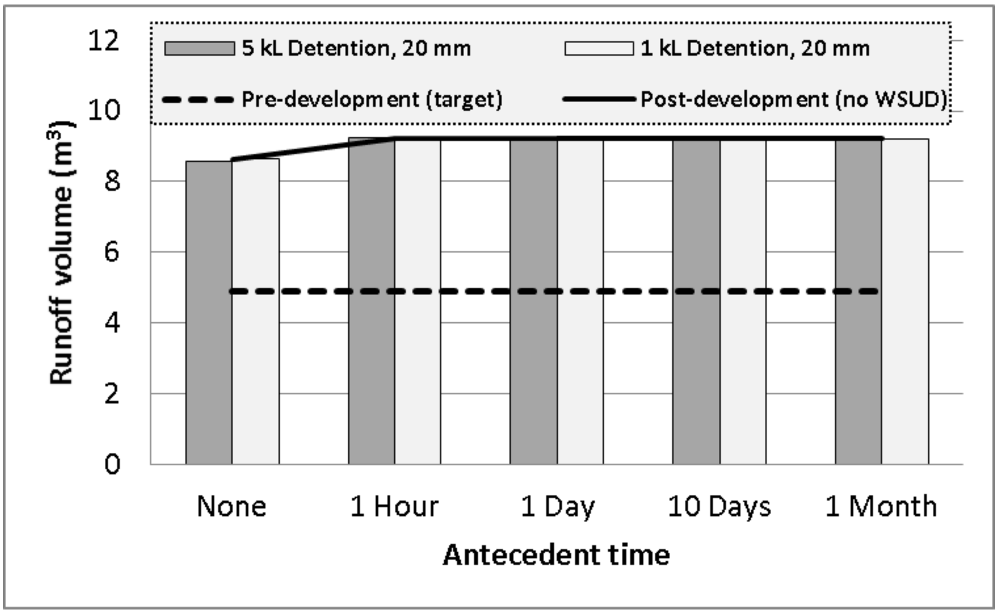

Figure 3-9 - The effect of antecedent conditions on the performance of detention based WSUD for improving runoff volume from the selected observed 20% AEP event on the allotment scale catchment with a 30 minute duration

The runoff volume results for the allotment fitted with WSUD systems were similar to the results for peak flow rates. 5 kL retention tanks were effective at reducing the runoff volume of the event without antecedent conditions. The impact of up to one day of antecedent conditions was very minor. However, antecedent conditions of ten days made 5 kL tanks with only 100 L/d extraction completely ineffective. With an extraction of 500 L/day, the tanks remained very effective. The data is not shown for detention systems which were ineffective at retaining volume. As previously noted (Section 3.3.2), retention volume was assessed based on an analysis of flows up to six hours following the event. The six hour time period was greater than the tank emptying time (the emptying time for a 5 kL tank with a 20 mm orifice is 2.6 hours, and for a 1 kL tank it is 0.8 hours, although these times may vary depending on assumed tank shape).

There is an increase in the runoff volume from the redeveloped allotment when antecedent rain is considered without WSUD. This was due to additional runoff in time steps leading up to the event which contributed some flow volume from the beginning of the rainfall event. Figure 3-10 demonstrates this indicating the additional runoff prior to and in the initial stage of the main storm event which begins at 60 minutes in this case.

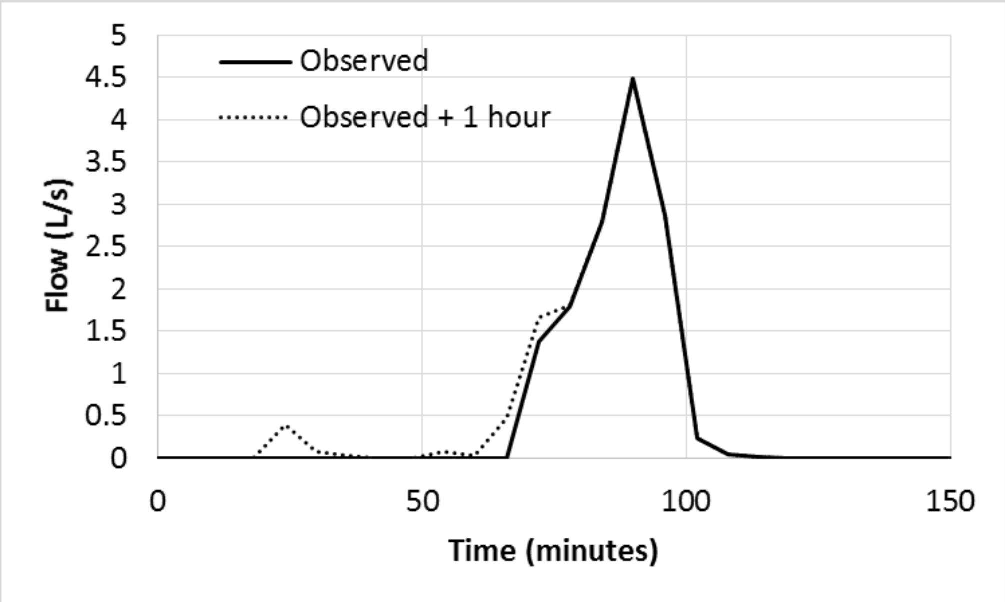

Figure 3-10 - Comparison of hydrographs from the same storm event with and without antecedent rainfall, indicating the source of additional flow volume

Overall, this analysis has shown that the impact of antecedent conditions on the performance of WSUD systems was dependent on the size and emptying time of the storage of the WSUD device. The most effective systems for restoring pre-infill development peak flow rates and runoff volumes for a redeveloped catchment were retention systems with a 5 kL storage and a relatively rapid withdrawal of 500 L/day (which did not go to the drainage system). 1 kL retention tanks were not effective at restoring a 20% AEP in any circumstances. Detention systems were generally effective at restoring peak flows, although their outflow contributed to the peak flow rate to some extent and did not influence the runoff volume.

The results of selecting zero, 1 hour, 1 day, 10 days or 30 days of antecedent conditions for the observed 30 minute storm event from the Adelaide (Kent Town) rainfall time series on the peak flow of runoff from the redeveloped street scenario with bioretention is shown in Figure 3-11.

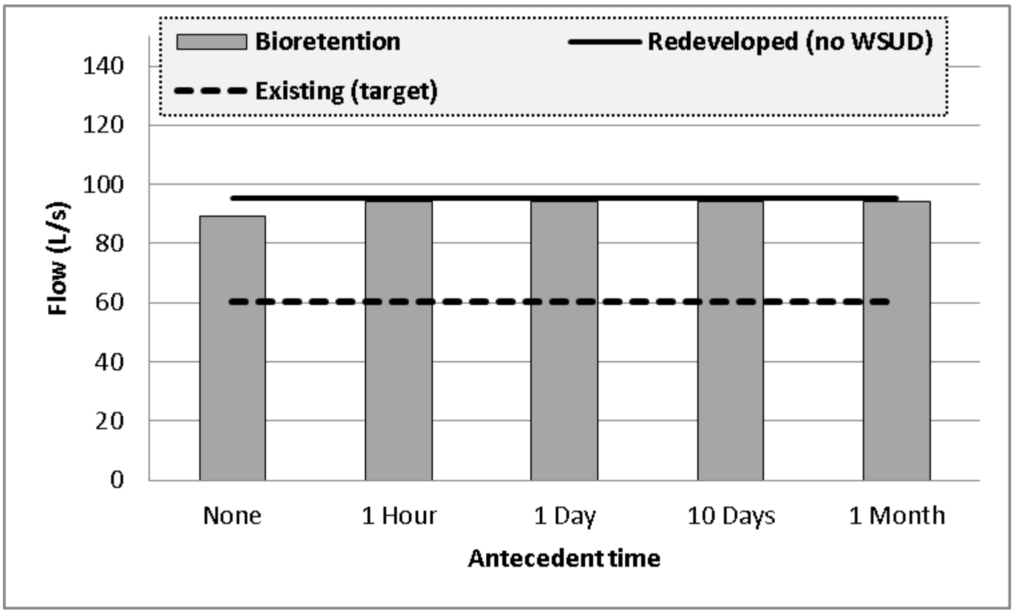

Figure 3-11 - The effect of selecting zero, 1 hour, 1 day, 10 days or 30 days of antecedent conditions on the simulated performance of WSUD for peak flow reductions from the street scale catchment and a 30 minute storm

The results indicate that the street scale bioretention systems could not restore peak flows to the pre-developed state of the catchment with the assumed arrangement in this case. This may be because of the additional impervious area that was connected. The bioretention systems were also limited because while the 1 kL allotment storage tanks provide 20 kL total storage across the catchment, the rain gardens only provide approximately 15 kL. This is also linked to all impervious area, not just a portion, which means that they can be partly filled or at capacity before the peak flow rate even occurs.

The bioretention systems were affected to some extent by increasing the period of assumed antecedent rainfall prior to the occurrence of the design event. For example, the simulated peak flow rate following the occurrence of the event was found to be 7% lower than the no WSUD case without considering any antecedent conditions, but only 1% lower when one day or more of antecedent conditions were considered.

3.5 Discussion

The results illustrate that antecedent conditions are an important consideration in the assessment of WSUD measures for managing flows.

It is difficult to assign a definite period over which design rainfall events should consider antecedent conditions. In this case study, we demonstrated how a 5 kL retention tank could reduce the peak flow and runoff volume of a redeveloped allotment catchment and street catchment to the original conditions prior to redevelopment. However, when ten days of antecedent conditions were included, only a relatively high rate of withdrawal (500 L/day) allowed the tank to be effective as the tank was full at a reuse rate more typical of indoor demand (100 L/d). As such, the bare minimum antecedent period for a particular stormwater event should consider the emptying time of the device. A conservative approach would be to consider the storage full at the beginning of the antecedent period.

The intention of this analysis was to demonstrate the impact of the antecedent period. However, it is also clear that the selection of an each individual storm event will affect the assessment of a storage based WSUD device. Discussion of these results with practitioners revealed ongoing concerns over the use of the design storm, particularly the tendency for designers applying short duration storms for the design of detention tank systems to comply with local government pre- and post-development flow requirements in South Australia. While this is a separate issue from this research, the concern is strong enough to warrant further comment. Current design practice for detention and retention design tends to be undertaken on the assumption that the highest intensity storm is the critical design event in order to maintain pre-and post-development peak flows. While this process is subject to antecedent conditions as demonstrated here, a further complication arises in that the catchment specific impacts of detaining only the short duration storm are not considered, despite the fact that such approaches may have negative consequences at the catchment scale for longer storms, or when detained flows subsequently combine during the event. Interested readers should note that there is a separate research project currently underway investigating this issue and outcomes should be available in late 2016.

The analysis in this report was based on relatively small catchments fitted with storages. It should be noted that results may vary somewhat for larger catchment areas that are typical of stormwater management plans. Analysis of these larger catchments may need to consider the saturation of soil in pervious areas which may contribute to runoff. This analysis has also not addressed the question of what size of retention and detention system, or rain garden arrangement, would be most effective at reducing the impact of urbanisation. It is highly recommended that the scenarios in this project are used to determine the best design volume and placement of retention, detention and rain gardens to maximise effectiveness for flow management.

It should be noted that a revised version of *AR&R* is currently being developed. It is anticipated that the revised version of *AR&R* will include procedures and rainfall data records that are suitable for continuous simulation of peak flows. Coombes and Roso (2015) reviewed the changes in urban water management since the previous complete revision of the AR&R in 1987. This has included the mainstream acceptance of WSUD approaches for a more integrated approach to stormwater management to achieve multiple objectives beyond the collection and conveyance of peak stormwater flows in a drainage network. The authors argue that the use of event based approaches may not reliably be used for the design of integrated stormwater management strategies that address social, environmental and economic objectives. The rise of more powerful personal computing has also made continuous simulation models more feasible for users. Coombes and Roso (2015) suggest that the revised version of AR&R needs to support appropriate design methods that are suitable for more integrated approaches and that account for the spatial and temporal variability of rainfall events. These methods are likely to include continuous simulation and Monte Carlo frameworks.

Weinmann (2007) argued that for the analysis of relatively frequent storm events the catchment conditions experienced prior to the runoff event significantly influence the runoff behaviour, which means continuous simulation is needed to accurately represent runoff behaviour. Figure 3-12 illustrates the analysis methods that are likely to be required for different runoff event return frequencies.

Based on the findings of previous literature and this report, it is recommended that SMP Guidelines provide more specific guidance on the examination of retention and detention systems. While continuous simulation approaches generally recommended in literature, there is no broadly accepted approach for undertaking continuous simulation with for stormwater events with a specified return period. As such, it is recommended that the outcomes of the AR&R revision process are monitored. If an applicable approach is provided with supporting information (such as rainfall data) included in forthcoming SMP guidelines.

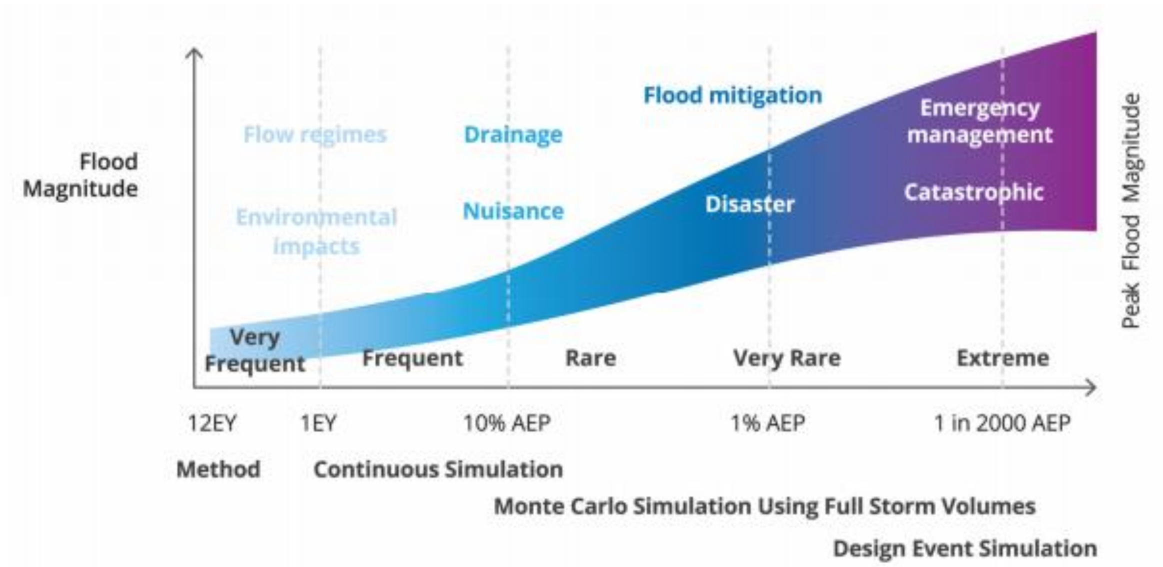

Figure 3-12 – Analysis methods for different flood frequencies and management focus

Source: Coombes and Roso (2015) (adapted from: Weinmann, 2007)

3.6 Summary

This section demonstrated that the design of WSUD systems for flow and runoff volume management are influenced by antecedent conditions, which limits the effectiveness of using design storm events for sizing WSUD retention and detention systems. On average it was found that the antecedent rainfall in the two hours prior to a design storm contained rainfall depths greater than the initial loss value of Australian urban catchments (1mm). This indicates that for typical events with a 20% or 50% AEP, the initial loss values in an event based simulation may be considered to be diminished to zero by the time an storm event of interest for flood management occurs, and thus an initial loss should not be adopted. This also indicates the importance of considering the impact of antecedent conditions on the effectiveness of any retention or detention based systems for flow rate or runoff volume management.

Current literature also supports the need for a different approach to modelling storage based systems, with recommendations for continuous simulation approaches. It is understood that the revision of the Australian Rainfall and Runoff Guideline will include approaches for continuous simulation and it is recommended that SMP Guidelines include requirements on the assessment of storage based approaches for assessing storage based WSUD.

3.7 References

Brattebo, BO & Booth, DB 2003, 'Long-term stormwater quantity and quality performance of permeable pavement systems', *Water Research,* vol. 37, no. 18, pp. 4369-4376.

Coombes, P & Roso, S 2015, 'Urban Drainage Philosophy', in J Ball (ed), *Australian Rainfall and Runoff: A Guide to Flood Estimation - Draft for Industry Comment*, Commonwealth of Australia (Geosciences Australia).

Davis, AP, Traver, RG, Hunt, WF, Lee, R, Brown, RA & Olszewski, JM 2012, 'Hydrologic Performance of Bioretention Storm-Water Control Measures', *Journal of Hydrologic Engineering,* vol. 17, no. 5, pp. 604-614.

Fassman, EA & Blackbourn, S 2010, 'Urban Runoff Mitigation by a Permeable Pavement System over Impermeable Soils', *Journal of Hydrologic Engineering,* vol. 15, no. 6, pp. 475-485.

Hatt, BE, Fletcher, TD & Deletic, A 2009, 'Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale', *Journal of Hydrology,* vol. 365, no. 3-4, pp. 310-321.

Melbourne Water 2010b, *MUSIC guidelines - Recommended input parameters and modelling approaches for MUSIC users*, Melbourne Water, Melbourne, Victoria, Australia.

Myers, B, Cook, S, Maheepala, S, Pezzaniti, D, Beecham, S, Tjandraatmadja, G, Sharma, A, Hewa, G & Neumann, L 2011b, *Interim Water Sensitive Urban Design Targets for Greater Adelaide,*, Goyder Institute for Water Research, Adelaide, SA, Australia.

Myers, B, Pezzaniti, D, Kemp, D, Chavoshi, S, Montazeri, M, Sharma, A, Chacko, P, Hewa, GA, Tjandraatmadja, G & Cook, S 2014b, *Water Sensitive Urban Design Impediments and Potential: Contributions to the Urban Water Blueprint (Phase 1) Task 3: The Potential Role of*

WSUD in Urban Service Provision, Goyder Institute for Water Research, Adelaide, South Australia.

Pathiraja, S, Westra, S & Sharma, A 2012, 'Why continuous simulation? The role of antecedent moisture in design flood estimation', *Water Resources Research,* vol. 48, no. 6, pp. n/a-n/a.

Phillips, BC, Goyen, AG, Thomson, R, Pathiraja, S & Pomeroy, L 2014, *Australian rainfall and runoff Revision Project 6: Loss models for catchment simulation - Urban losses*, Engineers Australia, Barton, ACT, Australia.

Pilgrim, DH (ed.) 1999, *Australian Rainfall and Runoff*, 3 edn, The Institution of Engineers, Australia, Barton, ACT, Australia.

Stovin, V, Vesuviano, G & Kasmin, H 2012, 'The hydrological performance of a green roof test bed under UK climatic conditions', *Journal of Hydrology,* vol. 414–415, 1/11/, pp. 148-161.

Tonkin Consulting 2012, *Discussion paper - Retention storage systems - Stormwater Management Plan - Cities of marion and Holdfast Bay*, Tonkin Consulting, Adelaide, SA, Australia.

Tonkin Consulting 2013c, *Stormwater Management Plan - Coastal Catchments Between Glenelg and Marino*, Tonkin Consulting, City of Marion, City of Holdfast bay, Adelaide, SA.

Vaes, G & Berlamont, J 2001, 'The effect of rainwater storage tanks on design storms', *Urban Water,* vol. 3, no. 4, pp. 303-307.

Villarreal, EL, Semadeni-Davies, A & Bengtsson, L 2004, 'Inner city stormwater control using a combination of best management practices', *Ecological Engineering,* vol. 22, no. 4–5, 7/1/, pp. 279-298.

Voyde, E, Fassman, E & Simcock, R 2010, 'Hydrology of an extensive living roof under sub-tropical climate conditions in Auckland, New Zealand', *Journal of Hydrology,* vol. 394, no. 3–4, 11/26/, pp. 384-395.

Water by Design 2010, *MUSIC modelling guidelines*, South East Queensland Healthy Waterways Partnership (SEQHWP), Brisbane, Queensland, Australia.

Weinmann, E 2007, 'Hydrology and water resources: the challenge of finding the water balance', *Australian Journal of Water Resources,* vol. 11, no. 2, 2007/01/01, pp. 121-132.

Part IV Assessing Water Quality Improvement: MUSIC Modelling Recommendations for South Australia

4 Assessing Water Quality Improvement: MUSIC Modelling Recommendations for South Australia

4.1 Introduction

There are several modelling tools available for conducting water quality assessment of a pre- and post-developed catchment in Australian conditions. These include the United States Environment Protection Agency Stormwater Management Model (ES EPA SWMM), and commercial variants of this model including PCSWMM (from CHI Software) and XP SWMM (from XP Solutions). However, the most common tool for estimating stormwater pollutant loads in Australian conditions in the Model for Urban Stormwater Improvement Conceptualisation (MUSIC). The MUSIC model has been applied widely across Australia and more recently, internationally, for estimating pollutant loads and the performance of structural WSUD treatment measures (Imteaz et al., 2013).

MUSIC is also being applied in South Australian conditions to estimate catchment pollutant loads and the ability of structural WSUD systems to achieve WSUD targets. In 2011, the Goyder Institute for Water Research conducted research to provide recommendations for WSUD targets for South Australian urban development (Myers et al., 2011a). The recommendations included water quality improvement targets. Since this time, there has been a strong desire to develop guidelines for the use of MUSIC in South Australian conditions.

It is a requirement that SMPs which are developed for SMA approval in South Australia include some consideration of water quality. For example, SMP guidelines indicate that in the identification of problems and opportunities for a catchment, analysis should be undertaken 'using accepted hydrological, hydraulic, water quality and yield modelling techniques'. The plan should include identification of 'Stormwater quality issues within streams and receiving waters both within the catchment and downstream from the catchment'. In Section 2 of this report, it was apparent that this was most often achieved using simulation to estimate pollutant loads from the catchment. In some cases, multiple scenarios were conducted including scenarios for the catchment under current, future and future with proposed WSUD conditions. Where pollutant loadings and treatment were estimated, water quality simulation was conducted using the MUSIC software. MUSIC was also commonly applied in many cases where the yield of a harvesting scheme was estimated.

The review of SMPs in Section 2 of this report also found that the underlying assumptions of MUSIC modelling were generally not explicitly provided. This further demonstrates the need for guidance on the use of MUSIC in South Australia to enable uniform application of MUSIC for a scoping and planning tool. In this section of the report, we provide guidance on the use of MUSIC for SMPs and for assessing urban development in South Australia. Background to the MUSIC software and existing guidelines is provided in Section 4.2. The methodology used to undertake a literature review and simulation to support recommendations for MUSIC simulation guidelines for South Australia are presented in Section 4.3. The outcomes of the systematic literature review, research findings and recommendations for MUSIC simulation in South Australia are presented in Section 4.4, and a summary of findings is provided in Section 4.5.

4.2 Background

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) was developed by the Cooperative Research Centre for Catchment Hydrology. It is intended to be used for simulating the quality and quantity of runoff from catchments ranging from a single house block up to many square kilometres. Since its initial release in 2002, the MUSIC software has become a common approach to explore the effectiveness of WSUD measures for improving water quality and predicting runoff quantity and harvesting performance. It has been widely adopted by the profession and local government across Australia.

Guidelines on the use of MUSIC are available in several regions of Australia. For example, guidelines have been presented at the local government level (DesignFlow, 2008; Ecological Engineering, 2010; Gold Coast City Council, 2006) and at the regional level (Melbourne Water, 2010b; Sydney Catchment Authority, 2012). However, there is no guideline on the use of MUSIC available for any part of South Australia.

4.3 Methodology

To develop recommendations on the use of the MUSIC software in South Australia, the MUSIC simulation process was divided into discrete modelling steps. MUSIC simulation guidelines from Gold Coast City Council (2006) provided a framework which breaks MUSIC simulation up into discrete steps. Although these guidelines appear to have been superseded by subsequent regional guidelines from Water by Design (2010), the framework provides a useful template to developing MUSIC modelling recommendations for practitioners in South Australia because it covers each step in the modelling process. The framework was adapted slightly and is presented in Figure 4-1.

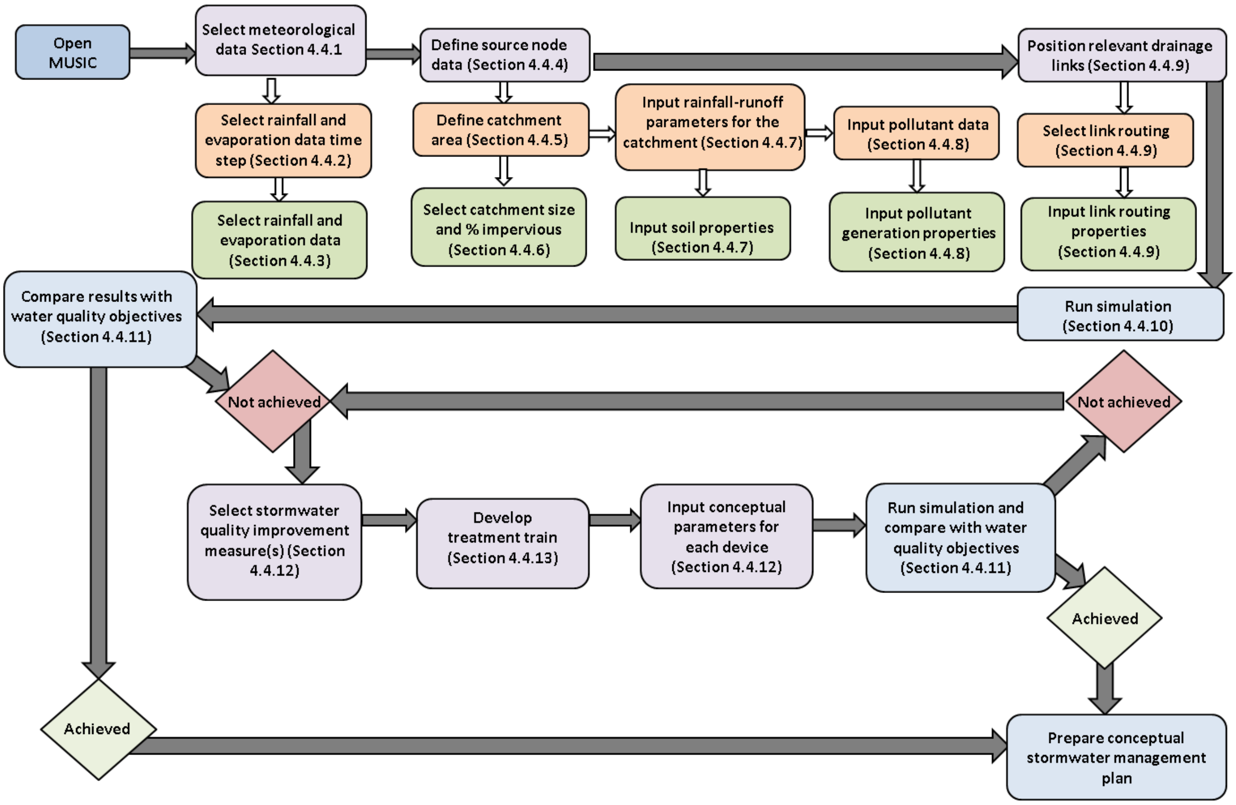

Figure 4-1 - MUSIC model development framework (adapted from Gold Coast City Council, 2006)

A literature review was then conducted which included published research relevant to each step in the modelling framework in Figure 4-1, and recommendations for these steps in guidelines available across Australia. In some cases, there were multiple versions of MUSIC simulation guidelines available across regions, ranging from guidelines developed by local government to state government entities. As such, the review of existing guidelines focused on the most recent MUSIC modelling guidelines from, where possible, state government entities. The review included the following guidelines:

- The MUSIC software manual (eWater, 2014a) which applies to all users
- *MUSIC guidelines - Recommended input parameters and modelling approaches for MUSIC users* (Melbourne Water, 2010b) which applies to catchments in the Melbourne region, Victoria
- *MUSIC Modelling Guidelines* (Water by Design, 2010) which applies to catchments in South East Queensland.
- *Using MUSIC in Sydney's Drinking Water Catchment* (Sydney Catchment Authority, 2012) which applies to catchments in Greater Sydney and surrounding regions in NSW.
- *Water sensitive urban design - Stormwater quality modelling guide* (McAuley & Knights, 2009) which applies to catchments in the Darwin Harbour region, NT.

In many cases, the existing literature was sufficient to provide a recommendation for a part of the MUSIC simulation process in Figure 4-1. Where existing literature was considered deficient in evidence, or where recommendations were considered to be locally specific, further research was undertaken using simulation based studies. These studies have been provided in full in the appendices (including methodology and results). Based on literature and any further research, recommendations for South Australian guidelines are then presented. Unless otherwise specified, this document refers to the most current Australian version of MUSIC in 2015 (MUSIC Version 6).

4.4 Results and Recommendations for MUSIC Simulation in South Australia

4.4.1 Select Meteorological Data

MUSIC converts rainfall and evapotranspiration data into surface runoff and baseflow based on the data provided for source nodes. It requires the selection of a rainfall data time step (effectively the modelling time step) (Section 4.4.2) and selecting appropriate rainfall and evapotranspiration data (Section 4.4.3).

4.4.2 Select Rainfall and Potential Evapotranspiration Data Time Step

Review of Previous Literature

According to eWater (2014a), the selection of a modelling time step for MUSIC is a compromise between accuracy and run time. Recommendations for selecting a time step are as follows (eWater, 2014a):

1. *Calculate or estimate the time of concentration (t_c) of the smallest sub-catchment within the model* (Note: in this case subcatchment refers to the smallest catchment represented by a node in the model)
2. *Calculate or estimate the shortest expected detention time of proposed treatment measures*
3. *Select a time step which is equal to or smaller than the smaller of 1 and 2.*

eWater (2014a) also note that wherever possible, a 6 minute time step (the minimum possible in MUSIC) should be used because it will “output the most accurate results” (there was no explanation provided). There does not appear to be any specific guidelines provided by eWater with respect to an acceptable duration for the model run.

Melbourne Water (2010b) provide the same recommendation as eWater (2014a) in the selection of a time step for MUSIC modelling.

Water by Design (2010) specify that all MUSIC models submitted for a development application must be run at a six minute time step.

The Sydney Catchment Authority (SCA) (2012) requires all models submitted to demonstrate compliance with their ‘Neutral or Beneficial Effect’ (NorBE) targets for water quality to be run at a six minute time step for assessment.

Guidelines presented for the Darwin Harbour WSUD strategy by McAuley and Knights (2009) recommend that modellers use a six minute time step for water quality modelling and a minimum duration of 10 years. For water quantity modelling, it is recommended that a daily time step is adopted for at least 50 years.

Developing a Recommendation for South Australia

There appears to be a consensus from the model developers, eWater, and existing regional guidelines that a six minute time step should be adopted for water quality assessment of a catchment using MUSIC modelling. Six minute rainfall data is available for MUSIC modelling in South Australia. Data is provided for some locations in the current version of MUSIC based on BOM rainfall data records (Parafield Airport 023013, Edinburgh RAAF 023083). Additional rainfall and potential evapotranspiration (PET) data is available at a six minute time step from organisations including the Australian Bureau of Meteorology and the South Australian Department of Environment, Water and Natural Resources (DEWNR).

Appendix F examined the influence of time step and duration on modelling outcomes in MUSIC. This demonstrated that modelling water quality impacts of WSUD treatment systems at a daily time step would overestimate performance. For example, using the assumed catchment model, it was found that the impact of time step selection on simulated reductions in total nitrogen was relatively negligible up until one hour, but increased in a linear fashion beyond one hour for every increase in modelling time step. At the daily time step the results indicate an 18% increase in the nitrogen reduction compared to the same sized wetland simulated in MUSIC using a rainfall record with a six minute time step. It is therefore recommended that the time step used for water quality modelling in MUSIC reflects the time it takes runoff to travel through the catchment (time of concentration). In the absence of justification, a six minute time step should be adopted. A daily time step may be considered suitable for water harvesting studies which do not consider water quality treatment systems or pollutant loads in the analysis.

4.4.3 Select Rainfall and PET Data

Review of Previous Literature

MUSIC requires the user to select rainfall and potential evapotranspiration (PET) data suitable for the catchment being considered. Only one series of rainfall and evapotranspiration data can be used in any single model. The MUSIC manual by eWater (2014a) provides a step-by-step description of how to produce a new climate data file for MUSIC modelling given a predetermined dataset. They indicate that a “user should always try to find the most locally applicable rainfall data for the locality being modelled and import this into MUSIC either as an ASCII file or in one of the preformatted rainfall data file types”.

Melbourne Water (2010b) provide modellers in their region of interest with six climate data templates for use in MUSIC. These templates consist of one year of rainfall data and average monthly PET values. These are provided based on the mean annual rainfall, the distribution of rainfall and the 90th percentile rainfall depth for each region. A map is used to indicate the appropriate rainfall record for a given location.

Water by Design (2010) provide modellers with 21 climate data templates for their region of interest in South East Queensland, including ten years of rainfall data and average monthly PET values for each. The rainfall stations and modelling periods were selected because they characterised the mean annual rainfall of the surrounding region and have minimal amounts of missing or accumulated data.

SCA (2012) provide modellers in their region of interest with nine alternative climate data templates, including five years of rainfall data and average monthly PET data. These have been selected based on climate zones across the Sydney drinking water catchment area. The basis of selection is not indicated.

Guidelines for the Darwin harbour WSUD strategy by McAuley and Knights (2009) recommend five years of rainfall and monthly average PET data from a single station to represent the entire area of interest in the guidelines. At least 50 years of data is recommended for water quantity simulation.

Developing a Recommendation for South Australia

The regional guidelines cited above all provide the user with recommended rainfall data files. Based on this, it is recommended that guidelines for MUSIC modelling in South Australia provide advice on rainfall and evapotranspiration data records specific to South Australian climate regions. The selection of records should as a minimum be based on mean annual rainfall and availability of a ten year data period with minimal missing or accumulated data.

An examination of appropriate rainfall records for South Australian conditions has been provided in Appendix D. This examination was conducted using available rainfall records from the Bureau of Meteorology and DEWNR. It demonstrated the difference in rainfall patterns across South Australia and the potential implications for the design of WSUD treatment systems. The outcomes of the examination proposed hydrologic design zones for South Australia and Greater Adelaide based on differences in mean annual rainfall and existing administrative and natural resource management boundaries. Regions are presented in Figure 4-2 for South Australia and Figure 4-3 for Greater Adelaide. Selected rainfall stations are proposed for each of these regions based on those stations that have at least 10 years of data with minimal gaps, are still operating, and record rainfall at a 6 minute time step. Table 4-5 and Table 4-6 list the pluviograph stations that can be used to represent rainfall in the different hydrologic design zones. Appendix G provides mean monthly areal potential evapotranspiration for each of the selected rainfall stations. It is recommended that if local data is available for a project from a good data source that is representative of the area, it should be applied.

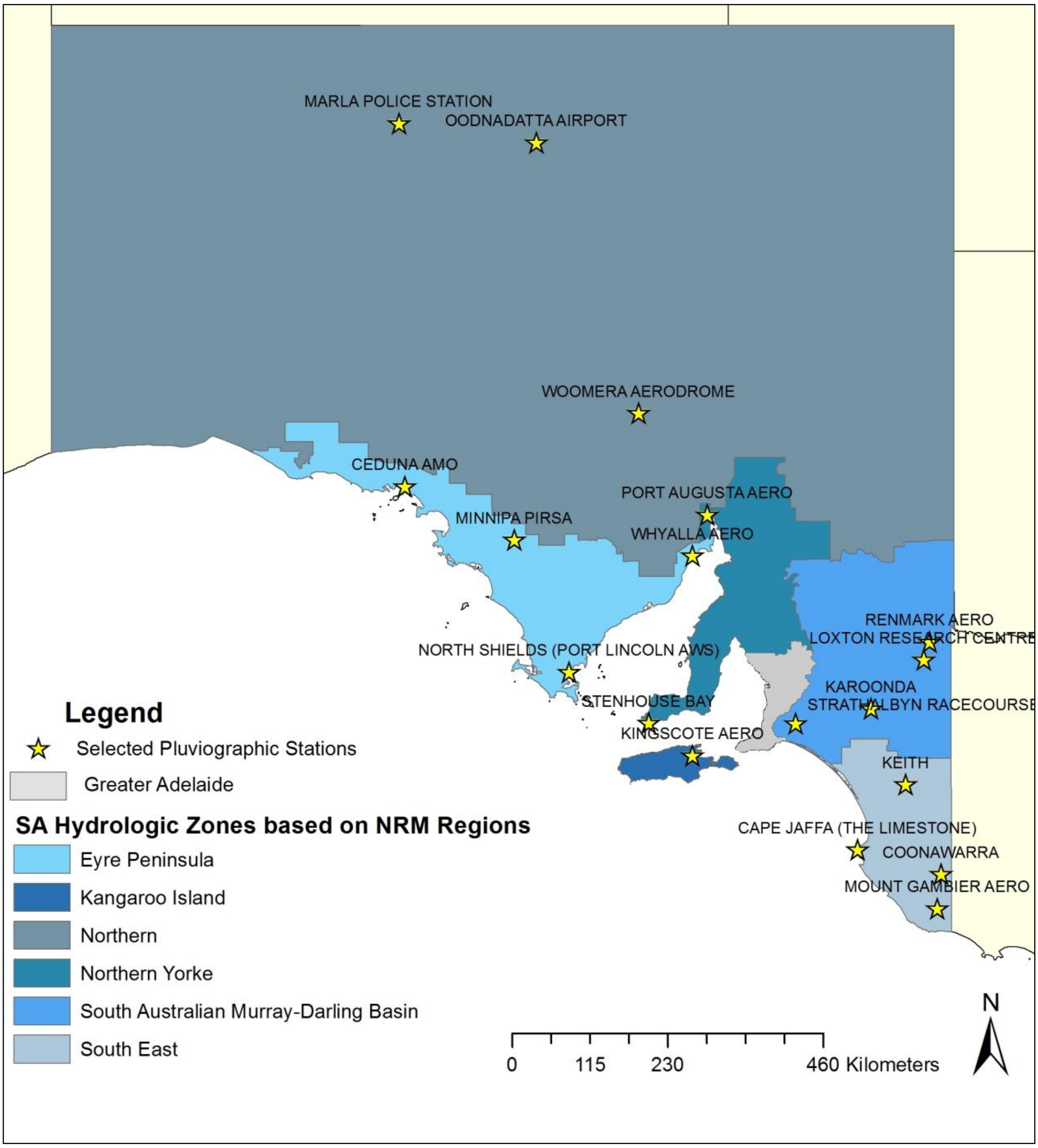

Figure 4-2 - Proposed hydrologic design zones for South Australia

n

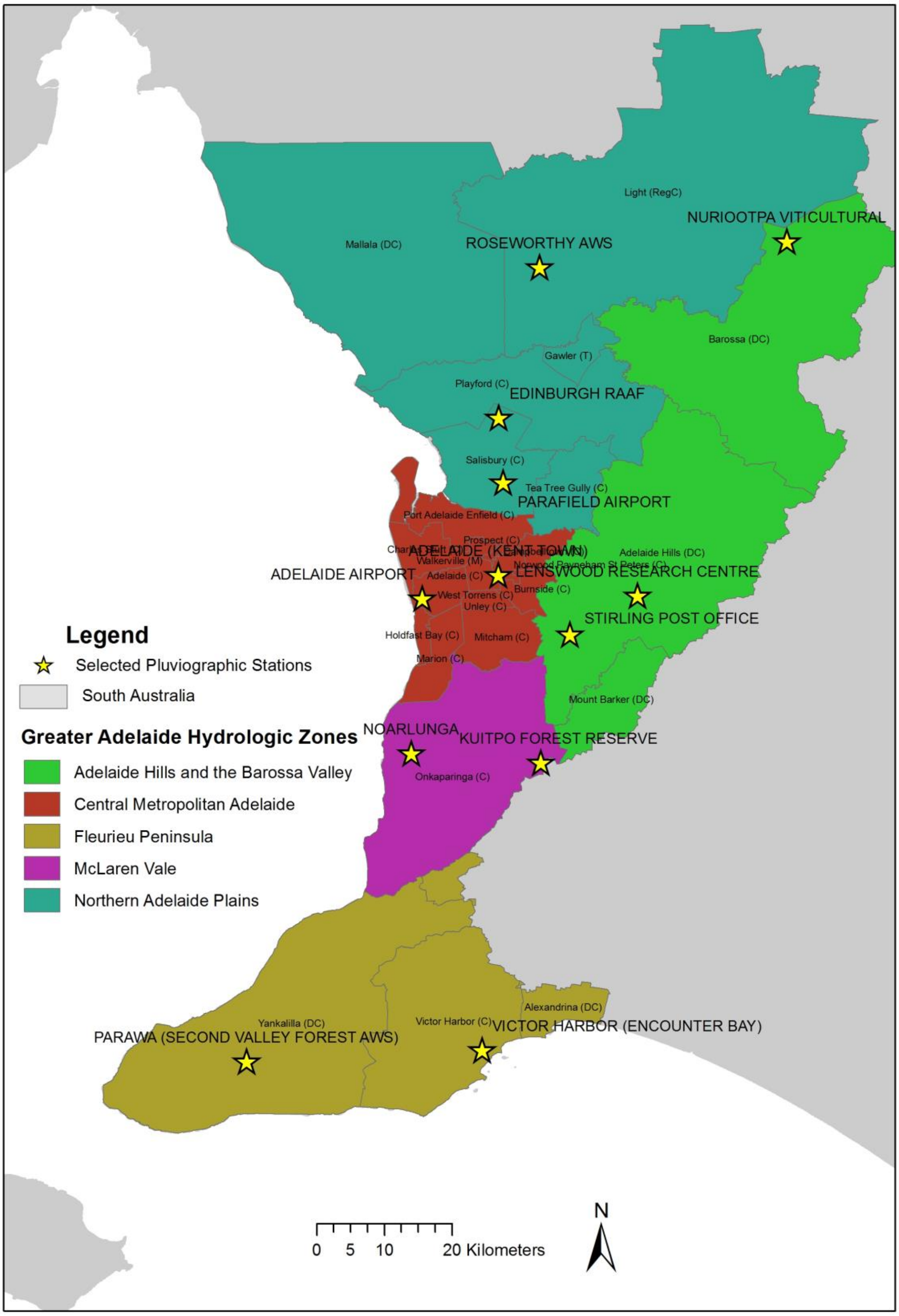

Figure 4-3 - Hydrologic design zones for Greater Adelaide

Table 4-5: Pluviograph stations for Greater Adelaide hydrologic design zones and data availability

Region	Station	Station #	Rainfall record available
Adelaide Hills and the Barossa	Lenswood Research Station	23801	05/10/1972 – 31/01/2010
	Mount Crawford Forest HQ	23763	13/10/1970 – 31/07/2010
	Nuriootpa Viticultural	23373	11/10/1999 – 31/07/2010
Central Metropolitan Adelaide	Adelaide Airport	23034	13/01/1967 – 31/07/2010
	Kent Town	23090	12/02/1977 – 31/03/2010
Fleurieu Peninsula	Parawa (Second Valley Forest AWS)	23875	09/11/1999 – 30/06/2010
	Victor Harbour (Encounter Bay)	23804	01/04/2001 – 31/07/2010
McLaren Vale	Noarlunga	23885	09/10/2001 – 31/01/2010
	Kuitpo Forest Reserve	23887	20/12/2001 – 30/11/2009
Northern Adelaide Plains	Parafield Airport	23013	18/08/1972– 31/05/2010
	Edinburgh RAAF	23083	01/01/1980 – 31/03/2010
	Roseworthy AWS	23122	01/05/1999 – 30/06/2010

Table 4-6: Pluviograph stations for Greater South Australia hydrologic design zones and data availability

Region	Station	Station #	Rainfall record available
Northern	Marla Police Station	16085	27/08/1985 – 31/07/2010
	Oodnadatta Airport	17043	01/01/1961 – 31/03/2010
	Woomera Aerodrome	16001	08/09/1955– 31/07/2010
Eyre Peninsula	Ceduna AMO	18012	26/01/1954 – 31/08/2010
	Minnipa PIRSA	18120	23/10/2000 – 30/04/2010
	North Shields (Port Lincoln AWS)	18195	01/07/1997 – 31/07/2010
	Whyalla Aero	18192	25/10/2000 – 30/06/2010
Northern Yorke	Port Augusta Aero	19066	09/07/2001 – 30/04/2010
	Stenhouse Bay	22049	30/11/1999 – 31/03/2010
Kangaroo Island	Kingscote Aero	22841	12/02/2002 – 28/02/2010
South Australian Murray Darling Basin	Renmark Aero	24048	29/05/2001 – 30/04/2010
	Loxton Research Centre	24024	20/015/1976 – 30/04/2010
	Karoonda	25006	26/02/1969 – 31/07/2010
	Strathalbyn Racecourse	24580	02/04/2002 – 30/04/2010
South East	Keith	25507	19/08/1989– 29/02/2004

Region	Station	Station #	Rainfall record available
	Mount Gambier Aero	26021	19/01/1942– 31/07/2010
	Coonawarra	26091	25/09/1985 – 30/04/2010
	Cape Jaffa (The Limestone)	26095	10/07/2000 – 31/01/2010

4.4.4 Define Source Node Data

Source nodes specify the means by which rainfall and evapotranspiration data in the previous modelling step is converted into runoff. This step requires the user to specify the catchment characteristics (Section 4.4.6) the size and imperviousness (Section 4.4.7), the rainfall/runoff properties (Section 4.4.8) and the pollutant generation assumptions (Section 4.4.9). Overall, the selection and manipulation of source node data will influence the quantity of runoff generated by a model and the pollutant load it carries.

4.4.5 Define Reuse Demand for Harvested Stormwater

Review of Previous Literature

In MUSIC stormwater treatment nodes that store a permanent water volume there is the opportunity to model opportunities for reuse of detained or retained runoff. This reuse could be for irrigation or other non-potable uses. Potential demand for harvested stormwater is usually assessed on a ‘fit-for-purpose’ basis, where the quality of the harvested stormwater is matched to the quality required by the end-use. The South Australian *Stormwater Strategy* sets out the framework for the future management of stormwater as a resource in South Australia, including how it can be used (Department of Water, 2011).

In modelling reuse in MUSIC the size of the storage and the yield is sensitive to demand, and it is therefore recommended to use a 6 minute time step where possible (Water by Design, 2010). Water by Design (2010) also notes that if the storage is less than four to five times the average daily demand then yield may be overestimated.

The main parameters in MUSIC in modelling reuse opportunities in a stormwater treatment node include defining the maximum drawdown from the storage and the demand properties. The drawdown setting determines the depth of the storage from the stormwater treatment device that is available for reuse.

Demand can be modelled in MUSIC based on the following options:

- Annual demand that is adjusted for the daily potential evapotranspiration in the climate file used to create the model;
- Annual demand that is adjusted for daily potential evapotranspiration minus the daily rainfall, so that reuse only occurs when PET exceeds rainfall;
- Annual demand that a user can define the monthly distribution through a graphical editor that specifies the percentage of annual rainfall that falls in each month;
- Daily demand; or,
- A user defined demand time series, which enables more detailed representation of demand by including aspects like trends in demand.

End use studies can be used to characterise demand for captured runoff in MUSIC modelling. In Australia, there have been a number of comprehensive end use studies that have been widely used to characterise residential water demand. This has included studies in Melbourne (Roberts, 2005) and South East Queensland (Beal & Stewart, 2014; Willis et al., 2013). There has been a recent study undertaken by the *Goyder Institute for Water Research* to better understand household water demand in the South Australian context (Arbon et al., 2014). Arbon et al., (2014) used a mixture of surveys of selected households, end-use flow monitoring, analysis of water use drivers and predictive modelling to better define water end use characteristics in Adelaide. This study provides a breakdown of per capita daily indoor water use by major end use, as well as the split between indoor and outdoor demand, and characterised peak demand both daily and seasonal.

Based on results presented by Arbon et al., (2014), Figure 4-4 illustrates the monthly distribution of residential irrigation demand in Greater Adelaide. While, Figure 4-5 provides a breakdown per capita indoor water demand. Toilet demand is likely to be the most common indoor demand for harvested stormwater.

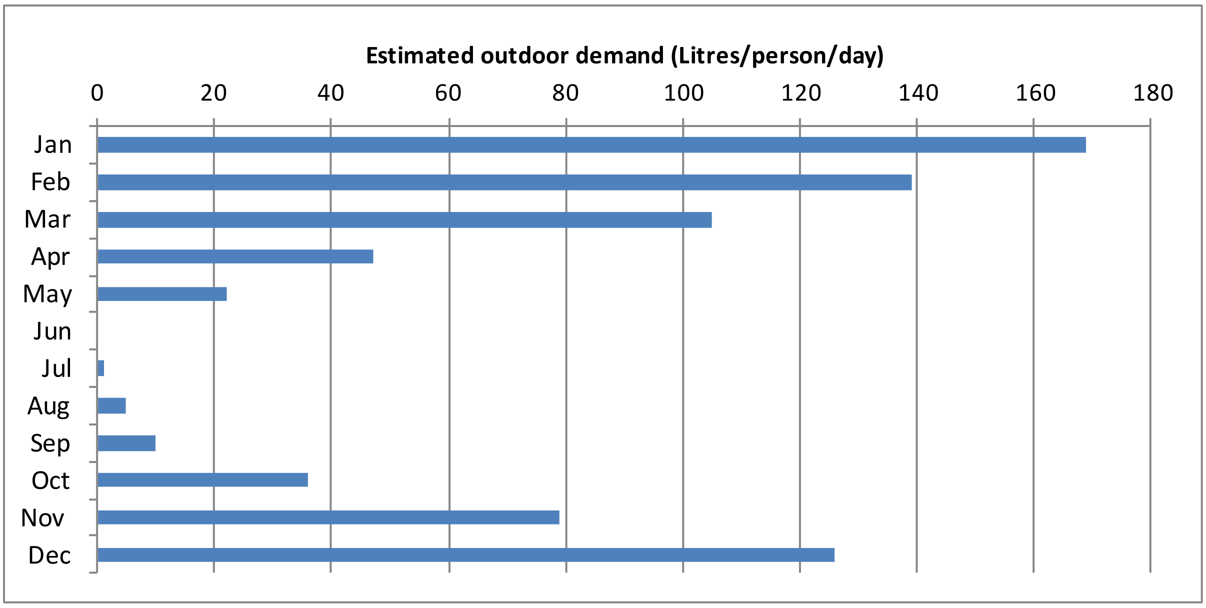

Figure 4-4 – Seasonality of residential outdoor demand in Greater Adelaide

Source: Adapted from Arbon et al., (2014)

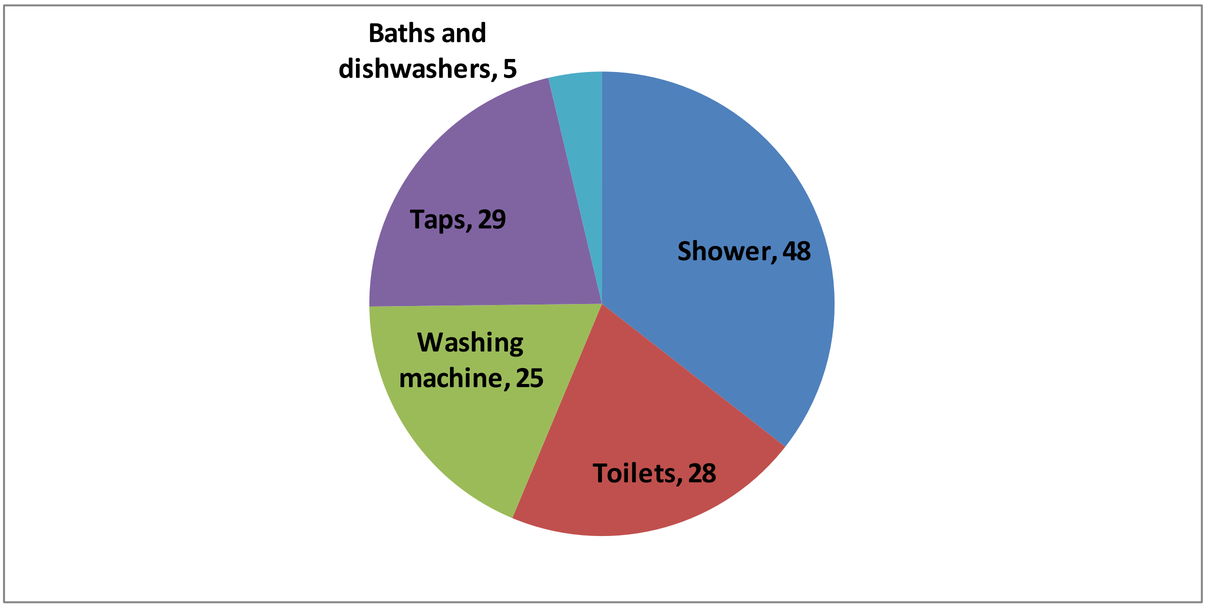

Figure 4-5 – Indoor water demand breakdown for Greater Adelaide (Litres/person/day)

Source: Adapted from Arbon et al., (2014)

Developing a Recommendation for South Australia

In Adelaide outdoor water demand is strongly seasonal, with peak demand occurring during the hot dry summer months. Therefore, it is recommended that when modelling the reuse of harvested stormwater in MUSIC for outdoor demand that seasonality is accounted for. Arbon et al., (2014) found that seasonal water use was higher for households with larger garden areas, which indicates that irrigation demand should be adjusted for area irrigated . However, it was noted that the results were based on a monitoring study over a single summer so there is the need for more extended monitoring studies to better understand and characterise the drivers of seasonal water demand in Greater Adelaide.

If the water harvested from a WSUD device is to be used indoors for toilet flushing then demand can be modelled based on a constant daily value as studies have shown this demand is independent of climate. The values presented here for daily per capita indoor water demand are averages from the households monitored. However, it was observed there was significant variation among households in indoor demand. Therefore, where possible the estimated demand for reuse should be adjusted for the expected household demographics.

Non-residential demand (commercial and industrial) is likely to be site specific. Therefore, there it is difficult to provide standard reuse demands in guidelines. Water by Design (2006) recommends that any estimated demand for industrial and commercial reuse of stormwater is justified to the assessment authority.

4.4.6 Define Catchment Area

Review of Previous Literature

There are two considerations in the definition of a catchment area in MUSIC simulations. These are the manner in which a catchment area is broken up into representative land use or surface types, and the selection of nodes to represent them.

eWater (2014a) provide little guidance on the breakup of a catchment for MUSIC modelling, except that the model has been designed to simulate stormwater from catchment areas ranging from the allotment to larger catchments. It is also noted that MUSIC allows the user to define one of five catchment types:

1. Urban catchment
2. Agricultural catchment
3. Forest catchment
4. User defined catchment
5. Imported data catchment

The first four of these nodes are the same in every way, except that the default surface runoff and baseflow pollutant generation data is different. The urban, agricultural and forest catchment nodes have default parameters based on a review of international literature with respect to land use. The user defined node has no default pollutant generation data. As such, any of these four nodes can be used to represent any catchment if the user manually adjusts the default surface runoff and baseflow pollutant parameters accordingly. The imported data catchment is used to provide a catchment area with known, imported data for flow, TSS, TP, TN and gross pollutants.

Melbourne Water (2010b) provide no guidance on how a model should be constructed based on land use or surface type, or on appropriate node selection.

Water by Design (2010) specify two approaches to constructing a MUSIC model based on the purpose of the model. The two approaches are referred to as 'split' modelling and 'lumped' modelling. 'Split' modelling is to be used for development applications and smaller catchment areas, and it means that catchment areas must be divided into different surface types. Sites therefore must be broken up into subcatchment areas representing:

- roof source nodes,
- road source nodes (including parking area and verges), and,
- ground level source nodes, representing the mixed pervious and impervious area not included in the previous two nodes.

An example of how a typical allotment may be broken up into the three surface area categories is reproduced in Figure 4-6.

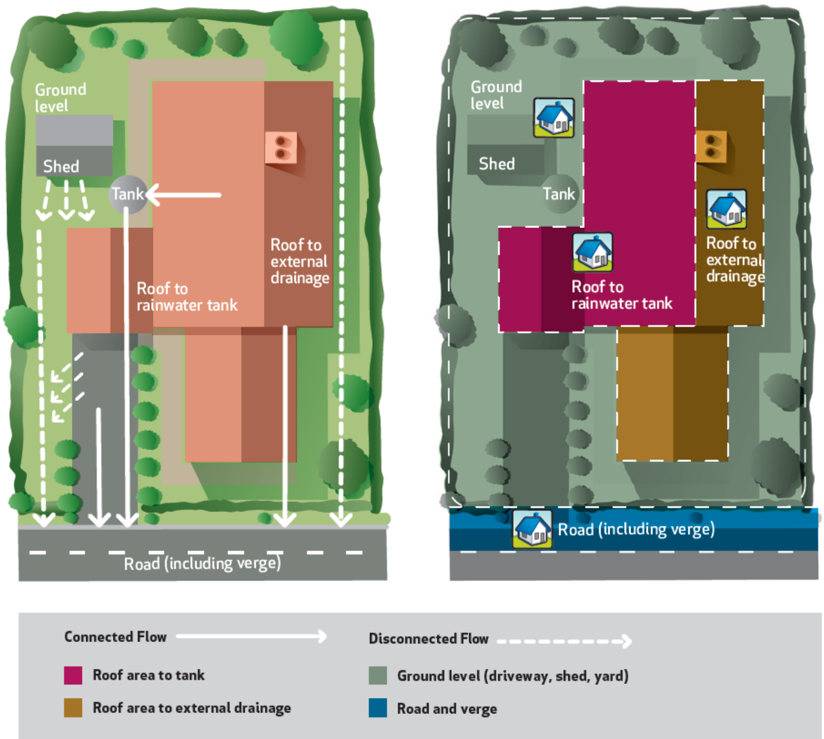

Figure 4-6 - The split node representation of a typical allotment (Source: WaterbyDesign, 2010)

When MUSIC is being used in the production of a concept plan, master plan or catchment management plan with homogenous land uses, modellers may opt to use a 'lumped' modelling approach. 'Lumped' nodes are large areas of uniform land use which are lumped into a single node with lumped properties. The land use categories specified by Water by Design (2010) are:

- Residential
- Rural residential
- Industrial
- Commercial
- Forest
- Agriculture

The first four of these land uses are to be represented by the urban source node. The forest node is used for undisturbed bushland areas (which must be approved as such before being included in a simulation) and the agricultural node is used for cropping and grazing land. Photographs must be provided to verify that agricultural land is not being developed. Locally derived pollutant generation parameters are specified for each type of land use in this planning level modelling (see Section 4.4.9).

McAuley and Knights (2009) adopt a similar approach to Water by Design (2010), except that their focus is on development level modelling, with little consideration of large scale planning studies. As such, the land use categories provided are typical of 'split' modelling. and include roads, roofs and general urban (representing other paved areas). Since most WSUD features only treat surface runoff, McAuley and Knights (2009) also indicated that pervious area runoff is simulated and fed in to the model as two imported data nodes representing pervious surface area surface runoff and baseflow separately. This is recommended to ensure that that baseflow can proceed past a treatment system to a junction or receiving node, with surface runoff only being treated. Otherwise, it is recommended that all pervious area runoff bypass a system. This was considered conservative. Details are not provided, but it is likely because baseflow pollutant concentrations are by default lower and when they enter a treatment system it may lead to dilution occurring during treatment and therefore an over-prediction of treatment train performance. McAuley and Knights (2009) were the only guideline reviewed which made this recommendation.

In terms of node selection, McAuley and Knights (2009) recommend that:

- the urban node is used for "low to high density residential, retail, and commercial areas. These areas comprise private allotments together with all associated facilities, such as roads, parks, school grounds".
- The agricultural node is used for "areas of large scale cropping or grazing"
- The forested node is used for "natural bushland areas" where canopy densities are greater than 50%.
- Imported data source node is used for modelling pervious areas in order to separate surface and base flows.

SCA (2012) also adopt the same approach as Water by Design (2010) providing examples of how a model should be assembled ranging from:

- Single lot sites (such as rural, residential or commercial lots) where split modelling is required - nodes are selected based on surface type;
- Multiple lot sites (such as a 10 lot rural subdivision) where split modelling is required but surface types may be lumped, and
- Large scale subdivisions, where 'lumped' modelling is used and nodes may be selected based on land use zones.

Examples of these three categories are provided to guide the modeller. It is a requirement that only the urban, agricultural and forest nodes be used in MUSIC models for assessment of the specified NORBE targets. SCA (2012) provide a list of appropriate nodes and pollutant generation parameters for a variety of surface types and land use zoning. These are broadly reproduced in Table 4-7, with some modification to suit South Australian catchments.

Developing a Recommendation for South Australia

Based on a review of existing guidelines, most recent guidelines provide specific guidance on model structure to ensure that catchment models are assembled by practitioners in a consistent manner, and to avoid modelling which may over- or under-estimate runoff volume and the performance of WSUD features. Key modelling recommendations include the following:

- For smaller scale models (such as those for development applications), the separation of a catchment area should be separated into roof area(s), road area(s) (including car parks and verges) and other surface components (McAuley & Knights, 2009; Water by Design, 2010).
- For larger scale simulations such as those for SMPs, a catchment should be disaggregated according to land use. Appropriate zones include those that are provided by SCA (2012), and reproduced in Table 4-7.

The importance of separating a catchment based on land use or surface type is self-evident. For example, at the smaller scale, it is known that pollutant loads from roof areas, road pavements and other surfaces vary (Wong, 2006) and it is therefore important that a model is set up to consider this. Similarly, at the scale of a SMP, pollutant loads differ from residential, commercial, industrial and rural land uses. It is recommended that the surface types and land uses adopt water quality parameters for the major categories as outlined in Table 4-19.

Table 4-7 –Surface types and land uses and major categories for MUSIC simulation in South Australia - adapted from SCA (2012)

Surface type / Land use	**Adopt parameters for…**
Surface Types	
Roof	Roof
Unsealed/partly sealed roads	Unsealed roads
Sealed roads	Sealed roads
Private landscaping, gardens	Residential
Revegetated land	Rural
Land use / Zoning	
All urban residential zones	Residential
All commercial zones	Commercial
All industrial zones	Industrial
Schools	Residential
Urban parks	Residential
National park	Forest
Protected land	Forest
Rural residential	Rural residential
Rural grazing	Agriculture
Nurseries, horticulture	Agriculture
Quarries, mines (active and under rehabilitation	Unsealed roads

4.4.7 Select Catchment Size and Percentage Imperviousness

Once a catchment has been broken up into surface types or land use in accordance with Section 4.4.6, the size of each catchment node can be determined. The area represented by each node may be derived from aerial photos (for existing catchments) or plans (for existing or proposed sites).

The next step is to determine the impervious and pervious area fraction of each catchment. There are three potential definitions for the impervious area of a catchment when conducting a MUSIC model simulation. These are:

- the total impervious area (TIA), representing the sum of all impervious area in a catchment;
- the directly connected impervious area (DCIA), representing impervious area that is directly connected to a drainage path, and therefore contributes most rapidly to runoff with very little losses, and
- the effective impervious area (EIA). EIA is a value for impervious area in MUSIC simulation, and it is a single term representing the imperviousness for a catchment node. In reality, it will lie between the EIA and DCIA values.

Review of Literature

The selection of catchment area and percentage imperviousness in MUSIC is critical to the performance of the model and must be undertaken independently by the user. For area, eWater (2014a) indicate that source nodes should be between 0.01 Ha and 10 000 Ha in size, which gives good guidance on the applicability of the model to an urban catchment. While there is no guidance on the catchment imperviousness, it is noted that “the [MUSIC] model is significantly more sensitive to the accurate definition of the fraction imperviousness and the selection of simulation time step." Furthermore, "the volume of runoff generated and the stormwater runoff time series from an urban catchment are not very sensitive to variation in the parameters defining the pervious area response to rainfall, except where directly connected imperviousness percentages are low". eWater (2014a) also note that "The impervious percentage for an urban catchment will typically be closer to the directly connected impervious area than the total impervious area". In other words, the value of EIA adopted in MUSIC is generally expected to be closer to the DCIA than the TIA.

This statement is further supported by the findings of Dotto et al. (2010), who studied the calibration of the MUSIC model to urban catchments in Melbourne. Of the 13 parameters in the MUSIC model which can be adjusted during rainfall runoff modelling, Dotto et al. (2010) found that only two were of key importance in a highly urbanised catchment - EIA and the runoff routing parameter, *k*.

Melbourne Water (2010b) do not provide guidance on measuring a catchment area, but do provide recommended values for imperviousness in MUSIC simulations. They provide values for TIA based on land use zoning for MUSIC simulation. The guidelines specify that consideration be given to the catchment modelled, and that significant variation from the imperviousness figures provided must be justified using model calibration data.

Water by Design (2010) specify that the catchment area should be selected to consider several factors, including:

- the boundary of the proposed development site, proposed road or allotment road;
- topography, including levels following any planned earthworks;
- the influence of an existing or proposed drainage system;
- the location of stormwater treatment measures, and
- the location and drainage from any external sites beyond the catchment boundary.

Water by Design (2010) provide advice regarding imperviousness of subcatchment nodes based on the adoption of 'split' modelling and 'lumped' modelling (as defined in Section 4.4.6). For split modelling, which is recommended for development approval sites, the imperviousness of a catchment in MUSIC should be measured and the TIA value adopted. This would appear to be a conservative measure which will tend to over-estimate flow, based on the statement from eWater (2014a) indicating that the effective impervious area is "closer to the directly connected impervious area than the total impervious area". However, this may also reflect that impervious area in new development areas tends to be DCIA. For small sites where development approval is not being sought, and for broad scale master planning, impervious area values are provided based on surface type and land use. The assumed imperviousness of surface types for 'split' modelling are shown in Table 4-4. The imperviousness of land use types for lumped modelling are shown in Table 4-5.

Table 4-4 – Imperviousness of surface types for 'split' modelling from Water by Design (2010)

Development Type	Imperviousness of surface type (%)		
	Road reserve	**Roof**	**Ground**
Residential – 10 dwellings per hectare	60	100	15
Residential – 15 dwellings per hectare	60	100	20
Residential – 40 dwellings per hectare	70	100	30
Residential – 80 dwellings per hectare	80	100	50
Industrial	75	100	60
Commercial	75	100	80

Table 4-5 - Imperviousness of land use types for 'lumped' modelling from Water by Design (2010)

Development Type	Impervious fraction	
	Range	**Preferred minimum**
Residential		
Residential – 10 dwellings per hectare	40 to 55	45
Residential – 15 dwellings per hectare	50 to 60	55
Residential – 40 dwellings per hectare	60 to 70	65
Residential – 80 dwellings per hectare	70 to 95	85
Industrial		
Typical (warehouse, manufacturing)	70 to 95	90
Garden and landscape suppliers	30 to 60	50
Commercial		
Business or town centre	70 to 95	90
Offices	70 to 95	90
Bulky goods	70 to 95	90
Public zone		
Public open space	5 to 50	20
Car parks	70 to 95	90
Library, sports area, depots	50 to 90	70
Schools and universities	50 to 80	70
Infrastructure		
Highway and roads	60 to 90	70
Rail	50 to 80	65
Other		
Rural residential (lots > 0.4 Ha)	5 to 20	10
Rural residential (lots < 0.4 Ha)	10 to 25	20
Rural	0 to 5	2
Forest or conservation	0 to 5	0

SCA (2012) provide similar advice to Water by Design (2010) in the delineation of subcatchments and determining subcatchment areas. A diagram is provided as an example of how all the factors cited above could be considered in the development of sub-catchment areas for a model. This is reproduced in Figure 4-7.

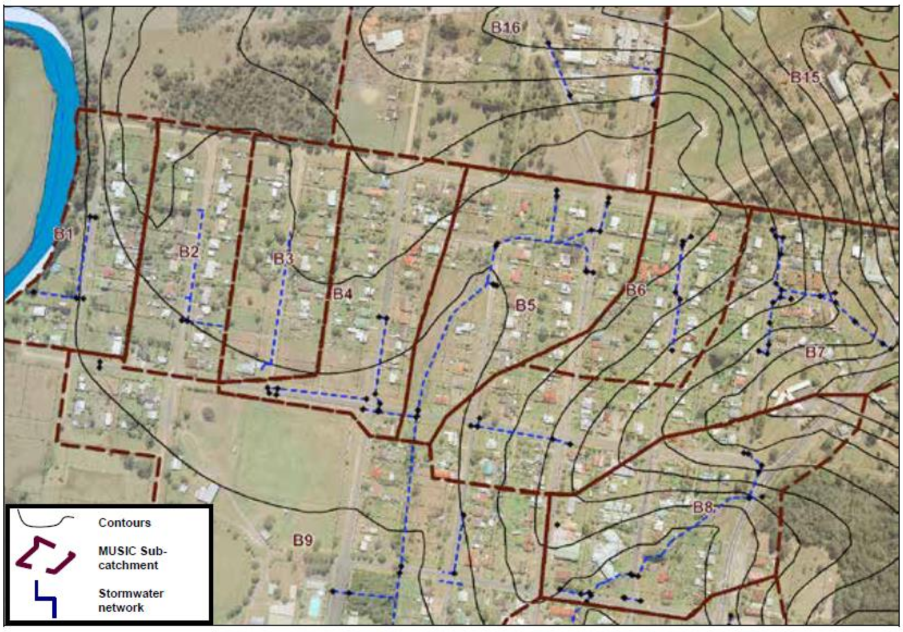

Figure 4-7 - Delineation of a catchment area based on topography and drainage [Source: SCA (2012)]

SCA (2012) recommend adopting an EIA value for a catchment impervious area. The guidelines provide a table which indicates the proportion of TIA which should be translated to EIA based on the surface type. The values are based on specific surface coverage types when dealing with smaller catchments. For example, a roof is assumed to be 100% effective impervious area, paved landscaping is 50% effective impervious area, and unpaved landscape is 5% effective impervious area. For planning studies on larger development, EIA values are provided based on broad land use – for example, residential areas are 55% EIA and industrial areas are 90% EIA.

Guidelines for presented for the Darwin Harbour WSUD strategy by McAuley and Knights (2009) indicate that the impervious area of a development scenario can be estimated on the basis of building density controls and confirmed using aerial photos of recent development.

The determination of EIA was explored for South Australian catchments in some detail by the Goyder Institute for Water Research. (Myers et al., 2014b) calibrated the MUSIC model to two South Australian urban catchments, including the Frederick Street catchment in Glengowrie and the Paddocks catchment in Para Hills. The study found that the use of DCIA was sufficient to achieve a good estimate of flow volume and peak flow. For the Frederick Street catchment, the DCIA value was 31% and the TIA value was measured to be 47% (so DCIA represented 64% of TIA). When DCIA was adopted as EIA in the MUSIC model for Frederick Street, it provided a good estimate of peak flow and underestimated the total annual runoff of the catchment by 5.8%. This was improved by increasing EIA to 33% to produce a 1% over estimate of annual flow, however increasing the EIA for the catchment also had a detrimental effect on peak flow rate estimation. There were similar findings for the Paddocks catchment simulation. In this case, the DCIA of the catchment was 24% and the TIA was 38%, so DCIA represented 60% of TIA. DCIA was found to be a good estimate of EIA to produce a good compromise of flow rate and volume.

Developing a Recommendation for South Australia

Where provided, regional guidelines have adopted similar recommendations in the determination of a catchment area for study. Based on this, it is recommended that South Australian guidelines adopt a catchment area determination and delineation approach similar to that described by Water by Design (2010) and SCA (2012). The catchment delineation for South Australian catchments should consider:

- the boundary of the proposed development site, proposed road or allotment road (where relevant for a development site study);
- topography, including levels following any planned earthworks;
- the influence of an existing or proposed drainage system;
- the location of stormwater treatment measures, and
- the location and drainage from any external sites beyond the catchment boundary.

This will ensure a consistent catchment area is proposed for any broad area study or development approval process.

The approach to adopting a value for impervious area is mixed in literature. A recommendation that users determine their own appropriate EIA parameter without standard guidance may lead to inconsistency in modelling approaches for what is a highly sensitive modelling parameter. This is because the EIA value must be calibrated to produce a truly representative value, which is not possible with proposed development sites and seldom possible with existing urban catchments that may be the focus of stormwater management plans.

To ensure the approach to EIA is consistent, the following two approaches may be adopted:

1. The use of TIA as EIA as adopted by Water by Design (2010) and Melbourne Water (2010b)
2. EIA values produced as a fraction of TIA with respect to surface type, as adopted by SCA (2012)

The assumption of TIA as equal to EIA is straightforward for the modeller. The calculation of TIA for a catchment may be based on aerial photography (for an existing catchment) or on plan area from a development plan (for a proposed catchment). Appropriate local data may also be used to support generic TIA values based on land use. However, blanket adoption of TIA is expected to produce an overestimation of the EIA in MUSIC, and therefore an over-estimate of flow rate and volume, especially in catchments where the impervious area drains over pervious surfaces before reaching the catchment outlet. This will in turn overestimate total annual runoff volume and corresponding pollutant loads. Appendix H tested the impact of varying the EIA for a calibrated model of the Frederick Street catchment. This showed that there was an almost linear relationship between changes in the EIA and runoff volume, which demonstrated the sensitivity of the modelled WSUD performance to changes in the EIA.

The recommendation of EIA values is also straightforward providing that factors are provided in guidelines based on landuse. The benefit of this approach is that they are applied to TIA and provide a consistent conversion of TIA to EIA. Existing research has indicated that at the local scale, EIA is much closer to DCIA than to TIA. However, applying factors to produce an EIA value may still over- or under-estimate the resulting runoff and pollutant load from a catchment, depending on the 'true' EIA of the catchment. There is also limited information at the local scale regarding the adoption of such factors. Based on two residential catchments in South Australia, EIA was 60 and 64% of TIA. Reduction factors for other land uses, such as industrial, commercial and higher density residential development sites are not available at the local scale.

Since calibration to two local catchments found that DCIA was a much better estimate of EIA (Myers et al., 2014b), it is recommended that EIA values are determined based on reduction factors applied to TIA values. In the absence of further information for South Australian catchments, it is recommended that the reduction factors in Table 4-6 are applied to TIA values. These values have been adopted based on the recommendations of SCA (2012), with alterations only to the residential land use. Surface types may be accepted as is, as they are not expected to be locally specific. However, land use values may need refinement as local data becomes available on DCIA of these areas. It is also recommended that stormwater management plans have the flexibility to adjust these recommended factors should a documented analysis of local DCIA and TIA values be provided. For example, a portion of a large, relatively uniform catchment/sub-catchment can be analysed to estimate the EIA using the surface type values. A weighted average EIA value can then be determined which may be reasonably indicative of the broader catchment area. It is also recommended that future research is conducted to assess South Australian catchments to develop indicative TIA values based on land use, and where possible to verify the applicability of the reduction factors to convert TIA to EIA in MUSIC using calibration of the model to observed flows.

Table 4-6 – Recommended EIA conversion factors based on TIA for MUSIC modelling in South Australia

Surface Type / Land use	Effective Impervious Area Factor
Surface Types (for split modelling) For smaller catchments and development sites	
Roof area	1.00 × TIA
Sealed road	1.00 × TIA
Pervious pavement	1.00 × TIA
Unsealed road	0.50 × TIA
Paved landscape (not directly connected to drainage)	0.50 × TIA
Vegetated landscape	0.05 × TIA
Revegetated land	0.00 × TIA
Land use (for lumped modelling) For large catchments and stormwater management plans	
Residential	0.65 × TIA
Commercial	0.80 × TIA
Industrial	0.90 × TIA
Rural residential	0.05 × TIA
Agriculture, grazing (open air only)	0.00 × TIA
Native vegetation, bushland	0.00 × TIA

4.4.8 Select Rainfall-Runoff Parameters for the Catchment and Soil Properties

The MUSIC model has several properties relating to rainfall / runoff processes at the catchment surface. These include one property for impervious surfaces, and five for pervious surfaces (including infiltration and soil storage properties). The relevant properties are:

- Impervious area properties
    - Rainfall threshold (mm)
- Pervious Area Properties
    - Soil storage capacity (mm)
    - Initial Storage (% of capacity)
    - Field capacity (mm)
    - Infiltration capacity coefficient – a (no units)
    - Infiltration capacity exponent – b (no units)

Review of Literature

eWater (2014a) provide estimated values to represent rainfall threshold and soil properties for Australian state capital cities. These are reproduced in Table 4-7. Based on these and the MUSIC default parameters, the list of recommended impervious, soil and groundwater parameters for Adelaide are shown in Table 4-8. Calibration of these parameters is recommended where possible, using the estimated values in Table 4-8 as a starting point. There were no recommendations for other urban areas in Australia.

Table 4-7 – Soil Parameters for Australian capital cities recommended by eWater (2014a)

Location	Soil store capacity (mm)	Field capacity (mm)
Darwin	300	250
Brisbane	120	80
Sydney	200	170
Canberra	40	25
Melbourne	30	20
Hobart	30	20
Adelaide	40	30
Perth	250	230

Table 4-8 – Initial rainfall runoff parameter values recommended for Adelaide by eWater (2010)

Rainfall threshold (mm)	1
Soil storage capacity (mm)	40 *
Initial Storage (% of capacity)	30
Field capacity (mm)	30 *
Infiltration capacity coefficient – a	200
Infiltration capacity exponent – b	1

* Values suggested for Adelaide conditions

Melbourne Water (2010b) provide no recommendations for a rainfall threshold. It is recommended that modellers adopt default soil storage and groundwater data, except that values for the soil storage capacity and field capacity should be replaced with data provided by eWater (2014a) for Melbourne (see Table 4-7). Any deviation from these figures must be annotated in the modelling report when submitted for approval.

Water by Design (2010) provide users with rainfall threshold, soil storage and groundwater properties for four land uses: urban residential, commercial and industrial, rural residential and forested. The recommendations are reproduced in Table 4-9. Users may deviate from the specified values but only when agreed to by an approving authority, or with calibration to local stream records.

Table 4-9 – Pervious area properties recommended for MUSIVC simulation in South East Queensland by Water by Design (2010)

Parameter	Land use			
	Urban residential	Commercial and industrial	Rural residential	Forested
Surface water properties				
Rainfall threshold (mm)	1	1	1	1
Soil storage capacity (mm)	500	18	98	20
Initial storage (%)	10	10	10	10
Field capacity (mm)	200	80	80	80
Infiltration capacity coefficient, *a*	211	243	84	200
Infiltration capacity exponent, *b*	5.0	0.6	3.3	1.0
Groundwater properties				
Initial depth (mm)	50	50	50	50
Daily recharge rate (%)	28	0	100	25
Daily baseflow rate (%)	27	31	22	3
Daily deep seepage rate (%)	0	0	0	0

McAuley and Knights (2009) recommend the use of data provided by eWater (2014a) for in Darwin. These are shown in Table 4-7.

Guidelines from the SCA (2012) provide detailed advice on the adoption of a rain fall threshold, soils and groundwater parameters. Their recommendations are based on work conducted by (MacLeod, 2008) and all values are reproduced in Appendix H. Firstly, the guidelines specify rainfall threshold values based on land use. The guidelines then assume that the root depth of vegetation shall be only up to 500 mm across the region and based on this, the user is provided with soil storage capacity and field capacity values for 17 soil types. It is up to the user to determine the existing and intended soil type at their site. The infiltration capacity coefficient, infiltration capacity exponent and the baseflow properties may then be determined based on four soil categories (an aggregation of the previous 17 soil types).

(Dotto et al., 2011b) conducted research which involved parameter estimation and calibration of the MUSIC model to five catchments in Melbourne, Australia. Results indicated that MUSIC was over-parameterised, with several parameters having little impact on model results. These included the initial pervious area storage, initial groundwater storage and the infiltration capacity exponent, *b*.

(Myers et al., 2014b) developed calibrated models for two sites in greater Adelaide, South Australia. Parameter estimation software was used to derive soil parameters for the two catchments. Groundwater was excluded from the calibration because there was little evidence of baseflow at the point where flow gauges were located. Previous research was undertaken which explored the effective pervious area soil parameters for two gauged urban catchments in South Australia. For the two catchments, optimal parameters were determined based on accurate simulation of peak flow rate and annual runoff volume. Results of the parameter estimation suggested that the infiltration capacity coefficient *a* and the infiltration capacity exponent *b* had little impact on simulated outcomes. The pervious area parameters derive in this study are shown in Table 4-10.

Table 4-10 – Impervious storage and pervious area parameters for MUSIC

Parameter	Frederick Street Catchment	Paddocks Catchment
Surface water properties		
Rainfall threshold (mm)	1.5	0.5
Soil storage capacity (mm)	68	47
Initial storage (%)	-	-
Field capacity (mm)	30	33
Infiltration capacity coefficient, *a*	200	200
Infiltration capacity exponent, *b*	1	1

Developing a Recommendation for South Australia

Existing guidelines vary in their recommendations for appropriate rainfall threshold, soil and groundwater properties for MUSIC simulation. Based on the detailed information provided by SCA (2012) and MacLeod (2008), the need to provide information of this detail was explored further. Research was conducted and is presented in Appendix H to identify the influence of soil parameters based on the previous work by MacLeod (2008) and using the calibrated Frederick Street catchment. This showed that the MUSIC model was not very sensitive to changes in soil parameters, which confirmed previous work by (Dotto et al., 2011b) and (Myers et al., 2014b). The modelling showed that simulation results were not very sensitive to changes in the soil parameters. As the value of EIA increased, the effect of soil parameters becomes less influential. In heavily urbanised catchments with high impervious area the user may elect to reduce effort and resources in calibrating the model to local soil conditions due to the limited influence of soil properties on the simulated performance of WSUD treatment systems.

Based on this research and existing guidelines, specific guidance for each set of parameters is listed as follows:

Rainfall threshold - a value of 1 mm is recommended by almost all guidelines, and should be adopted for South Australian conditions unless there is justification for adopting a different value.

Pervious area properties - based on this investigation and the parameters derived for two urban catchments by (Myers et al., 2014b) in Table 4-10, the default information provided by eWater (2014a) in Table 4-8 is considered a simple, straightforward and widely available resource for rainfall threshold and soil parameter values which are suitable for MUSIC simulation in Greater Adelaide to estimate runoff volume from ungauged catchment areas.

As there is currently no calibration data available for other South Australian regions, and little for Greater Adelaide, modellers may choose to adopt pervious area parameters based on soil type. It is therefore recommended that the parameter information based on soil type is provided for reference, in addition to links for soil information in South Australian regions. These will be of greater importance for a lower density development where soil parameters will influence flow rates, volumes and treatment system performance.

4.4.9 Input Pollutant Data and Pollutant Generation Properties

Pollutants in surface runoff and baseflow may be stochastically generated by the MUSIC model (using the mean and standard deviation of observed data) or produced as a single, continuous value based on the mean observed value. The difference between simulations using either approach is that stochastic generation will produce a continuously variable pollutant concentration, the mean of which may be slightly different to the mean value input by the user, especially for a short duration simulation. Adopting the mean will produce a consistent value, which does not consider fluctuations in water quality. If stochastic generation is used, there is the option of providing a serial correlation value, where the stochastic nature of the pollutant generation is influenced by the value of the previous time step (forcing the production of a more 'realistic' pollutograph). Default data for stochastic pollutant generation is provided in the MUSIC model for three land uses: urban, rural and forested catchments.

Review of Literature

eWater (2014a) indicate that the default data for total suspended solids (TSS), total phosphorous (TP) and total nitrogen (TN) for these three land uses is based on a comprehensive review of international stormwater quality data by (Duncan, 1999), which has been supplemented by additional local data. This data is shown in Table 4-11. With appropriate information, however, the user may adopt any suitable value. eWater (2014a) do not provide a recommendation on whether to adopt stochastic or mean values, but they do indicate that "the autocorrelation coefficient will not significantly affect the treatment train effectiveness produced by music, but simply ensures that the variation over time in concentrations during storm events and baseflow conditions is more 'realistic'".

Table 4-11 – Default pollutant concentrations adopted in MUSIC

Land use	Runoff	Total suspended solids - $\log_{10}$(mg/L)		Total phosphorous - $\log_{10}$(mg/L)		Total nitrogen - $\log_{10}$(mg/L)	
		Mean	SD	Mean	SD	Mean	SD
Urban	Baseflow	1.1	0.17	-0.82	0.19	0.32	0.12
	Surface	2.2	0.32	-0.45	0.25	0.42	0.19
Agriculture	Baseflow	1.4	0.13	-0.88	0.13	0.074	0.13
	Surface	2.3	0.31	-0.27	0.3	0.59	0.26
Forest	Baseflow	0.9	0.13	-1.5	0.13	-0.14	0.13
	Surface	1.9	0.2	-1.1	0.22	-0.075	0.24

Melbourne Water (2010b) require that stochastic pollutant generation is always used, 'except where the behaviour of a particular storm event or set of operating conditions' are being simulated. Serial correlation must be set to zero. It is recommended that the default pollutant data in Table 4-11 be applied to MUSIC nodes unless additional data is available, which must be confirmed in writing with Melbourne Water before use. There is no justification provided for these requirements.

Water by Design (2010) require that stochastic pollutant generation is used for generating pollutant data, without justification. It is also a requirement that serial correlation be adopted using values provided by eWater (2014a). It is noted that this will not influence loads, contrary to the advice of eWater (2014a), but will 'ensure that pollutant generation simulated by MUSIC during any one event will be more consistent with what happens in real events and may provide better estimates of the performance of devices for particular events'. The Water by Design (2010) guidelines provide users with surface and baseflow pollutant data for all node types in both a split modelling approach and a lumped modelling approach. Water quality parameters for split' modelling are shown in Table 4-12 and the water quality parameters for lumped modelling are shown in Table 4-13.

Table 4-12 – Water quality parameters for 'split' modelling in South East Queensland from Water by Design (2010)

Land use		Total suspended solids - $\log_{10}$(mg/L)		Total phosphorous - $\log_{10}$(mg/L)		Total nitrogen - $\log_{10}$(mg/L)	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Urban residential							
Baseflow	Roof	N/A	N/A	N/A	N/A	N/A	N/A
	Roads	1	0.34	-0.97	-0.31	0.2	0.2
	Ground	1	0.34	-0.97	-0.31	0.2	0.2
Surface	Roof	1.3	0.39	-0.89	-0.31	0.26	0.23
	Roads	2.43	0.39	-0.3	-0.31	0.26	0.23
	Ground	2.18	0.39	-0.47	-0.31	0.26	0.23
Industrial							
Baseflow	Roof	N/A	N/A	N/A	N/A	N/A	N/A
	Roads	0.78	0.45	-1.11	0.48	0.14	0.2
	Ground	0.78	0.45	-1.11	0.48	0.14	0.2
Surface	Roof	1.3	0.44	-0.89	0.36	0.25	0.32
	Roads	2.43	0.44	-0.3	0.36	0.25	0.32
	Ground	1.92	0.44	-0.59	0.36	0.25	0.32
Commercial							
Baseflow	Roof	N/A	N/A	N/A	N/A	N/A	N/A
	Roads	0.78	0.39	-0.6	0.5	0.32	0.3
	Ground	0.78	0.39	-0.6	0.5	0.32	0.3
Surface	Roof	1.3	0.38	-0.89	0.34	0.37	0.34
	Roads	2.43	0.38	-0.3	0.34	0.37	0.34
	Ground	2.16	0.38	-0.39	0.34	0.37	0.34

Table 4-13 - Water quality parameters for 'lumped' modelling in South East Queensland from Water by Design (2010)

Land use		Total suspended solids - $\log_{10}$(mg/L)		Total phosphorous - $\log_{10}$(mg/L)		Total nitrogen - $\log_{10}$(mg/L)	
		Mean	SD	Mean	SD	Mean	SD
Urban residential	Baseflow	1	0.34	-0.97	0.31	0.2	0.2
	Surface	2.18	0.39	-0.47	0.32	0.26	0.23
Industrial	Baseflow	0.78	0.45	-1.11	0.48	0.14	0.2
	Surface	1.92	0.44	-0.59	0.36	0.25	0.32
Commercial	Baseflow	0.78	0.39	-0.6	0.5	0.32	0.3
	Surface	2.16	0.38	-0.39	0.34	0.37	0.34
Rural residential	Baseflow	0.53	0.24	-1.54	0.38	-0.52	0.39
	Surface	2.26	0.51	-0.56	0.28	0.32	0.3
Forest	Baseflow	0.51	0.28	-1.79	0.28	-0.59	0.22
	Surface	1.9	0.2	-1.1	0.22	-0.075	0.24
Agriculture	Baseflow	1	0.13	-1.155	0.13	-0.155	0.13
	Surface	2.477	0.31	-0.495	0.3	0.29	0.26

As noted previously (Section 4.4.6), Water by Design (2010) require a catchment to be modelled as a split system for development approval, but users may adopt a lumped modelling approach for larger scale planning. There are nine categories of potential surface types and corresponding pollutant values for split system modelling and six categories for large scale planning assessment. Pollutant loading parameters are provided based on data from Brisbane City Council monitoring and research into agricultural land use by BMT WBM (2009), as cited by Water by Design (2010). The parameters for urban residential and forest catchments are similar to the default data in MUSIC (Table 4-11).

McAuley and Knights (2009) recommend that stochastic pollutant generation is adopted for MUSIC simulation in the Darwin region. There was no justification provided. There is no mention of serial correlation in the guideline. Water quality parameters for the Darwin region are provided based on the node types in Section 4.4.6. Water quality parameters are provided for forest, agriculture, roof areas, road reserves and general urban areas. The water quality parameter data was based on the initial work by Duncan (1999) and updated with data from Fletcher et al. (2004). The information from Fletcher et al. (2004) is summarised for TSS, TP and TN in Table 4-14. It should be noted that the information from Fletcher et al. (2004) did not include a review of baseflow concentration data.

Table 4-14 – Quality of runoff for various land use as reviewed by Fletcher et al. (2004)

Land use	Total suspended solids - log_{10}(mg/L)		Total phosphorous - log_{10}(mg/L)		Total nitrogen - log_{10}(mg/L)	
	Mean	SD	Mean	SD	Mean	SD
High urban roads	2.41	0.46	-	-	-	-
Low urban roads	1.84	0.66	-	-	-	-
Roads	-	-	-0.59	0.44	0.33	0.3
Roofs	1.55	0.38	-0.89	0.29		
High urban	2.19	0.48	-	-	0.42	0.28
Residential	-	-	-0.4	0.34	-	-
Non residential, high urban	-	-	-0.5	0.4	-	-
Agricultural	2.27	0.47	-0.27	0.45	0.59	0.39
Forest	1.9	0.3	-1.14	0.34	-0.08	0.36

SCA (2012) require modellers to adopt stochastic generation without justification. They also require models to have no serial correlation. This is because 'serial correlation makes stochastically modelled outcomes more variable. This makes it harder to assess models in relation to the required 10% improvement in modelled pollutant loads needed to meet NorBE.' SCA (2012) provide the user with a mean and standard deviation of pollutants in runoff and baseflow for MUSIC modelling. These pollutant values are based on surface types including roofs, sealed roads, unsealed roads, eroding gullies, vegetated land and quarries. For larger planning based studies, values are also provided for general residential, commercial, industrial, rural residential, agricultural and forest catchments. The data was derived for NSW based on the data presented by Fletcher et al. (2004) shown in Table 4-14, with some additional surface types added from an unknown source.

Developing a Recommendation for South Australia

There is general agreement in existing MUSIC guidelines that stochastic generation should be adopted. Based on this, stochastically generated pollutant data is recommended for South Australia. There is variation regarding the adoption of serial correlation. Based on the recommendations of SCA (2012) and eWater (2014a), it is recommended that no serial correlation is employed to ensure that model results are not influenced by successive model runs.

It is recommended that MUSIC guidelines provide pollutant generation data that is suitable for Adelaide, based on water quality monitoring data. However, there is little information available at the local scale which can be tied to land use. A recent review most relevant to Adelaide was conducted by (Fleming et al., 2010) which compiled water quality data from the Mount Lofty Ranges, however land use in all cases was mixed, and therefore not useful for the modeller who needs to estimate the load from an existing or proposed land use. It is understood that forthcoming research from the Goyder Institute for Water Research (Project U.2.5 - Targeting stormwater interventions to support integrated urban water management that delivers improved coastal water quality) will also include a review and analysis of pollutant data for Greater Adelaide. Until more data is available, it is recommended that, as an interim measure, water quality parameters with respect to land use and surface types for MUSIC simulation may be considered based on reviews of Australian and international literature. A summary of values considered suitable, and their source, are provided in Table 4-19. References have been provided to ensure traceability of the recommended source data, which should carry through to the adopted guidelines. It should be noted that some flexibility should be allowed in the selection of pollutant parameters, especially in the compilation of a SMP where research into suitable local parameters suggests different parameters may be appropriate. It is important however that the source of water quality parameters are explicitly stated with reasoning for non-standard parameters. Pending the outcome of the outstanding work of the Goyder Institute for Water Research, research on water quality with respect to landuse is recommended for South Australian conditions. To assist MUSIC modelling and other water quality studies throughout the state.

Table 4-19 – A summary of water quality parameters for suitable for MUSIC in South Australia

		Total suspended solids		**Total phosphorous**		**Total Nitrogen**		**Source***
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Surface type								
Roof area	Baseflow	-	-	-	-	-	-	1
	Surface	1.25	1.14	-0.91	-1.11	0.18	-0.09	2
Road, incl verge	Baseflow	1.10	0.17	-0.82	0.19	0.32	0.12	3
	Surface	2.41	0.46	-0.59	0.44	0.33	0.30	4
Other ground	Baseflow	1	0.34	-0.97	-0.31	0.2	0.2	5
	Surface	2.18	0.39	-0.47	-0.31	0.26	0.23	5
Land use								
Residential	Baseflow	1	0.34	-0.97	0.31	0.2	0.2	5
	Surface	2.18	0.39	-0.47	0.32	0.26	0.23	5
Commercial	Baseflow	0.78	0.39	-0.6	0.5	0.32	0.3	5
	Surface	2.16	0.38	-0.39	0.34	0.37	0.34	5
Industrial	Baseflow	0.78	0.45	-1.11	0.48	0.14	0.2	5
	Surface	1.92	0.44	-0.59	0.36	0.25	0.32	5
Rural residential	Baseflow	0.53	0.24	-1.54	0.38	-0.52	0.39	5
	Surface	2.26	0.51	-0.56	0.28	0.32	0.3	5
Agriculture	Baseflow	1.4	0.13	-0.88	0.13	0.074	0.13	3
	Surface	2.27	0.47	-0.27	0.45	0.59	0.39	4
Native vegetation, bushland	Baseflow	0.9	0.13	-1.5	0.13	-0.14	0.13	3
	Surface	1.9	0.3	-1.14	0.34	-0.08	0.36	4
* 1 – Roofs have no baseflow, 2 - (National Resource Management Ministerial Council (NRMMC) et al., 2009), 3 - eWater (2014a), 4 - Fletcher et al. (2004), 5 - Water by Design (2010)								

4.4.10 Position relevant drainage Links, Select Link Routing and Input Link Routing Properties

Links are used in the MUSIC model to route water from a catchment to a downstream treatment, junction or model end point. In MUSIC simulations where routing parameters are not provided, runoff from nodes occurs immediately after it is generated and is transferred to the next node without delay or transformation. Link routing parameters are used on links to delay and/or transform the rate at which runoff proceeds downstream to ensure that catchment runoff is timed appropriately and to produce more accurate flow rate estimates.

Review of Literature

eWater (2014a) indicate that there are three routing options for any drainage link – no routing, translation routing or Muskingum-Cunge routing. Translation routing is a simple delay added as a multiple of the time step for a catchment. The delay results in an instantaneous release of water after the delay period. The Muskingum Cunge routing method was originally used for routing flow in channels. It requires a translation value *k* and an attenuation factor θ, which applies a non-linear lag on the rate at which flow proceeds along a drainage link. Effective application of Muskingum Cunge routing typically requires measured data and model calibration.

Melbourne Water (2010b) recommends appropriate routing is enabled in MUSIC modelling based on a time of concentration for a catchment calculated using a recognised procedure. Nor recognised procedures are stated. An applicant may choose not to apply routing, as generally this is a conservative assumption which will produce higher peak flow rates and under-predict the performance of any treatment measures in a MUSIC simulation.

Water by Design (2010) indicate that the default link routing of 'no translation' is a conservative approach for assessing treatment performance of WSUD measures. For small catchments, where the time of concentration is no longer than the modelling time step, it is not recommended to use routing. There is no advice on the appropriate use of routing in other circumstances.

McAuley and Knights (2009) recommend that link routing is disabled for MUSIC modelling as it will result in the most conservative modelling scenario. Users may adopt routing to reflect the travel time of a flood wave through a catchment, but it must be supplemented with justification of the selected routing parameters.

SCA (2012) do not provide any recommendations regarding link routing.

Despite little guidance on the selection of routing parameters, link routing can be highly influential on the accuracy of a MUSIC simulation. In the calibration of MUSIC to five catchments in Melbourne, (Dotto et al., 2011b) found that the estimation of EIA and the Muskingum Cunge routing delay *k* were the most influential parameters, while the selection of attenuation had a limited impact and any number between 0.1 and 0.3 was suitable for most catchments.

Developing a Recommendation for South Australia

Appendix I contains the results of a modelling exercise that evaluated the sensitivity of MUSIC results to different routing approaches. This modelling was undertaken based on the calibrated Frederick Street catchment. The following scenarios were evaluated:

Scenario 1: Calibrated, Muskingum Cunge (k = 14 mins, θ = 0.3)

Scenario 2: Calibrated, Muskingum Cunge attenuation disabled (k = 14 mins, θ = 0.49)

Scenario 3: Translation only (k = 12 minutes)

Scenario 4: No link routing

The modelling results in Appendix I showed that calibrated routing more skilfully simulates observed flows, and in particularly the magnitude of peaks. However, negligible differences were observed between scenarios with calibrated routing and without in terms of mean annual flow and mean annual treatment efficiency. The modelling results indicate that calibrated routing is likely to be important when sizing stormwater treatment devices as this requires an accurate representation of peak flows. Routing is likely to be less important when modelling the impact of stormwater treatment devices on mean annual reductions in flows or pollutant loads.

Based on the literature and modelling results, it is recommended that:

- Routing is not required in South Australian MUSIC modelling undertaken for compliance with water quality targets to ensure results are conservative, and
- Users who choose to adopt routing techniques must provide adequate reasoning for their adopted routing method and assumptions.

It is also recommended that future research is undertaken to explore appropriate routing parameters for varying catchment sizes and slopes to identify whether there is a potential for a size/slope based recommendation regarding routing parameter use in MUSIC.

4.4.11 Run Simulation

While the model run process does not require user input, eWater (2014a) indicate that MUSIC provides a 'warm up' simulation prior to the simulation run. This warm up function will run one year of data (value cannot be adjusted) before starting the simulation itself to estimate groundwater depth, soil storages and any WSUD storage levels at the beginning of the simulation. A 'cold' start adopts user data for the condition of catchment storage, but assumes that any WSUD storages are full.

Review of Literature

Water by Design (2010) recommend that MUSIC is run with the warm up feature enabled to ensure that water storages are stable and reflective of in-situ conditions. Guidelines from

Melbourne Water (2010b), SCA (2012) and McAuley and Knights (2009) do not make any recommendations regarding the selection or otherwise of a warm up feature in MUSIC.

The Brisbane City Council (2003) noted that if a ten year rainfall record is used for simulation in MUSIC then the duration is long enough for the soil stores to reach equilibrium without the warm-up function having a significant influence on the overall results.

Developing a Recommendation for South Australia

Only one of the reviewed guidelines mentioned the warm up feature in MUSIC. The influence of the warm-up function on the end result of a MUSIC simulation was evaluated using a calibrated catchment to the West of Adelaide's CBD - the Frederick Street catchment. This analysis, which has been described in Appendix F, found that the influence of the warm-up function on modelled flows was negligible, and as would be expected the influence declined for models that used longer climate records. The use of ten years of climate data would mean there was sufficient time for storages in the catchment source node to reach equilibrium and the warm-up function was unlikely to make a material difference on modelled flows. However, to reduce the influence of user input for catchment and treatment node storage, especially for models which are run for short periods, it is recommended that the warm up feature is enabled for MUSIC simulation.

4.4.12 Compare Results with Water Quality Objectives

The results of a MUSIC model for a proposed development are typically compared with objectives established for a catchment in SMPs. For a proposed development submitted to an approving authority, the objectives are typically provided by a local or state authority. Such objectives include reducing post development runoff quantity and/or quality, or maintaining/improving the post development runoff quantity/quality compared to the existing site.

Review of Literature

The comparison of MUSIC output with stated objectives is beyond the scope of the MUSIC model manual (eWater, 2014a) which is focussed on the correct implementation of the model only. There are however several regional guidelines which provide explicit requirements on what should be presented for consideration of a proposed project.

Melbourne Water (2010b) provide a list of the specific information available from MUSIC that must be presented as part of a functional design report, in addition to the model run file itself.

Water by Design (2010) also provide details of the information that must be generated and submitted to demonstrate compliance with runoff quality targets in South East Queensland, depending on whether mean annual loads or pollutant concentration data is required.

SCA (2012) provide details on the derivation of flow based sub-sample data from pre- and post-development simulation cases to assess compliance with the SCA's Neutral or Beneficial Effect 'NorBE' targets.

McAuley and Knights (2009) do not provide guidance on the interpretation of data generated by MUSIC.

A review of South Australian SMPs in Section 2.3 of this report indicated that few SMPs provided detailed information on the assumed parameters of MUSIC simulation, including catchment properties and treatment node properties, when simulation was undertaken.

Developing a Recommendation for South Australia

Most regional guidelines have provided guidance on what should be submitted for a development application. The most for SA is that provided by the *SA WSUD Policy* (SA Department of Envrionment Water and Natural Resources (DEWNR), 2013). The water quality provisions of this are as follows:

Achieve the following minimum reductions in total pollutant load, compared with that in untreated stormwater runoff, from the developed part of the site:

- *Total suspended solids by 80 per cent;*
- *Total phosphorus by 60 per cent;*
- *Total nitrogen by 45 per cent;*
- *Litter/gross pollutants by 90 per cent.*

It is understood that local government, NRM Boards and EPA SA (via development application referrals) are already requesting compliance with the SA WSUD policy. It is important that guidelines make it clear that the comparison here is between two catchment models of the developed site, one without WSUD (as a baseline) and one with proposed WSUD approaches. In this case, the modelling approach is simple, because the 'no WSUD' case is automatically simulated in every MUSIC model, so the user can assess their proposed WSUD by using the 'mean annual loads' tool. As more stormwater management plans are developed, different approaches and targets may be developed. For example, in redevelopment locations, neutral or beneficial effect recommendations may be generated, in which case two separate pre- and post-development models may be required. The methodology for this would ideally be provided by MUSIC modelling guidelines.

It is also strongly encouraged that where MUSIC modelling forms part of a submission to an approving authority, guidelines should explain how to demonstrate compliance (such as by submission of a model or reporting template) and what information must be presented with any reporting requirements. As a minimum, it is recommended that a submission include the MUSIC model run file. It is also recommended that a summary of mean annual flow and pollutant loads are identified and any percentage reductions (all of which are easily derived using the mean annual loads tool). It is also suggested that the default output of the MUSIC summary reporting tool is provided to allow an experienced MUSIC user to quickly assess default input.

4.4.13 Select Stormwater Quality Improvement Measures

One of the primary uses of the MUSIC model is simulating runoff and pollutant loads from a catchment to determine the best stormwater treatment devices for a given situation. The stormwater treatment devices in MUSIC are described by eWater (2014a) and include the following nodes:

- Gross Pollutant Trap
- Wetland
- Buffer Strip
- Vegetated Swale
- Bioretention System
- Infiltration System
- Media Filtration System
- Pond
- Sediment Basin
- Detention Basin
- Rainwater Tank
- Generic Treatment Node.

Review of Literature

Water by Design (2010) and SCA (2012) provide guidance for almost all of these nodes. All nodes have generic guidance; for example, it is noted that users should adopt the default pollutant treatment parameters that are provided with the MUSIC model (*k*, *C** and *C*** values). There is also advice specific to other parameters for each node. For example, this included:

- the arrangement of nodes (such as the arrangement of lumped or separate rainwater tanks)
- the appropriate use of nodes (for example, buffer strips may only be applied to areas with diffuse runoff as they are not appropriate for channelised flow) and
- appropriate input data (for example, appropriate assumptions for reuse from rainwater tanks, and appropriate input values for bioretention).

In each case, the advice has been based on local information where available. Local data includes water demand and irrigation demand data. Other recommendations, such as design parameters, are presented in a similar fashion to, or with reference to, a separate design guideline.

McAuley and Knights (2009) provide guidance on parameter selection for all nodes in the Darwin region, but provide less detail than Water by Design (2010) and the SCA (2012). They do not provide locally specific data. Melbourne Water (2010b) provide limited information compared to the other three guidelines. They do not provide recommendations regarding the input data for these nodes, but focus on advice regarding design which must be reflected in the MUSIC model parameters.

Developing a Recommendation for South Australia

It is recommended that MUSIC guidelines for South Australia provide users with guidance on the appropriate determination of each parameter in MUSIC treatment nodes to ensure that parameters have been selected in a consistent manner. Where possible, these should make reference to local guidelines or locally acquired information.

Appendix I provides an overview of the different stormwater treatment devices available in MUSIC. It provides an outline of the underlying approach that is applied in MUSIC to simulate the performance of different stormwater treatment devices in the removal of pollutants and managing runoff. Appendix I also highlights key issues that need to be considered in setting MUSIC parameter values to model the performance of WSUD stormwater treatment devices in meeting best practice guidelines in South Australia.

It is recommended that supporting information from the MUSIC manual and other WSUD guidelines is provided in a MUSIC modelling guideline document. For example, default data on soil exfiltration rates, and images explaining the filter area perimeter for bioretention (as two examples) should be provided to ensure the user does not have to refer back to the MUSIC manual for additional guidance.

4.4.14 Develop treatment train

A treatment train is the placement of two or more treatment mechanisms in series. The concept of a treatment train is to progressively treat runoff prior to its disposal to receiving waters.

Review of Literature

eWater (2014a) recommend that a treatment train is selected such that the first treatment devices collect larger particles and devices are then selected which can treat smaller particles in runoff. eWater (2014a) and SCA (2012) provide tables which illustrate the suitability of treatment measures for targeting different particle sizes and scale of application, which displays how a treatment train can be designed to remove larger sediment before treatments measures for smaller particle sizes are implemented.

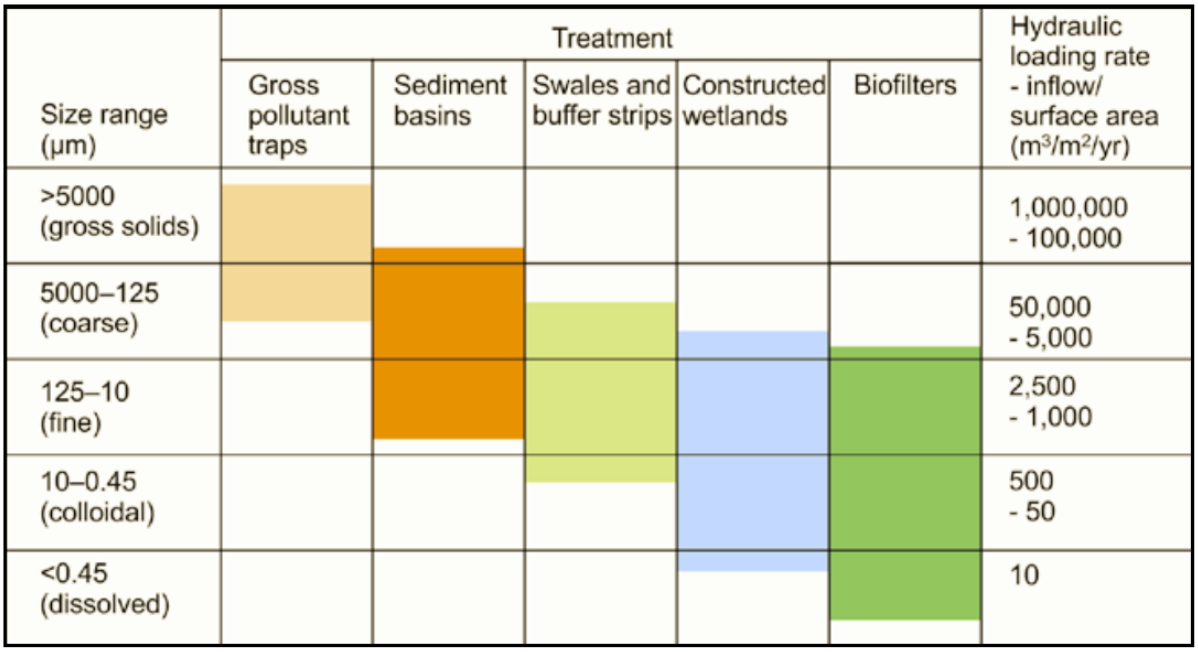

Figure 4-8 – Target particle size range of several treatment measures from SCA (2012) (citing (eWater, 2014a)

Guidance on the actual selection of treatment mechanisms is not provided by Melbourne Water (2010b), Water by Design (2010) or McAuley and Knights (2009). However there are additional WSUD scoping and design tools available which are intended to advise on the selection of appropriate WSUD measures in their regions of interest.

Developing a Recommendation for South Australia

Locally derived guidelines for WSUD have been produced by the (South Australian Department of Planning and Local Government, 2010) which provide background and advice for the selection of WSUD measures in Chapters 1, 2 and 3. It is recommended that MUSIC guidelines for South Australia include or refer to the selection of a treatment train based on this existing guidance .

4.5 Discussion

Recommendations for the appropriate use of the MUSIC software have been presented throughout Section 4.4. These recommendations have been based on information currently available from South Australian and interstate studies, and should not be considered to be a 'final word' on the appropriate use of MUSIC in South Australia.

A significant limiting factor in the simulation of treatment systems in South Australia is the lack of locally derived research data that could support locally specific recommendations for the treatment efficiency *k* factor and background concentrations *C** and *C***. The adoption of existing values, which has currently been recommended, will provide a consistent basis for estimating treatment train performance. However, it is noted in literature that the performance of treatment systems will be dependent on a range of factors. For example, detailed wetland design guidelines (Kadlec & Wallace, 2009) provide details on the performance of wetlands for the removal of specific pollutants worldwide. They indicate that a variety of factors can influence wetland performance. These include design based factors (such as shape of wetland flow paths, depth and vegetation selection) as well as factors independent of design such as temperature, presence or absence of snow, rainfall and seasons.

In other research, (Imteaz et al., 2013) demonstrated the limitations of MUSIC for predicting the performance of bioretention systems, grass swales and porous pavements. MUSIC simulations were conducted based on published field performance data for systems in Australia and overseas. Results showed variations in the simulated and measured outcomes. For example, when simulating bioretention systems, it was found that MUSIC produced a good estimate of flow and TSS removal, but TP and TN treatment efficiency did not match experimental results. However, when the same process was applied to a Brisbane study, TSS and TP removal were 'fairly accurate', but flow and TN were not. Differences in this case were attributed to soil leaching characteristics.

It is therefore recommended that research into the field performance of South Australian WSUD sites is undertaken to quantify the volumetric and water quality benefits they provide in such a way that local parameters for treatment performance can be estimated. It should be noted that most guidelines do not present alternative parameters for k, C^*, and C^{**} values, however there are some examples, including Blacktown City Council in NSW, who specify alternative values in the new MUSIC-Link feature.

Additional research is also required on the pollutant removal performance of plants that are currently adopted in vegetated systems (such as wetland and bioretention systems) in South Australia. This is known to vary from recommendations in some circumstances because of a need to consider indigenous species to South Australian sites, the pollutant removal performance of which have not been studied. Likewise, it is known that the ideal soil (filter media) for filtration based systems is not available from South Australian quarries, and a near match is used. The performance of this filter media for pollutant removal (or leaching) should also be examined to further refine input parameters and to derive calibrated water quality treatment estimates. The accuracy of current estimates may under- or over-estimate the performance of treatment solutions. This is especially important for studies such as stormwater management plans where an under-or over-estimate of performance may impact on expenditure at the broader catchment scale.

Further research is also warranted into runoff quality associated with landuse in South Australia. Existing SA studies have tended to be undertaken on larger catchment areas (e.g. Fleming et al., 2010) where land use upstream of a gauging station is mixed. At present, interstate data for the quality of runoff from surface types (such as roads, roofs and pervious areas) and land uses (such as residential, industrial and commercial) has been adopted as a recommendation. While this data may provide a reasonable estimate, variations in rainfall frequency and sediment deposition across metropolitan Adelaide, for example, compared to other regions in Australia may produce different event mean concentration data. Locally derived data will assist in providing a good estimate of runoff for stormwater management planning.

4.6 Summary

MUSIC is commonly used in Australia to explore the effectiveness of WSUD measures for improving water quality and predicting runoff quantity and harvesting performance. Guidelines are available in many parts of Australia for the use of MUSIC in demonstrating how best practice WSUD targets will be met. However, there is no guideline on the use of MUSIC available for any part of South Australia.

In some areas South Australian specific recommendations for the use of MUSIC in planning and assessing WSUD systems can be adopted from the review of other guidelines already developed in other Australian jurisdictions. However, there areas where the application of MUSIC would be improved through applying South Australian specific data and analysis. This includes the following: climate data, soil parameters, run-off pollutant generation data, household end-use data to assess reuse opportunities, and local performance data on the efficiency of different stormwater treatment devices in removing pollutants.

4.7 References

Arbon, N, Thyer, M, Hatton MacDonald, D, Beverley, K & Lambert, M 2014, *Understanding and predicting household water use for Adelaide*, Goyder Insitute for Water Research.

Beal, CD & Stewart, RA 2014, 'Identifying Residential Water End Uses Underpinning Peak Day and Peak Hour Demand', *Journal of Water Resources Planning and Management,* vol. 140, no. 7, p. 04014008.

Brisbane City Council 2003, *Guidelines for Pollutant Export Modelling in Brisbane* Brisbane City Council, Brisbane.

Department of Water 2011, *Stormwater Strategy - The future of stormwater management*, Department of Water, Adelaide.

DesignFlow 2008, *Mackay Regional Council MUSIC guidelines (Version 1.1)*, Mackay Regional Council, Mackay, Queensland, Australia.

Dotto, CBS, Kleidorfer, M, Deletic, A, Fletcher, TD, McCarthy, DT & Rauch, W 2010, 'Stormwater quality models: Performance and sensitivity analysis', *Water Science and Technology,* vol. 62, no. 4, pp. 837-843.

Dotto, CBS, Kleidorfer, M, Deletic, A, Rauch, W, McCarthy, DT & Fletcher, TD 2011b, 'Performance and sensitivity analysis of stormwater models using a Bayesian approach and long-term high resolution data', *Environmental Modelling Software,* vol. 26, no. 10, pp. 1225-1239.

Duncan, HP 1999, *Urban stormwater quality: A statistical overview*, Cooperative Research Centre for Catchment Hydrology, Melbourne, Australia.

Ecological Engineering 2010, *DRAFT MUSIC modelling guidelines - Ku-ring-gai Council*, Ku-ring-gai Council, Ku-ring-gai, NSW, Australia.

eWater 2014a, *MUSIC Manual*, eWater CRC, Canberra, ACT, Australia. viewed July 2012,

Fleming, NK, Cox, JW, He, Y, Thomas, S & Frizenschaf, J 2010, *Analysis of Total Suspended Sediment and Total Nutrient Concentration data in the Mount Lofty Ranges to derive event mean concentrations*, eWater Cooperative Research Centre Technical Report.

Fletcher, TD, Duncan, HP, Poelsma, P & Lloyd, SD 2004, *Stormwater flow and quality, and the effectiveness of non-proprietary stormwater treatment measures - A review and gap analysis*, Cooperative Research Centre for Catchment Hydrology, Melbourne.

Gold Coast City Council 2006, *Gold Coast City Council MUSIC Modelling Guidelines*, Gold Coast City Council.

Imteaz, MA, Ahsan, A, Rahman, A & Mekanik, F 2013, 'Modelling stormwater treatment systems using MUSIC: Accuracy', *Resources, Conservation and Recycling,* vol. 71, 2//, pp. 15-21.

Kadlec, RH & Wallace, SD 2009, *Treatment wetlands [electronic resource]*, 2nd edn, CRC Press, Boca Raton, FL.

MacLeod, A 2008, 'MUSIC calibration based on soil conditions', *New South Wales and Queensland Joint Stormwater Industry Association Conference*, Stormwater Industry Association, Queensland.

McAuley, A & Knights, D 2009, *Water sensitive urban design - Stormwater quality modelling guide - Final*, Northern Territory Department of Planning and Infrastructure, Darwin, Northern Territory, Australia. viewed May 2009, Melbourne Water 2010b, *MUSIC guidelines - Recommended input parameters and modelling approaches for MUSIC users*, Melbourne Water, Melbourne, Victoria, Australia.

Myers, B, Cook, S, Maheepala, S, Pezzaniti, D, Beecham, S, Tjandraatmadja, G, Sharma, A, Hewa, G & Neumann, L 2011a, *Interim Water Sensitive Urban Design Targets for Greater Adelaide*, Goyder Institute for Water Research, Adelaide, SA, Australia.

Myers, B, Pezzaniti, D, Kemp, D, Chavoshi, S, Montazeri, M, Sharma, A, Chacko, P, Hewa, GA, Tjandraatmadja, G & Cook, S 2014b, *Water Sensitive Urban Design Impediments and Potential: Contributions to the Urban Water Blueprint (Phase 1) Task 3: The Potential Role of WSUD in Urban Service Provision*, Goyder Institute for Water Research, Adelaide, South Australia.

National Resource Management Ministerial Council (NRMMC), Environmental Protection and Heritage Council (EPHC) & National Health and Medical Research Council (NHMRC) 2009, *Australian guidelines for water recycling: Managing health and environmental risks (phase 2) - Stormwater harvesting and reuse*, National Water Quality Management Strategy, Canberra, ACT, Australia. viewed July 2009,

Roberts, P 2005, *Yarra Valley Water 2004 Residential End Use Measurement Study*, Yarra Valley Water.

SA Department of Envrionment Water and Natural Resources (DEWNR) 2013, *Water sensitive urban design - creating more liveable and water sensitive cities for South Australia*, Government of South Australia, Adelaide, SA, Australia. viewed October 2013,

South Australian Department of Planning and Local Government 2010, *Water sensitive urban design technical manual - Greater Adelaide region*, Department of Planning and Local Government, South Australia, Adelaide, SA, Australia. <http://www.planning.sa.gov.au/go/wsud>.

Sydney Catchment Authority 2012, *Using MUSIC in Sydney's Drinking Water Catchment*, Sydney Catchment Authority, Penrith, NSW, Australia.

Water by Design 2006, *WSUD Technical Guidelines for South East Queensland*, South East Queensland Healthy Waterways Partnership, viewed March 2015, <http://waterbydesign.com.au/fdc/WSUD-Technical-Design-Guidelines-Online.pdf>.

Water by Design 2010, *MUSIC modelling guidelines*, South East Queensland Healthy Waterways Partnership (SEQHWP), Brisbane, Queensland, Australia.

Willis, RM, Stewart, RA, Giurco, DP, Talebpour, MR & Mousavinejad, A 2013, 'End use water consumption in households: impact of socio-demographic factors and efficient devices', *Journal of Cleaner Production,* vol. 60, 12/1/, pp. 107-115.

Wong, THF (ed.) 2006, *Australian Runoff Quality: A guide to Water Sensitive Urban Design*, Engineers Australia, NSW.

Part V Flow Regime Assessment for Waterway Protection

5 Flow Regime Assessment for Waterway Protection

5.1 Introduction

WSUD offers the potential to reduce the adverse impacts urbanisation has on the flow regime of streams. This research has found little consideration of frequent flow management in existing stormwater management plans (Section 2.4.3). However, flow management of runoff is important in many circumstances where flow regimes are altered due to land use change. Typically, the conversion of a rural or natural catchment to an urban form results in runoff that is significantly higher in velocity, magnitude and frequency and with a shorter duration. Figure 5-1 shows an urban stream with permanent water pool and bank erosion. The impervious land characteristic associated with the urban landscape alters a raft of hydrological processes leading to greater surface runoff and reduced infiltration (Walsh et al., 2012).

Figure 5-1 –The bed of Brown Hill Creek, Adelaide showing bank erosion (Source: epa.sa.gov.au)

Most aquatic habitats develop and survive because of the existing (natural or altered) flow regime. Stream geomorphology is also characterised by the existing flow regime. Alterations to a flow regime can therefore lead to significant changes in geomorphology and aquatic habitat due to changes in stream erosion, sediment deposition and alignment.

Due to this, when considering land use change such as urbanisation it is important to evaluate the pre-developed stream flow regime. The objective of this evaluation should be to determine the critical flow regime indices that support and sustain any existing habitat and prevent major stream geomorphology changes. These indices are generally associated with the low flow regime and the high flow, full bank / channel forming flow conditions.

5.2 Background

Minimising the impact of land use change on stream flow regime is a significant challenge and the implementation of WSUD measures offers an opportunity to reduce the impact of urbanisation. The predominant land use change which occurs in Greater Adelaide is urbanisation, with a typical example shown in Figure 5-2.

Figure 5-2 - A depiction of an area in Blackwood, SA, prior to and following urbanisation

The increased surface imperviousness associated with urban development generally results in increased runoff flow volumes, higher runoff flow rates and less infiltration to the soil (Burns et al., 2014). Urbanisation generally results in reduced vegetation and increased impervious area. The removal of vegetation reduces evapotranspiration, and rainfall interception, resulting in reduced catchment response time, increased runoff volume and magnitude. The increased impervious area reduces infiltration losses, depressed storage area losses and decreases surface roughness, increases surface runoff volume and magnitude and reduces the catchment response time. Figure 5-3 outlines the links between the changes in hydrological processes resulting from urbanisation (Subhashini, 2014).

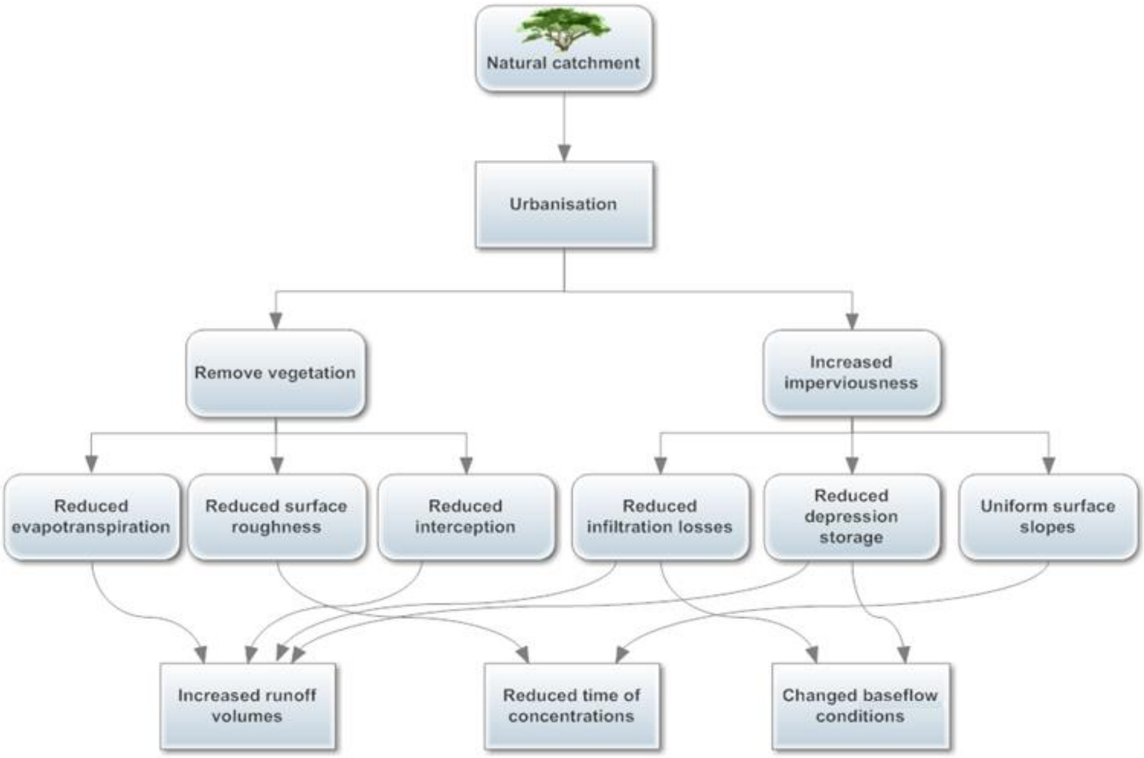

Figure 5-3 - Effect of urbanisation on the hydrological processes (Subhashini, 2014)

Many WSUD measures involve functions that attempt to mimic hydrological processes prior to development. For example, bioretention devices have a storage and vegetation component and can often be designed to allow infiltration to the surrounding soil. These functions are equivalent to the natural losses associated with evapotranspiration, depression storage and infiltration. Some of the WSUD measures hold the runoff for a temporary period, extending the flow duration periods and reducing the flow magnitude. The South Australian Government has produced technical guidelines for WSUD[3] and the effectiveness of key systems has been explored locally in previous research by the Goyder Institute for Water research (Myers et al., 2014b).

5.3 Stream Flow Management in Greater Adelaide

In the context of stream flow regime management, low flows and channel forming flows are two main considerations. Channel forming flows are important when considering stream flow management as these are generally associated with erosion and deposition processes resulting in changes to the stream morphology. Many of the streams located in the Greater Adelaide region are ephemeral so the existence of permanent aquatic habitats is not prevalent, particularly in the Adelaide plains. However, many natural streams were formerly

[3] https://www.sa.gov.au/topics/housing-property-and-land/building-and-development/land-supply-and-planning-system/water-sensitive-urban-design

characterised by having sites such as waterholes/pools that provided refuge during periods of no flow. Some streams in the Adelaide Hills and Adelaide's Southern region exhibit base flow from ground water sources (e.g. Field River and Scott Creek) and these tend to support various levels of aquatic habitat that may be unique to the stream. For this reason streams with low flow require additional consideration when considering flow regime requirements.

The South Australian Government (van Laarhoven & van der Wielen, 2009) undertook a considerable review and assessment of environmental flows for streams in the Mount Lofty Ranges region. 135 stream sites were assessed and a set of metrics for environmental water requirements was developed. The metrics were used to assess the status of existing flow regimes. The assessment revealed that 50% of the sites passed three quarters of the metrics. Many of the steams did not meet the low flow metric while full bank flows were not significantly different. It found that meeting environmental water requirements during the low flow season was the most critical period for sustaining aquatic biota. The outputs were to be used to inform limits on stream flow extractions (by agricultural users) and determine environmental releases and low flow bypass flow rates for dams.

(van Laarhoven & van der Wielen, 2009) also examined the relationships between flow and stream habitat characteristics. This assessment was undertaken for key components of a stream that are known to support habitat, such as deep pools, shallow riffles, bank and bank full benches. This assessment provides further information when identifying appropriate flow thresholds that achieve critical channel water level or depth inundation. Table 5-1 provides the flow regime indicator for flow regime components and corresponding hydrologic measure located in the Mount Lofty Ranges.

Table 5-1 - Flow regime component for flow components in streams located in the Mount Lofty Ranges (van Laarhoven & van der Wielen, 2009)

Component	**Hydrological measure**
Low flow	80^{th} percentile exceedance flow for the flow season of interest (calculated on non-zero flows)
Fresh	2 times the median of all non-zero flows in the flow season of interest
Bankfull/overbank	1.5 annual return interval flow (based on annual maximum flows)

EPA SA monitors waterways (lakes, creeks and rivers) in South Australia and the monitoring data is used to produce Aquatic Ecosystem Condition Reports (AECRs). These reports are useful for identifying the need to consider stream flow management requirements for aquatic habitats. The AECR provides a range of information on the stream flora and fauna habitats as well as activities that are having an impact on the health of the stream such as stormwater inflow and bank erosion. In addition the reports provide an overall condition rating and proposed actions for improving the health of the stream. AECR reports are valuable source of information and available on the SA EPA website[4]. An example of the imagery available at this website is shown in Figure 5-4

Figure 5-4 – An image of Scott Creek, Adelaide Hills from the AECR resource (Source: EPA SA)

Several major streams in the Greater Adelaide region have major reservoirs for storing catchment runoff, intended for reticulated (potable quality) water supply by SA Water. In collaboration with SA Water, the Adelaide and Mount Lofty Natural Resources Management Board have implemented a program of environmental flow releases. The releases are designed to reduce the impact that the reservoirs have on flow regimes and aquatic habitat by returning water to the rivers in a manner that broadly reflects natural flow patterns. This includes a carefully planned regime of low flows, freshening and higher volume flushes that are essential for the health of the plants, fish and insects found in the rivers. More information on the regulated environmental flow releases can be found at the AMLR NRMB website[5].

5.4 Stream Flow Analysis

In the majority of cases it is the hydrological process and associated flow regimes that dictate stream habitat characteristics and shape. (van Laarhoven & van der Wielen, 2009) list a number of components where aquatic and riparian biota are dependent on stream flow regimes and they are:

- flows that stimulate fish spawning
- flows that flush excess sediment from the stream bed

[4] http://www.epa.sa.gov.au/data_and_publications/water_quality_monitoring/aquatic_ecosystem_monitoring_evaluation_and_reporting

[5] http://www.naturalresources.sa.gov.au/adelaidemtloftyranges/water/managing-water/water-courses/environmental-flows

- groundwater levels that are accessible to vegetation
- flows that entrain organic material from the floodplain
- flows that maintain channel forms

To understand the characteristics of the flow regimes, statistical analysis of a long stream flow time series is required. Several statistical parameters that describe flow regime indices are examined, however the two key ones are:

- flow spell duration frequency (SPDF) : inter flow event frequency characteristics, and
- channel forming flows (CFF): flow rate and time characteristics

SPDF is needed when identifying the flow spell and CFF rate thresholds. It provides the percentage of time that a stream flow exceeds a particular flow rate for the period of time being examined. The analysis is typically presented in a graphical format as a flow duration curve (FDC). (Lee et al., 2008) describes the use of FDC for examining the use of WSUD measures for improving flow regimes in urbanised catchments. Flow duration frequency analysis is particularly focussed on the stream low flows that occur in the range of 70 to 90% time exceedance (Smakhtin, 2001). (van Laarhoven & van der Wielen, 2009) set the low flow threshold at 80% of flow time exceedance (i.e. non zero periods) for streams in the Mount Lofty Ranges region. This range is important as the type and extent of stream ecosystems mainly exists due to the low flow characteristics.

FDCs vary according to the catchment characteristics and the hydrological and hydrogeological processes that interact with the stream. Base flow has a strong influence on flow duration characteristics. Scott Creek to the south of Adelaide has base flow for the majority of the year so the flow duration curve extends past the 90% time exceedance level. For all streams, including ones such as Scott Creek, a diverse range of flora and fauna habitats will be dependent on low flows and base flows but it will also be important to assess additional flow regime indices, such as spell duration and CFFs. Examples of streams with significant base flow are presented in Figure 5-5 for Scott Creek (based on 30 years of flow monitoring data) and Myponga River (based on 33 years of flow monitoring data). While the FDC for streams are generally determined using a daily time step, a shorter timestep was available and data is presented on this basis, resulting in a slightly steeper FDC in each case.

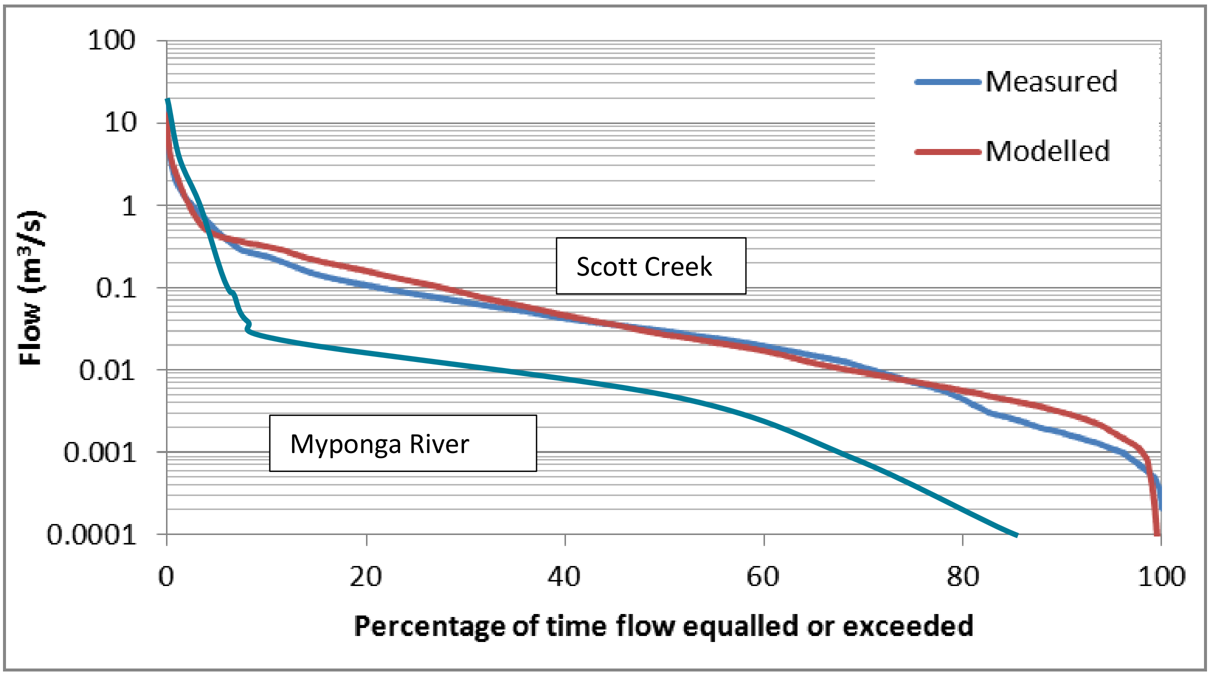

Figure 5-5 - Scott Creek and Myponga River flow duration curve (data source at 5 min time step)

For catchments with significant dam storage or no natural base flow the flow duration curve might only extend to 10% time exceedance or less. Figure 5-6 shows the flow duration frequency for Dry Creek in the City of Salisbury, based on 22 years for flow observation at Bridge Road. For smaller catchments the flow time exceedance will be less than 10%, as show in Figure 5-7 (Myers et al., 2014b). This shows the flow duration curve for pre and post development cases for a small catchment (16 Ha) located at Flagstaff Hill south of Adelaide. The analysis was determined using a hydrological model using 21 years of historical rainfall data at a six minute time step.

A short frequency duration (10% of the year) is generally common for many of the unregulated streams located in the Greater Adelaide region, particularly in the upper reaches where the catchment is small. Where there is little or no water dependent habitat in a catchment, consideration of low flow and spell duration may not be required and changes to the frequency of CCFs are most important.

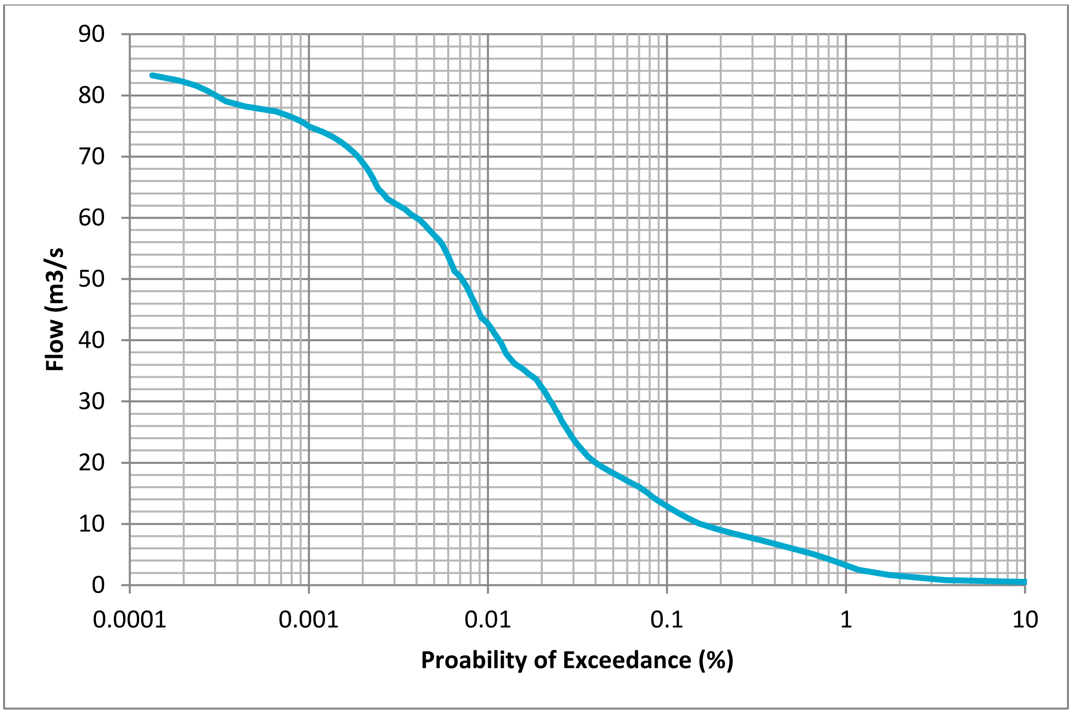

Figure 5-6 - Dry Creek flow duration curve based on 22 years for stream flow records (5 min time step)

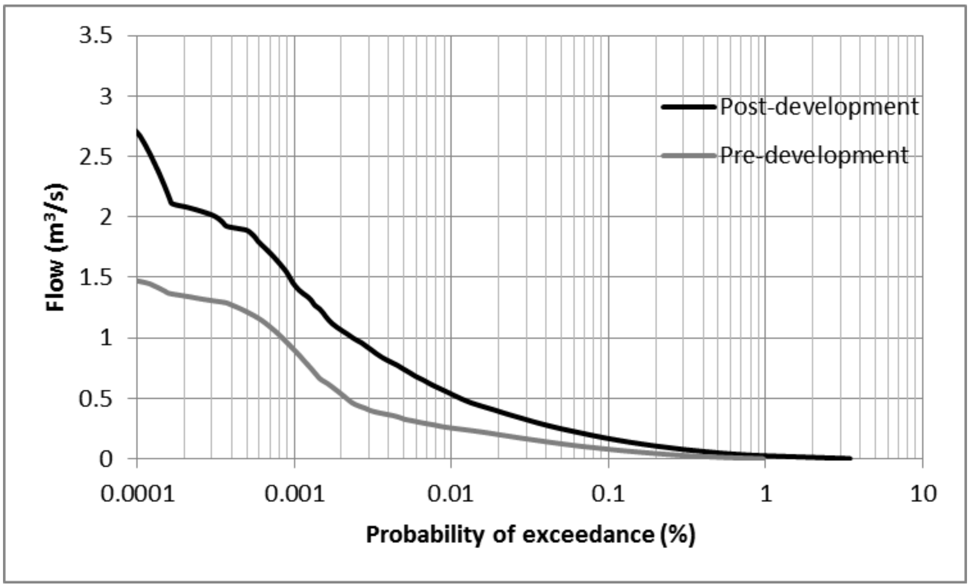

Figure 5-7 - The Pre- and post-development flow duration curve for the Flagstaff Pines catchment prior to the detention basin (Myers et al., 2014b)

5.4.1 Spell Duration Frequency

Spell duration analysis is generally carried out to identify the inter-low flow event duration characteristics. This information is important for understanding the ability for stream habitats to tolerate periods of very low flow and/or no flow events. A spell is considered to occur when there is a period of time below a low flow threshold. The threshold value corresponds to a percentage of time that flow is exceeded and this is usually determined by identifying the requirements of the stream flow dependent habitat. Smakhtin (2001) mentions that the low flow threshold varies for streams but they are generally between 70% and 99% of the time exceedance, derived by frequency analysis of observed stream flow data. This is consistent with the South Australian Government adoption of 80% time exceedance (van Laarhoven & van der Wielen, 2009) for streams in the Adelaide Mount Lofty ranges. The low flow threshold may also been expressed as a percentage of mean daily flow corresponding to the flow frequency duration curve (Smakhtin, 2001), but there has been limited application of a threshold in this format in SA (Lee et al., 2008).

(Lee et al., 2008) undertook a spell duration analysis of Scott Creek. The threshold adopted for the analysis was derived from an aquatic habitat study and it was found that the low flow threshold was equivalent to the 90% time exceedance. Figure 5-8 presents a spell duration analysis for Scott Creek, including the natural (observed) case, the urbanised case and the urbanised case with simulated WSUD measures. For the urbanised case without WSUD measures there is a significant increase in the spell frequencies for the low the medium spell periods while at the long spell period the difference is small. WSUD measure 1 examined retention systems with infiltration to natural soil, a storage depth of 30 to 50 mm and an equivalent infiltration basin area approximately 5% of each subcatchment. The soil hydraulic conductivity used was 0.35mm/h. The model allowed the retention storage to spill when its capacity was exceeded. WSUD measure 2 examined retention systems with infiltration to natural soil and an extended detention release, a storage depth of 1 m and an equivalent infiltration basin area approximately 3% of each subcatchment. The soil hydraulic conductivity used was also 0.35 mm/h. The model allowed the retention storage to spill when its capacity was exceeded. The analysis did not distinguish the spell frequencies for wet and dry seasons which may be important for stream flows without significant base flow because of the seasonal nature of rainfall in the Adelaide and Mount Lofty Ranges.

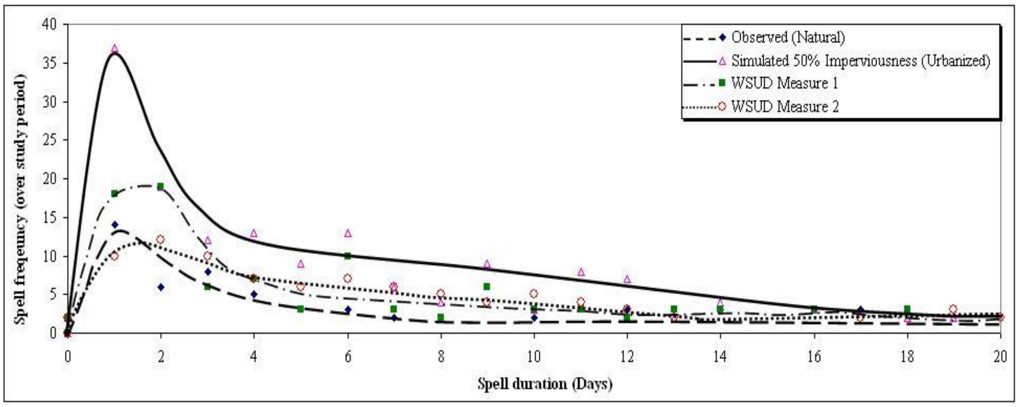

Figure 5-8 - Spell duration curve for Scott Creek, showing spell frequencies for natural, urban and two WUSD measures (Lee et al 2007) Note: WSUD1 case represents retention strategy with infiltration to natural soil

while the WSUD2 case is a combination of extended detention runoff discharge and infiltration to the natural soil.

Storage allowances in WSUD systems such as wetlands could be considered for controlled releases to suppoer aquatic habitat, however the availability of excess water is unlikely to exist during lengthy dry periods. WSUD measures that have extended detention and infiltration to natural soil processes do have the potential to mimic the low flow regimes and this will assist in reducing the spell periods. The use of historical stream flow and hydrological model research on SA catchments (Subhashini, 2014; Wella-Hewage et al., 2016) has also demonstrated that it is possible to maintain pre-developed stream flow regimes when WSUD measures with extended detention and infiltration losses are distributed across a catchment.

Consideration should also be given to WSUD measures that extract stream flow, such as harvesting schemes, such as those involving managed aquifer recharge. While there is little investigation into these catchments, investigations into flow interception in rural areas by van Laarhoven and van der Wielen (2009) showed there was a correlation between water extraction (water used) and the number of flow regime metrics that 'passed' (thresholds or targets being met), as presented in Figure 5-9.

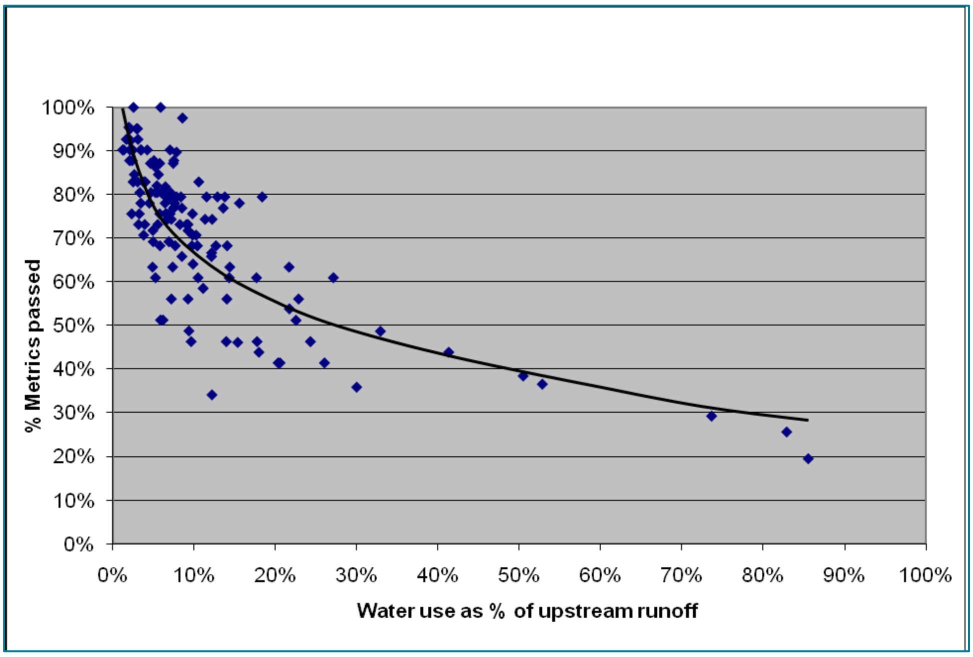

Figure 5-9 – Correlation between water extraction and the number of flow regime metrics being met in the Mount Lofty Ranges streams (van Laarhoven & van der Wielen, 2009)

5.4.2 Channel Forming Flows

Channel forming flows (CFF) are an important stream flow indicator for understanding flow regimes that influence the stream shape. Flows that influence the stream shape will vary according to local conditions but they are flows that initiate bed movement and lead to bank erosion. Some examples of stream bank erosion in the Adelaide metropolitan area are shown in Figure 5-10 (Thrushgrove Creek, Morphett Vale) and Figure 5-11 (Dry Creek, Pooraka). These examples reveal the risks that bank erosion present to neighbouring properties. Bank erosion is a function of flow rate, flow duration and the stream erosion potential index. The erosion potential index is based on the shear stress of the stream channel and takes into account a number of factors including the stream reach length, channel confinement, bank material characteristics, vegetation, channel slope and geometry. (Subhashini, 2014) suggests caution should be exercised in using the shear stress index when determining the full bank flow capacity as this approach does not account for the frequency of the flows below the stream capacity and their erosive effects. This highlights the importance of maintaining the flow frequency relationship well below the full bank flow capacity.

Figure 5-10 – Image of severe creek erosion in Thrushgrove Creek, Morphett Vale

Figure 5-11 – Image of Dry Creek bed in Pooraka, showing unsuccessful measures at scour protecting private properties

According to a literature review by (Subhashini, 2014), the reported CFF frequency level varies. However, the reported recurrence interval is generally between 1 and 2 years. (Harman et al., 2008) assessed 114 river sites in Southern Australia (Victoria) and compared the full bank geometry with several independent variables, including flood discharge, bed and bank texture and proportion of riparian vegetation. The assessment concluded that the 2-year recurrence stream flow interval was found to be the dominant variable with a strong correlation to stream width and depth characteristics. (Brown et al., 2009) noted considerable variability and suggested a lower threshold flow equivalent to 20% of the CFF be considered to account for sediment movement and deposition that results in geomorphological changes. (van Laarhoven & van der Wielen, 2009) also refer to the link between 2 year recurrence flow and channel form and scour of sediments. It also mentioned that lowering the magnitude of the 2 year recurrence interval flow rate may have undesirable consequences that are not well understood.

CCF analysis is carried out by examining historical flow data or the flow outputs of a suitable continuous hydrological model that is considered to be reliable. Ideally a hydrological model should be calibrated and tested to observed data (Subhashini et al., 2013) and when data does not exist caution should be exercised in the interpretation of model inputs and outputs. The recurrence interval is determined by undertaking a partial series analysis as described in *Australian Rainfall and Runoff* (Pilgrim, 1999). An example of a partial series analysis for Dry Creek is presented in Figure 5-12. The partial series analysis was applied to 22 years of historical stream flow data (1994 to 2016) at 5 min time steps. It shows the 2 year ARI flow is approximately 40 m^3/s. It should be noted that the Dry Creek catchment is partially urbanised and has been undergoing further urbanisation over this timeframe, which may impact the determination of CFF. The observed flow data in this case is expected to be higher than would be the case for a pre-developed, natural catchment. Applying the condition of maintaining the 2 year ARI flow, Figure 5-13 shows the portion of the flow duration curve that requires attention when targeting CFFs.

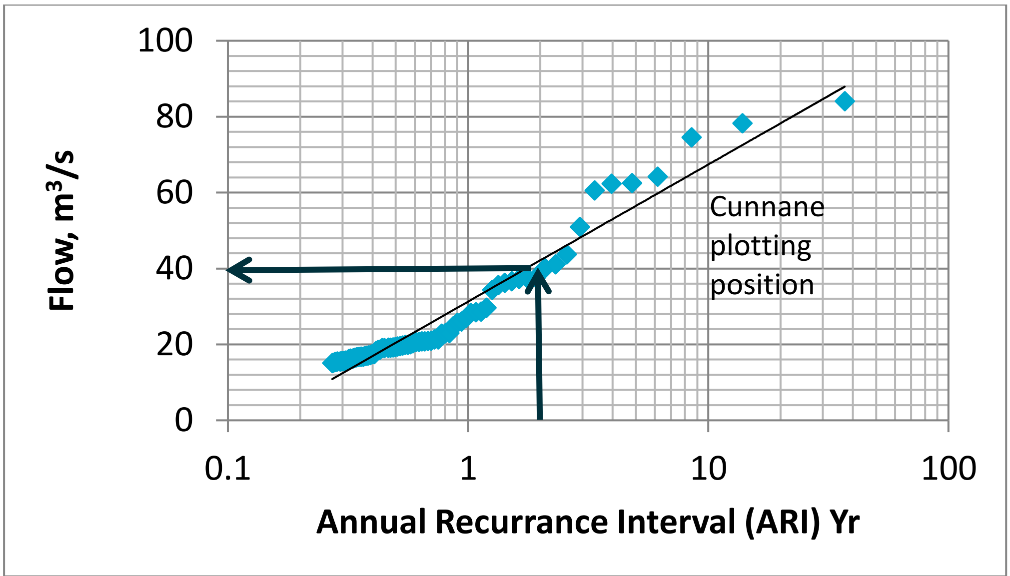

Figure 5-12 - Dry Creek flow duration curve based on 22 years of stream flow record (5 min)

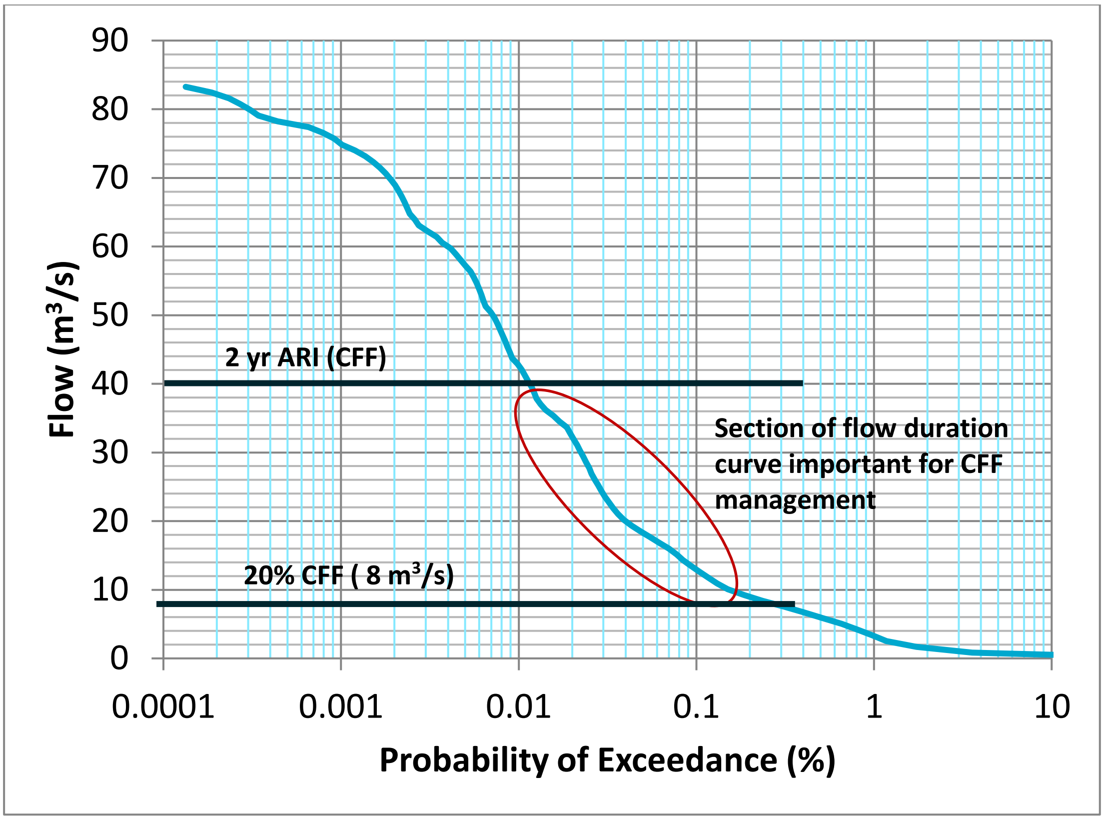

Figure 5-13 - Portion of the Dry Creek flow duration curve for managing CFFs

5.5 Recommendations

The recommendations below are intended to provide guidance on the assessment of stream flow for the protection of habitat and management of stream geomorphology based on local information and literature. The approaches for undertaking stream flow assessments allow the impact of urban development to be examined and to identify stormwater management options (such as WSUD) which may assist in maintaining or preserving the pre-development condition of aquatic habitat and stream geomorphology.

5.5.1 Streams where water dependent habitat have not been assessed.

- Where streams have water dependent habitat, an assessment of the flora and fauna types should be undertaken. This may require specialists, such as an aquatic scientist, to assess the habitat and its dependence on stream flow characteristics. The stream assessment data provided by the EPA SA is a useful on-line source of information on stream habitats and stream condition. The SA Government Department for Environment, Water and Natural Resources should also be consulted. (van Laarhoven & van der Wielen, 2009) provide a substantial body of information for streams located in the Adelaide and Mount Lofty ranges region.

- Where poor water quality in stream flows have been identified, strategies for water quality improvement in the catchment should be pursued. Catchment managers may also consider using tools like MUSIC to identify the potential problem source and solutions (Section 4).

5.5.2 Streams where water dependent habitat has been identified.

- Where significant or important stream habitat has been identified, flow analysis is recommended. The analysis should determine spell duration and flow frequency characteristics relevant to the stream habitat. The impact of altering the catchment land use should be examined and the strategies required for managing the impacts and maintaining flow characteristics that support stream habitat should be identified.
- Where pre- and post-development land use change scenarios require an assessment of stream flow characteristic, a suitable hydrological model should be used. The model should be capable of continuous modelling using 10 to 20 years of input data (historical flow or rainfall). Where flow data does not exist, the model should adopt representative hydrological characteristics and processes. Data sets for the South Australia and, more specifically, the Adelaide metropolitan region, which have a minimum 10 year time series were provided in Section 4 and may be suitable if local data is not available or not of adequate quality.
- In line with the findings of (van Laarhoven & van der Wielen, 2009), a flow frequency of 80% (excluding non-flow events) should be adopted when examining spell duration frequencies.
- Consideration should be given to the flow requirements for deep pools, shallow riffles, bank and bank full bench levels in streams.
- Water quality requirements should be considered using tools such as those outlined in Section 4.

5.5.3 Streams with little or no significant dependent habits

- In all cases where land use changes will alter the hydrological processes, pre- and post-development flow regimes should be assessed for CFF characteristics. The post-development CFF should be as close as possible to the pre-development CFF with the objective of maintaining a stable natural stream shape without excessive erosion, sediment transport and deposition. The CFF or full bank flow should be set at the 2 year ARI. To manage erosion, sediment transport and deposition during low flow periods, flow duration frequency below the CFF level should be maintained, preferably to 20% of the CFF rate.

- The model should be capable of continuous modelling using 10 to 20 years of input data (historical flow or rainfall). Where flow data does not exist, the model should adopt representative hydrological characteristics and processes. Small computational time steps 10 min or less should be selected when the response time of the catchment is less than 2 hours. Recommended data sets for the Adelaide metropolitan regions outlined for MUSIC modelling in Section 4 should be considered where local data is not available or not adequate.

5.6 Summary

The importance of flow regime management is recognised in the existing WSUD policy document from the (SA Department of Envrionment Water and Natural Resources (DEWNR), 2013). ‘Mimicking a more natural runoff regime’ downstream of urban areas is reflected in the water quality and water quantity objectives. It is also recognised in the ‘State-wide WSUD Performance Principles and Performance Targets’ provided by this document. Specifically, under the performance principle for runoff quantity, there is an intent to ‘Help protect waterways and, where relevant, promote their restoration by seeking to limit flow from development to predevelopment levels’.

WSUD strategies that have a mixture of detention and retention/infiltration functions have the ability to produce flow regimes that are similar to predeveloped flow regimes and should be considered when developing stormwater management plans.

It is important that there is an appropriate understanding of the land use change impact on the stream flow regimes. Where a water dependent stream habitat exists, special consideration to stream flow regimes is required and this involves an assessment for low flow and spell duration frequency. Where a stream hosts little or no water dependent habitat, consideration of low flow and spell duration frequency is not necessary or is less important than the changes to the frequency of CFFs, and the preservation of CFFs should be prioritised to ensure erosion, sediment transport and deposition is not increased. These flows are linked to persistent geomorphological changes to the stream channel and are associated with stream erosion and sediment loads which discharge to receiving water bodies such as the Adelaide coastal waters or the River Torrens Lake.

5.7 REFERENCES

Brown, S, Porter, S & Hecht, B 2009, *Hydromodification management plan for the Fairfield-Suisun Urban Runoff Management Program* Balance Hydraulics Inc. and the Fairfield-Suisun Urban Runoff Management Program, Berlkely, CA, USA.

Burns, M, Fletcher, T, Walsh, C, Ladson, A & Hatt, B 2014, 'Flow-Regime Management at the Urban Land-Parcel Scale: Test of Feasibility', *Journal of Hydrologic Engineering,* vol. 20, no. 12, 2015/12/01, p. 04015037.

Harman, C, Stewardson, M & DeRose, R 2008, 'Variability and uncertainty in reach bankfull hydraulic geometry', *Journal of Hydrology,* vol. 351, no. 1–2, 3/30/, pp. 13-25.

Lee, A, Hewa, G, Pezzaniti, D & Argue, JR 2008, 'Improving Stream Low Flow Regimes in Urbanized Catchments Using Water Sensitive Urban Design Techniques', *Australian Journal of Water Resources,* vol. 12, no. 2, pp. 121-132.

Myers, B, Pezzaniti, D, Kemp, D, Chavoshi, S, Montazeri, M, Sharma, A, Chacko, P, Hewa, GA, Tjandraatmadja, G & Cook, S 2014b, *Water Sensitive Urban Design Impediments and Potential: Contributions to the Urban Water Blueprint (Phase 1) Task 3: The Potential Role of WSUD in Urban Service Provision*, Goyder Institute for Water Research, Adelaide, South Australia.

Pilgrim, DH (ed.) 1999, *Australian Rainfall and Runoff*, 3 edn, The Institution of Engineers, Australia, Barton, ACT, Australia.

SA Department of Envrionment Water and Natural Resources (DEWNR) 2013, *Water sensitive urban design - creating more liveable and water sensitive cities for South Australia*, Government of South Australia, Adelaide, SA, Australia. viewed October 2013,

Smakhtin, VU 2001, 'Low flow hydrology: a review', *Journal of Hydrology,* vol. 240, no. 3–4, 1/10/, pp. 147-186.

Subhashini, WHC, G.A., H & Pezzaniti, D 2013, 'Assessing the ability of infiltration-based WSUD systems to manage channel-forming flow regimes in greenfield catchment developments: A catchment scale investigation', *20th International Congress on Modelling and Simulation*. <www.mssanz.org.au/modsim2013>.

Subhashini, WHC 2014, 'Methodologies to assess the performance of WSUD systems in greenfield catchment developments', PhD thesis, School of Natural and Built Environments, University of South Australia, Adelaide, Australia.

van Laarhoven, J & van der Wielen, M 2009, *Environmental water requirements for the Mount Lofty Ranges prescribed water resources areas*, Department of Water, Land and Biodiversity Conservation, Adelaide, South Australia.

Walsh, CJ, Fletcher, TD & Burns, MJ 2012, 'Urban stormwater runoff: a new class of environmental flow problem', *PLoS One,* vol. 7, no. 9, p. e45814.

Wella-Hewage, CS, Alankarage Hewa, G & Pezzaniti, D 2016, 'Can water sensitive urban design systems help to preserve natural channel-forming flow regimes in an urbanised catchment?', *Water Sci Technol,* vol. 73, no. 1, pp. 78-87.

Part VI Conclusions

This project was Phase 2 of the Goyder Institute for Water Research 'Water Sensitive Urban Design' (WSUD) (U.1) Urban Water Theme. The purpose of this project was to address the outcomes of Phase 1, which identified key areas that influenced the impediments for WSUD uptake and where opportunities exist to overcome impediments. Several potential activities were outlined and the most desirable activities were selected for this project based on a priority ranking activity involving the Goyder WSUD project Phase 1 Steering Committee (including state government, local government and industry representation).

The project was strongly aligned with Goyder Institute for Water Research WSUD roadmap priorities as well as Action 10 of the SA Government WSUD Policy document: "Promote support for WSUD in catchment-based Stormwater Management Plans". The refinement of existing WSUD approaches in stormwater management plans (SMPs) recently commenced and is expected to be completed in December 2016.

The project has delivered two separate reports, as follows:

1. Pathways for Implementation of Water Sensitive Urban Design Policy in South Australia
2. Implementing Water Sensitive Urban Design in Stormwater Management Plans

Report 1 undertook the following activities:

- A review of WSUD policy in other Australian jurisdictions;
- A review of the current policy framework for WSUD and development planning and approval in South Australia; and
- Identification of potential avenues to better incorporate WSUD principles in the planning process for new developments in South Australia.

The review of experiences of other Australian jurisdictions revealed that all states have undertaken efforts to incorporate WSUD principles into the planning and development process at state/territory and local government levels. However, only Victoria and the ACT have what may be considered a form of mandated WSUD targets at the state level. In other cases, state level policies and guidelines provide a framework, but implementation is typically at the local government level through local planning instruments. In SA, mandatory WSUD is limited to the requirement for an alternative water source for new developments and some extensions, and is otherwise not mandatory, with other measures subject to interpretation by the approving authority.

Potential avenues to better incorporate WSUD principles in the planning process for new developments in South Australia were:

1. Implementation of WSUD in local government development plans. This included three different approaches including:
    a. The application of existing WSUD principles for proposed developments based on existing principles in the Natural Resources section of most development control plans.
    b. The adoption and application of additional, more specific WSUD principles to development plans using the development plan amendment process.

    c. The adoption and application of additional, more specific WSUD principles in the South Australian Planning Policy Library for uptake by local governments.
2. Implementation of WSUD objectives and targets into minimum engineering service level standards.
3. Implementation of WSUD into an amended residential code.
4. Implementation of a stormwater quantity and/or quality control service charge.
5. Implementation of further mandatory WSUD requirements into the SA component of the Building Code of Australia.
6. Production of further Minister's Specifications regarding WSUD in new development works.

It was also noted that the SA Government was currently undertaking a planning reform process and that to achieve the best outcome in a range of development contexts and scales there may need to be a mix of policy instruments that enable WSUD uptake at different levels of the planning hierarchy.

Report 2 contributed to a growing body of research that is informing the uptake of WSUD in South Australia from a technical perspective. The following activities were reported:

1. A review of existing SMPs in South Australia, and in particular evaluating how WSUD approaches had been considered, assessed and recommended;
2. An evaluation of the implications of antecedent conditions on the performance of WSUD storage devices;
3. Recommendations on the use of the already widely applied MUSIC software tool for planning and designing WSUD approaches in South Australia; and
4. Analysis of how frequent flows should be considered in planning stormwater management approaches incorporating WSUD.

The review of existing SMPs in SA demonstrated that they were based on rigorous and comprehensive analyses, and considered WSUD to manage stormwater quantity and quality. However, there were limitations and inconsistencies in the way in which WSUD was proposed, analysed and reported and recommendations to improve the inclusion of WSUD were reported.

The hydrological assessment of storage based WSUD systems for quantity management demonstrated that the design of WSUD systems for flow and runoff volume management is influenced by antecedent conditions. This can limit the effectiveness of the current standard practice of using design storm events for sizing WSUD retention and detention systems. While no guideline currently exists with appropriate alternative methodologies, it is understood that the revised *Australian Rainfall and Runoff* guideline will include consideration of an approach, which should be referenced in any revision of the current SMP guidelines.

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is commonly applied in Australia and SA to estimate stormwater runoff volume, pollutant loads and the effectiveness of WSUD approaches in reducing them. Unlike other states, there were no guidelines for the use of MUSIC specific to SA. This project developed recommendations for the use of MUSIC in SA at the SMP or developer level. This included identifying opportunities for further research and refinement of guidelines.

Frequent flow management approaches for maintaining natural (pre-urbanised catchment) stream habitat and geomorphology were reviewed. Case studies and approaches were investigated and a set of recommendations were developed. This included the need to adopt a minimum flow frequency threshold for maintaining aquatic habitats and the pre-urbanised two year recurrence interval flow rate for geomorphology management. Guidance on the type of WSUD functions that mimic the natural flow regimes was provided.

Appendix A – Assessment of WSUD Content in Individual Stormwater Management Plans

The consideration of WSUD in stormwater management plans was conducted using the framework provided in Section 2.2.

A.1 Truro SMP

The Truro SMP (Australian Water Environments, 2010a) was conducted on the urban area of Truro within the Mid Murray council local government area. The study boundaries extended to the north side of Truro Creek with 620 Ha of contributing catchment. There was limited urban growth projected for the catchment, and as such the study tended to focus only on drainage and water quality and quantity improvement measures in the existing township of Truro.

1. WSUD was considered by the SMP (e.g. Section 8.3).
2. WSUD measures were included in the SMP recommendations (Section 9).
3. WSUD measures proposed for the Truro township were assessed to determine their water quality, harvesting or flow reduction benefits using MUSIC (Section 8.4).
4. Alternative WSUD options were presented at some sites, but no decision making process was noted (Section 9).
5. The WSUD measures were prioritised in a ranked list of projects along with the flood mitigation infrastructure works (Section 9).
6. The SMP estimated the cost of WSUD measures. These were presented as capital and recurring costs (Section 9).
7. WSUD measures were typically proposed separately to other stormwater management measures. The opportunity to undertake them in conjunction with other works was not noted, except in the case of one GPT which was indicated to be an opportunity with a new pipe upgrade (Section 8.3.2 c)
8. The plan did not provide policy recommendations with respect to WSUD, but this may be due to the limited growth projection for the area considered by the SMP.
9. Opportunities for harvesting were considered (Section 7 & 8)
10. Opportunities to reduce runoff volume were considered (Section 8.3.2 a, b).
11. Opportunities to improve water quality were considered (Section 7 & 8).
12. Objectives for WSUD were set in the SMP (Section 4).
13. The objectives were qualitative and based on consultation (Section 4).
14. Quantitative targets for water quality were identified, encompassing TSS, TP and TN concentrations in runoff from the catchment (Section 8.1).
15. The water quality targets were based on concentration values in the EPA SA's *Environment Protection (Water Quality) Policy* (Section 8.1).

16. The impact of WSUD on runoff volume was identified (Section 9). There was no methodology presented in the SMP to support data.
17. The impact of WSUD on peak flow rate was not assessed.
18. The impact of WSUD on water demand was not assessed.
19. There were no harvesting schemes suggested for the catchment, and there were no sources of demand identified.
20. The impact of the WSUD recommendations on water quality was assessed (Section 8.4).
21. The WSUD measures considered in this SMP were GPTs, kerb protuberances, erosion protection and passive street tree irrigation. Permeable paving and bioretention basins were also considered but were thought to have limited application and benefit to the catchment.

A.2 Streaky Bay SMP

The Streaky bay SMP (Tonkin Consulting, 2011) was conducted for the District Council of Streaky Bay on a catchment area of 2238 Ha, of which 870 Ha was a current urban area or area of potential future urban growth. The boundaries were determined by considering the area influenced by the existing township and future areas zoned for residential growth.

1. WSUD was considered by the SMP (e.g. Section 5).
2. WSUD measures have been included in the SMP recommendations (Sections 5 & 6).
3. No analysis or simulation was reported to support the effectiveness of WSUD recommendations. Reference was made to a previous report in the urban area of the catchment by DesignFlow (Section 5.2), but the nature of or results of any simulation was not indicated.
4. WSUD options were considered in the SMP however there were no alternatives presented for any one feature (Section 5.2). While this process may have taken place in the cited DesignFlow report, it was not reported.
5. WSUD measures were prioritised into High-Medium-Low priority timelines. WSUD measures were listed with other infrastructure upgrade works (Table 6.1).
6. The SMP estimated the cost of WSUD measures. These were presented as capital cost only (Table 6.1).
7. The WSUD recommendations did not always compliment other works. However the installation of a swale was noted to be required for drainage and water quality benefits (Section 5.2). Also, existing infrastructure was reported to play a role in the proposed water reuse scheme (Section 5.3)
8. The plan makes policy recommendations for greenfield land development to manage water quality during construction and to demonstrate consideration of WSUD (Section 5.2).
9. Opportunities for harvesting were considered (Section 5.3).
10. Opportunities to reduce runoff volume were considered as a benefit of harvesting (Section 3.2.3).
11. Opportunities to improve water quality were considered (Section 5.2).

12. Objectives for WSUD were set by the SMP (Section 3.3.2, 3.3.3, 3.3.4).
13. The basis of these objectives was not clearly reported.
14. There were no quantitative targets used for assessment of WSUD options.
15. Recommendations for WSUD works were made with reference to a previous report titled *Streaky Bay: Reducing stormwater impacts on coast and marine environments* (Designflow, 2010) but there was no indication of a quantitative target.
16. The impact of WSUD on runoff volume was assessed for a harvesting scheme (Section 5.3). However there was no methodology reported to support the estimated harvest.
17. The impact of WSUD on peak flow rates was not assessed.
18. The impact of WSUD on water demand was not assessed.
19. The potential demand for the proposed water harvesting scheme was not assessed in detail. However, the study indicates a need to assess the demand for harvested water (Section 5.3), and it is noted that existing wastewater recycling schemes do not meet the current irrigation demand (Sections 2.6, 3.2.3).
20. The impact of WSUD on water quality was not assessed.
21. The WSUD works recommended include a wetland, swales, rain gardens and a harvesting scheme (Section 5).

A.3 Wasleys SMP

The Wasleys SMP (Australian Water Environments, 2010b) was conducted on a catchment in the Light Regional Council local government area. The catchment was bounded by the extent of the current Wasleys township, with consideration of surrounding rural areas and Templers Creek which provided runoff to the township.

1. WSUD was considered by the SMP (e.g. Sections 7 and 8).
2. WSUD measures were included in the SMP recommendations (Section 9).
3. Simulation was conducted to support the harvesting scheme recommended by the SMP. This included an Excel based water balance model and a MUSIC model to estimate runoff volumes approaching the harvesting scheme (Section 7).
4. WSUD options were considered in the SMP however there were no alternatives presented for any one feature (Section 6 & 7).
5. One WSUD measure, a water harvesting scheme, was recommended as part of a prioritised list of works (Table 13).
6. The SMP estimated the cost of the WSUD measure. These were presented as capital and recurring costs (Table 13).
7. WSUD recommendations were generally independent from other scheduled drainage works however the harvesting scheme was tied to a proposed urban development in the plan (Sections 6 & 7).
8. The plan made policy recommendations regarding WSUD by stating a need for a detention requirement on new urban subdivisions (Section 6.6.1).
9. Opportunities for harvesting were considered (Section 7).

10. Opportunities for runoff quantity management were not explicitly referred to in the plan however may be considered to be a benefit of the proposed harvesting scheme (Section 8).
11. Opportunities to improve water quality were considered (Section 8).
12. Objectives relating to WSUD were stated (Section 3.2).
13. The basis for qualitative objectives was consultation with the community (Section 3.1).
14. There was no targets established for assessing WSUD options, although the pollutant loads of runoff were quantified (Section 8)
15. -
16. The impact of WSUD on runoff volume was assessed (Section 7). The methodology was reported (Section 7.2.3).
17. The impact of WSUD on peak flow rates was not assessed.
18. The impact of proposed WSUD on water demand was assessed (Section 7.2.2).
19. The potential demand sources of water from the proposed stormwater harvesting scheme was reported (Section 7.2.2) including a projected security of supply (Section 7.2.6).
20. The impact of WSUD measures on water quality was assessed (Section 8). Note that there appears to be no target or baseline for the interpretation of results (Section 8).
21. Rainwater tanks and water reuse were considered as part of this SMP. Swales were recommended for drainage infrastructure, however these were recommended as cuttings, with no consideration of water quality benefit indicated.

A.4 Brown Hill Keswick Creek Stormwater Project SMP (2012)

The Brown Hill Keswick Creek Stormwater Project SMP (WorleyParsons Services Pty Ltd., 2012) was conducted on a catchment that encompasses Brown Hill, Keswick, Parklands and Glen Osmond Creeks. The 68.7 km^2 catchment area considered by the SMP is noted to have a 'high flood risk, a low standard of flood protection, and a long history of flooding issues' (p.1). The SMP is a follow up to a previous stormwater Master Plan, and is unique due to the size of the catchment, the extent of works recommended for flooding and the extent of previous reporting supporting recommended and commenced flood control and WSUD works. Several WSUD systems discussed within the plan were being constructed at the time it was written (e.g. aquifer storage and recovery at Ridge Park, wetlands in the Southern parklands of the CBD).

1. WSUD was considered by the SMP (e.g. Report A, Section 13.9, Report B, Section 2.4).
2. WSUD measures were not included in the SMP recommendations (Report B, Section 2.4) but were considered and recommended as part of the report body (Report B, Section 4.3)
3. WSUD was not assessed as part of the SMP.

4. There were several WSUD opportunities considered as part of the SMP which were rejected based on previous studies of their impact of the central issue of flood control in the catchment (Report B, Section 2.4).
5. WSUD options were not prioritised; works include a stream rehabilitation program which is mainly focussed on channel capacity.
6. WSUD options were not costed.
7. Yes, the option of harvesting was proposed based on the development of a flood detention basin (Report B, Section 2.4.1).
8. The plan made policy recommendations regarding WSUD. These included the adoption of text by all affected councils from the *South Australian Planning Policy Library* regarding WSUD (Report A, Section 5.2) and the continued adoption of WSUD by councils (Report A, Objectives 3.2 and 3.3).
9. Opportunities for harvesting were considered (Report A, Section 13.8).
10. Opportunities for runoff quantity management were not specifically reviewed by the plan.
11. Opportunities to improve water quality were not considered, and the plan makes it clear that there were no investigations that would enable a water quality target to be set in the catchment (Report A, Section 13.9, Objective 2.1).
12. Objectives relating to WSUD were stated (Report A, Section 13.9).
13. Objectives were based on the EPA SA's *Adelaide Coastal Water Quality Improvement Plan*, (Section 3.1) and harvesting objectives were attributed to an Adelaide and Mount Lofty Ranges Natural resource management Board target of 75%, which was not tied to a specific source.
14. No, WSUD related infrastructure was not specifically proposed by the plan
15. -
16. The impact of WSUD on runoff volume was not assessed.
17. The impact of WSUD on peak flow rates was not assessed.
18. The impact of WSUD on water demand was not assessed.
19. Demand sources of water from the proposed stormwater harvesting scheme were not reported, although there was a detailed overview of existing schemes and their capacity (Report A, Section 13.8).
20. The impact of WSUD measures on water quality was not assessed.
21. The SMP considered only harvesting as part of the SMP. Additional measures were mentioned but not assessed in the catchment. These included wetlands (Parklands Creek Wetlands in the south eastern portion of the Adelaide parklands) and detention (in the form of a detention basin at Ridge Park).

A.5 Port Lincoln SMP

The Port Lincoln SMP (Tonkin Consulting, 2014) was undertaken on a catchment in the City of Port Lincoln local government area. The catchment was approximately 2480 Ha in size and included the urbanised area of Port Lincoln and surrounding rural areas. The area was noted to be growing with some greenfield areas identified for new development.

1. WSUD was considered by the SMP (e.g. Section 4)
2. WSUD measures were included in the SMP recommendations (Table 8.1)
3. Water quality was assessed by the SMP (Section 4), and involved the creation of a MUSIC model to estimate stormwater pollutant loads into Boston Bay and Proper Bay. The performance of some WSUD measures, generally wetlands, was also assessed using MUSIC (see for example Mallee Park wetland and ASR, p. 38)
4. WSUD options were considered in the SMP however there were no alternatives presented for any one feature (Section 4).
5. WSUD measures were prioritised into High-Medium-Low priority timelines and listed with other infrastructure upgrade works (Table 8.1).
6. The SMP estimated the cost of WSUD measures. These were presented as capital and recurring costs (Table 8.1).
7. Some proposed WSUD features were linked with proposed or existing drainage infrastructure. These included the Mallee Park Expansion, with the potential to incorporate a wetland (Section 7.2.1, Strategy 1).
8. The plan makes recommendations for policy to reduce water quality loads from proposed developments (Section 7.2.5) including car parks, land divisions, storage yards and industrial land. Recommendations were in the form of general advice and not quantitative or prescriptive. However, the SMP also recommended increasing the minimum rainwater tank size for new homes (Section 7.3.2).
9. Opportunities for harvesting were considered (Section 7.3.1).
10. Opportunities to reduce runoff quantity were not explicitly referred to (although runoff quantity management was a direct benefit of the proposed harvesting scheme (Section 7.3.1).
11. Opportunities to improve water quality were considered (Section 7.2.1)
12. Objectives for the SMP were established. These objectives were for water use, water quality and harvesting (Section 6.3.2).
13. A literature review of existing targets was undertaken. The review included targets available from the then current *Water Sensitive Urban Design Consultation Statement* (Department for Water, 2011), the *South Australian Water Sensitive Urban Design Technical Manual* (South Australian Department of Planning and Local Government, 2010) and *Australian Runoff Quality* (Wong, 2005).
14. Targets were not developed for modelling.
15. It was noted that *Australian Runoff Quality* (Wong, 2005) was a recognised standard and that this document was used as a guide.
16. The impact of WSUD on runoff volume was assessed to a limited extent (Section 7.3). Although figures for quantity management were provided in MUSIC results for the

proposed wetland, there was no description of how the reduction occurs or any assumption reported that would underpin the estimate.

17. The impact of WSUD on peak flow rates was not assessed.
18. The impact of WSUD on water demand was assessed in the approximate quantification of harvest volumes for proposed schemes (Section 7.3.1).
19. The source of demand for proposed harvesting schemes was not identified. However, demand was considered in the proposal to increase minimum rainwater tank requirements (Section 7.3.2).
20. The impact of proposed WSUD measures on water quality was assessed using MUSIC modelling (see, for example, Section 6.3.1).
21. Water quality measures considered include wetlands (p.38) and GPTs (p.40). The study also cites the outcomes of a 2010 assessment by DesignFlow titled *Port Lincoln: Reducing stormwater impacts on coast and marine environments*, which identified locations for water quality improvement infrastructure. These include rain gardens and buffer strips in key locations with conceptual design and costings.

A.6 Moonta, Moonta Bay, Port Hughes SMP

The Moonta, Moonta Bay and Port Hughes SMP (Southfront, 2014) was undertaken on a catchment area of 54 km^2 (including the 1652 Ha Moonta Mines catchment) and a 2604 Ha area of predominantly agriculture, commercial and residential land use which drains to Moonta Bay. The catchment was located in the District Council of the Copper Coast local government area.

1. WSUD was considered by the SMP (e.g. Section 8).
2. WSUD measures were included in the SMP recommendations (Section 11).
3. MUSIC modelling was conducted to compare the existing scenario and a future scenario including recommended WSUD measures (Section 8).
4. WSUD options were considered in the SMP on a catchment by catchment basis (Section 8.4). In some cases, WSUD features were proposed in a staged manner, however there was no decision making process on the ultimate solution to adopt (all features were provided in the recommendations) (Section 8.4.8).
5. The recommended WSUD measures were prioritised into High-Medium-Low priority and were listed separately to other flood mitigation infrastructure upgrade works (Table 11.3).
6. The SMP estimated the cost of WSUD measures. These were presented as capital and recurring costs (Table 11.3).
7. Several of the proposed WSUD opportunities complemented proposed drainage upgrades and were intended to be undertaken in tandem (Section 8.4).
8. The study does not make any new policy recommendations strictly relating to WSUD. It included an overview of the current policies in place by the District Council of the Copper Coast, including a requirement for rainwater tanks of between 5 kL to 22 kL, depending on development size. The SMP recommended that this policy should remain in place (Section 8.5). It also recommended a more detailed investigation be

undertaken into WSUD opportunities in key areas of concern in the catchment, such as the Moonta cliff tops (Section 11.3.2).

9. Opportunities for harvesting were considered. This included an assessment of key areas of water demand (Section 2.6) and the layout of proposed harvesting measures (Section 8.4.8).
10. Opportunities to reduce runoff quantity were considered (e.g. Section 7.7.1).
11. Opportunities to improve water quality were considered (Section 8.4)
12. Objectives relating to WSUD were stated by the SMP (Section 3). These included water conservation, water quality and integrated design targets.
13. The WSUD objectives were developed with reference to the then Department for Water's *WSUD Consultation Statement* (2011). Reference was made to the proposed target assisting to be in line with the goals of the *Adelaide Coastal Waters Study* (Fox et al., 2007).
14. Quantitative targets, as noted in the objectives, were used to assess proposed WSUD measures.
15. These targets were from the then Department for Water's *WSUD Consultation Statement* (2011).
16. The impact of WSUD on runoff volume was not assessed across the catchment or individually. MUSIC modelling was undertaken to assess the performance of WSUD measures in the catchment (Section 8.6), but the results for runoff volume were not reported.
17. The impact of WSUD on runoff peak flows was not assessed.
18. The impact of proposed WSUD on demand was assessed by quantifying the potential harvest volume of proposed reuse schemes (Table 11). There was no methodology presented for the harvest estimation. Demand was also considered in the recommendation for maintaining rainwater tank requirements which were larger than the state minimum (Section 8.5).
19. The source of demand for proposed harvesting schemes was assessed (Section 2.6).
20. The water quality impact of WSUD recommendations was assessed (Section 8.6).
21. The structural WSUD measures assessed in the SMP included wetlands, bioretention/rain gardens, swales, GPTs, detention storages and rainwater tanks.

A.7 Hallett Cove Creeks SMP

The Hallett Cove Creeks SMP (Southfront, 2013) was conducted on a 715 Ha, mainly residential catchment with some growth potential in defined areas. The catchment was located in the City of Marion local government area.

1. WSUD was considered by the SMP (e.g. Section 7).
2. WSUD measures were included in the SMP recommendations (Section 8, Table 8.1)
3. MUSIC modelling and desktop analysis was conducted to compare the existing catchment scenario and a future scenario which included the proposed WSUD measures (Section 7.5).
4. WSUD options were considered in the SMP however there were no alternatives presented for any one feature (section 7.4).

5. WSUD measures were prioritised into High-Medium-Low priority timelines and were listed with other infrastructure upgrade works (Table 8.1).
6. The SMP estimated the cost of WSUD measures. These were presented as capital and recurring costs (Table 8.1).
7. The WSUD works were not explicitly complimentary to drainage works. However the dual benefits of creek upgrades for drainage and water quality were indicated (Section 7.4.3).
8. Policy recommendations were part of the SMP. These included the recommendation for increasing the minimum rainwater tank size requirements on new development (Section 7.4.5).
9. Opportunities for harvesting were considered (Section 7.4).
10. Opportunities for reducing runoff quantity were considered (Section 3.4, 7.4).
11. Opportunities to improve water quality were considered (Section 7.5).
12. Objectives relating to WSUD were stated by the SMP (Section 3). These included water conservation, water quality and integrated design targets.
13. The WSUD objectives were developed with reference to the then Department for Water's *WSUD Consultation Statement* (2011) and City of Marion's strategic objectives. Reference was made to the proposed target assisting to meet the goals of the *Adelaide Coastal Waters Study* (Fox et al., 2007).
14. Quantitative targets, as noted in the objectives, were used to assess proposed WSUD measures.
15. These targets were from the then Department for Water's *WSUD Consultation Statement* (2011).
16. The impact of WSUD on runoff volumes was assessed (Section 7.5).
17. The impact of WSUD on peak flow rates was not assessed.
18. The impact of the WSUD recommendations on water demand was assessed (Section 7.5).
19. The potential demand for harvested water was assessed (Section 2.6).
20. The impact of WSUD on the water quality was assessed (Section 7.5).
21. WSUD features which were included in the analysis included detention storages, wetlands, rainwater tanks, bioretention swales and GPTs.

A.8 Coastal Catchments Between Glenelg and Marino SMP

The Marion Holdfast SMP (Tonkin Consulting, 2013c) was conducted on a 35 km^2 catchment in the City of Marion and the City of Holdfast Bay. The catchment size made it one of the larger of the approved SMPs. Approximately 30 km^2 was urbanised, with the remaining 5 km^2 represented by open space. The urbanised area was generally residential and commercial. Development trends were identified in detail by a contributing report to the SMP (Jensen Planning and Design, 2009). This indicated infill development may be significant in the catchment. The study identified the impact of infill development on stormwater management in the catchment.

1. WSUD was considered by the SMP (e.g. Sections 8 to 11).

2. WSUD measures were included in the SMP recommendations. These were detailed in Sections 8 (water quality), 9 (harvesting), 10 (watercourse improvement and restoration) and 11 (planning policy measures).
3. The WSUD oriented recommendations were supported by an investigation into their effectiveness. For example, a separate discussion paper was produced as part of the SMP reporting to explore the impact of WSUD oriented policy on infill development (Tonkin Consulting, 2012). Analysis was based on DRAINS modelling. The export of pollutants from the catchment surface and the potential for WSUD measures to reduce the mean annual load of pollutants (in accordance with stated objectives) were also explored in another discussion paper (Tonkin Consulting, 2013b). This was based on MUSIC modelling of the catchment.
4. WSUD options were considered in the SMP however there were no alternatives presented for any one feature (Sections 9, 10, 11, accompanying discussion papers).
5. WSUD measures were prioritised into High-Medium-Low priority timelines and were listed with other infrastructure upgrade works (Section 14).
6. The SMP estimated the cost of WSUD measures. These were presented as capital costs only (Section 13). Additional detail was provided regarding any cost sharing arrangement between the two affected councils.
7. WSUD strategies were proposed as separate projects to other measures. While there was no explicit link made for specific projects, the opportunity for biofiltration to be retrofitted with drainage or road infrastructure upgrades was noted (Section 8.1.1). WSUD was also recommended as a consideration in planning and design of council building projects (Section 8.2) and planning measures are recommended which would apply to new development in the catchment (Section 8.3).
8. The SMP makes a variety of policy recommendations (Section 11). The SMP includes separate discussion papers to support some of the WSUD related policy recommendations (Tonkin Consulting, 2012). This SMP stands alone in providing a detailed economic and technical justification for policy recommendations.
9. Opportunities for harvesting were considered (Section 9).
10. Opportunities for reducing runoff quantity were considered (Tonkin Consulting, 2013b).
11. Opportunities to improve water quality were considered (Section 8).
12. WSUD related objectives were established by the SMP (Section 6.2).
13. Objectives for WSUD related objectives were developed following a review of literature. A discussion paper describing historic water quality data related to the catchment (Tonkin Consulting, 2013a) was also undertaken.
14. Water quality targets were used to assess WSUD options in a discussion paper (Tonkin Consulting, 2013b). Runoff reduction targets were also established as part of a discussion paper (Tonkin Consulting, 2012).
15. Following a review of potential targets, the SMP adopts the objectives of the *Adelaide Coastal Water Quality Improvement Plan* (McDowell & Pfennig, 2013) to assess water quality runoff form the catchment (Tonkin Consulting, 2013b). Runoff reduction targets were developed based on neutral or beneficial effect principles.

16. The impact of proposed WSUD on runoff volumes were assessed in the development of a policy for on-site retention systems (Tonkin Consulting, 2012).
17. The impact of proposed WSUD on peak flow rates were assessed in the development of a policy for on-site retention systems (Tonkin Consulting, 2012).
18. The impact of WSUD on water demand was not assessed.
19. The potential source of demand for any harvesting schemes was not identified.
20. The water quality impact of WSUD was assessed in discussion papers of the SMP (Tonkin Consulting, 2013b).
21. The SMP considers implementation of wetlands, noting insufficient open space for additional wetlands to those already present. Bioretention was considered and recommended for consideration in road reconstruction works. Rainwater tanks were considered in terms of policy - the SMP recommends it would be desirable to increase the minimum 1 kL rainwater tank requirement for new homes and significant home additions. GPTs were recommended for all outlets to the coast where not already in place.

A.9 North Arm East Catchment SMP

The North Arm East Catchment SMP (Tonkin Consulting, 2014) covers an area of 2116 Ha lying predominately within the City of Port Adelaide Enfield. The land use within the catchment was mainly low density residential with small portions of commercial and industrial use. It has been noted that the area is likely to experience redevelopment and subsequent growth.

1. WSUD was considered by the SMP (e.g. Section 6).
2. WSUD measures were included in the SMP recommendations (Section 9.1). However, the recommendations were primarily drainage measures with additional water quality and/or harvesting benefits noted.
3. An assessment of WSUD using MUSIC modelling was undertaken in Section 6.2.1. Options for remaining WSUD alternatives proposed in Section 6 were analysed with respect to flow interception and harvestable yield but the methodology and any assumptions for these estimates were not reported.
4. WSUD options were considered in the SMP however there were no alternatives presented for any one feature (Section 6.1, 6.2 and 6.3). It should be noted that none of the measures were included in the final list of recommended projects (Section 9).
5. WSUD measures were not explicitly included in the recommendations in Section 9, however the potential water quality and harvesting benefits of detention based projects were mentioned in the report.
6. The SMP estimated the cost of WSUD measures. These were presented as capital cost only (Section 7) excluding any land acquisition costs.
7. Harvesting solutions tended to complement other drainage works, and the additional benefits to the flooding based measures listed in Section 9 include water quality benefits.

8. Policy recommendations for WSUD were considered in the SMP. The implementation of on-site retention measures were qualitatively discussed and it is concluded that on-site measures should not be pursued to a greater level than already required (Section 6.1.9).
9. Opportunities for harvesting were considered (Section 6.3).
10. Opportunities for runoff quantity management were considered (Section 6.3).
11. Opportunities to improve water quality were considered (Section 6.2).
12. WSUD related objectives were provided (Sections 5.3.2, 5.3.3, 5.3.4).
13. Water quality targets were catchment specific. For example, targets for water quality were based on maintaining levels of pollution at current levels to ensure the current performance of the Barker Inlet wetland were preserved (Section 5.3.2).
14. Quantitative targets were not established in the assessment of WSUD features.
15. –
16. The impact of WSUD measures on runoff volume was assessed (Section 6.3.1.4 and 6.3.1.5). There was no indication of how these harvest volumes were derived.
17. The impact of proposed WSUD on peak flow rates was not assessed.
18. The impact of WSUD measures on water demand was indicated in estimating harvest volumes (Sections 6.3.1.4 and 6.3.1.5)
19. The impact of rainwater tanks on water demand was indicated (Section 6.3.1.5). The importance of demand was indicated in the discussion of potential future harvesting sites (Section 9.3.3)
20. The impact of proposed WSUD on water quality was assessed (Section 6.2). This was only performed for GPTs which were not subsequently included in the final recommendations.
21. The SMP considered the use of wetlands (Section 6.3) though due to limited available area and proximity of current wetlands they were not recommended. Bioretention swales were mentioned as an alternative to GPTs as a planning measure but there was no recommendation or assessment (Section 6.2.5). Additionally rainwater tanks were considered (Section 6.3.1.5) and GPTs were considered however not recommended (Section 6.2.1). Detention storage was considered at a number of individual sites (Section 6.1) for flood management purposes, with additional benefits and potential for permanent storage identified.

A.10 References

Australian Water Environments 2010a, *Truro Stormwater Management Plan*, AWE on behalf of Mid Murray Council, Adelaide, SA, Australia.

Australian Water Environments 2010b, *Wasleys Stomrwater Management Plan*, AWE on behlaf of Light Regional Council, Adelaide, SA, Australia.

Department for Water 2011, *Water sensitive urban design - Consultation statement*, Department for Water, Adelaide, SA.

Fox, DR, Batley, GE, Blackburn, D, Bone, Y, Bryars, S, Cheshire, A, Collings, G, Ellis, D, Fairweather, P, Fallowfield, H, Harris, G, Henderson, B, Kämpf, J, Nayar, S, Pattiaratchi, C, Petrusevics, P, Townsend, M, Westphalen, G & Wilkinson, J 2007, *The Adelaide coastal waters study - Final report, Volume 1 - Summary of study findings*, CSIRO, Glen Osmond, Australia. <http://www.clw.csiro.au/acws/>.

Jensen Planning and Design 2009, *Stormwater management plan: Cities of Holdfast Bay and Marion - Discussion paper: development potential within the catchment*, Report prepared for Cities of Holdfast Bay and Marion, Adelaide, SA, South Australia.

McDowell, LM & Pfennig, P 2013, *Adelaide Coastal Water Quality Improvement Plan (ACWQIP)*, Environment Protection Authority, South Australia, Adelaide, SA.

South Australian Department of Planning and Local Government 2010, *Water sensitive urban design technical manual - Greater Adelaide region*, Department of Planning and Local Government, South Australia, Adelaide, SA, Australia. <http://www.planning.sa.gov.au/go/wsud>.

Southfront 2013, *Hallett Cove Creeks Stormwater management Plan*, Southfront on behalf of City of Marion, Adelaide, SA, Australia.

Southfront 2014, *Moonta, Moonta bay and Port Hughes Stormwater Management Plan*, Southfront on behalf of District Council of the Copper Coast, Adelaide, SA, Australia.

Tonkin Consulting 2011, *Streaky bay Stormwater Management Plan*, Tonkin Consulting on behalf of District Council of Streaky Bay, Adelaide, SA, Australia.

Tonkin Consulting 2012, *Discussion paper - Retention storage systems - Stormwater Management Plan - Cities of marion and Holdfast Bay*, Tonkin Consulting, Adelaide, SA, Australia.

Tonkin Consulting 2013a, *Discussion Paper - Water Quality Data - Stormwater management Plan - Cities of Marion and Holdfast Bay*, Tonkin Consulting, Adelaide, SA, Australia.

Tonkin Consulting 2013b, *Discussion paper - Water quality model - Stormwater Management Plan - Cities of Marion and Holdfast Bay*, Tonkin Consulting, Adelaide, SA, Australia.

Tonkin Consulting 2013c, *Stormwater Management Plan - Coastal Catchments Between Glenelg and Marino*, Tonkin Consulting, City of Marion, City of Holdfast bay, Adelaide, SA.

Tonkin Consulting 2014, *Port Lincoln Stormwater Mangement Plan*, Tonking Consulting on behalf of City of Port Lincoln, Adelaide, SA, Australia.

Wong, THF (ed.) 2005, *Australian Runoff Quality*, Institution of Engineers Australia, Sydney.

WorleyParsons Services Pty Ltd. 2012, *Brown Hill Keswick Creek Stormwater Project Stormwater Management Plan*, The Cities of Adelaide, Burnside, Mitcham, Unley and West Torrens, Adelaide, SA, Australia.

Appendix B – IFD Information for Adelaide (Kent Town) and Observed Events

IFD Data

Infiltration-Frequency-Duration (IFD) data for the location of the Adelaide (Kent Town) rain gauge is presented in Table B 1. The corresponding IFD chart is presented in Figure B 1.

Table B 1 – IFD values of rainfall depth derived for the location of the Adelaide (Kent Town) rain gauge location

	EY	Annual Exceedance Probability (AEP)					
Duration	**1EY**	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
1 min	1.3	1.5	2.1	2.6	3.1	3.9	4.5
2 min	2.3	2.6	3.6	4.5	5.4	6.8	7.9
3 min	3	3.4	4.9	6	7.2	9	10.6
4 min	3.6	4.1	5.9	7.3	8.7	10.9	12.7
5 min	4.2	4.8	6.8	8.3	10	12.5	14.6
10 min	6	6.9	9.9	12.1	14.6	18.2	21.2
12 min	6.6	7.5	10.8	13.3	15.9	19.8	23.1
15 min	7.3	8.3	11.9	14.7	17.6	22	25.6
18 min	7.9	9	12.9	15.9	19.1	23.8	27.8
30 min	9.7	11.1	15.9	19.5	23.4	29.2	34.1
1 hour	12.6	14.3	20.4	25	30	37.4	43.8
1.5 hour	14.5	16.5	23.4	28.6	34.3	42.7	49.9
2 hour	16.1	18.2	25.7	31.4	37.6	46.7	54.5
3 hour	18.4	20.9	29.3	35.7	42.6	52.8	61.4
6 hour	23.2	26.1	36.3	44	52.2	64.1	74.1
12 hour	28.7	32.4	44.6	53.6	63	76.5	87.7
24 hour	35.1	39.4	53.6	63.9	74.5	89.4	101.5
48 hour	42	46.9	62.8	74.2	85.7	101.5	114.1
72 hour	46.2	51.4	68.1	79.8	91.6	107.5	120.1
96 hour	49.3	54.7	71.8	83.6	95.4	111.1	123.4
120 hour	51.9	57.4	74.8	86.6	98.1	113.5	125.3
144 hour	54.1	59.8	77.3	89	100.3	115.1	126.3
168 hour	56.1	61.9	79.5	91.1	102.1	116.3	126.8

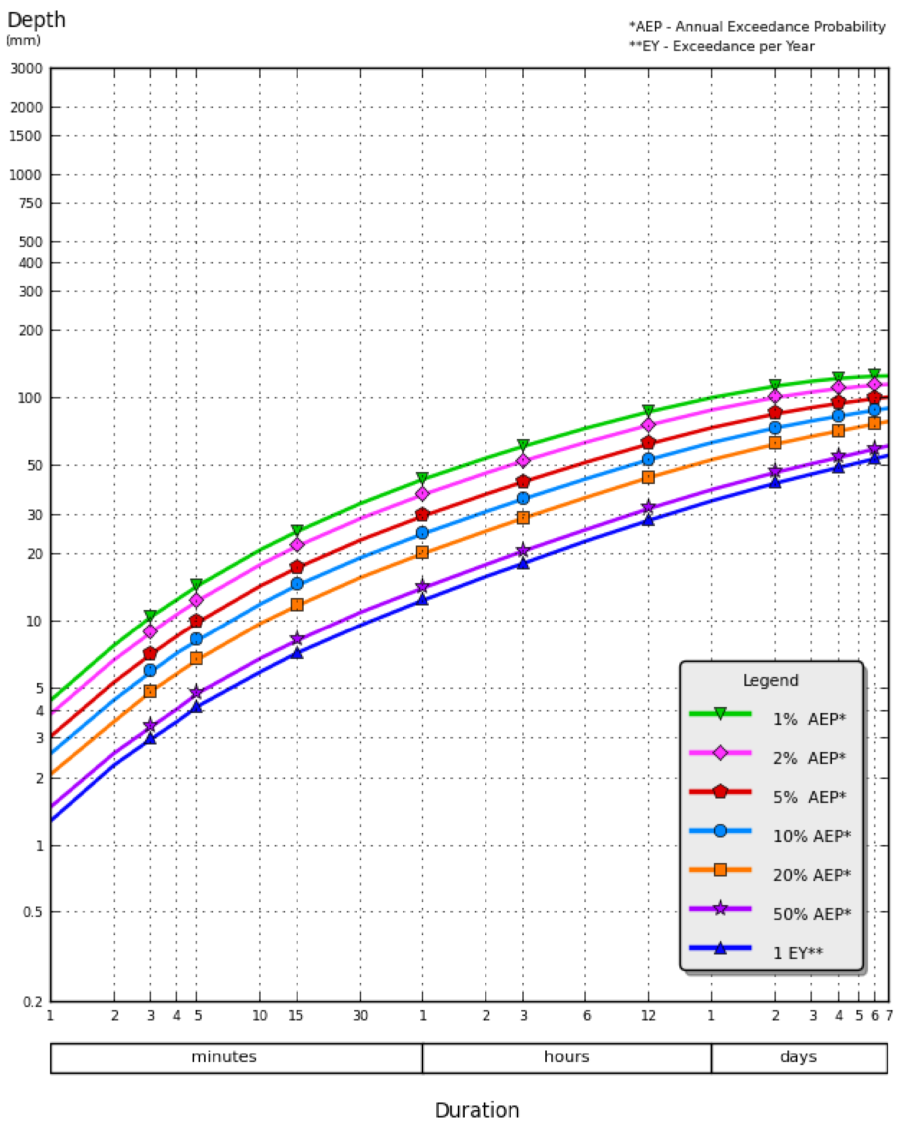

Figure B 1 – IFD chart derived for the location of the Adelaide (Kent Town) rain gauge location

The following tables detail the observed rainfall events from the Adelaide (Kent Town) rain gauge which correspond to design events based on the IFD data. Events were identified which had a 50% AEP and a duration of 12 minutes (Table B 2), 30 minutes (Table B 3), one hour (Table B 4), 90 minutes (Table B 5) and two hours (Table B 6). Corresponding data for events with a 20% AEP are then provided in Table B 7 to Table B 11.

Table B 2 – Adelaide (Kent Town) rain gauge events with a 50% AEP, 12 minute duration

Date	Event rain (mm)	Rainfall preceding event (mm)								
		30 min	60 min	90 min	120 min	12 Hr	24Hr	72 Hr	10 day	30 day
2/03/1983	8.5	2.9	3.2	3.6	4.9	7.8	7.8	14.7	14.7	15.7
17/11/1992	8.4	3.0	8.7	11.2	11.4	16.4	16.4	16.4	16.4	41.3
14/12/1993	8.5	3.3	4.5	6.9	8.1	16.2	16.2	30.3	30.9	32.5
7/02/1998	8.4	6.4	9.4	9.6	10.2	16.7	16.7	16.7	16.7	21.8
13/10/1999	9.4	0.4	0.4	0.4	0.4	6.4	7.6	11.6	28.4	72.2
21/06/2005	8.2	6.8	6.8	6.8	6.8	16.8	39.0	47.6	48.4	105.7
16/12/2005	8.2	0.0	0.0	0.0	0.0	0.0	0.0	13.4	15.0	22.4
14/03/2012	9.4	2.4	2.4	2.4	2.4	3.2	3.2	3.2	3.2	19.2
Mean	**8.6**	**3.1**	**4.4**	**5.1**	**5.5**	**10.4**	**13.4**	**19.3**	**21.7**	**41.4**

Table B 3 - Adelaide (Kent Town) rain gauge events with a 50% AEP, 30 minute duration

Date	Event rain (mm)	Rainfall preceding event (mm)								
		30 min	60 min	90 min	120 min	12 Hr	24Hr	72 Hr	10 day	30 day
22/09/1978	11.7	5.1	6.0	7.5	8.1	8.6	14.8	14.8	22.3	37.6
19/01/1979	10.4	2.2	2.2	2.6	4.6	7.8	7.8	7.8	23.8	25.0
21/04/1979	10.2	1.9	1.9	2.0	3.0	5.4	5.4	9.2	30.9	31.4
8/06/1979	11.3	1.6	3.1	3.1	3.1	3.1	3.6	3.6	3.8	39.3
2/03/1983	11.4	0.9	1.5	1.7	5.4	5.8	5.8	12.8	12.8	13.7
19/12/1992	11.2	0.0	0.0	0.0	0.0	0.0	20.6	25.9	25.9	33.9
14/12/1993	11.1	3.1	4.2	6.4	8.3	15.5	15.5	29.6	30.2	31.8
31/12/1995	10.5	0.6	0.6	0.6	0.6	1.6	2.2	2.2	2.2	5.8
7/02/1998	10.4	7.4	7.4	7.8	10.2	14.7	14.7	14.7	14.7	19.8
2/10/1999	12.0	2.2	2.2	4.4	4.4	7.4	7.4	7.4	17.2	19.8
13/10/1999	10.4	0.0	0.0	0.0	0.0	6.0	7.2	11.2	28.0	71.8
22/03/2000	10.4	4.6	4.8	5.0	5.2	5.2	5.2	5.6	5.8	5.8
16/12/2005	10.4	0.0	0.0	0.0	0.0	0.0	0.0	13.4	15.0	22.4
6/05/2006	10.8	2.2	4.0	6.2	7.2	8.8	8.8	10.8	17.8	30.6
Mean	**10.9**	**2.3**	**2.7**	**3.4**	**4.3**	**6.4**	**8.5**	**12.1**	**17.9**	**27.8**

Table B 4 - Adelaide (Kent Town) rain gauge events with a 50% AEP, one hour duration

Date	Event rain (mm)	Rainfall preceding event (mm)								
		30 min	60 min	90 min	120 min	12 Hr	24Hr	72 Hr	10 day	30 day
21/02/1977	14.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-
17/06/1978	13.5	3.2	7.8	12.9	14.2	15.5	15.6	15.6	25.6	67.8
5/07/1978	13.9	1.8	2.0	2.1	2.1	2.2	2.6	6.4	10.6	37.0
19/01/1979	8.2	8.0	8.0	8.0	10.4	13.6	13.6	13.6	29.6	30.8
16/04/1979	13.0	0.5	0.7	0.7	1.2	1.5	1.5	1.5	1.5	17.5
21/04/1979	12.9	0.1	0.1	0.3	2.1	3.6	3.6	7.4	29.4	29.6
8/06/1979	14.1	1.0	2.4	2.4	2.4	2.4	2.8	2.8	3.0	38.5
2/03/1983	13.1	0.3	0.9	1.1	4.8	5.2	5.2	12.2	12.2	13.1
8/05/1989	7.3	5.5	10.9	10.9	10.9	10.9	10.9	14.0	14.0	59.0
17/11/1992	15.3	5.4	6.5	6.7	6.7	11.8	11.8	11.8	11.8	36.6
14/12/1993	14.7	3.3	4.5	6.9	8.1	16.2	16.2	30.3	30.9	32.5
31/12/1995	13.1	0.1	0.1	0.1	0.1	1.1	1.6	1.6	1.6	5.2
6/02/1997	13.6	1.2	1.8	1.8	2.8	5.2	5.2	5.2	5.2	5.4
22/09/1998	15.0	0.0	0.0	0.0	0.0	0.6	0.6	0.8	1.0	11.6
18/05/2002	14.0	0.8	0.8	0.8	0.8	0.8	0.8	7.6	7.6	12.9
20/01/2005	15.2	4.4	5.0	5.0	5.2	6.2	6.2	6.2	6.4	10.2
6/05/2006	13.0	1.8	4.0	5.0	6.4	6.6	6.6	8.6	15.6	28.4
Mean	**13.2**	**2.2**	**3.3**	**3.8**	**4.6**	**6.1**	**6.2**	**8.6**	**12.1**	**27.3**

Table B 5 - Adelaide (Kent Town) rain gauge events with a 50% AEP, 90 minute duration

Date	Event rain (mm)	Rainfall preceding event (mm)								
		30 min	60 min	90 min	120 min	12 Hr	24Hr	72 Hr	10 day	30 day
17/06/1978	17.3	4.4	8.2	9.7	9.7	10.5	10.6	10.6	20.6	62.8
5/07/1978	15.8	0.4	0.4	0.5	0.6	0.6	1.1	5.2	9.0	35.4
19/01/1979	16.1	0.0	0.0	2.5	2.5	5.7	5.7	5.7	21.6	22.9
8/06/1979	15.2	1.5	1.6	1.6	1.6	1.8	2.0	2.0	2.2	37.7
10/04/1983	16.9	4.2	4.7	4.7	4.7	4.8	18.7	20.5	20.9	40.7
30/08/1992	14.9	1.1	3.5	6.4	7.2	13.8	32.3	34.9	34.9	54.2
14/12/1993	18.0	1.7	3.9	5.0	13.5	13.5	13.5	27.6	28.2	29.8
6/02/1997	17.4	1.2	1.8	1.8	2.8	5.2	5.2	5.2	5.2	5.4
22/09/1998	17.0	0.0	0.0	0.0	0.0	0.6	0.6	0.8	1.0	11.6
29/04/2000	15.0	1.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	14.4
25/01/2001	17.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18/05/2002	16.0	0.2	0.2	0.2	0.2	0.2	0.2	7.0	7.0	12.3
21/12/2003	15.8	0.4	0.4	0.4	0.4	0.4	0.4	10.6	10.6	11.4
6/05/2006	15.0	1.8	3.2	4.8	4.8	5.0	5.0	7.0	14.0	26.8
8/12/2010	16.4	0.8	0.8	1.0	1.0	47.0	47.2	53.0	53.0	69.8
13/02/2014	16.0	2.6	3.8	6.4	6.4	7.4	7.4	7.4	7.4	7.4
Mean	**16.3**	**1.3**	**2.2**	**2.9**	**3.6**	**7.4**	**9.5**	**12.5**	**14.9**	**27.7**

Table B 6 - Adelaide (Kent Town) rain gauge events with a 50% AEP, two hour duration

Date	Event rain (mm)	Rainfall preceding event (mm)								
		30 min	60 min	90 min	120 min	12 Hr	24Hr	72 Hr	10 day	30 day
8/06/1979	16.7	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.7	36.2
5/10/1980	17.2	2.8	4.3	5.6	6.9	9.5	9.5	9.5	9.5	10.3
24/06/1981	18.0	2.6	3.3	3.5	3.5	4.4	4.6	49.6	53.8	81.6
14/12/1993	20.0	3.3	4.5	6.9	8.1	16.2	16.2	30.3	30.9	32.5
6/02/1997	19.0	0.6	1.2	1.6	2.8	4.6	4.6	4.6	4.6	4.8
31/10/1997	16.4	1.0	3.6	4.6	5.8	47.8	63.2	67.0	67.0	67.0
7/02/1998	18.6	0.8	3.8	4.4	6.0	7.1	7.1	7.1	7.1	12.2
22/09/1998	19.0	0.0	0.0	0.0	0.0	0.6	0.6	0.8	1.0	11.6
29/04/2000	18.2	1.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	14.4
25/01/2001	17.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21/12/2003	16.8	0.2	0.2	0.6	0.6	0.6	0.6	10.8	10.8	11.6
6/05/2006	17.0	1.0	2.4	2.4	2.4	2.6	2.6	4.6	11.6	24.4
8/12/2010	17.6	0.2	0.4	0.4	0.4	46.4	46.8	52.4	52.4	69.2
13/02/2014	19.8	2.4	4.6	7.4	7.4	8.4	8.4	8.4	8.4	8.4
Mean	**18.0**	**1.2**	**2.2**	**2.8**	**3.3**	**10.8**	**11.9**	**17.7**	**18.6**	**27.4**

Table B 7 - Adelaide (Kent Town) rain gauge events with a 20% AEP, 12 minute duration

Date	Event rain (mm)	Rainfall preceding event (mm)								
		30 min	60 min	90 min	120 min	12 Hr	24Hr	72 Hr	10 day	30 day
8/06/1979	9.9	2.5	3.7	4.6	4.6	4.6	5.0	5.0	5.2	40.7
22/05/1999	9.8	8.2	15.0	15.8	18.2	18.6	23.2	27.2	27.2	54.3
6/06/2001	11.4	5.8	5.8	5.8	5.8	9.4	26.2	26.4	26.5	62.7
21/09/2009	11.0	6.0	6.8	6.8	6.8	10.6	10.6	11.0	14.0	23.6
Mean	**10.5**	**5.6**	**7.8**	**8.2**	**8.8**	**10.8**	**16.3**	**17.4**	**18.2**	**45.3**

Table B 8 - Adelaide (Kent Town) rain gauge events with a 20% AEP, 30 minute duration

Date	Event rain (mm)	Rainfall preceding event (mm)								
		30 min	60 min	90 min	120 min	12 Hr	24Hr	72 Hr	10 day	30 day
8/06/1991	14.6	0.9	1.9	2.4	5.0	8.0	14.8	23.9	33.8	69.7
25/01/2001	15.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21/12/2003	15.6	0.2	0.2	0.6	0.6	0.6	0.6	10.8	10.8	11.6
21/06/2005	14.8	0.2	0.2	0.2	0.2	10.4	32.6	41.0	41.8	99.1
14/03/2012	16.6	0.0	0.0	0.0	0.0	0.8	0.8	0.8	0.8	16.8
Mean	**15.4**	**0.3**	**0.5**	**0.6**	**1.2**	**4.0**	**9.8**	**15.3**	**17.4**	**39.4**

Table B 9 - Adelaide (Kent Town) rain gauge events with a 20% AEP, one hour duration

Date	Event rain (mm)	Rainfall preceding event (mm)								
		30 min	60 min	90 min	120 min	12 Hr	24Hr	72 Hr	10 day	30 day
26/06/1981	19.3	1.0	1.3	1.6	2.3	5.7	8.4	53.3	91.8	110.8
8/06/1991	20.3	0.9	1.9	2.4	5.0	8.0	14.8	23.9	33.8	69.7
2/10/1999	19.0	2.2	2.2	4.4	4.4	7.4	7.4	7.4	17.2	19.8
21/06/2005	19.2	0.2	0.2	0.2	0.2	10.4	32.6	41.0	41.8	99.1
21/09/2009	21.2	0.0	0.0	0.0	2.2	3.8	3.8	4.2	8.0	16.8
14/03/2012	19.2	0.0	0.0	0.0	0.0	0.8	0.8	0.8	0.8	16.8
Mean	**19.7**	**0.7**	**0.9**	**1.4**	**2.4**	**6.0**	**11.3**	**21.8**	**32.2**	**55.5**

Table B 10 - Adelaide (Kent Town) rain gauge events with a 20% AEP, 90 minute duration

Date	Event rain (mm)	Rainfall preceding event (mm)								
		30 min	60 min	90 min	120 min	12 Hr	24Hr	72 Hr	10 day	30 day
26/06/1981	21.4	0.2	0.5	1.0	1.6	4.9	7.6	52.6	91.0	110.0
2/03/1983	23.9	0.9	1.5	1.7	5.4	5.8	5.8	12.8	12.8	13.7
31/12/1983	21.2	1.3	1.3	1.3	1.3	1.3	2.7	7.1	7.1	8.3
8/06/1991	21.2	1.0	1.5	4.1	4.1	7.1	13.9	26.4	33.0	68.8
2/10/1999	22.0	0.4	0.8	2.6	2.6	5.6	5.6	5.6	15.4	18.0
21/09/2009	21.2	0.0	0.0	2.2	2.2	3.8	3.8	4.2	8.2	16.8
Mean	**21.8**	**0.6**	**0.9**	**2.2**	**2.9**	**4.8**	**6.6**	**18.1**	**27.9**	**39.3**

Table B 11 - Adelaide (Kent Town) rain gauge events with a 20% AEP, two hour duration

Date	Event rain (mm)	Rainfall preceding event (mm)								
		30 min	60 min	90 min	120 min	12 Hr	24Hr	72 Hr	10 day	30 day
2/03/1983	25.1	0.4	0.8	2.1	4.7	4.9	4.9	11.9	11.9	12.9
8/06/1991	23.5	0.2	1.3	3.1	4.3	7.3	14.1	23.6	33.2	69.0
Mean	**24.3**	**0.3**	**1.0**	**2.6**	**4.5**	**6.1**	**9.5**	**17.8**	**22.5**	**40.9**

Appendix C – Additional Results from the Design Storm, Observed Storm and Antecedent Rainfall Analysis

Comparison of a Design Storm or an Equivalent Observed Storm to Predict Catchment Peak Flow and Runoff Volume

The effect of selecting a design storm event or equivalent observed storm event periods from the Adelaide (Kent Town) rainfall gauge was described in Section 3.4.2. Figure C 1 shows the comparison of the 20% AEP runoff peak flow rates from the street scale catchment resulting from simulations of the design storm and equivalent observed storm on 08/06/1991. A comparison of runoff volume is shown in Figure C 2.

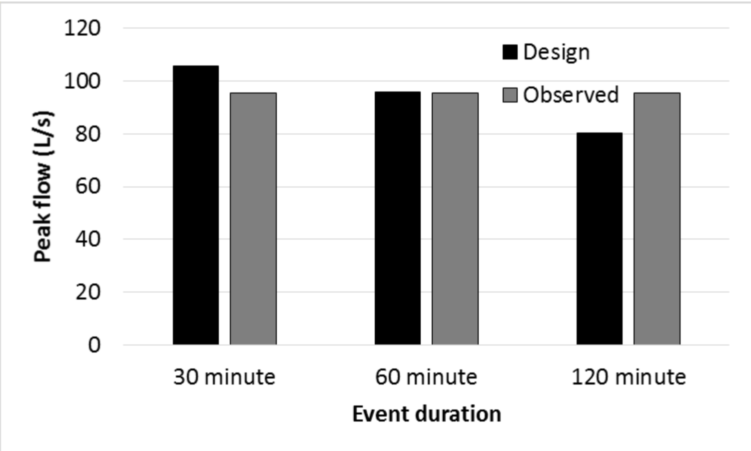

Figure C 1 - A comparison of the simulated peak flow from the redeveloped street when selecting a 20% AEP design storm or an equivalent observed storm based on rainfall data from Adelaide (Kent Town)

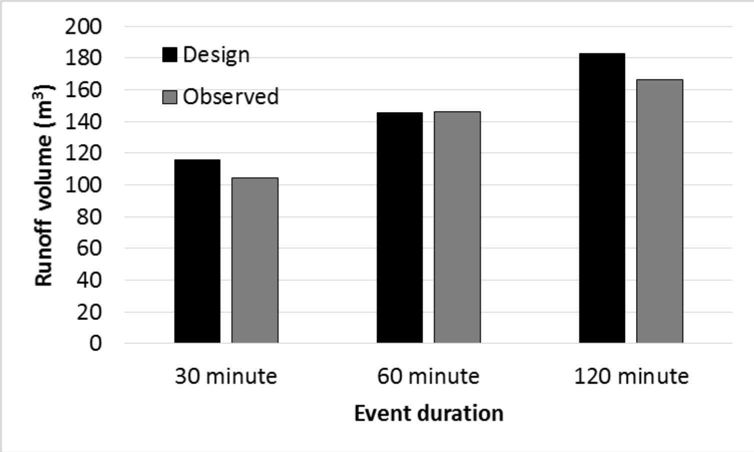

Figure C 2 - A comparison of the total runoff volume from the redeveloped street when selecting a 20% AEP design storm or an equivalent observed storm based on rainfall data from Adelaide (Kent Town)

Appendix D - Establishing MUSIC Climate Parameters and Hydrological Zones

D.1 Introduction

This section investigates the temporal and spatial influences on MUSIC modelling for South Australia. The South Australian Government has set State-wide performance targets for WSUD in new developments (Department of Environment Water and Natural Resources, 2013). These targets are currently not mandated but provide a performance measure for the implementation of best practice WSUD. For water quality these targets are expressed in the minimum reductions in total pollutant load compared with pollutant load in untreated stormwater. The water quality targets are:

- Reduction in Total Suspended Solids (TSS) by 80%;
- Reduction in Total Phosphorous (TP) by 60%;
- Reduction in Total Nitrogen (TN) by 45%; and,
- Reduction in gross pollutants by 90%.

The State-wide performance targets also specify how WSUD should manage runoff to minimise the hydrological impact of urban development. The WSUD targets for managing runoff quantity are:

- For waterway protection – manage the rate of runoff from the site so it does not exceed the pre-development 1 year Average Recurrence Interval (ARI) flow; and,
- For flood management – ensure that the capacity of existing drainage is not exceeded and that there is no increase in the 5 year ARI peak flow and no increase in flood risk for 100 year ARI peak flow compared to existing conditions.

In reality, many councils already request developers to demonstrate that there is no increase in the 10 year ARI peak flow rate on commercial and industrial developments (pers. Comm., Mellissa Bradley, Water Sensitive SA). A range of WSUD treatment approaches are available to achieve these targets. However, the performance of these WSUD systems will vary depending on the existing hydraulic conditions and the local climate. The design and sizing of WSUD treatment to meet performance targets is often undertaken using computer tools such as the Model for Urban Stormwater Improvement Conceptualisation (MUSIC), which was first developed by the Cooperative Research Centre for Catchment Hydrology (eWater CRC, 2015). The use of MUSIC to design and size WSUD treatment systems needs to consider the appropriate time step that maximises model accuracy while minimising computational time and data requirements. There is also a need to provide South Australian specific guidelines for the selection of appropriate climate station data that is representative of the region being modelled.

D.2 Methodology

The definition of hydrologic zones for this analysis was adapted from the method first presented by Melbourne Water's *WSUD Engineering Procedures: stormwater* (Melbourne Water, 2005). This approach was also reported by Wettenhall and Wong (2007) for Melbourne.

The following outlines the broad steps in the methodology applied:

- Select a performance measure for evaluating effectiveness of WSUD systems in different locations. In this case the water quality target for nitrogen was applied (45% reduction in annual loads), as this was found to be the limiting parameter for meeting overall water quality objectives.
- Select a reference site for comparing performance across different climate zones in terms of the area (e.g. wetland area) required to meet performance measure. In this case Adelaide Kent Town was selected as the reference site.
- Define hydrologic design regions for South Australia based on a number of climate factors and elevation. It was assumed that within each region a consistent adjustment factor could be applied (relative to the reference site) to estimate size of WSUD elements.

D.3 Selecting hydrologic regions

Data was analysed for 32 pluviograph stations, which are listed in Table D 1. The stations were selected on the basis of the following attributes of the pluviograph record:

- Still currently operating and collecting data;
- A rainfall record that was available for at least 10 years, and preferably data available for the period 2000 to 2010;
- Rainfall data available at 6 minute time steps with minimal gaps in data; and,
- Selection of stations that represent rainfall across major urban centres in South Australia.

Table D 1 - Bureau of Meteorology rainfall district numbers, selected pluviographic stations and period of record used

BoM Rainfall District	Rainfall District No.	Stations	Station No.	Start Date	End Date
Northwest	16	Woomera Aerodrome	16001	01/01/2000	31/07/2010
		Marla Police Station	16085	01/01/2000	31/07/2010
Far North	17	Oodnadatta Airport	17043	01/01/2000	31/03/2010
Western Agricultural	18	Ceduna Airport	18012	01/01/2000	31/08/2010
		Minnipa PIRSA	18120	01/01/2000	31/07/2010
		Whyalla Aero	18192	23/10/2000	30/04/2010
		North Shields (Port Lincoln AWS)	18195	25/10/2000	30/06/2010
Upper North	19	Port Augusta Power Station	19066	09/07/2001	30/04/2010

BoM Rainfall District	Rainfall District No.	Stations	Station No.	Start Date	End Date
West Central	22A, 22B	Stenhouse Bay	22049	30/11/1999	31/03/2010
		Kingscote Aero	22841	12/02/2002	28/02/2010
East Central	23A, 23B, 23C	Roseworthy AWS	23122		
		Nuriootpa Viticulture	23373	11/10/1999	31/07/2010
		Mount Crawford Forest HQ	23763	01/01/1999	31/07/2010
		Stirling Post Office	23785		
		Lenswood Research Station	23801	01/01/1999	31/01/2010
		Victor Harbour (Encounter Bay)	23804		
		Parawa (Second Valley Forest AWS)	23875		
		Noarlunga	23885		
		Kuitpo Forest Reserve	23887		
		Edinburgh	23083		
		Parafield	23013		
		Adelaide Airport	23034		
		Adelaide Kent Town	23090	01/01/2000	31/07/2010
Murray River	24A, 24B	Loxton Research Centre	24024	01/01/1999	30/04/2010
		Renmark Aero	24048	29/05/2001	30/04/2010
		Strathalbyn Racecourse	24580	02/04/2002	30/04/2010
Murray Mallee	25A	Karoonda	25006	01/01/1999	31/07/2010
Upper Southeast	25B	Keith	25507	01/01/1994	29/02/2004
Lower Southeast	26	Mount Gambier Aero	26021	01/01/1999	31/07/2010
		Cape Jaffa (The Limestone)	26095	10/07/2000	31/01/2010
		Coonawarra	26091	01/01/1999	31/01/2010

To consider potential hydrologic zones and suitable pluviograph stations that could be used to represent those zones, the following factors were considered:

- Mean Annual Rainfall (MAR) over the period data was available;
- Mean number of annual rain-days;
- The ratio of mean summer rain-days to mean winter rain-days. This was taken as an indicator of how seasonal the rainfall pattern was; and,
- Relationship between MAR and elevation.

Figure D 1 depicts the selected stations across South Australia against classification of annual average rainfall. The areas receiving on average 300 mm or more of rainfall per year, to the east of

Ceduna, approximately correspond to Goyder's Line. This line was defined in 1865 by the South Australian Surveyor-General George Goyder on the basis of a distinct vegetation boundary between arid areas to the north vegetated by salt-brush and Mallee scrub to the south. This vegetation boundary demarcates the areas to the south that receive greater than 254 mm of rain per year and were therefore deemed potentially suited to agriculture (Meinig, 1961) .

Figure D 2 shows the distribution of population across South Australia, with the vast majority of the population located in the Greater Adelaide region. For this reason, 13 of the 32 pluviographic stations analysed were located in the Eastern Central Rainfall District, which incorporates Greater Adelaide.

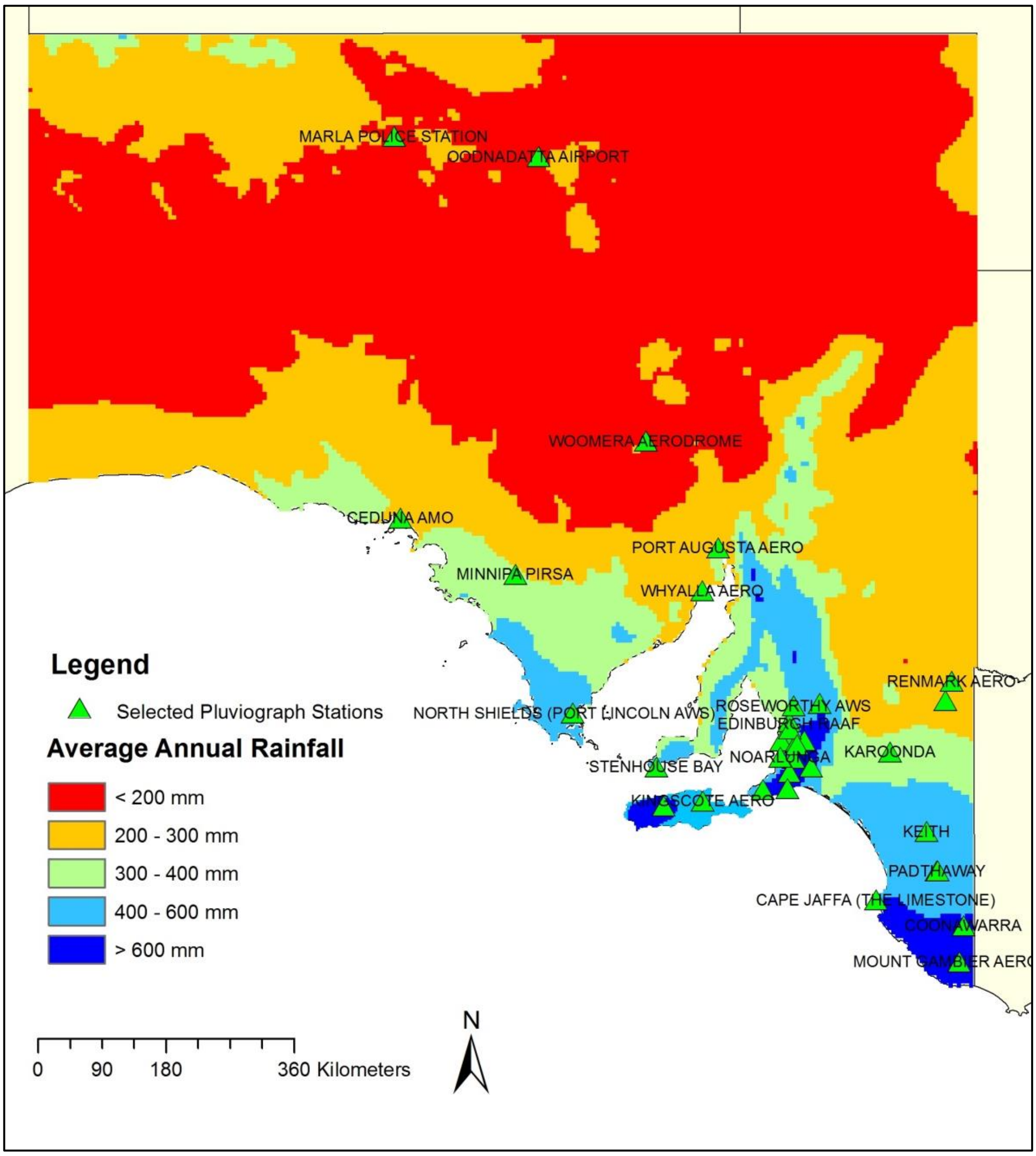

Figure D 1 - Selected Pluviograph Stations and Annual Average Rainfall

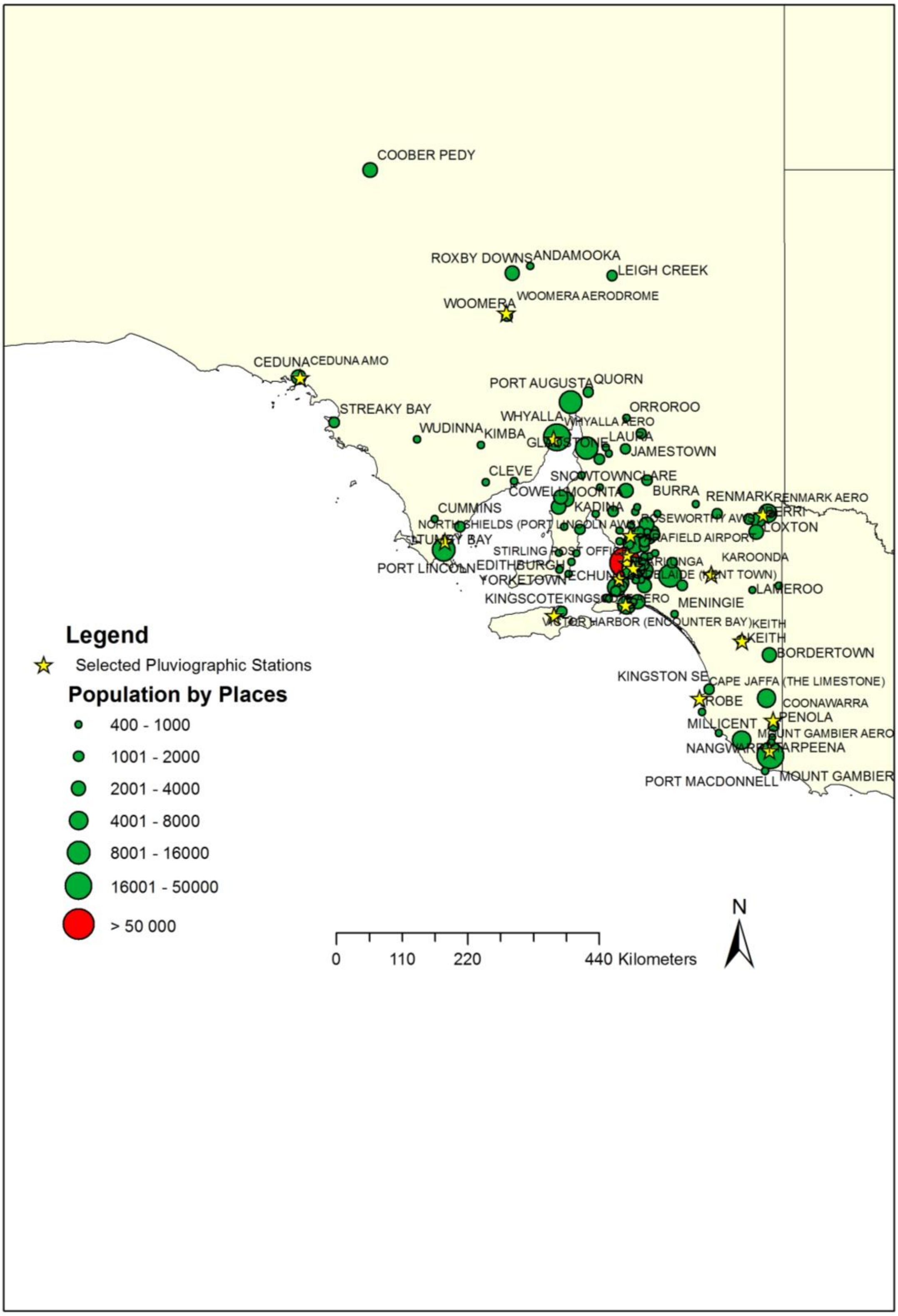

Figure D 2 - Selected Pluviograph Stations and Population Distribution in South Australia

Figure D 3 shows the mean annual rainfall of the selected pluviograph stations. The seasonality of rainfall is shown in Figure D 4, and was calculated as the difference between mean summer rain-days and mean winter rain-days. This shows that rainfall in South Australia is generally highly seasonal, with less than half the rainfall falling summer compared to winter. The exception to this pattern is the stations in the arid north, which can receive more rainfall over summer months as monsoonal troughs from the tropics move southwards.

Figure D 5 shows the mean number of rain-days across South Australia for the selected pluviograph stations. The pattern of mean rain-days is similar to that of MAR across South Australia. There is a strong correlation between MAR and mean annual rain-days (r = 0.86).

Rainfall is generally positively correlated with elevation across South Australia. In the East Central Rainfall District the correlation between rainfall and elevation (r = 0.89) is stronger than for pluviograph stations in other areas of the state (r= 0.65). Figure D 6 depicts the relationship between MAR and elevation for the selected pluviograph station in the East Central District, which shows the highest annual rainfall in the Adelaide Hills area.

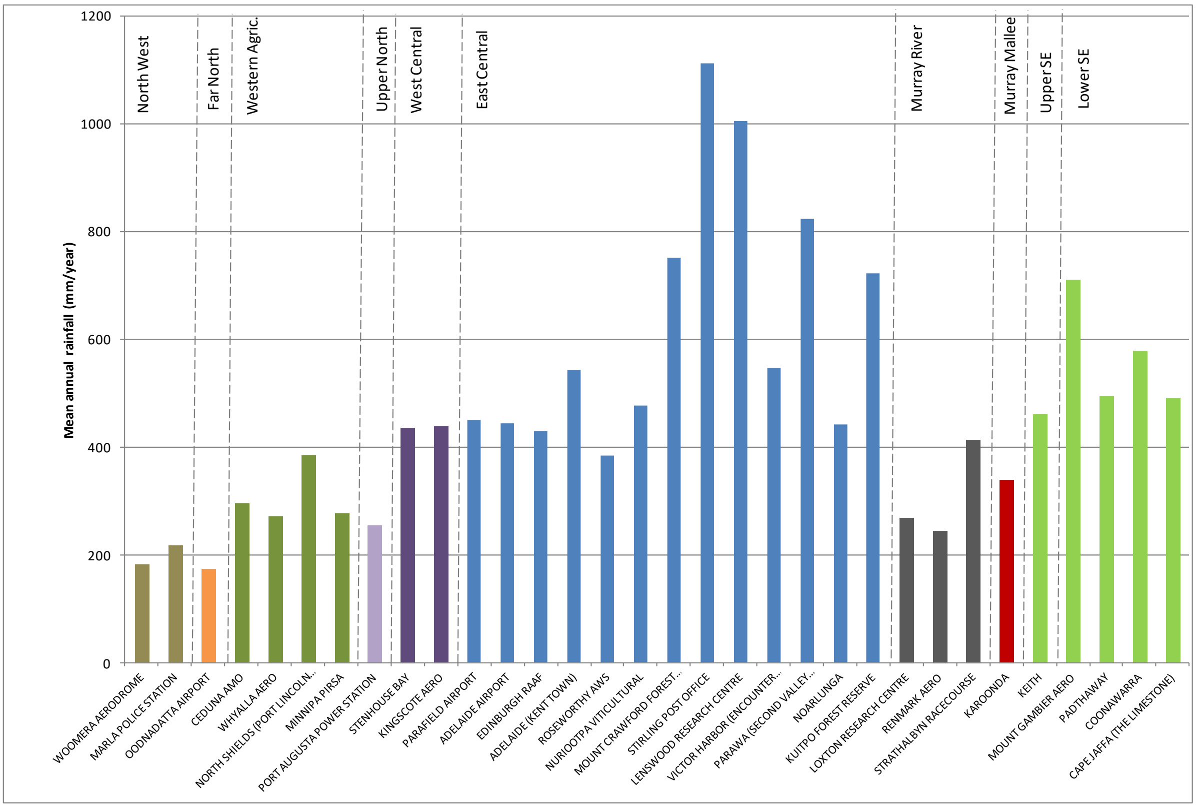

Figure D 3 - Mean Annual Rainfall (MAR) at selected pluviograph stations

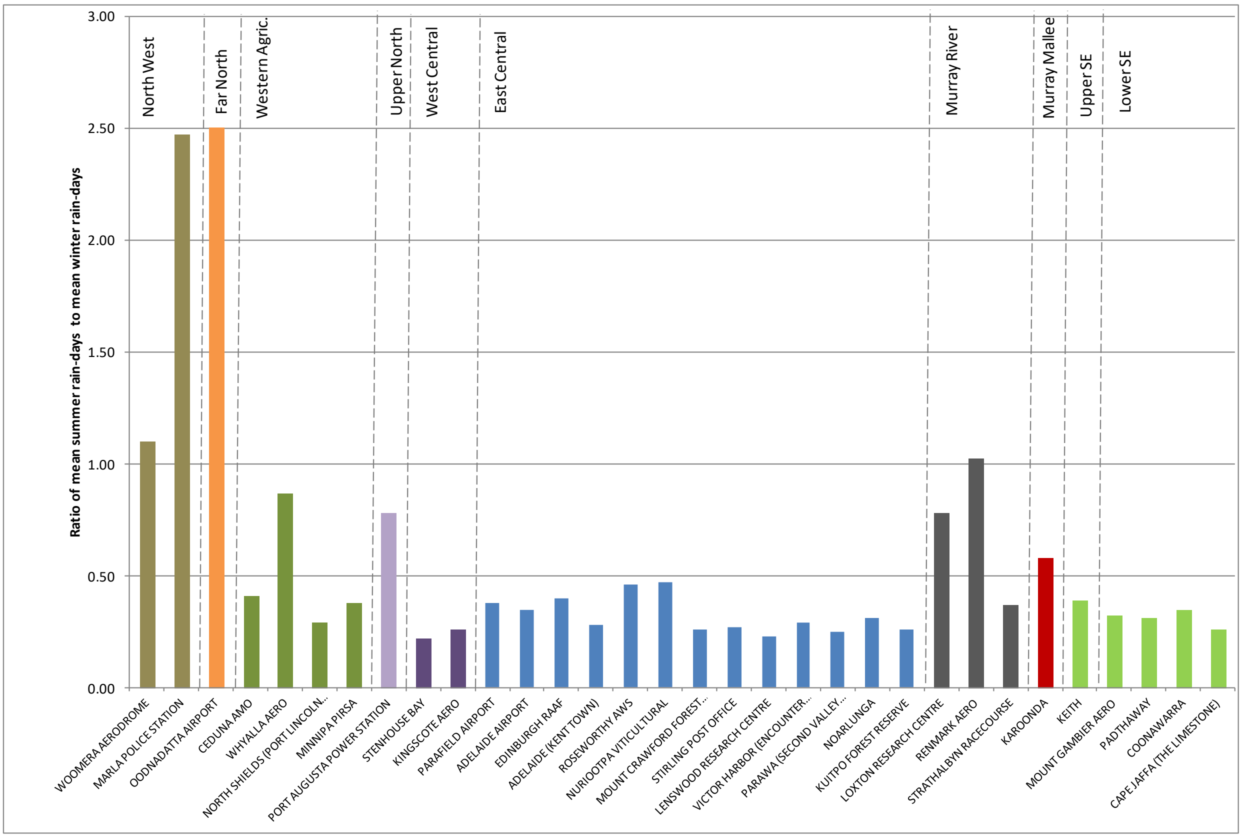

Figure D 4 - Seasonality - ratio of mean summer rain-days to mean winter rain-days at selected pluviograph stations

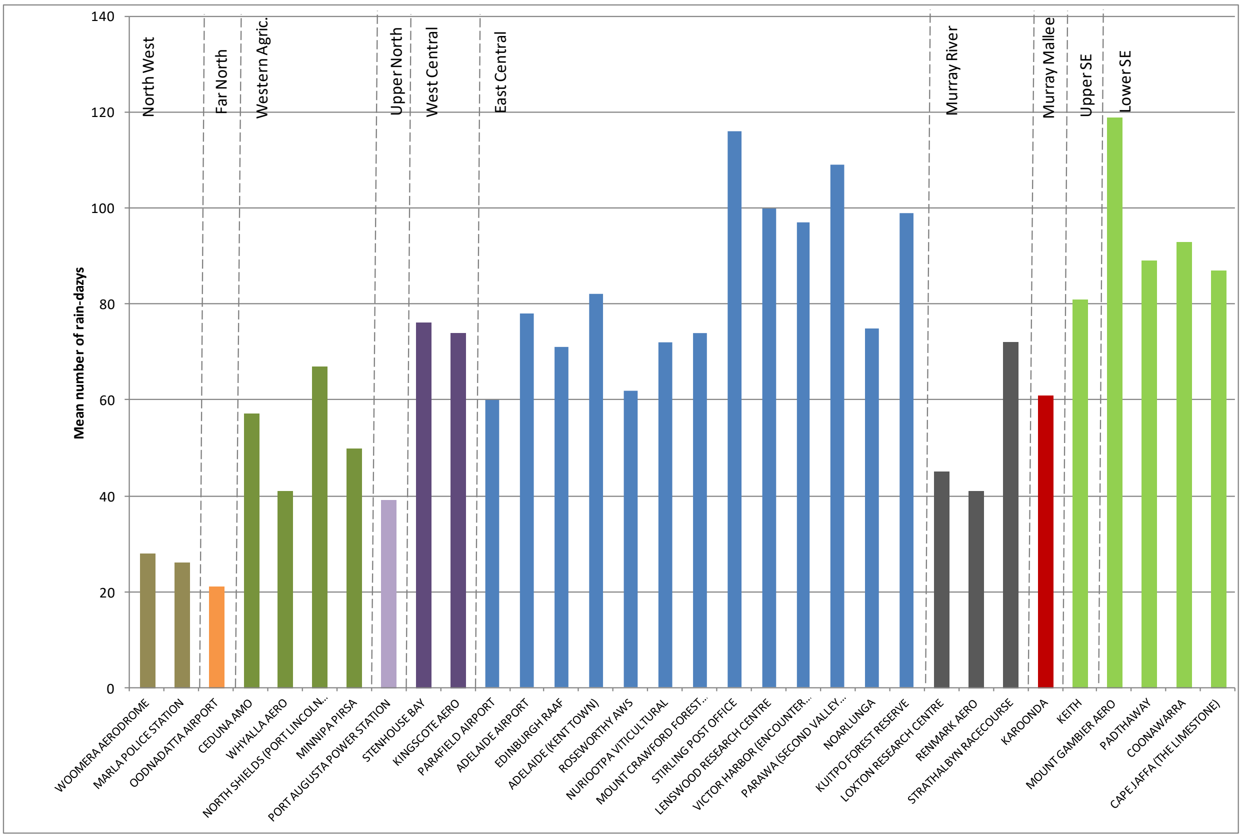

Figure D 5 - Mean number of rain-days at selected pluviograph stations

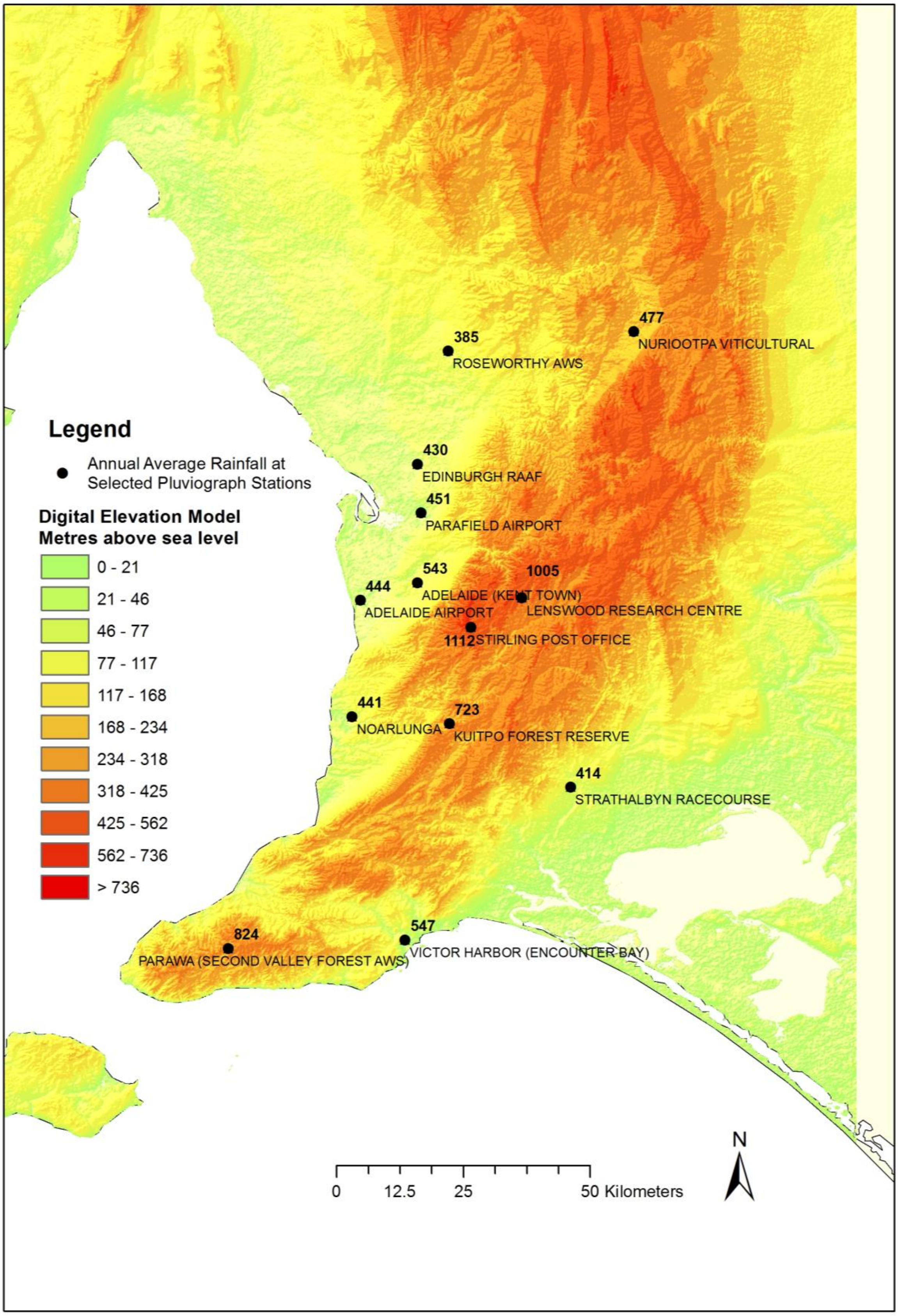

Figure D 6 - Elevation and Average Annual Rainfall

The definition of hydrologic zones used Mean Annual Rainfall (MAR) to classify zones. This was based on findings reported by Melbourne Water (2005), Wettenhall and Wong (2007) and the

Tasmanian EPA (2012). All of these studies found that MAR was the most influential factor on the performance and sizing of WSUD treatment devices. Analysis was undertaken for the 32 pluviograph stations across South Australia to determine the relationship between the percentage of the contributing catchment required for a particular treatment measure to meet stormwater quality objectives (reduction in total nitrogen by 45%) and the different climate factors. This analysis found changes in treatment area required was most strongly related to MAR (r = 0.7). There was a similarly strong relationship between changes in treatment area required and elevation, which is explained by the high correlation between MAR and elevation. We decided to use MAR to define hydrologic design zones to be consistent with previous studies.

Figure D 7 shows the proposed hydrologic design zones for South Australia (excluding Metropolitan Adelaide). The boundaries are based on NRM regions for South Australia, as these approximately represented the major distinctions in rainfall patterns across the state. The exception is the Northern Hydrologic Zone, as this combined the NRM regions – Alinytjara Wilurara and South Australian Arid Lands. This was done due the paucity of both urban settlements and pluviographic data for this region. The selected pluviographic stations indicate stations that have a good data record and are representative of rainfall in the region. In some cases, such as the South East, a number of pluviographic stations have been suggested as potentially suitable when representing climate for the design of WSUD treatment in MUSIC modelling. This was due to significant differences in rainfall patterns across the design region.

Figure D 8 depicts the proposed hydrologic design zones for Greater Adelaide. The zones have been based on patterns of MAR across Greater Adelaide, but also have been defined to be consistent with administrative boundaries, in particular local government areas. Tables D 2 and D 3 list the pluviograph stations that can be used to represent rainfall across each of the hydrologic design zones and the availability of rainfall data for each station.

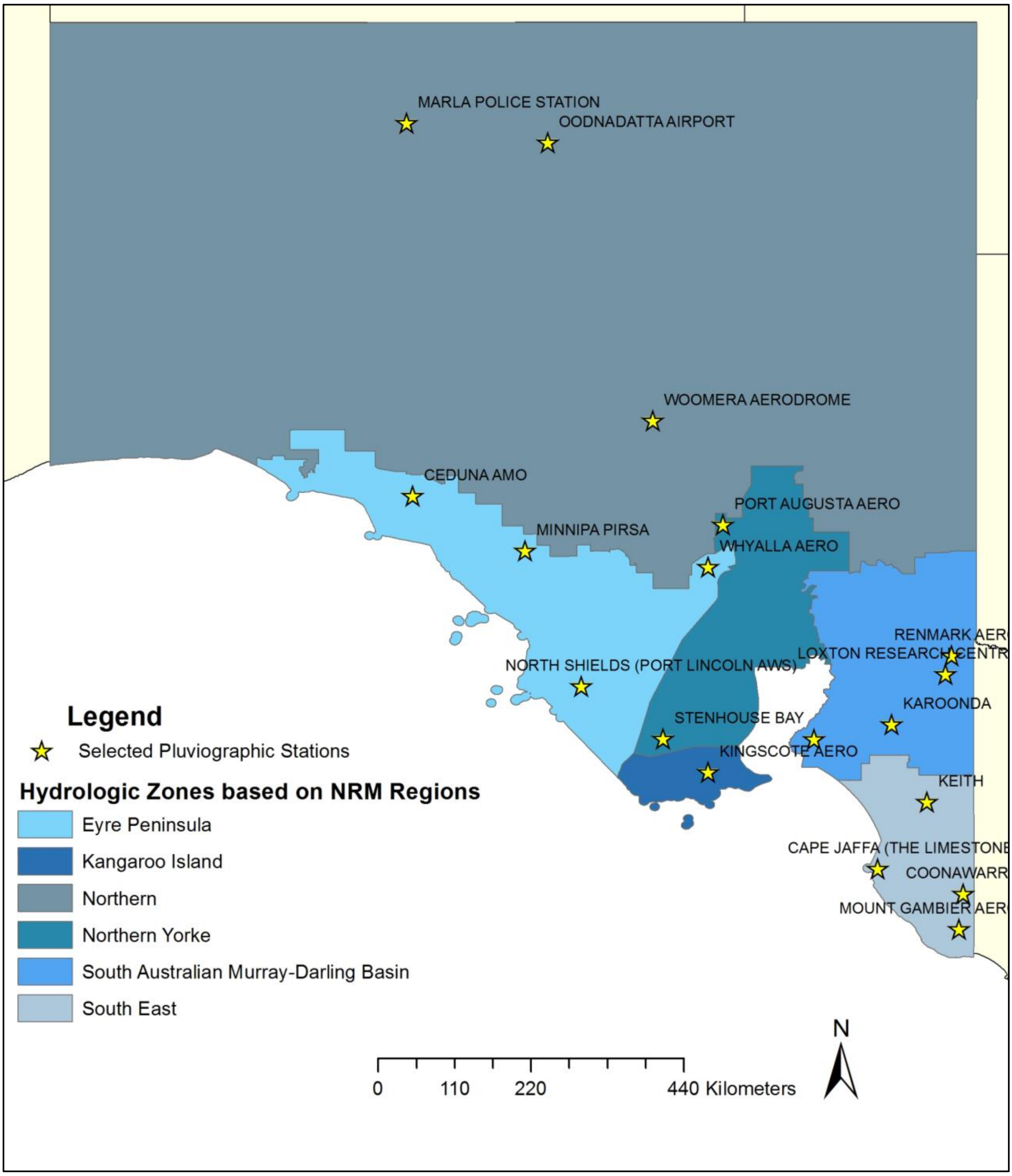

Figure D 7 - Proposed hydrologic design zones for Greater South Australia

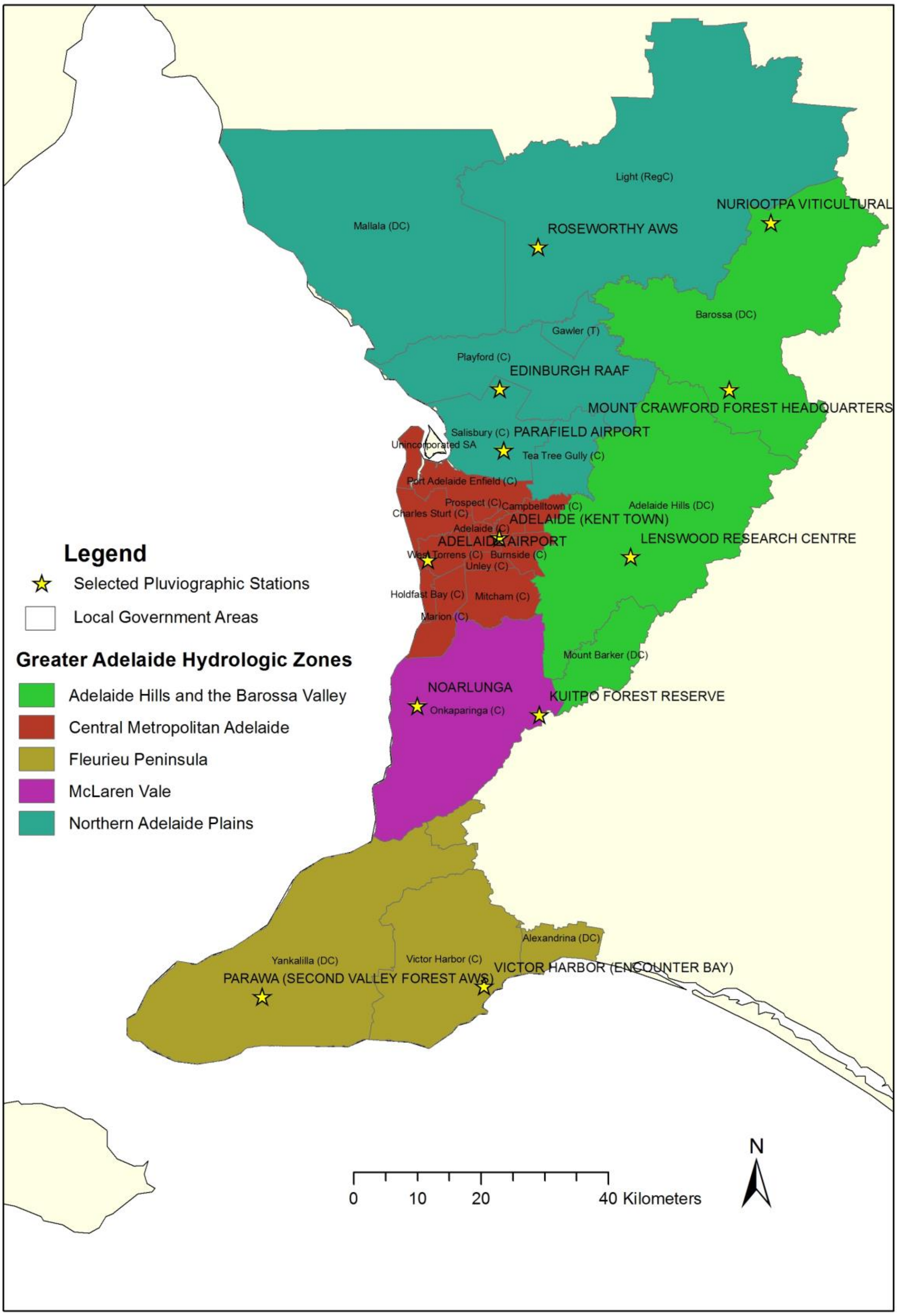

Figure D 8 - Hydrologic design zones for Greater Adelaide

Table D 2 – Pluviograph stations for Greater Adelaide hydrologic design zones and data availability

Region	Station	Station #	Rainfall record available
Adelaide Hills and the Barossa	Lenswood Research Station	23801	05/10/1972 – 31/01/2010
	Mount Crawford Forest HQ	23763	13/10/1970 – 31/07/2010
	Nuriootpa Viticultural	23373	11/10/1999 – 31/07/2010
Central Metropolitan Adelaide	Adelaide Airport	23034	13/01/1967 – 31/07/2010
	Kent Town	23090	12/02/1977 – 31/03/2010
Fleurieu Peninsula	Parawa (Second Valley Forest AWS)	23875	09/11/1999 – 30/06/2010
	Victor Harbour (Encounter Bay)	23804	01/04/2001 – 31/07/2010
McLaren Vale	Noarlunga	23885	09/10/2001 – 31/01/2010
	Kuitpo Forest Reserve	23887	20/12/2001 – 30/11/2009
Northern Adelaide Plains	Parafield Airport	23013	18/08/1972– 31/05/2010
	Edinburgh RAAF	23083	01/01/1980 – 31/03/2010
	Roseworthy AWS	23122	01/05/1999 – 30/06/2010

Table D 3 – Pluviograph stations for Greater South Australia hydrologic design zones and data availability

Region	Station	Station #	Rainfall record available
Northern	Marla Police Station	16085	27/08/1985 – 31/07/2010
	Oodnadatta Airport	17043	01/01/1961 – 31/03/2010

	Woomera Aerodrome	16001	08/09/1955– 31/07/2010
Eyre Peninsula	Ceduna AMO	18012	26/01/1954 – 31/08/2010
	Minnipa PIRSA	18120	23/10/2000 – 30/04/2010
	North Shields (Port Lincoln AWS)	18195	01/07/1997 – 31/07/2010
	Whyalla Aero	18192	25/10/2000 – 30/06/2010
Northern Yorke	Port Augusta Aero	19066	09/07/2001 – 30/04/2010
	Stenhouse Bay	22049	30/11/1999 – 31/03/2010
Kangaroo Island	Kingscote Aero	22841	12/02/2002 – 28/02/2010
South Australian Murray Darling Basin	Renmark Aero	24048	29/05/2001 – 30/04/2010
	Loxton Research Centre	24024	20/015/1976 – 30/04/2010
	Karoonda	25006	26/02/1969 – 31/07/2010
	Strathalbyn Racecourse	24580	02/04/2002 – 30/04/2010
South East	Keith	25507	19/08/1989– 29/02/2004
	Mount Gambier Aero	26021	19/01/1942– 31/07/2010
	Coonawarra	26091	25/09/1985 – 30/04/2010
	Cape Jaffa (The Limestone)	26095	10/07/2000 – 31/01/2010

D.4 References

Department of Environment Water and Natural Resources 2013, *Water Sensitive Urban Design - Creating more liveable and water senstive cities in South Australia*, Government of South Australia, viewed June 2015, <http://www.environment.sa.gov.au/files/516f3ac2-16ff-43fd-b078-a26900b99a81/water-sensitive-urban-design-policy-gen.pdf>.

Environment Protection Authority 2012, *WSUD Engineering Procedures for Stormwater Management in Tasmania* Department of Primary Industries, Water and Environment, viewed June 2015, <http://epa.tas.gov.au/documents/wsud_manual_2012.pdf>.

eWater CRC 2015, *MUSIC Version 6.1*, eWater Cooperative Research Centre, Canberra, Australia.

Meinig, DW 1961, 'Goyder's Line of Rainfall: the role of a geographic concept in South Australian land policy and agricultural settlement', *Agricultural History,* vol. 35, no. 4, pp. 207-214.

Melbourne Water 2005, *WSUD Engineering Procedures: Stormwater*, CSIRO Publishing, Melbourne, Victoria, Australia.

Wettenhall, G & Wong, THF 2007, 'Hydrologic regions for sizing of stormwater measures in Victoria', *Water Practice and Technology,* vol. 2, no. 2.

Appendix E - Adjustment factors for reference rainfall stations

E.1 Introduction

The analysis outlined here is based on procedures outlined by Melbourne Water (2005) and the Tasmanian Environment Protection Authority (2012). The purpose is to develop adjustment factor equations (for WSUD treatment devices) for the 32 selected pluviograph stations, which are grouped into the hydrologic zones defined previously. The approach is to provide a simple approach to estimate the size of a WSUD feature (in this case a wetland) needed to achieve stormwater quality objectives relative to a reference location. The procedure provides an estimate of the different size requirements for WSUD systems to meet best practice targets. It is likely that the design of WSUD systems for most developments will require site specific modelling to ensure that design reflects the local conditions and the required water quality and quantity performance of WSUD treatment systems. However, a procedure such as that outlined can provide an initial assessment of the sizing of a WSUD treatment system needed to meet best practice targets in different climate zones. This could provide the basis for a simple design process for small scale systems (e.g. infill) where detailed modelling may be an impediment due to the expertise and time required to apply a computer model such as MUSIC.

The Adelaide Kent Town pluviograph station was selected as the reference point due to its central location to metropolitan Adelaide. Figure E 1 depicts for Kent Town the required wetland area (48 hour notional detention time) required to meet the stormwater management objectives of 80% reduction in total suspended solids, 60% reduction in total phosphorous and 45% reduction in total nitrogen. For this reference pluviograph station the wetland size needs to be around 1.9% of the area of the contributing impervious area in the catchment to achieve 45% reduction in total nitrogen.

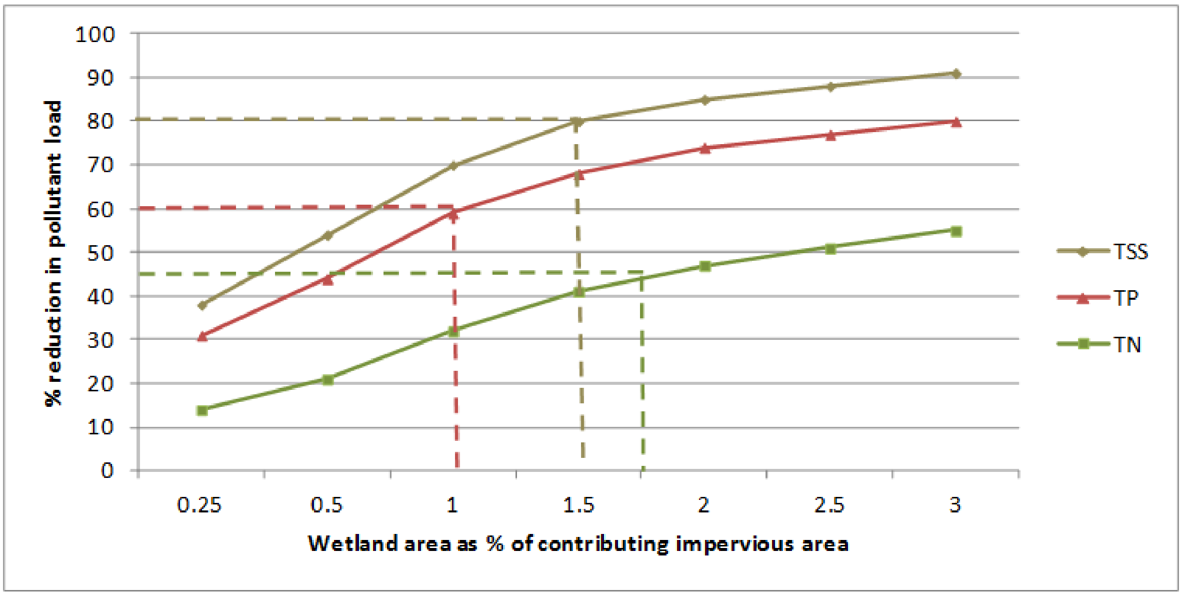

Figure E 1 - Performance curve for wetland (Reference site - Adelaide Kent Town)

E.2 Method

The change in WSUD treatment performance across South Australia was modelled in MUSIC for the 32 selected pluviograph stations, which represented rainfall in the different hydrologic design zones (See: Figure D 7 and Figure D 8). Ten years of rainfall data was used for continuous simulation of WSUD performance using a 6 minute time step.

A hypothetical urban catchment was defined for the purposes of modelling WSUD performance in MUSIC across the different hydrologic zones. The hypothetical catchment was 10 hectares in area with 55 per cent of the area covered by effective impervious surfaces.

The modelling results were compared with different climate parameters (MAR, seasonality and number of rain days) and elevation. This was to determine if inclusion of these factors would improve the estimated adjustment factors for the 32 pluviograph stations included in the analysis.

E.3 Results

The surface area required for WSUD approaches (wetlands and bioretention) was evaluated across the selected pluviograph stations in South Australia. A line of best fit was calculated for each of the regions in Greater South Australia between the adjusted size of the wetland needed to meet total nitrogen best performance and MAR. Figure E 2 shows that in general differences in MAR did not explain changes in the wetland area required to meet a best practice reduction in total nitrogen. The exception was the South East Region. For this reason the adjustment factors were not corrected for MAR. Modelling results indicated that in the Northern Hydrologic Zone variability in the stormwater treatment performance was influenced by seasonality of rainfall. In the South East MAR had a greater influence on the area required to meet best practice performance target for nitrogen reduction. For Greater Adelaide there were insufficient pluviograph stations for each hydrologic zone to evaluate the influence of different climate factors within a hydrologic zone in improving the estimated treatment size needed to meet best practice reduction for total nitrogen.

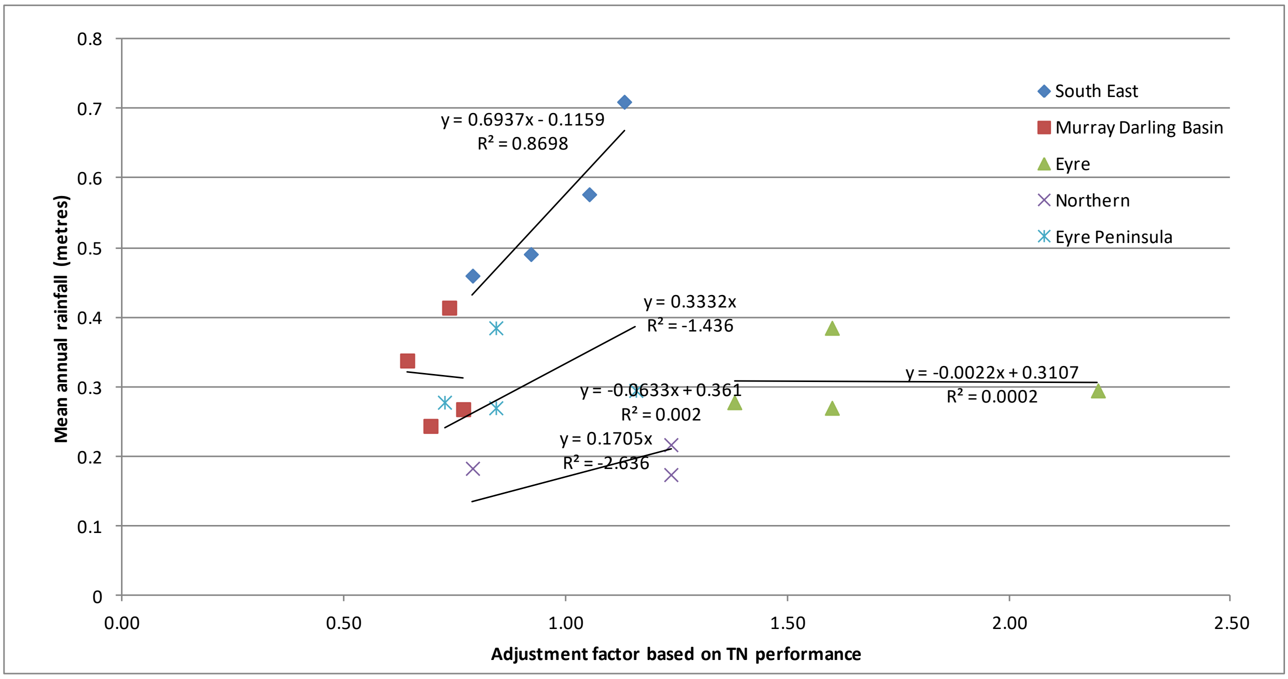

Figure E 2 - Plot of wetlands adjustment factor versus mean annual rainfall for Greater South Australia

Table E 1 lists the suggested adjustment factors for the selected pluviograph stations for the hydrologic regions in Greater South Australia, while Table E 2 provides the estimated adjustment factors for Greater Adelaide. These factors represent the difference in treatment size needed for bioretention and wetlands relative to Kent Town. The procedure detailed in Melbourne Water (2005) suggested adopting adjustment factors that are 1.1 times greater than those estimated by the adjustment factors to provide a conservative estimate of the size of the WSUD treatment needed to meet best practice reductions in total nitrogen.

The following provides an example application of the adjustment factor for a development in the Northern Adelaide Plains (Edinburgh RAAF) with a MAR of 430 mm, and a catchment area of 20 Ha, where the effective impervious area is 50% of the total catchment. This applies an adjustment factor that is 1.1 times greater than estimated, which as indicated above provides a conservative estimate of treatment performance.

1. Figure E 1 indicates that for the reference wetland in Kent Town the treatment area needs to be 1.9% of the contributing impervious area to meet best practice guidelines,
   i.e. contributing impervious area = 0.5 x 200,000 = 100,000 m^2
   reference wetland size = 1.1 * (0.019 x 100,000) = 2,090 m^2
2. The adjustment factor for Northern Adelaide Plains (Edinburgh RAAF) is listed in Table E 2 as 0.88. To provide a conservative estimate, as outlined above, the adjustment factor adopted can be 10% greater than estimated, which gives the required wetland size as:
   1.1 *(0.97 x 1,900) = 1,843 m^2

This indicates that a wetland in the Northern Adelaide Plains, which has a lower MAR than the reference station, would need to be 1,843 m^2 to provide the same level of treatment as a 2,090 m^2 wetland located in Kent Town.

Table E 1 - Greater South Australia adjustment factors

Region	Station	Wetland	Bioretention
Northern	Marla Police Station	1.24	2.32
	Oodnadatta Airport	1.24	1.84
	Woomera Aerodrome	0.79	1.47
Eyre Peninsula	Ceduna AMO	1.16	0.86
	Minnipa PIRSA	0.73	0.86
	North Shields (Port Lincoln AWS)	0.84	0.89
	Whyalla Aero	0.84	1.32
Northern Yorke	Port Augusta Aero	0.73	1.45
	Stenhouse Bay	0.87	0.86
Kangaroo Island	Kingscote Aero	0.74	0.80
South Australian Murray Darling Basin	Renmark Aero	0.69	0.98
	Loxton Research Centre	0.77	1.19
	Karoonda	0.79	0.84
	Strathalbyn Racecourse	0.64	0.78
South East	Keith	0.79	0.84
	Mount Gambier Aero	1.13	0.84
	Coonawarra	1.05	0.97
	Cape Jaffa (The Limestone)	0.92	0.93

Table E 2 - Greater Adelaide adjustment factors

Region	Station	Wetland	Bioretention
Adelaide Hills and the Barossa	Lenswood Research Station	2.11	1.22
	Mount Crawford Forest HQ	1.5	1.05
	Nuriootpa Viticultural	0.97	0.96
Central Metropolitan Adelaide	Adelaide Airport	0.84	0.89
	Kent Town	**1.0**	**1.0**
Fleurieu Peninsula	Parawa (Second Valley Forest AWS)	1.39	0.96
	Victor Harbour (Encounter Bay)	0.82	0.77
McLaren Vale	Noarlunga	0.87	0.96
	Kuitpo Forest Reserve	1.29	0.96
Northern Adelaide Plains	Parafield Airport	0.89	1.02
	Edinburgh RAAF	0.88	0.89
	Roseworthy AWS	0.87	0.89

E.4 Summary

The procedure outlined here provides an estimate on the difference across South Australian climate zones in sizing of WSUD features to meet best practice targets. It is likely that the design of WSUD systems for most developments will require site specific modelling to ensure that design reflects the local conditions and the required water quality and quantity performance of WSUD treatment systems. However, a procedure such as that outlined can provide an initial assessment of the sizing of a WSUD treatment system needed to meet best practice targets in different climate zones. This could provide the basis for a simple design process for small scale systems (e.g. infill) where detailed modelling may be an impediment due to the expertise and time required to apply a computer model such as MUSIC.

The hydrologic zones proposed in this section can help to illustrate the influence that climate characteristics such as mean annual rainfall has on the design and performance of WSUD treatment systems. This can be used to inform a regional approach to the development of stormwater management strategies and the design of WSUD systems, where the influence of climate conditions is considered.

Environment Protection Authority 2012, *WSUD Engineering Procedures for Stormwater Management in Tasmania* Department of Primary Industries, Water and Environment, viewed June 2015, <http://epa.tas.gov.au/documents/wsud_manual_2012.pdf>.

Melbourne Water 2005, *WSUD Engineering Procedures: Stormwater*, CSIRO Publishing, Melbourne, Victoria, Australia.

Appendix F – Selecting Time step and Duration of MUSIC Simulation

F.1 Introduction

This section looks at the influence of the selected modelling time-step and also the length of the climate record selected on the modelled output in MUSIC. Section 4.4.2 reviewed existing MUSIC guidelines, which identified that existing guidelines recommend where possible using climate data at a 6 minute time step. The review identified that there was less guidance around the recommended duration of the climate record that should be used. However, the guidelines prepared for the Darwin Harbour Strategy by McAuley and Knights (2009) recommended that 6 minute time step and duration of 10 years should be applied for simulating the impact of WSUD on water quality using MUSIC. While for water quantity modelling it was recommended that a daily time step is used for at least 50 years.

F.2 Method

This section examined the impact of varying the time-step and the duration of rainfall data used for MUSIC simulation. The sensitivity of MUSIC modelling results to changes in time-step and duration was simulated by comparing the difference in annual total nitrogen loads and flow volume. The baseline used was for a hypothetical urban catchment in Kent Town, Adelaide, where a wetland had been sized to achieve a 45% reduction in annual total nitrogen loads. This baseline was simulated using rainfall data at a 6 minute time step over a 10 year period.

The other assumptions used in the model are detailed below:

- The simulation used the same hypothetical catchment that was modelled for determining the influence of different climate regions on the performance of WSUD systems across South Australia in Appendix E;
- The climate record for Kent Town was used, which is the reference station used in the Appendix E;
- Ten years of data (2000 – 2010) was used from the Kent Town Pluviograph Station (#23090), which was available at a 6 minute time step;
- Potential evapo-transpiration (PET) was set according to the average monthly PET default values for Adelaide provided in MUSIC; and,
- MUSIC parameters were for the wetland assumed a notional detention time of 48 hours, other MUSIC parameters used default value provided by MUSIC (Version 6.1.0).

F.3 Results

Time step

Figure F 1 shows the impact of changing the time step on the simulated reduction of total nitrogen using a ten year rainfall record for Kent Town. This shows that running the model at a coarser time step overestimates the performance of the wetland in reducing total nitrogen loads. The impact on simulated reductions in total nitrogen was relatively negligible up until one hour, but increased in a linear fashion beyond one hour for every increase in modelling time step. At the daily time step the results indicate an 18% increase in the nitrogen reduction compared to the same sized wetland simulated in MUSIC using a rainfall record with a six minute time step. Figure F 2 shows that this relationship is almost linear. This behaviour is explained by the fact that rainfall intensity rather than rainfall quantity is the main driver of pollutant loads generated from urban catchments. The peak flow (cubic metres per second) for a model run on 6 minute time step is two orders of magnitude higher than when the same catchment is simulated using a daily time step. This means that the hydraulic loading to the wetland treatment node is much lower when modelled on daily time step which may increase treatment efficiency. Hence the recommendation is to model WSUD performance applying a hydrologic routing that reflects the time of concentration in the catchment.

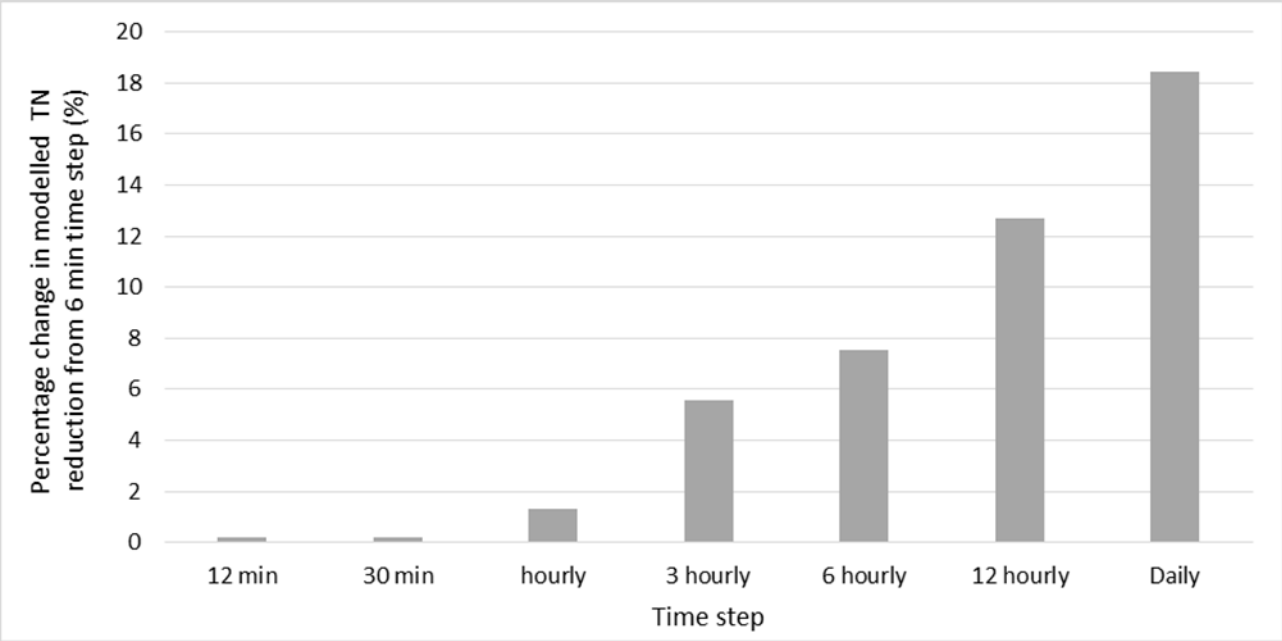

Figure F 1 - Impact of change in time-step on simulated reduction in total nitrogen

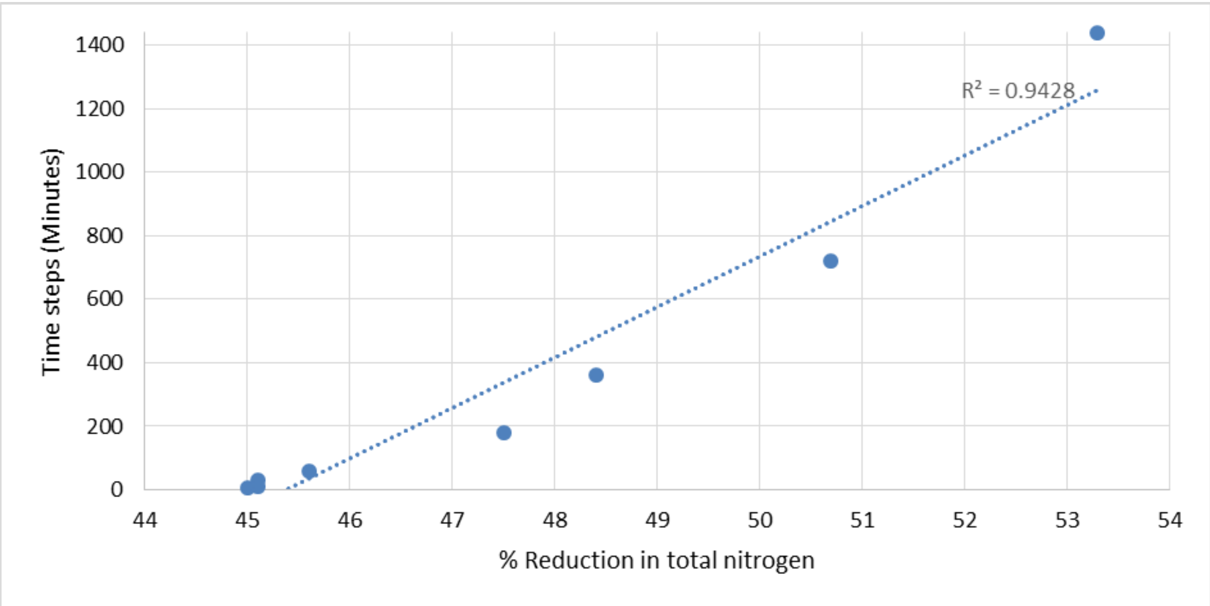

Figure F 2 - Relationship between increased time step of rainfall record and simulated nitrogen reduction

Duration

As previously identified in Section 4.4.2 MUSIC guidelines commonly recommend that a 10 year rainfall record is used when modelling the impact of WSUD on water quality. This section compares the difference in simulated total nitrogen reduction for different duration rainfall records when compared with a benchmark of 10 years (6 minute time step). The benchmark is the hypothetical urban catchment located near Kent Town where a wetland has been sized to reduce post development mean annual nitrogen loads by 45%.

The mean annual nitrogen reduction simulated in MUSIC using ten years of rainfall record was compared with the following based on Figure F 3:

- An “average” year – the annual rainfall closest to the mean[6]
- A “low” year – annual rainfall below the 10th percentile
- A “high” year – annual rainfall above the 90th percentile
- A single year – most recent annual rainfall
- 3 years – three most recent years
- 5 years – five most recent years

Figure F 4 shows that using five years of rainfall data or selecting a year that is close to the average of the ten years can provide a reasonable representation of WSUD performance. However, selecting a single year without an analysis of how representative the rainfall is of a longer period could lead to over or under estimation of the performance of a WSUD layout. Therefore, it is recommended that if a single year of rainfall record is going to be used to model the expected performance of WSUD systems, then a representative (‘average”) year should be selected. However, longer durations tend to produce more accurate results because they account for the impact of years with higher and lower rainfall.

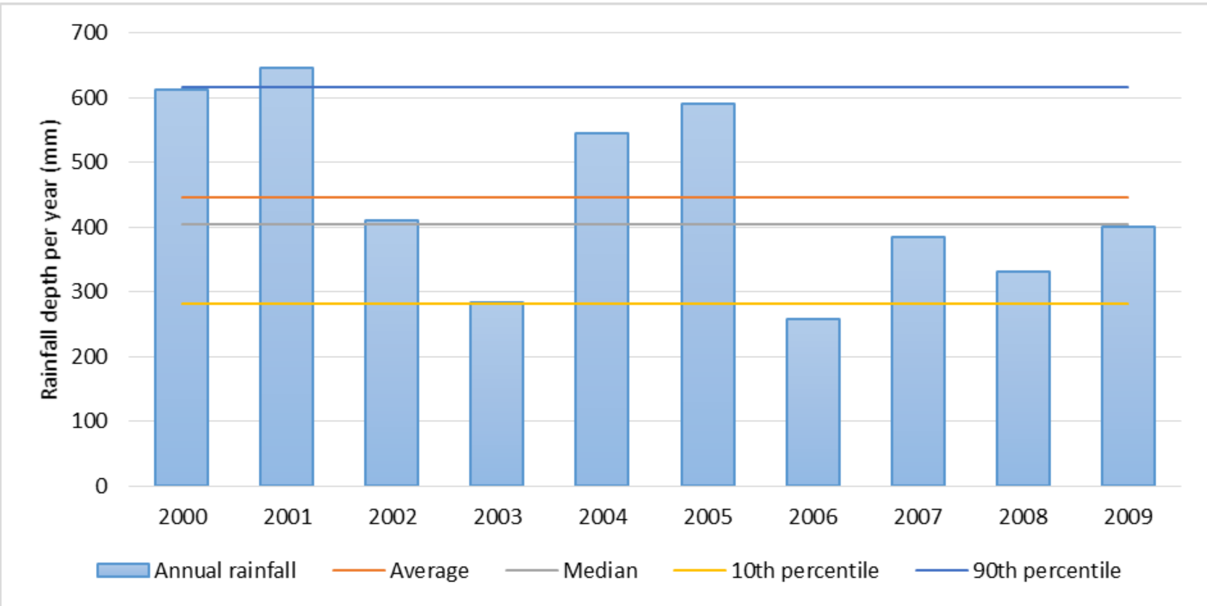

Figure F 3 - Kent Town Annual Rainfall

[6] The mean was based only on the ten years of selected data not the entire rainfall record from the Kent Town station

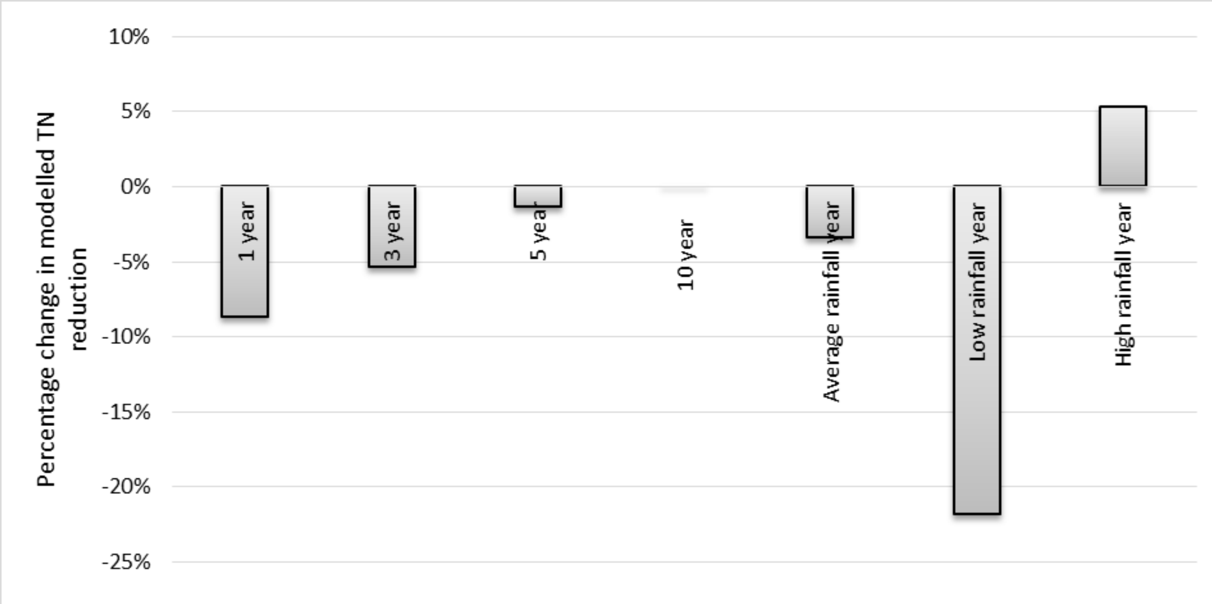

Figure F 4 - Difference in modelled mean TN reduction for different simulation durations

Warm-up function

MUSIC contains a warm-up function, which if enabled estimates the initial storage levels by running one year of data prior to the full simulation. This is to provide a more realistic representation of the initial groundwater depth and pervious soil storage (eWater CRC, 2015). The influence of the warm-up function on the end result was evaluated using a calibrated catchment to the West of Adelaide's CBD - the Frederick Street catchment in Glengowrie as previously reported by Myers et al. (2014b). The effect of the warm-up was evaluated over three time periods of the calibration: 1 year, 2 years and 2.5 years. Table F 1 shows that the influence of the enabling the warm-up function on modelled flows was negligible, and as would be expected the influence declined for models that used longer climate records. The use of ten years of climate data, as recommended, would mean there is sufficient time for storages in the catchment source node to reach equilibrium and the warm-up function is unlikely to make a material difference on modelled flows.

Table F 1 - Influence of warm-up period on modelled flows

Period	Total observed flow (ML)	Total modelled flow with warm-up function enabled (ML)	Total modelled flow with warm-up function disabled (ML)	Percentage difference in modelled flow with and without warm-up function (%)
1 year (02/07/1992 - 01/07/1993)	82,332	103,831	106,664	3%
2 years (02/07/1992 – 01/07/1994)	159,984	173,793	176,626	2%
2.5 years (02/07/1992 – 01/01/1995)	177,015	183,123	185,956	2%

F.4 References

eWater CRC 2015, *MUSIC Version 6.1*, eWater Cooperative Research Centre, Canberra, Australia.

McAuley, A & Knights, D 2009, *Water sensitive urban design - Stormwater quality modelling guide - Final*, Northern Territory Department of Planning and Infrastructure, Darwin, Northern Territory, Australia. viewed May 2009,

Appendix G – Selection of Potential Evapotranspiration (PET) Data

MUSIC comes with a range of monthly files that represent PET for Australian cities. These files use the monthly mean areal potential evapotranspiration as defined in the Climatic Atlas of Australia. The method used to estimate mean areal potential evapotranspiration is detailed in Wang et al. (undated). The monthly areal potential evapotranspiration maps were downloaded from the Bureau of Meteorology's Climate Data Online. The values for specific pluviograph stations were extracted in ArcGIS software. Table G 1 (overleaf) lists the extracted values for each of the selected pluviograph stations in South Australia.

Wang, QJ, McConachy, FLN, Chiew, FHS, James, R, de Hoedt, GC & Wright, WJ undated, *Climatic Atlas of Australia- Maps of Evapotranspiration*, Bureau of Meteorology, viewed September 2015, <http://www.bom.gov.au/climate/averages/climatology/evapotrans/text/et-txt.shtml>.

Table G 1 - Mean monthly evapotranspiration by selected pluviograph stations

Site	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
16001	WOOMERA AERODROME	183	143	122	72	46	34	39	52	81	123	154	171
16085	MARLA POLICE STATION	192	151	133	83	52	37	44	59	91	136	161	180
17043	OODNADATTA AIRPORT	198	156	136	83	51	36	42	57	89	136	164	185
18012	CEDUNA AMO	177	138	120	78	51	35	43	56	85	119	148	160
18120	WHYALLA AERO	183	142	118	73	46	31	36	51	78	115	147	167
18192	NORTH SHIELDS (PORT LINCOLN AWS)	181	143	122	80	51	36	43	56	86	122	155	160
18195	MINNIPA PIRSA	171	134	106	65	43	30	36	51	75	107	139	152
19066	PORT AUGUSTA POWER STATION	184	143	122	74	47	32	36	51	77	117	152	169
22049	STENHOUSE BAY	176	143	117	74	48	34	41	56	87	123	151	162
22841	KINGSCOTE AERO	171	139	114	74	49	36	44	57	88	124	148	153
23013	PARAFIELD AIRPORT	175	141	116	70	44	31	37	51	75	118	145	154
23034	ADELAIDE AIRPORT	170	140	113	71	45	34	39	53	76	117	143	148
23083	EDINBURGH RAAF	175	141	116	70	44	31	37	51	75	118	145	154
23090	ADELAIDE (KENT TOWN)	164	135	115	71	47	36	43	55	77	116	139	144
23122	ROSEWORTHY AWS	174	140	111	68	44	32	38	52	77	115	143	150
23373	NURIOOTPA VITICULTURAL	168	137	108	65	45	34	39	53	78	112	137	145
23763	MOUNT CRAWFORD FOREST HEADQUARTERS	163	133	109	68	48	37	43	56	80	116	137	144
23801	LENSWOOD RESEARCH CENTRE	163	132	110	69	48	38	45	56	79	115	138	145
23804	VICTOR HARBOR (ENCOUNTER BAY)	166	136	113	68	45	32	36	51	74	116	139	148
23875	PARAWA (SECOND VALLEY FOREST AWS)	167	135	111	68	46	33	38	53	77	116	140	147
23885	NOARLUNGA	165	133	108	70	46	35	41	54	78	117	139	144

Site	Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
23887	KUITPO FOREST RESERVE	159	128	105	69	47	37	43	55	79	115	137	139
24024	LOXTON RESEARCH CENTRE	156	127	97	66	38	25	29	45	65	103	131	143
24048	RENMARK AERO	162	130	99	59	38	24	28	43	63	105	129	148
24580	STRATHALBYN RACECOURSE	171	136	109	67	44	32	36	51	75	116	143	151
25006	KAROONDA	159	127	105	63	40	27	32	49	72	109	133	147
25507	KEITH	173	141	115	69	43	31	38	53	76	120	145	156
26021	MOUNT GAMBIER AERO	152	123	99	63	42	34	39	51	75	114	132	140
26091	COONAWARRA	150	121	94	59	41	34	37	50	72	107	125	133
26095	CAPE JAFFA (THE LIMESTONE)	159	132	105	67	41	35	40	53	79	119	140	141

Appendix H - Sensitivity analysis of pervious area parameters in MUSIC

H.1 Background

The purpose of this exercise was to determine the sensitivity of MUSIC results to soil properties. In particular, the objective was to identify the impervious surface ratio at which the soil parameters in MUSIC have negligible influence on the modelling results. The sensitivity of MUSIC results given different catchment contexts can guide the effort that is invested in accurately representing local soil properties such as storage capacity and field capacity.

There have been a number of previous studies that have looked at the sensitivity of the MUSIC model to different parameter settings including dominant soil and the average soil depth of the root zone. The work of Macleod (2008) has been widely referenced to provide an indication of pervious area parameters for MUSIC. Table H 1 depicts the rainfall runoff parameters presented by Macleod (2008) to indicate the soil storage capacity (the maximum water storage capacity) and field capacity (the maximum water storage in the soil without drainage by gravity to groundwater) based on dominant soil type. Table H 2 indicates the remaining pervious area parameters that were recommended for use in MUSIC.

Table H 1 - Soil storage capacity and field capacity for a 0.5 m root zone depth

Dominant soil description	Soil storage capacity (mm)	Field capacity (mm)
Sand	175	74
Loamy sand	139	69
Clayey sand	107	75
Sandy loam	98	70
Loam	97	79
Silty loam	100	87
Sandy clay loam	108	73
Clay loam	119	99
Clay loam, sandy	133	89
Silty clay loam	88	70
Sandy clay	142	94
Silty clay	54	51
Light clay	98	73
Light-medium clay	90	67
Medium clay	94	70
Medium-heavy clay	94	70
Heavy clay	90	58

Source: Presented in Sydney Catchment Authority (2012) adapted from Macleod (2008)

Table H 2 - Other MUSIC soil-runoff parameters for a 0.5 m root zone depth

Dominant soil description	Infiltration capacity coefficient-a (mm/d)	Infiltration capacity exponent-b	Daily recharge rate (%)	Daily baseflow rate (%)	Daily seepage rate (%)
Sandy, loamy sand	360	0.5	100	50	0
Clayey sand, sandy loam, loam, silty loam, sandy clay loam	250	1.3	60	45	0
Clay loam, sandy clay loam, silty clay loam, sandy clay, silty clay	180	3.0	25	25	0
Light clay, light medium clay, medium heavy clay, heavy clay	135	4.0	10	10	0

Source: Presented in Sydney Catchment Authority (2012) adapted from Macleod (2008)

In Southern Queensland a detailed soil investigation was undertaken to better represent the saturated hydraulic conductivity of local soil in a catchment (Gaffeny, 2013). The effects of using specific local soil data or applying generic soil parameters in MUSIC was found to only marginally affect the modelled performance of WSUD systems. In general, generic soil parameters underestimated the performance of the WSUD systems compared to parameters based on specific local data. However, when a model based on generic parameters and one based on local data was compared there was around an 8% increase in the surface area of WSUD treatment for the generic model to achieve treatment targets for the same inflow (Gaffeny, 2013). This suggested that WSUD systems designed using generic pervious area parameters based on dominant soil type would not be significantly overdesigned.

A sensitivity analysis of MUSIC parameters by Dotto (2011a) found that pervious area parameters were not very sensitive when applied to heavily urbanised catchments. However, when the effective impervious percentage of the catchment was less than 30% the pervious area parameters were found to be important. For this reason it was recommended by the authors that the field capacity of catchments should be calibrated for catchments with an effective impervious percentage of less than 30% (Dotto et al., 2011a). Kleidorfer et al. (2012) examined the impact of objective function choice for calibrating a rainfall-runoff model (the MOPUS rainfall runoff model). Like MUSIC, MOPUS was developed based on the SimHyd model and uses very similar parameters. This analysis found that pervious soil store capacity was the least sensitive of all the model's objective functions in the case of MOPUS.

H.2 Method

An analysis was undertaken to examine the sensitivity of MUSIC's pervious area parameters for a South Australian site. This was applied to a calibrated catchment to the West of Adelaide's CBD - the Frederick Street catchment in Glengowrie as previously reported by (Myers et al., 2014b). The catchment covers an area of 45 hectares with an effective impervious percentage of 36%. Rainfall data from the Frederick Street catchment was based on averaged data from two rain gauges within the catchment. Table H 3 shows the properties used for the calibration of a MUSIC model to observed data from the catchment.

Table H 3 - MUSIC simulation catchment properties

Rainfall	Average of two sites (DEWNR gauges A5040561 & A5040556)
PET	Adelaide default
Period	1992 to 1995
Muskingum Cunge routing, *k*, min	14
Muskingum Cunge routing θ	0.3
Soil storage capacity, mm	60
Field Capacity, mm	30
Impervious Area (%)	36
Total Modelled Vol (1992-1995)	183,123 m^3 (3 % higher)
Total Observed Vol (1992-1995)	177,015 m^3

Table H 4 provides a summary of validation rainfall events that were used to compare the efficiency of the calibrated MUSIC model in simulating observed data in the catchment. The Average Recurrence Interval (ARI) was calculated for each of these events using the Bureau of

Meteorology's Intensity-Frequency-Duration data system (AR&R87 IFDs)[7] . This shows that the events used to validate the calibrated model were frequent flow events, with the exception of Event #3 that was likely to occur once every 10 to 20 years.

Table H 4 - Summary of validation rainfall events – modelled and observed data

Event	Date	Time	Obs. peak (m^3/sec)	Mod. peak (m^3/sec)	Rainfall avg. (mm)	Intensity (mm/hr)	ARI
1	30/08/93	14:00 to 20:00	0.8	1.23	11.5	2.3	< 1
2	19/09/93	10:42 to 14:00	0.93	1.13	8.4	2.55	< 1
3	13/12/93	22:18 to 05:00	1.49	1.96	51	7.61	10 - 20
4	17/06/94	02:30 to 09:00	1.01	1.18	9.8	1.57	< 1

The Nash-Sutcliffe efficiency (*E*) was used to compare the efficiency of the model, and the sensitivity of pervious area parameters. This measure has been widely used to assess hydrological models, and was calculated as:

$$E = 1 - \frac{\sum_{i=1}^{n} (X_{obs,i} - X_{model})^2}{\sum_{i=1}^{n} (X_{obs,i} - \overline{X_{obs}})^2}$$

Where: where X_{obs} is observed values and X_{model} is modelled values at time/place *i*.

Nash-Sutcliffe efficiencies can range from -∞ to 1. An efficiency of 1 (E = 1) corresponds to a perfect match between model and observations. An efficiency of 0 indicates that the model predictions were as accurate as the mean of the observed data, whereas an efficiency less than zero (-∞ < E < 0) occurs when the observed mean is a better predictor than the model. This means that the closer the model efficiency is to 1, the more accurate the model is.

Figure H 1 shows that for the selected events depicted in Table H 4 for each six minute time step there was a very good fit between the flows modelled in MUSIC with observed flows. Figure H 2 shows the hydrographs for the same events and also shows that the MUSIC model was quite efficient in simulating the observed peak flows.

[7] http://www.bom.gov.au/hydro/has/cdirswebx/cdirswebx.shtml

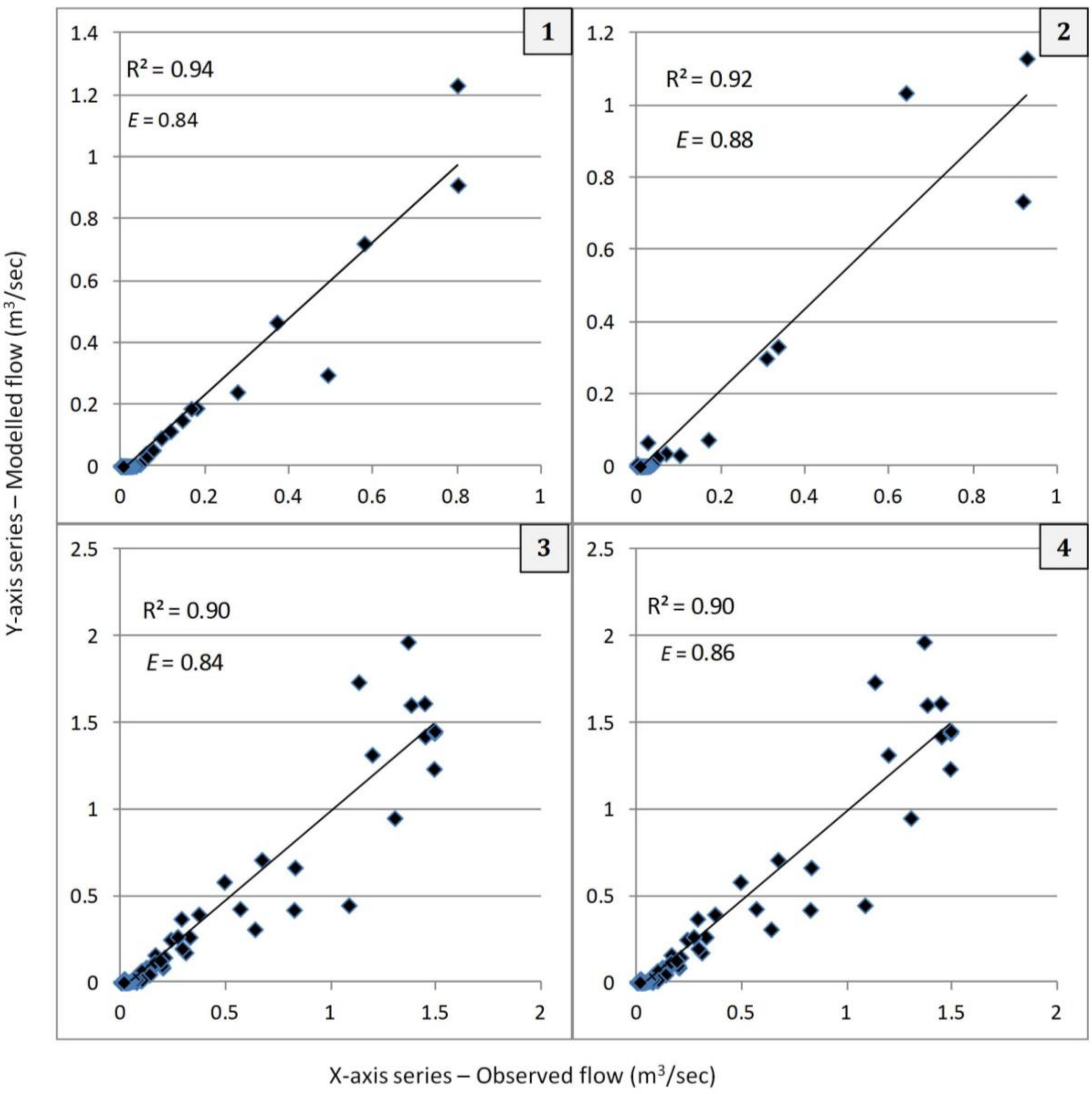

Figure H 1 - Modelled versus observed flow for selected validation events (six minute time step)

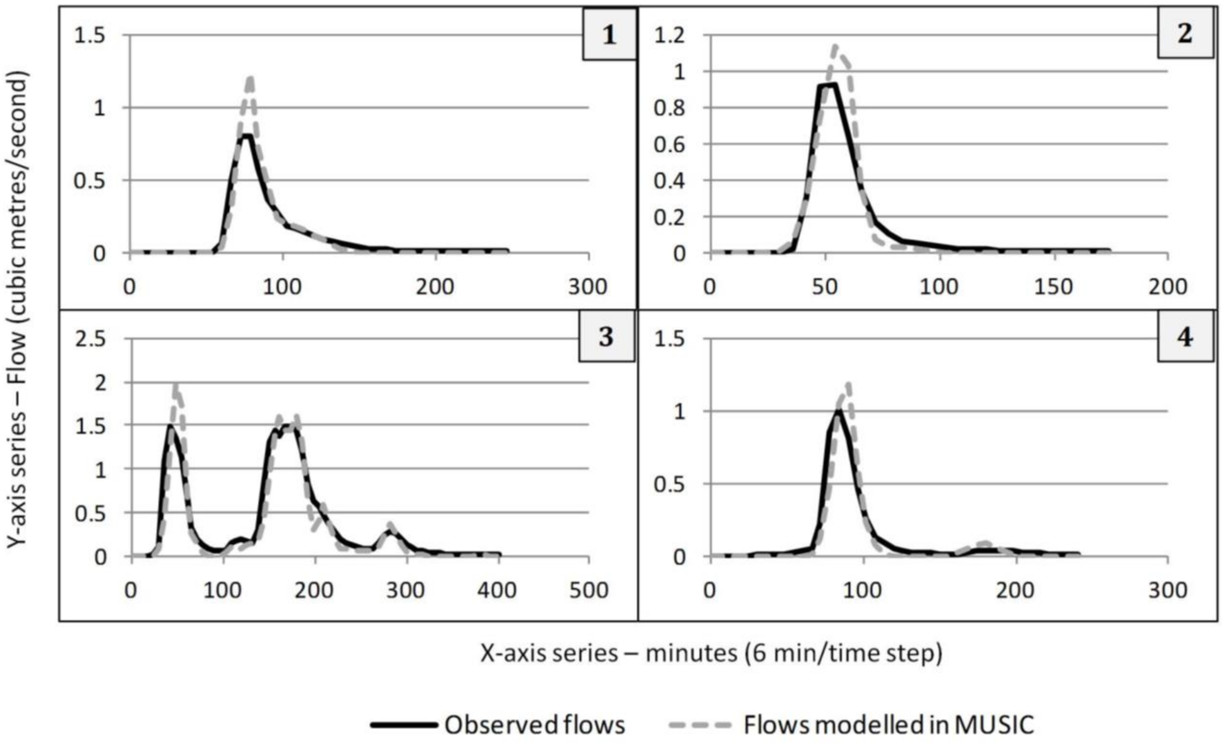

Figure H 2 - Hydrographs of observed and modelled flows for selected validation rainfall events

H.3 Results

Figure H 3 shows the sensitivity of MUSIC results to changes in the effective impervious area. The calibrated model had an impervious area of just over 35% of the total catchment, with a difference in total observed and modelled mean annual flows of around 3.5%. It can be seen that modelled mean annual flows were quite sensitive to changes in effective impervious area. The modelled relationship between observed flow and effective impervious area was almost perfectly linear (r^2 = 0.997).

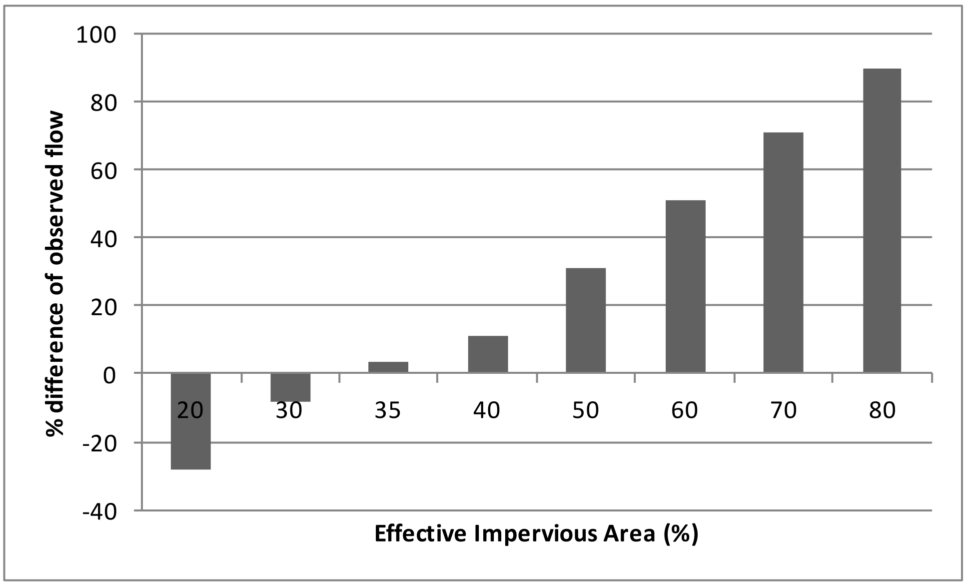

Figure H 3 - Sensitivity of MUSIC results to changes in effective impervious area

The sensitivity analysis compared both the impact of changing the pervious area parameters as defined by Macleod (2008) listed in Table H 1 and Table H 2, and the effective impervious area ratio. The pervious area parameters were applied for the following soil types:

- Sandy
- Sandy loam
- Clay loam
- Heavy Clay

The results found that the pervious area parameters did not have much influence on the model outcomes. The effect of these parameters also declined as the percentage of effective impervious area increased. Put another way, the rate of change (slope), where a change in soil storage capacity resulted in a change in modelled flows, decreased with increasing impervious area. However in all cases the effect of soil storage capacity and field capacity for different soil types was limited. Figure H 4 shows that differences in pervious area parameters based on soil type had a negligible effect on modelled flows, while increased impervious area had a linear relationship with modelled flows.

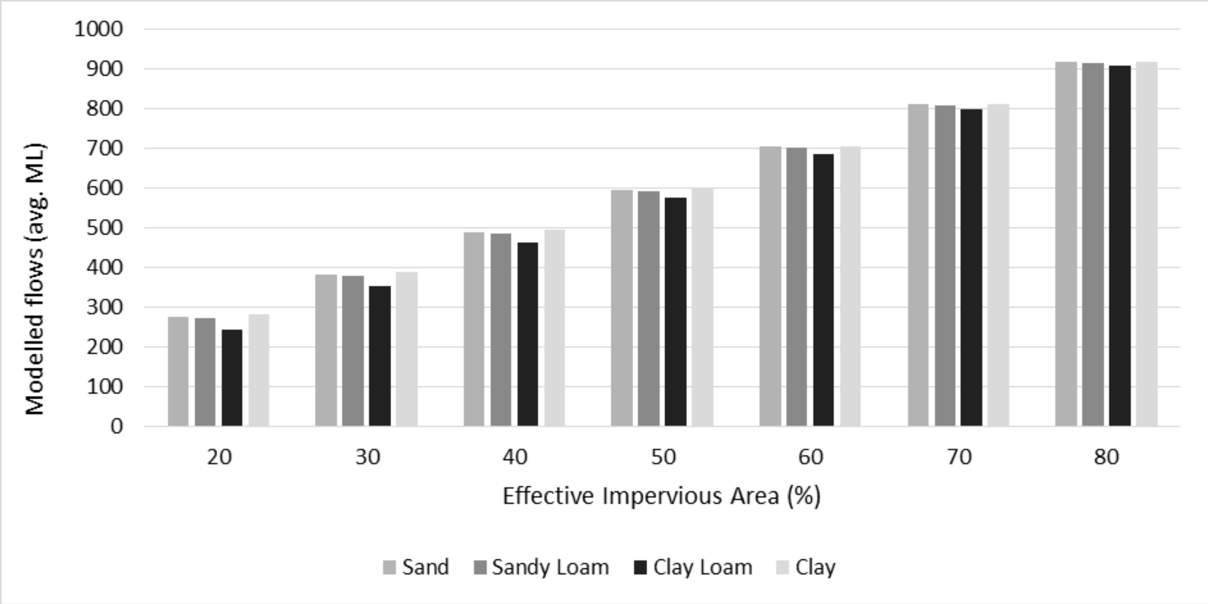

Figure H 4 - Sensitivity of modelled flows to changes in impervious area and pervious area parameters based on soil type.

To understand the sensitivities of other pervious area parameters in MUSIC a sensitivity analysis was undertaken using the calibrated Frederick Street catchment. This analysis varied each of the calibrated parameters individually, while holding all other parameters at their calibrated value. This was to evaluate how sensitive the calibrated model was to changes in each of the pervious area parameters.

Figure H 5 shows the sensitivity of the calibrated Frederick Street MUSIC model to changes in the soil storage capacity. Figure H 6 depicts the sensitivity for field capacity. It can be seen that model outputs were moderately sensitive to changes in the soil storage capacity, with a doubling of storage capacity resulting in a 6% change in modelled flows. Field capacity was less sensitive - once a field capacity of 100 mm was reached, further increases had no effect on the modelled flows.

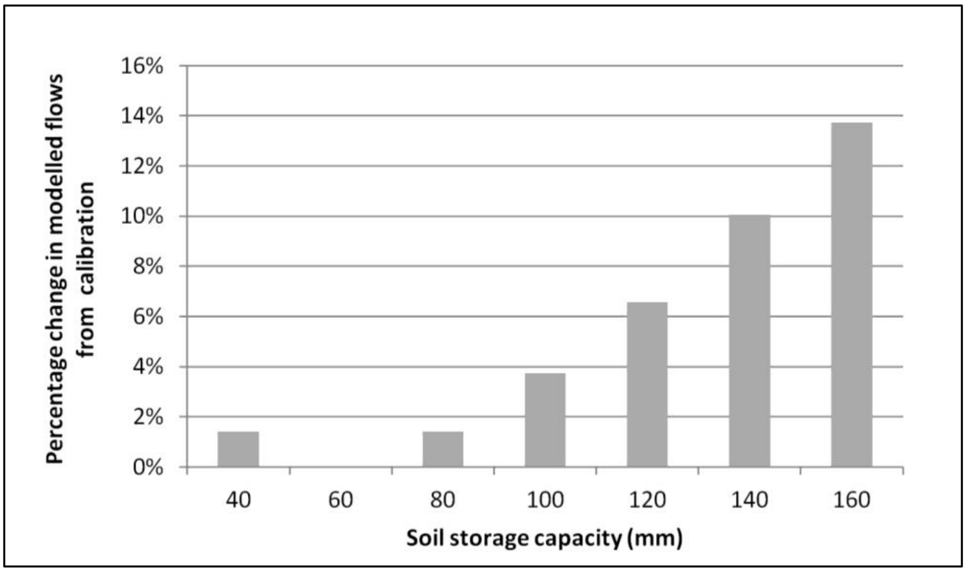

Figure H 5 - Sensitivity of soil storage capacity - mm (calibrated value 60)

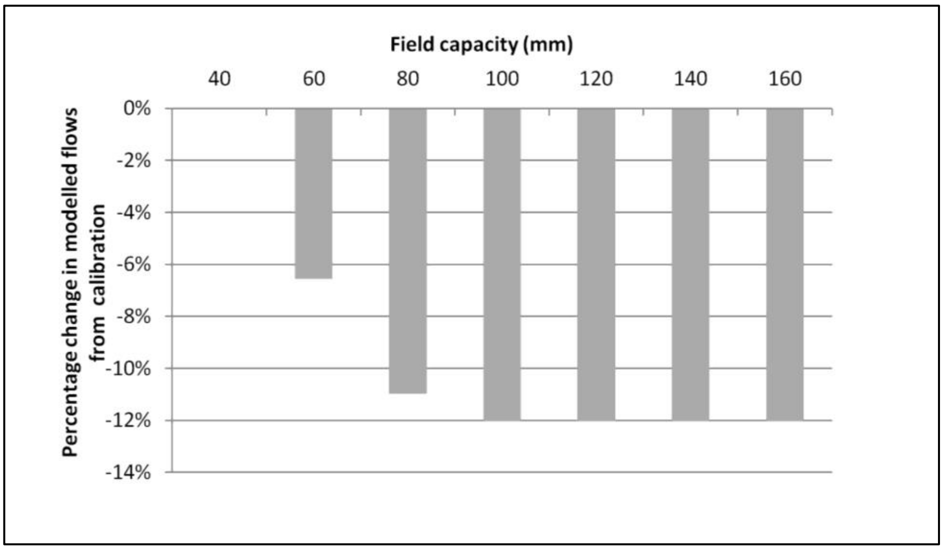

Figure H 6 - Field capacity - mm (calibrated value 40)

The sensitivity analysis showed that a number of the pervious area parameters in MUSIC were not sensitive, as changes in these values had no effect on the modelled flows from the calibrated Frederick Street catchment model.

- Infiltration capacity coefficient-a (mm/d) – was varied from 80 to 120 with no impact on modelled flow volumes
- Infiltration capacity exponent-b – was varied from 0.5 to 5 with no impact on modelled flow volumes
- Initial storage volume (% of capacity) – was varied from 25% to 100% with no impact on modelled flow volumes
- Groundwater initial depth (mm) – was varied from 10 mm to 50 mm with no impact on modelled flow volumes
- Daily base flow rate (%) – was varied from 5% to 25% with no impact on modelled flow volumes

(Dotto et al., 2011b) suggested that the MUSIC model was over parameterised, as a number of the parameters had little effect on the model results. This analysis on a calibrated Adelaide catchment has indicated that in fact a number of the pervious area parameters were insensitive. Where the parameter is insensitive the user may elect to use the default parameters without impacting on the accuracy of the model outcome. In heavily urbanised catchments with high impervious area the pervious area parameters relating to soil characteristics will have little influence when modelling the effectiveness of WSUD treatment in MUSIC. Therefore, the user may elect to not spend much time or resources in calibrating the model to local soil conditions, but rather focus on adequate representation of impervious area.

H.4 References

Dotto, CBS, Deletic, A, Fletcher, TD & McCarthy, DT 2011a, 'Parameter sensitivity analysis of stormwater models', *Proceedings of the 6th International Water Sensitive Urban Design Conference and Hydropolis*

Dotto, CBS, Kleidorfer, M, Deletic, A, Rauch, W, McCarthy, DT & Fletcher, TD 2011b, 'Performance and sensitivity analysis of stormwater models using a Bayesian approach and long-term high resolution data', *Environmental Modelling Software,* vol. 26, no. 10, pp. 1225-1239.

Gaffeny, A, H. 2013, 'Water Sensitive Urban Design for the Spring Creek catchment and MUSIC Sensitivity Analysis', Faculty of Health, Engineering & Sciences, University of Southern Queensland.

Kleidorfer, M, Chen, S, Dotto, CBS & McCarthy, DT 2012, 'Impact of objective function choice on model parameter senstivity', *9th International Conference on Urban Drainage Modelling*.

MacLeod, A 2008, 'MUSIC calibration based on soil conditions', *New South Wales and Queensland Joint Stormwater Industry Association Conference*, Stormwater Industry Association, Queensland.

Myers, B, Pezzaniti, D, Kemp, D, Chavoshi, S, Montazeri, M, Sharma, A, Chacko, P, Hewa, GA, Tjandraatmadja, G & Cook, S 2014b, *Water Sensitive Urban Design Impediments and Potential: Contributions to the Urban Water Blueprint (Phase 1) Task 3: The Potential Role of WSUD in Urban Service Provision*, Goyder Institute for Water Research, Adelaide, South Australia.

Sydney Catchment Authority 2012, *Using MUSIC in Sydney's Drinking Water Catchment*, Sydney Catchment Authority, Penrith, NSW, Australia.

Appendix I – The Impact of Runoff Routing in MUSIC

I.1 Introduction

The purpose of this exercise was to determine the sensitivity of a MUSIC simulation to selected routing parameters. In particular, the objective was to identify the impact of routing on the performance of hypothetical wetland and bioretention treatment systems.

Section 4.4.10 provided a background to the impact of link routing parameters. There was very little guidance in existing guidelines on how to select appropriate parameters. This is despite the importance of link routing in producing an accurate estimation of simulated peak flow rates (Dotto et al., 2011b; Myers et al., 2014b). Dotto et al. (2011a) found that in a sensitivity analysis of five catchments that MUSIC models were very sensitive to K (the translation factor in the Muskingum-Cunge routing method). Therefore they recommended that K should be calibrated as much as possible to ensure the accuracy of the flow routing method. Dotto et al. (2008) undertook a sensitivity analysis in order to evaluate sources of uncertainty in MUSIC due to settings used for 13 calibration parameters. This analysis found that for rainfall/runoff modelling only effective impervious area and the routing parameter K need to be calibrated, while for other parameters modellers can apply default values as the model outcomes are not sensitive to changes in these parameters.

Most guidelines tended to indicate that the selection of no link routing would be a conservative assumption, because this would overestimate peak flows and therefore may over-estimate the overflow volume of a treatment node.

I.2 Method

This analysis used the same model as that in Appendix H, namely the calibrated model of the Frederick Street catchment. The routing parameters of this model used were translation *k* = 14 minutes and attenuation θ = 0.3. Other modelling parameters were previously provided in Appendix H.

To assess the effect of assumed routing, the performance of a wetland was assessed by applying the calibrated model with and without routing parameters enabled. The simulated performance of the wetland for removing TSS, TP and TN were documented. There were four routing scenarios examined as follows:

Scenario 1: Calibrated, Muskingum Cunge (*k* = 14 mins, θ = 0.3)

Scenario 2: Calibrated, Muskingum Cunge attenuation disabled (*k* = 14 mins, θ = 0.49)

Scenario 3: Translation only (*k* = 12 minutes)

Scenario 4: No link routing

The wetland adopted was assumed based on the recommendations for conceptual design of a wetland in MUSIC provided in Appendix J, where a notional detention time of between 48 and 72 hours was targeted using reasonable adjustments to wetland area, outflow pipe diameter and overflow weir width. The wetland properties were constant in all routing scenarios, and are provided in Table I 1.

Table I 1 – Parameters of the assumed wetland

Low flow bypass (m^3/s)	0
High flow bypass (m^3/s)	2
Inlet pond volume (m^3)	90
Surface area (m^2)	1000
Extended detention depth (m)	0.5
Permanent pool volume (m^3)	50
Initial volume (m^3)	50
Exfiltration rate (mm/hr)	0
Evaporative loss (as % of PET)	125
Equivalent pipe diameter (mm)	40
Overflow weir width (m)	3
Notional detention time (Hrs)	52.7

I.3 Results

The results of the analysis indicate that in the case of the calibrated catchment with a wetland, there was very little impact when link routing was applied. The results did demonstrate that for Scenario 1, where the routing was calibrated to observed data, that there was no high flow by-pass of the wetland. While in other scenarios a very small amount (~0.5%) of the overall flow by-passed the wetland treatment due to the flow rate exceeding the peak design flow. The results demonstrated that there was very little difference in the performance of the wetland in reducing loads of pollutants. To enable comparison between the scenarios a mean was applied in generating pollutants rather than applying a stochastic process based on mean and standard deviation. The difference in treatment efficiency for total nitrogen reduction over the modelling period was less than 1%.

However, while there is no appreciable differences between the scenarios in terms of mean annual flows and treatment efficiency there is a significant difference in peak flows. Figure I 1 illustrates that the impact of different routing approaches on the peak flow and the timing of this peak in comparison to observed flows. The flows were compared for a rainfall event described previously in Table H – 4 (Event 3), which represents an event with an ARI of between 10 and 20 years. This shows that the calibrated routing most closely represents the observed flows. The model with no routing has much higher peak flow, while routing with translation only or with attenuation disabled also have a similar profile with a pronounced peak that rapidly declines. Therefore, not applying a calibrated routing may overestimate flow that by-pass the treatment device.

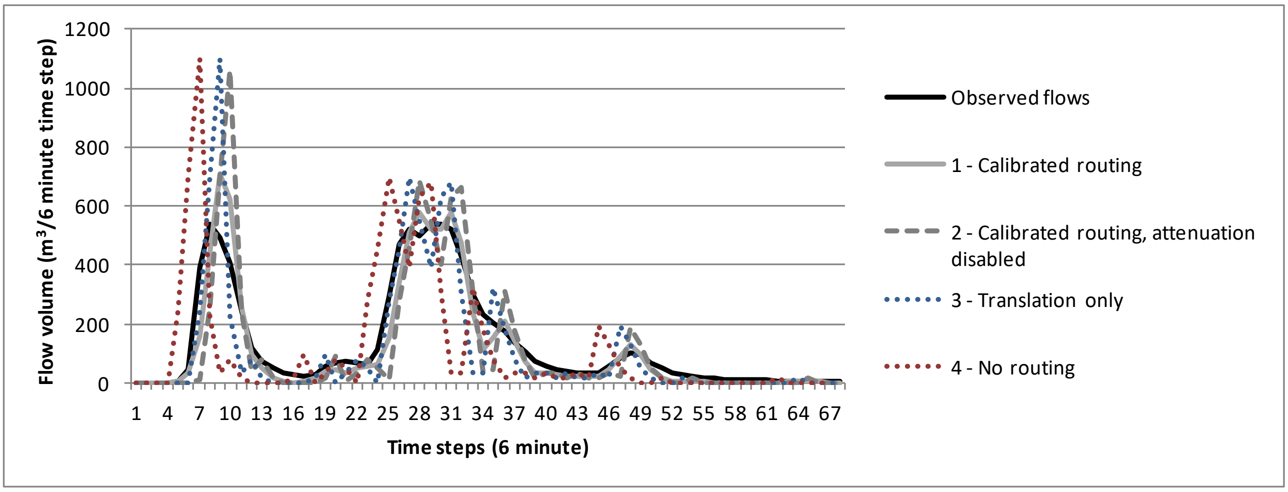

Figure I 1 – Impact of routing method on peak flows

I.4 Summary

This section has shown that calibrated routing more skilfully simulates observed flows, and in particularly the magnitude of peaks. However, negligible differences were observed between scenarios with calibrated routing and without in terms of mean annual flow and mean annual treatment efficiency. The modelling results indicate that calibrated routing is likely to be important when sizing stormwater treatment devices as this requires an accurate representation of peak flows. Routing is likely to be less important when modelling the impact of stormwater treatment devices on mean annual reductions in flows or pollutant loads.

I.5 References

Dotto, CBS, Deletic, A & Fletcher, T 2008, 'Analysis of uncertainty in flow and water quality from a stormwater model', *11th International Conference on Urban Drainage*.

Dotto, CBS, Deletic, A, Fletcher, TD & McCarthy, DT 2011a, 'Parameter sensitivity analysis of stormwater models', *Proceedings of the 6th International Water Sensitive Urban Design Conference and Hydropolis*

Dotto, CBS, Kleidorfer, M, Deletic, A, Rauch, W, McCarthy, DT & Fletcher, TD 2011b, 'Performance and sensitivity analysis of stormwater models using a Bayesian approach and long-term high resolution data', *Environmental Modelling Software,* vol. 26, no. 10, pp. 1225-1239.

Myers, B, Pezzaniti, D, Kemp, D, Chavoshi, S, Montazeri, M, Sharma, A, Chacko, P, Hewa, GA, Tjandraatmadja, G & Cook, S 2014b, *Water Sensitive Urban Design Impediments and Potential:*

Contributions to the Urban Water Blueprint (Phase 1) Task 3: The Potential Role of WSUD in Urban Service Provision, Goyder Institute for Water Research, Adelaide, South Australia.

Appendix J – Stormwater Treatment Devices in MUSIC

J.1 Introduction

This section outlines the different stormwater treatment devices available in MUSIC. It provides an outline of the underlying approach that is applied in MUSIC to simulate the performance of different stormwater treatment devices in the removal of pollutants and managing runoff. The section highlights key issues that need to be considered in setting parameter values in MUSIC for the planning and design of stormwater systems to meet best practice guidelines in South Australia.

J.2 Universal Stormwater Treatment Model (USTM)

Wong et al. (2006) noted that many of the treatment measures in MUSIC have a shared approach. Therefore, for modelling purposes the following stormwater treatment measures – vegetated swales, wetlands, ponds, sedimentation basins and infiltration systems can be considered as a single treatment approach where a simple first order kinetic model is joined to a model that simulates hydrodynamic behaviour. For example, a constructed wetland can be characterised as shallow densely vegetated system when compared to a pond that will usually have deeper open water and fringing vegetation (eWater, 2014b). While a grass swale can be considered as an ephemeral vegetated system that operates at a higher hydraulic loading than a constructed wetland (eWater, 2014b).

There are two basic modelling procedures that are applied in the unified modelling approach in MUSIC, which are:

- Hydrologic routing to simulate the movement of water through a treatment system; and,
- The first order kinetic model that simulates the removal of pollutants within a treatment device (eWater, 2014b).

The treatment of contaminants are modelled using a first order kinetic (k – C*) model. The k relates to the rate constant, while C* relates to the background concentration. The rationale is that in a parcel of water the contaminant concentrations moves by exponential decay towards an equilibrium value for that site at that time (eWater, 2014b). However, it has been found that k-rate constant and C* background concentration vary significantly with hydraulic loading and inlet concentration (Wong et al., 2006). More recent versions of MUSIC now have an additional parameter C**, which simulates the baseflow background concentration. This parameter applies when flows are largely confined to a low flow channel. In cases where a permanent pool is present then only C* applies, and C** can be disabled by setting it to the same value as C* (eWater, 2014b).

Wong et al., (2006) noted that the k-C* model assumes steady and plug-flow conditions, which rarely happen in the field. To address this, the kinetic model is coupled with a flow-hydrodynamic model – the Continuously Stirred Tank Reactor model.

MUSIC uses Continuously Stirred Tank Reactors (CSTRs) to simulate the movement and mixing of a water parcel through a treatment device. The number of CSTRs represents the different types of stormwater treatment devices (Scholes et al., 2008). Default values are provided in MUSIC for the different devices. For example, a sedimentation basin can be represented by a single CSTR as inflow is expected to occur immediately with complete mixing occurring with the existing contents of the basin. For long vegetated devices, such as swales or long vegetated wetlands, it is assumed that limited dispersion would occur. In this case, multiple CSTRs may be applied in the model (eWater, 2014b).

Scholes et al., (2008) noted that an advantage of MUSIC as conceptual analysis tool is that it comes loaded with default values that allow a user to rapidly compare scenarios and addresses the lack of monitoring data that is available to calibrate models. However, the removal processes that occur in stormwater treatment devices vary considerably in time and space (Scholes et al., 2008). For example, antecedent rainfall conditions and rainfall intensity can influence the appropriate C* value.

The MUSIC user manual provides some guiding principles that can be applied in setting appropriate k and C* values, which include (eWater, 2014b):

- The values for k for each of the devices in a stormwater treatment train should reflect the settling velocities of the targeted sediment size; C* for each stormwater treatment device should reflect the particle size range which the respective treatment device are not normally designed to remove;
- The value of k for TN and TP in relation to TSS for each stormwater treatment device should reflect the speciation of these water quality constituents by the particle size distribution of suspended solids; and,
- A conservative approach (i.e. lower k values and higher C* values) should be used where the user is unsure.

Other issues to consider in selecting k and C* values include: they should be considered as pairs, so if a higher k value is selected then a corresponding higher C* should also be selected; the values should reflect the position of a device in the stormwater treatment train; and, wherever possible local data should be used to calibrate these values in MUSIC and sensitivity testing should be undertaken of k and C* values (eWater, 2014b).

The MUSIC user manual provides the rationale for the default values supplied with each of the stormwater treatment devices. The theoretical framework for selecting k and C* values was based on the following monitoring studies, from which observed data was used to calibrate MUSIC treatment nodes (eWater, 2014b):

1. A vegetated swale in Brisbane
2. A stormwater pond/lake in Melbourne
3. A large constructed wetland in Melbourne

It is noted that default values for k and C* to represent TN removal are based on very little data, and in some cases (such as swales) there was no calibrated data available to develop default values for TN removal (eWater, 2014b). It is therefore strongly recommended that where possible local data is used to calibrate k and C* values. Therefore, given the sensitivity of modelled performance in MUSIC to appropriate k and c* values there is a need to calibrate stormwater treatment devices to South Australian climate and soil conditions. Scholes et al., (2008) identified that in many cases there is a lack of field monitoring studies that are needed to calibrate the performance of stormwater treatment devices in different locations.

(Imteaz et al., 2013) compared field measurements for different types of constructed stormwater devices with estimated values modelled using MUSIC. This study found that in general MUSIC could simulate flows with reasonable accuracy. However, predictions for the removal efficiencies of TP, TN and TSS were varied. For a bio-retention system in Melbourne MUSIC's predictions for flow and TSS removal efficiencies were consistent with field monitoring. However, the modelled removal efficiencies for TN and TP didn't match field monitoring results (Imteaz et al., 2013). The authors highlighted that the potential for MUSIC to over or underestimate removal efficiencies means that results should be used with caution, but that it is useful to compare the performance of different systems (Imteaz et al., 2013).

J.3 Reuse from treatment nodes

In the stormwater treatment nodes in MUSIC that store water there is the opportunity to model opportunities for reuse of detained or retained runoff. This reuse could be for irrigation or other non-potable uses

It is noted that size of the storage and the yield is sensitive to demand, and it is therefore recommended to use a 6 minute time step where possible (Water by Design, 2010). WaterbyDesign (2010) also notes that if the storage is less than four to five times the average daily demand then yield may be overestimated.

The main parameters in MUSIC in modelling reuse opportunities in a stormwater treatment node include defining the maximum drawdown from the storage and the demand properties. The drawdown setting determines the depth of the storage from the stormwater treatment device that is available for reuse.

Demand can be modelled in MUSIC based on the following options:

- Annual demand that is adjusted for the daily potential evapotranspiration in the climate file used to create the model;
- Annual demand that is adjusted for daily potential evapotranspiration minus the daily rainfall, so that reuse only occurs when PET exceeds rainfall;
- Annual demand that a user can define the monthly distribution through a graphical editor that specifies the percentage of annual rainfall that falls in each month;
- Specify a daily demand; or,
- Provide a user defined demand time series, which enables more detailed representation of demand by including aspects like trends in demand.

End use studies can be used to characterise demand for captured runoff in MUSIC modelling. In Australia, there have been a number of comprehensive end use studies that have been widely used to characterise residential water demand. This has included studies in Melbourne (Roberts, 2005) and South East Queensland (Beal & Stewart, 2014; Willis et al., 2013). There has been a recent study undertaken by the Goyder Institute for Water Research to better understand household water demand in the South Australian context (Arbon et al., 2014). Arbon et al., (2014) used a mixture of surveys of selected households, end-use flow monitoring, analysis of water use drivers and predictive modelling to better define water end use characteristics in Adelaide. This study provides a breakdown of per capita daily indoor water use by major end use, as well as the split between indoor and outdoor demand, and characterised peak demand both daily and seasonal.

J.4 Wetland

Wetlands are shallow, extensively vegetated waterbodies that provide for sedimentation, fine filtration other processes that remove pollutants from stormwater(Melbourne Water, 2005).

Melbourne Water (2010a) have developed detailed design guidelines for constructed wetlands. This includes guidance on the use of MUSIC for estimating the performance of a proposed wetland in the concept design phase. Table J 1 outlines some of the key MUSIC parameters for setting the properties of a wetland in MUSIC.

Table J 1 - Key wetland parameters in MUSIC

Key Parameters	Rationale	Suggested values
Low-flow bypass	The flow rate below which inflow bypasses the wetland.	0 m^3/sec, unless bypass exists.
High-flow bypass	The flow rate above which inflow is diverted to a bypass channel. This is done to protect the macrophyte zone.	High flow bypass can be estimated based on peak design flow using the rational method (Melbourne Water, 2010a).

Key Parameters	Rationale	Suggested values
Inlet Pond Volume	Simulates a sedimentation pond prior to a wetland. To be applied if wetland and sedimentation pond have the same extended detention depth. However, if the sediment pond has a higher extended detention depth, then it should be modelled as a separate node (Melbourne Water, 2010a).	If sedimentation pond is a separate node this should be set to 0. Otherwise sized to remove coarse sediment during a 1 year ARI storm event (eWater, 2014b).
Surface area	This defines the surface area of the macrophyte zone.	The surface area can be assumed to be the area of the wetland at normal water level (Melbourne Water, 2010a). Another approach is to calculate the surface area is based on the average of the normal water level and the top of the extended detention (eWater, 2014b).
Extended detention depth	Indicates the depth of the macrophyte zone available to detain and treat runoff. Flow in excess of this is diverted to an overflow weir.	Design needs to consider the optimal depth for the health of macrophytes. The default depth in MUSIC is 1 metre. However, this could be beyond the optimum depth for some macrophytes. Melbourne Water (2010a) indicate that that an extended detention depth of greater than 350 mm can start to impact on the establishment and persistence of some macrophytes species.

Key Parameters	Rationale	Suggested values
Permanent pool volume	This indicates the permanent pool volume based on average depth. This is taken as a constant in MUSIC. (i.e. it excludes ephemeral areas of the wetland)	This can be calculated based on an average depth of 0.2 to 0.3 metres, but in some cases constructed wetlands may be ephemeral so will not have a permanent pool volume.
Initial volume	This is the volume of the wetland at the start of the model run.	Testing showed that the value used for volume at time step zero had little influence on the model outcome when run over a 10 year period.
Exfiltration rate	This defines losses due to seepage from an unlined wetland into the underlying soil. Representative exfiltration rates are provided in the MUSIC user guide based on the major soil types (see: (eWater CRC, 2015)	As the exfiltration rate will also influence treatment, it is generally recommended to set the exfiltration rate to zero when demonstrating compliance with water quality objectives. This will provide a conservative approach.
Evaporative losses	Losses from the permanent pool volume due to evapotranspiration.	The default value in MUSIC is 125% of the daily PET. This is to account for losses by transpiration from macrophytes
Equivalent pipe diameter	This parameter defines the equivalent diameter of the wetland outlet. This can represent a number of outlets as wetlands are rarely configured with a single orifice (eWater CRC, 2015). This parameter along with storage size can be used to ensure that the wetland has sufficient detention time to reduce nutrient levels.	The equivalent pipe diameter can be adjusted to meet the required detention time. Water by Design (2010) and recommends a minimum detention time of 48 hours. South Australian guidelines (South Australian Department of Planning and Local Government, 2010), as well as Webner and Fletcher (2010) recommend between 48 and 72 hours.

Key Parameters	Rationale	Suggested values
Overflow weir width	Controls the discharge rate when the water level exceeds the top of the extended detention.	Water by Design (2010) recommends setting the overflow weir width as the "greater of either the surface area (m2) divided by 10 m or the weir width that would be required to convey a major storm flow with a 0.3 m head". There are no quantitative recommendations in the current SA WSUD guidelines.

J.5 Pond

Ponds in MUSIC represent basins or waterbodies where the primary stormwater treatment mechanism is the settling out of suspended sediments. They can also reduce peak flows from runoff events by detaining a volume of runoff during the storm event that is subsequently released. Ponds are conceptually similar to a sediment basin with a permanent water storage in MUSIC (Webner & Fletcher, 2010). A pond usually has a depth of greater than 1.5 metres, which limits growth of macrophytes to the pond fringes (~10% vegetation coverage is a default value). Webner and Fletcher (2010) recommend not to use ponds in MUSIC due to the potential for water quality issues, as the limited macrophyte coverage may not provide for effective treatment of nutrient loads entering the pond. It is recommended that a GPT and a vegetated treatment node precede a pond in a stormwater treatment train to ensure the water quality entering the pond minimises problems (Webner & Fletcher, 2010). Table J 2 outlines some of the key MUSIC parameters for setting the properties of a pond in MUSIC.

Table J 2 - Key pond parameters in MUSIC

Key Parameters	Rationale	Suggested values
Low-flow bypass	The flow rate below which inflow bypasses the pond.	0 m^3/sec, unless low flow bypass exists.
High-flow bypass	The flow rate above which inflow is diverted to a bypass channel. This is done to protect the macrophyte zone.	High flow bypass can be estimated based on peak design flow using the rational method (2010a)

Key Parameters	Rationale	Suggested values
Surface area	This defines the surface area of the pond.	The surface area can be assumed to be the area of the pond at normal water level (Melbourne Water, 2010a). Another approach is to calculate the surface area based on the average of the normal water level and the top of the extended detention (eWater, 2014b).
Extended detention depth	Indicates the depth of the pond available to detain and treat runoff. Flow in excess of this is diverted to an overflow weir.	MUSIC assumes the extended detention has vertical sides (Webner & Fletcher, 2010)
Permanent pool volume	This is indicates the permanent pool volume based on average depth. This is taken as a constant in MUSIC.	Calculated based on surface area and average depth.
Initial volume	This is the volume of the pond at the start of the model run.	Testing showed that the value used for volume at time step zero had little influence on the model outcome when run over a 10 year period.
Exfiltration rate	This defines losses due to seepage from an unlined pond into the underlying soil. Representative exfiltration rates are provided in the MUSIC user guide based on the major soil types (see: (eWater CRC, 2015)	As the exfiltration rate will also influence treatment, it is generally recommended to set the exfiltration rate to 0 when demonstrating compliance with water quality objectives. This will provide a conservative approach.
Evaporative losses	Losses from the permanent pool volume due to evapotranspiration.	The default value in MUSIC is 100% of the daily PET.

Key Parameters	Rationale	Suggested values
Equivalent pipe diameter	This parameter defines the equivalent diameter of the pond outlet. This parameter along with storage size can be used to ensure that the pond has sufficient detention time to reduce nutrient levels.	The equivalent pipe diameter can be adjusted to meet the required detention time.
Overflow weir width	Controls the discharge rate when the water level exceeds the top of the extended detention.	Water by Design (2010) recommends setting the overflow weir width as the "greater of either the surface area (m2) divided by 10 m or the weir width that would be required to convey a major storm flow with a 0.3 m head".

J.6 Sedimentation Basin

Sedimentation basins are configured to remove medium to coarse grained sediments (Melbourne Water, 2005). These can be a permanent feature of a stormwater treatment train or as a temporary measure during the construction phase of a development when sediment loads are likely to be greatest. The required size of the sediment basin can be calculated on the basis of the settling velocity of the target sediment size for the design flow (Melbourne Water, 2005). Table J 3 outlines some of the key MUSIC parameters for setting the properties of a sediment basin in MUSIC.

Table J 3 - Key sediment basin parameters in MUSIC

Key Parameters	Rationale	Suggested values
Low-flow bypass	The flow rate below which inflow bypasses the sedimentation basin.	0 m^3/sec, unless low flow bypass exists.

Key Parameters	Rationale	Suggested values
High-flow bypass	The flow rate above which inflow is diverted to bypass channel. This is done to minimise the potential for scouring of the basin (Webner & Fletcher, 2010).	High flow bypass can be estimated based on 50% of the 1 year ARI flow (Webner & Fletcher, 2010).
Surface area	This defines the surface area of the basin. The shape of the basin has a large influence on the effectiveness in retaining sediments.	It is recommended that a length to width ratio of 3:1 is achieved (Melbourne Water, 2005).
Extended detention depth	Indicates the depth of the basin available to detain runoff. Flow in excess of this is diverted to an overflow weir.	The default value in MUSIC is 2 m. It needs to be sufficient to enable the settling out of target sediment size and prevent scouring of previously settled sediments.
Permanent pool volume	It is considered good practice to include a permanent pool volume to reduce flow velocities and increase detention time (Melbourne Water, 2005).	The size of the basin needs to account for the capacity needed to retain sediments based on expected loads and desired cleaning (desilting) frequency (Melbourne Water, 2005).
Initial volume	This is the volume of the permanent pool at the start of the model run.	Testing showed that the value used for volume at time step zero had little influence on the model outcome when run over a 10 year period.

Key Parameters	Rationale	Suggested values
Exfiltration rate	This defines losses due to seepage from an unlined basin into the underlying soil. Representative exfiltration rates are provided in the MUSIC user guide based on major soil types (see: (eWater CRC, 2015).	The default value in MUSIC is 0 mm/hr. As the exfiltration rate will influence treatment, it is generally recommended to set the exfiltration rate to 0 when demonstrating compliance with water quality objectives. This will provide a conservative approach.
Evaporative losses	Losses from the permanent pool volume due to evapotranspiration.	The default value in MUSIC is 75% of the daily PET.
Equivalent pipe diameter	This parameter defines the equivalent diameter of the sediment basin outlet. This can be used to configure a notional detention time.	As sediment basins are not used for treatment of nutrients the notional detention time can be set at a maximum of 8 hours (Webner & Fletcher, 2010).
Overflow weir width	Controls the discharge rate when the water level exceeds the top of the extended detention.	A narrow weir may be adopted to enable a larger range of extended detention depths while ensuring the capacity needed to convey design discharge.

J.7 Detention Basin

Detention basins are designed to temporarily store stormwater runoff to reduce peak flow rates, therefore preventing localised flooding downstream. In MUSIC, detention basins are modelled exactly the same as sedimentation basins but they have different default k, C* and CSTR values. The main difference between the two is that the primary focus of detention basins is flow management rather than water quality, so in many cases the detention time may not be sufficient to allow for settling out of sediment load. Table J 4 outlines some of the key MUSIC parameters for setting the properties of a detention basin in MUSIC.

Table J 4 - Key detention basin parameters in MUSIC

Key Parameters	Rationale	Suggested values
Low-flow bypass	The flow rate below which inflow bypasses the detention basin.	0 m^3/sec, unless a low flow bypass exists.
High-flow bypass	The flow rate above which inflow is diverted to a bypass channel. This is done to minimise the potential for scouring of the basin (Webner & Fletcher, 2010).	High flow bypass can be estimated based on 50% of the 1 year ARI flow (Webner & Fletcher, 2010).
Surface area	This defines the surface area of the basin.	The sizing of the basin (area and depth) will be based on ensuring peak flows do not increase as a result of development for the design rainfall event.
Extended detention depth	Indicates the depth of the basin available to detain runoff. Flow in excess of this is diverted to an overflow weir.	The default value in MUSIC is 2 m. In some cases maximum depth may be limited to preserve amenity and minimise safety hazards.
Exfiltration rate	This defines losses due to seepage from an unlined basin into the underlying soil. Representative exfiltration rates are provided in the MUSIC user guide based on major soil types (see: (eWater CRC, 2015).	The default value in MUSIC is 0 mm/hr. As the exfiltration rate will also influence treatment, it is generally recommended to set the exfiltration rate to 0 when demonstrating compliance with water quality objectives, noting this is not the primary function of a detention basin.
Evaporative losses	Losses from the permanent pool volume due to evapotranspiration.	The default value in MUSIC is 100% of the daily PET.

Key Parameters	Rationale	Suggested values
Low flow pipe diameter	This parameter defines the equivalent diameter of the basin outlet. This can be used to configure detention time.	As basins are not used for treatment of nutrients the notional detention time can be set at a maximum of 8 hours (Webner & Fletcher, 2010).
Overflow weir width	Controls the discharge rate when the water level exceeds the top of the extended detention.	A narrow weir may be adopted to enable a larger range of extended detention depths while ensuring capacity needed to convey design discharge is maintained.

J.8 Infiltration System

Infiltration systems are designed to enable runoff to infiltrate into surrounding soils and either return to the atmosphere by evapotranspiration between events or proceed to deeper soil storage/aquifers. The performance of an infiltration system will depend on the local soil type, with infiltration systems most effective in sandy soils with deep groundwater (Melbourne Water, 2005). Infiltration systems are characterised by a shallow trench that has a storage capacity, often made up of gravel or a manufactured structure. The runoff is held in the storage while infiltration occurs into underlying soils (Department of Planning and Local Government, 2009).

An infiltration system needs to have pre-treatment, such as sedimentation, to reduce clogging. Clogging is an issue as it impacts on both the hydraulic performance of infiltration systems, and also impedes the interception of pollutants (Le Coustumer et al., 2009). In MUSIC, since the release of Version 5 onward, vegetated infiltration systems are modelled using the bio-retention treatment node (eWater CRC, 2015). Water by Design (2010) highlights that while infiltration systems can be important for flow management they are not considered to contribute to compliance with stormwater quality management. Table J 5 outlines some of the key MUSIC parameters for setting the properties of an infiltration system in MUSIC.

Table J 5 - Key infiltration system parameters in MUSIC

Key Parameters	Rationale	Suggested values
Low-flow bypass	The flow rate below which inflow bypasses the infiltration system.	0 m^3/sec, unless low flow bypass is intended.

Key Parameters	Rationale	Suggested values
High-flow bypass	The flow rate above which inflow is diverted to a bypass channel.	High flow bypass can be estimated based on peak design flow using the rational method (2010a).
Pond surface area	The surface area of the infiltration system required to achieve flow management targets such as peak flow reduction.	The area required to meet hydrologic effectiveness will depend upon soil hydraulic conductivity and detention storage, as well as the contributing impervious catchment and rainfall intensity.
Extended detention depth	Indicates the depth of the water ponding above the infiltration media before it starts to overflow.	The default value in MUSIC is 0.2 m.
Filter area	This specifies the area of the infiltration media	A conservative estimate of the filter media area assumes the filter area is equal to the surface area. This is based on vertical sides where in most cases an infiltration system will not have vertical sides (Water by Design, 2010).
Unlined filter media	This relates to the perimeter of the infiltration system, as MUSIC assumes infiltration through the sides of the drain.	A measurement of the infiltration system perimeter, excluding any lined areas (which may be required to prevent infiltration near infrastructure).
Depth of infiltration media	The depth of the infiltration media in metres.	Needs to be sized to meet design objectives in terms of runoff reduction.

Key Parameters	Rationale	Suggested values
Exfiltration rate	This defines infiltration rate into the surrounding soil, which will be determined by the hydraulic conductivity of both the filter media and the surrounding soil.	The default value in MUSIC is 100 mm/hr. In most cases the exfiltration rate is determined by the underlying soil rather than the filter media (Water by Design, 2010).
Evaporative losses	Losses from the permanent pool volume due to evapotranspiration.	The default value in MUSIC is 100% of the daily PET.
Overflow weir depth	Controls the discharge rate when the water level exceeds the top of the extended detention.	Major flood events can be used to design overflow weir depth (Melbourne Water, 2005).

J.9 Bioretention

Bioretention basins use ponding above a bioretention surface to maximise the treatment of runoff through a filtration media (Melbourne Water, 2005). Bioretention can be designed to either encourage infiltration to the native soil or as a conveyance system, where the collected water is discharged to downstream waters (Melbourne Water, 2005). Table J 6 outlines some of the key MUSIC parameters for setting the properties of a bioretention system in MUSIC.

Table J 6 - Key bioretention parameters in MUSIC

Key Parameters	Rationale	Suggested values
Low-flow bypass	The flow rate below which inflow bypasses the bioretention system.	0 m^3/sec, unless a low flow bypass is required.
High-flow bypass	The flow rate above which inflow is diverted to bypass channel.	High flow bypass can be estimated based on peak design flow using the rational method (2010a).

Key Parameters	Rationale	Suggested values
Surface area	The surface area represents the area available above the filter media that water can pond (Melbourne Water, 2005).	A conservative estimate of the surface area assumes the filter area is equal to the surface area. This is based on vertical sides where in most cases an bioretention surface storage will not have vertical sides (Water by Design, 2010).
Extended detention depth	Indicates the depth of the water ponding above the infiltration media before it starts to overflow (Water by Design, 2010).	It is recommended to use a depth of between 0 and 0.4 m. The MUSIC default is 0.2 m, which is the recommended depth for streetscape systems (Water by Design, 2010). The selected vegetation needs to be resilient to dry periods as well as inundation for extended periods (Water by Design, 2010).
Filter area	Area of the filter media. The Facility for Advancing Water Biofiltration (2008) illustrates that the design of bioretention basin in meeting best practice targets requires consideration of the relationship between extended detention depth, filter media hydraulic conductivity and filter surface area.	Facility for Advancing Water Biofiltration (2008) recommends that the filter area can be set between 1% to 4% of the connected impervious area of the contributing catchment

Key Parameters	Rationale	Suggested values
Unlined filter media perimeter	This relates to the perimeter of the infiltration system, as MUSIC assumes infiltration through the sides of the drain.	A measurement of the infiltration system perimeter, excluding any lined areas (which may be required to prevent infiltration near infrastructure).
Saturated hydraulic conductivity	This represents the hydraulic conductivity of the basin filter media. As mentioned above, this should be considered in relation to other factors (climate conditions, filter area and extended detention depth) in designing systems to meet best practice targets.	It is generally recommended that loamy sand is used as the filter media (Facility for Advancing Water Biofiltration, 2008; Water by Design, 2010). For a temperate climate like Adelaide, the hydraulic conductivity should be around 200 mm/hr (Facility for Advancing Water Biofiltration, 2008).
Filter depth	The filter media depth should match the rooting depth of selected vegetation (Water by Design, 2010).	The recommended depth of filter media is around 0.5 m to 0.6 m (Water by Design, 2010).
TN content of filter media	This refers to the TN available in the media. It may leach into stormwater at higher levels.	The default value in MUSIC is <800 mg/kg. This value may be measured in the intended soil.
Orthophosphate content of filter media	This refers to the amount of phosphate available in the filter media. It may leach into stormwater at higher levels.	Facility for Advancing Water Biofiltration (2008) recommends that phosphate content should be minimised in the filter media to less than 100 mg/kg.

Key Parameters	Rationale	Suggested values
Exfiltration rate	This defines infiltration rate into the surrounding soil.	The default value in MUSIC is 100 mm/hr. In most cases the exfiltration rate is determined by the underlying soil rather than the filter media (Water by Design, 2010).
Lining properties	Indicates if the base is lined or not. Facility for Advancing Water Biofiltration (2008) recommends where possible the base is unlined to encourage exfiltration to surrounding soils where possible.	Systems may need to be modelled as lined if they are unable to infiltrate (e.g. when located close to foundations, pavements or other infrastructure).
Vegetation properties	The selection of plant species has a significant impact on nutrient removal. Plant growth and rooting is also important in countering the effects of clogging and compaction to maintain hydraulic conductivity (Facility for Advancing Water Biofiltration, 2008).	It is recommended to select "vegetated with effective nutrient removal plants", which refers to suitable species of deep rooted plants. However, if the bioretention basin is only vegetated with turf, this should be represented in MUSIC as ineffective nutrient removal plants.
Overflow weir width	Controls the discharge rate when the water level exceeds the top of the extended detention.	It is recommended that as an initial setting that the overflow weir width (m) be estimated based the surface area (m^2) divided by 10 m (Water by Design, 2010).
Underdrain	Select if the bioretention system has an underdrain or not. Underdrains are used convey runoff away from the base of the biofilter.	In most cases bioretention systems will have an underdrain so it is recommended to select yes (Water by Design, 2010).

Key Parameters	Rationale	Suggested values
Submerged zone with carbon present	Determines if a submerged zone with carbon is present, and the depth of the zone.	The Facility for Advancing Water Biofiltration (2008) found that a 450 mm deep, permanently submerged zone (sand or gravel) that contained a carbon source promoted denitrification, which improved nitrate/nitrite removal.

J.10 Media Filtration

The media filtration treatment node in MUSIC is almost identical the bioretention treatment node in terms of parameters. It has been set up to allow for the modelling of propriety media filtration systems and unvegetated media filtration systems (eWater, 2014b) . It requires the user to specify pollutant removal efficiency, so it is recommended that caution is used in adopting values from commercial suppliers (Water by Design, 2010).

The media filtration node in MUSIC can be used to model the performance of any filtration system through media that doesn't use vegetation. This includes porous pavements and unvegetated sand filters (Water by Design, 2010).

J.11 Gross Pollutant Trap

Gross Pollutant Traps (GPTs) use physical processes to remove solid waste (gross pollutants) and coarse sediments from runoff. The processes that can be employed include: screening, rapid sedimentation and separation processes. The performance of these systems is usually based on performance values that are provided by suppliers of the GPTs (Melbourne Water, 2005). These claims on performance need to be assessed to determine if they have been adequately determined and verified using reliable data and fair test methodology (Melbourne Water, 2005). It is recommended to obtain independent, peer reviewed performance data for a specific GPT in a particular location (eWater CRC, 2015).

An important aspect of GPT design is to ensure the correct calculation of the high flow by-pass. Otherwise there is the risk that pollutant reductions will be attributed to bypassed flows (Water by Design, 2010). In MUSIC the GPT node can be used to model water quality improvements from proprietary products, where the user species pollutant removal efficiencies using a graphical interface (eWater CRC, 2015).

J.12 Swale

Swales are vegetated (usually grass) drains, which provide filtration for runoff prior to discharge to a downstream drain or receiving water (Deletic & Fletcher, 2006). Swales can be used instead of stormwater pipes or concrete drains to convey stormwater and are often used in conjunction with with buffer strips (Melbourne Water, 2005). Table J 7 outlines some of the key MUSIC parameters for setting the properties of a swale in MUSIC.

Table J 7 - Key swale parameters in MUSIC

Key Parameters	Rationale	Suggested values
Low-flow bypass	The flow rate below which inflow bypasses the swale.	0 m^3/sec, unless a low flow bypass is required.
Length	Representation of the length of the swale.	The length will often be influenced by the allowable width and side slope, which determine depth. The swale dimensions, along with vegetation type, will be capable of conveying flows to a certain rate after which the flow will top the swale banks – this point is considered the maximum length (Melbourne Water, 2005).
Bed slope (%)	The longitudinal slope of the swale.	It is recommended that the slope is between 1% and 4% (Melbourne Water, 2005). Slopes less than 1% may be prone to waterlogging and need an underdrain, while slopes greater than 4% have high velocities which increase scouring and will provide little if any treatment.

Key Parameters	**Rationale**	**Suggested values**
Base width	The width of the base of the trapezoidal channel.	Manning's equation is used to size the swale based on the design flow that needs to be conveyed. Constraints may need to be considered in sizing the swale, such as local council urban design requirements and/or the need to provide safe crossing points (Melbourne Water, 2005).
Top width	The width of the top of the trapezoidal channel.	Manning's equation is used to size the swale.
Depth	The depth of flow within the swale with any flow in excess of this by-passing the swale and not being treated	Manning's equation is used to size the swale and determine the flow capacity.
Vegetation height	Vegetation height helps to reduce flow velocity to reduce scouring, and provide filtration of sediments.	It is recommended that vegetation height should be above the treatment water flow level (Melbourne Water, 2005).
Exfiltration rate	This defines exfiltration rate to the surrounding soil, which will be determined by the hydraulic conductivity of the surrounding soil.	MUSIC provides representative exfiltration rates based on the particle size and saturated hydraulic conductivity of major soil types (eWater CRC, 2015).
Manning's N	This refers to a critical variable in Manning's equation that relates to channel roughness, which is estimated on the basis of flow depth, channel dimensions and vegetation height (Melbourne Water, 2005).	Flow velocities should be less than 0.5 m/s for minor storm discharges (e.g. 100 year ARI), and less than 1 m/s for major storm discharges (e.g. 100 year ARI).

Key Parameters	Rationale	Suggested values
Batter slope	This refers to the slope of the sides of the swale.	The appropriate slope will often be determined by local council regulations. The City of Onkaparinga's Technical service standards specifies swale batter slopes be 1:5 where possible (City of Onkaparinga, 2012).
Velocity	The speed of flow, which is calculated using Manning's equation.	Flow velocities should be less than 0.5 m/s for minor storm discharges (e.g. 5 year ARI), and less than 1 m/s for major storm discharges (e.g. 100 year ARI).
Hazard	This provides an indication of risks to public safety, which is based on depth multiplied by velocity	The standard from the Institution of Engineers recommends that the hazard score should be: < 0.4^2/s (Melbourne Water, 2005).
Cross sectional area	Cross sectional area which is used to calculate flow capacity of swale using Manning's equation (Melbourne Water, 2010a).	Calculated based on channel dimensions.
Swale capacity	This relates to the high flow bypass for other treatment devices. Flow in excess of the capacity given the known channel dimensions and vegetation height by-passes the swale.	Capacity needs to be calculated based on the design flow that the swale is meant to accommodate (e.g. capacity for 5 year ARI, 2 year ARI).

J.13 Buffer

Buffer strips are often used in combination with swales to provide for the removal of medium and coarse grained sediments (Melbourne Water, 2005). It is recommended that using buffers upstream of other stormwater treatment nodes is only appropriate where flow is dispersed (sheet flow) (Water by Design, 2010). Table J 8 outlines some of the key MUSIC parameters for setting the properties of a buffer strip in MUSIC.

Table J 8 - Key buffer parameters in MUSIC

Key Parameters	Rationale	Suggested values
Percentage of upstream area buffered	This indicates the proportion of the source node's impervious area that has buffer strips applied to it (eWater CRC, 2015).	The default value in MUSIC is 50%.
Buffer area (% of upstream impervious area)	This is the actual area of the buffer strips in relation to the upstream impervious catchment (eWater CRC, 2015).	The default value provided in MUSIC is 5% of the upstream impervious catchment.
Exfiltration rate	This defines infiltration rate into the surrounding soil, which will be determined by the hydraulic conductivity of the surrounding soil.	If the buffer is being modelled to assess reduction in pollutant loads it is recommended that exfiltration is set to 0 (WaterbyDesign, 2010).

J.14 Rainwater Tank

Rainwater tanks have been widely adopted in South Australia over the last 10 years. In part due to changes in the building code that made it mandatory for new Class 1 buildings to have an alternate water source, which is typically achieved using plumbed rainwater tanks (Goverrnment of South Australia, 2006). The requirements under the building code include all new Class 1 Dwellings and for all extensions to Class1 dwellings where more than 50 m^2 is added and where a toilet, laundry cold water tap or water is included (Goverrnment of South Australia, 2006). The code requires at least 50 m^2 of roof area to be connected to a minimum 1 kL rainwater tank where another alternate supply is present (such as recycled mains water or stormwater.

The primary purpose of this was to provide an alternative non-potable water source that would reduce demand for mains water supply. Rainwater tanks can also act as a stormwater retention device, but the effectiveness will depend upon the storage available at the start of the rainfall event.

Defining the demand in MUSIC for the reuse of runoff captured in a rainwater tank has been described previously in this section. The study by Arbon et al. (2014) defines for Adelaide the seasonal distribution of household water use and the breakdown of household end uses. This study can be used to define the demand for runoff captured in rainwater tank storages. Table J 9 outlines some of the key MUSIC parameters for setting the properties of a rainwater tank in MUSIC.

Table J 9 - Key rainwater tank parameters in MUSIC

Key Parameters	Rationale	Suggested values
Low-flow bypass	The flow rate below which bypasses the rainwater tank. This may include a first flush device that diverts the initial volume of a rainfall event to improve quality of captured water.	0 m^3/sec, unless low flow bypass exists in the intended tank installation.
High-flow bypass	The flow rate above which is diverted from the rainwater tank.	High flow bypass can be calculated based on the maximum flow capacity of the collection system.
Number of tanks	Rainwater tanks can be lumped or modelled individually. If lumped the tank storage properties are scaled-up to reflect combined volume of individual tanks (Water by Design, 2010).	Multiple tanks are modelled with uniform properties and demands. This may be used if land use is also lumped at the source node (e.g. represents multiple homes).
Volume below the overflow pipe	The storage volume available before the storage overflows.	Recommended to be at least five times greater than the maximum daily demand (Water by Design, 2010).
Depth above the overflow pipe	This can be used to simulate an extended detention, where the tank is used to attenuate peak flow. However, Water by Design (2010) indicates MUSIC is not an appropriate tool for estimating peak flow attenuation as it uses continuous simulation rather than event based method	The default value in MUSIC is 0.2 m.

	that models flow reduction for specified ARI events.	
Surface area	Defines the surface area of the tank in m^2 (eWater CRC, 2015).	The default value in MUSIC is 5 m^2
Initial volume	Volume of tank at the start of the simulation.	Estimated tank volume at start of model run based on antecedent rainfall and demand.
Overflow pipe diameter	Determines the flow rate from the overflow, which influences performance if tank capacity above overflow is used for peak flow attenuation.	The default value in MUSIC is 50 mm.

J.15 References

Arbon, N, Thyer, M, Hatton MacDonald, D, Beverley, K & Lambert, M 2014, *Understanding and predicting household water use for Adelaide*, Goyder Insitute for Water Research.

Beal, CD & Stewart, RA 2014, 'Identifying Residential Water End Uses Underpinning Peak Day and Peak Hour Demand', *Journal of Water Resources Planning and Management,* vol. 140, no. 7, p. 04014008.

City of Onkaparinga 2012, *Technical Service Standards - SD-230 Swale Installation (Type 1) - 900mm rock lined swale*, City of Onkaparinga,,

Deletic, A & Fletcher, TD 2006, 'Performance of grass filters used for stormwater treatment—a field and modelling study', *Journal of Hydrology,* vol. 317, no. 3–4, 2/20/, pp. 261-275.

Department of Planning and Local Government 2009, *Water Sensitive Urban Design Technical Manual for the Greater Adelaide Region*, Government of South Australia, Adelaide.

eWater 2014b, *MUSIC by eWater - User Manual*, Version 6.1.

eWater CRC 2015, *MUSIC Version 6.1*, eWater Cooperative Research Centre, Canberra, Australia.

Facility for Advancing Water Biofiltration 2008, *Advancing the design of stomrwater biofiltration*, Monash University, Melbourne.

Goverrnment of South Australia 2006, *Building Code of Australia : Mandatory plumbed rainwater tanks for Class 1 buildings -Development Act 1993*, Australia.

Imteaz, MA, Ahsan, A, Rahman, A & Mekanik, F 2013, 'Modelling stormwater treatment systems using MUSIC: Accuracy', *Resources, Conservation and Recycling,* vol. 71, 2//, pp. 15-21.

Le Coustumer, S, Fletcher, TD, Deletic, A, Barraud, S & Lewis, JF 2009, 'Hydraulic performance of biofilter systems for stormwater management: Influences of design and operation', *Journal of Hydrology,* vol. 376, no. 1–2, 9/30/, pp. 16-23.

Melbourne Water 2005, *WSUD Engineering Procedures: Stormwater*, CSIRO Publishing, Melbourne, Victoria, Australia.

Melbourne Water 2010a, *Constructed wetlands design manual*, Melbourne Water, Melbounre, viewed October 2015, <http://www.melbournewater.com.au/planning-and-building/standards-and-specifications/design-wsud/pages/constructed-wetlands-design-manual.aspx>.

Roberts, P 2005, *Yarra Valley Water 2004 Residential End Use Measurement Study*, Yarra Valley Water.

Scholes, L, Revitt, DM & Ellis, JB 2008, 'A systematic approach for the comparative assessment of stormwater pollutant removal potentials', *Journal of Environmental Management,* vol. 88, no. 3, 8//, pp. 467-478.

South Australian Department of Planning and Local Government 2010, *Water sensitive urban design technical manual - Greater Adelaide region*, Department of Planning and Local Government, South Australia, Adelaide, SA, Australia. <http://www.planning.sa.gov.au/go/wsud>.

Water by Design 2010, *MUSIC modelling guidelines*, South East Queensland Healthy Waterways Partnership (SEQHWP), Brisbane, Queensland, Australia.

Webner, T & Fletcher, T 2010, *Draft - NSW MUSIC Modelling Guidelines*, Sydney Metropolitan Catchment Authority.

Willis, RM, Stewart, RA, Giurco, DP, Talebpour, MR & Mousavinejad, A 2013, 'End use water consumption in households: impact of socio-demographic factors and efficient devices', *Journal of Cleaner Production,* vol. 60, 12/1/, pp. 107-115.

Wong, THF, Fletcher, TD, Duncan, HP & Jenkins, GA 2006, 'Modelling urban stormwater treatment—A unified approach', *Ecological Engineering,* vol. 27, no. 1, pp. 58-70.

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.