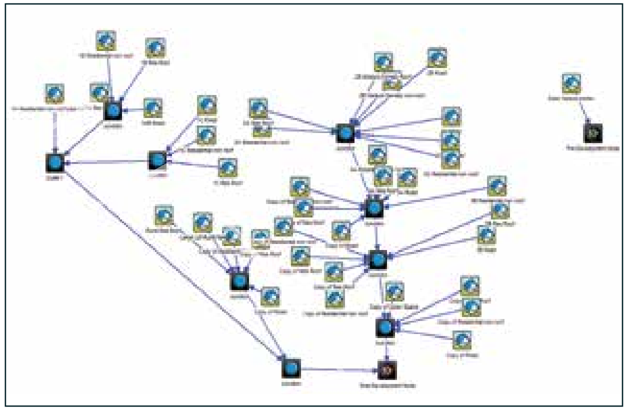
BMT WBM

"Where will our knowledge take you?"



NSW MUSIC Modelling Guidelines

August 2015

music by eWater

NSW Government
Local Land Services
Greater Sydney

NSW MUSIC Modelling Guidelines

Prepared for:	Greater Sydney Local Land Services
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies)

Offices

Brisbane
Denver
London
Mackay
Melbourne
Newcastle
Perth
Sydney
Vancouver

Document Control Sheet

BMT WBM Pty Ltd Level 8, 200 Creek Street Brisbane Qld 4000 Australia PO Box 203, Spring Hill 4004 Tel: +61 7 3831 6744 Fax: + 61 7 3832 3627 ABN 54 010 830 421 www.bmtwbm.com.au	**Document**	R.B17048.001.05.landscape.docx	**Client**	Greater Sydney Local Land Services
	Title	NSW MUSIC Modelling Guidelines	**Client Contact**	Michele Bailey
	Project Manager	Craig WittTony Weber	**Client Reference**	
	Authors	Craig WittMark Mainwright, Tony Weber	**Synopsis**	This document presents updated MUSIC modelling guidelines for NSW.

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
0 (Working Draft)	10th November '14	BD		MW	
1 (Draft)	11th August '15	TRW		MW	

DISTRIBUTION

Destination	Revision										
	0	1	2	3	4	5	6	7	8	9	10
Greater Sydney Local Land Services	PDF	PDF									
BMT WBM File	PDF	PDF									
BMT WBM Library	PDF	PDF									

Copyright and non-disclosure notice
The contents and layout of this report are subject to copyright owned by BMT WBM Pty Ltd (BMT WBM) save to the extent that copyright has been legally assigned by us to another party or is used by BMT WBM under licence. To the extent that we own the copyright in this report, it may not be copied or used without our prior written agreement for any purpose other than the purpose indicated in this report.

The methodology (if any) contained in this report is provided to you in confidence and must not be disclosed or copied to third parties without the prior written agreement of BMT WBM. Disclosure of that information may constitute an actionable breach of confidence or may otherwise prejudice our commercial interests. Any third party who obtains access to this report by any means will, in any event, be subject to the Third Party Disclaimer set out below.

Third Party Disclaimer
Any disclosure of this report to a third party is subject to this disclaimer. The report was prepared by BMT WBM at the instruction of, and for use by, our client named on this Document Control Sheet. It does not in any way constitute advice to any third party who is able to access it by any means. BMT WBM excludes to the fullest extent lawfully permitted all liability whatsoever for any loss or damage howsoever arising from reliance on the contents of this report.

Contents

List of Figures

List of Tables

1 Introduction

1.1 MUSIC – What is it?

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is a decision support tool for stormwater management. It helps with the planning and conceptual design of stormwater management systems. The MUSIC modelling software was developed by researchers and practitioners of the former CRC for Catchment Hydrology and eWater CRCs and is now developed and sold by eWater Solutions Pty Ltd. The software represents an accumulation of the best available knowledge and research on urban stormwater management in Australia. MUSIC is the preferred modelling tool for the assessment of water sensitive urban design strategies across Australia.

MUSIC estimates stormwater flows and pollution generation, and simulates the performance of single or multiple stormwater treatment measures that are typically connected in series to improve overall treatment performance. MUSIC estimates this performance over a continuous historical period rather than for discrete storm events. By simulating the performance of stormwater treatment measures, MUSIC is typically applied to evaluate whether a proposed treatment system conceptually would achieve stormwater flow and water quality targets.

1.2 When to use MUSIC

The decision to use MUSIC relates to the risk of a particular development impacting on stormwater quality and quantity. For a high risk development, the risk should be estimated via a detailed numerical model like MUSIC. Consideration of the size of a development and the likely risk it poses to waterway health are key elements to consider when deciding if MUSIC modelling is warranted. Within NSW, it is recommended that MUSIC be applied for assessing stormwater quantity and quality impacts of a proposed development in circumstances where the total proposed development area exceeds 2500 m2.

For smaller and low risk developments, a simplified approach or model may be appropriate. An on-line small scale stormwater quality tool (the S3QM) is available for a number of regions across NSW to demonstrate that stormwater quality management can be satisfactorily addressed for the proposed development (https://www.s3qm.com.au/). The S3QM can assist Local Government Authorities with reducing development assessment requirements for small scale developments that often make up the bulk of development applications.

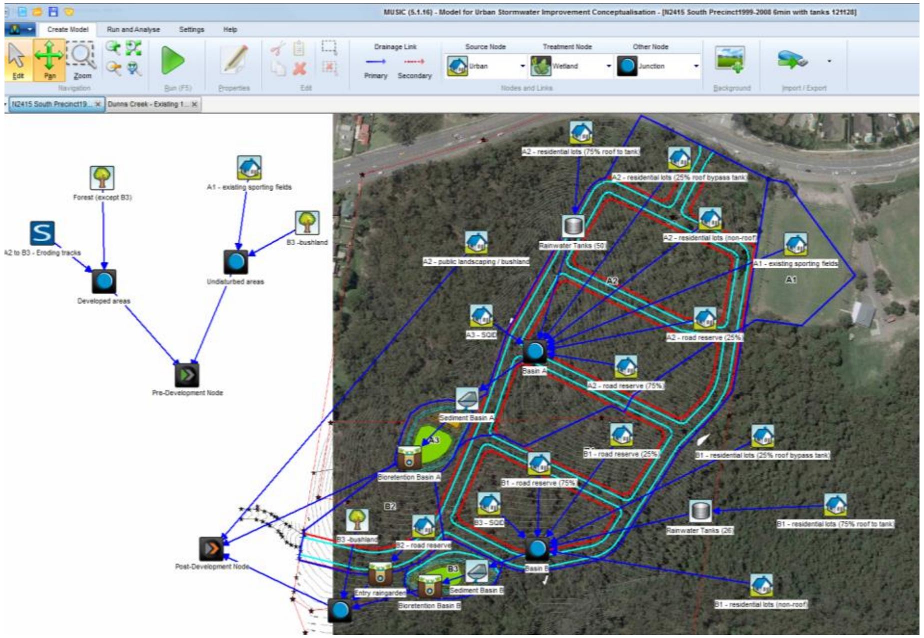


Figure 1-1 A typical MUSIC Model

In the latest version of MUSIC (MUSIC Version 6 at the time of publication), some Councils in NSW have subscribed to MUSIC-link (http://ewater.org.au/products/music/music-link) which allows pre-configuration of the MUSIC model such that some source and treatment nodes are parameterised with values that best reflect the particular Council's requirements in the use of the model. These guidelines should not take preference over those parameters or nodes but may provide additional information in configuring the model where particular nodes are not covered by MUSIC-link and may also provide guidance on model set up and use.

1.3 Applying MUSIC in Urban Catchments

MUSIC is ideally suited to modelling stormwater quality and quantity in highly impervious urban catchments. MUSIC can be used to assess stormwater quality for a range of development and land use types through appropriate parameterisation and configuration of the model. MUSIC is conventionally applied to assess pollutant loads and pollutant concentrations, however, it is increasingly being applied by experienced users to assess hydrologic objectives. Within urban catchments, hydrology and the associated water balance is highly influenced by surface runoff from impervious surfaces, and particularly those connected by a continuous series of impervious surfaces to a receiving environment.

1.4 Applying MUSIC in Rural Catchments

Whilst MUSIC is extensively applied to model urban catchments, the underlying hydrologic and pollutant generation models are very flexible and can also be parameterised by experienced users to represent a broad range of land uses.

The hydrology of highly pervious rural catchments is typically more complex than highly impervious urban catchments. Catchment characteristics including terrain, soils, geology, vegetation and rainfall patterns may have a more pronounced influence on hydrology in rural catchments when compared to urban catchments. These factors can influence the magnitude of interception, surface runoff, interflow, groundwater recharge, aquifer recharge, base flow and evapotranspiration for a particular site. Modelling of highly pervious catchments in MUSIC should be completed by experienced users with care and the model results checked against gauged flows and/or typical water balance estimates for sites in similar catchments.

The limitations in applying MUSIC to rural land uses include the accurate prediction of nutrient export from catchments (especially phosphorus). Phosphorus stormflow concentrations within MUSIC are correlated to suspended solids concentrations when the stochastic estimation method is selected. This limitation can be avoided by selecting the “mean” estimation method for generating nutrients.

In addition, the treatment performance of measures modelled in MUSIC has not been rigorously tested in rural catchments. Whilst it is expected that similar performance characteristics may be observed, care should be taken to consider the species of constituents (i.e. soluble or particulate) coming from the catchment and the measure’s ability to effectively treat them. For example, if a considerable proportion of the total phosphorus concentration from an agricultural catchment is soluble, the effectiveness of a grassed swale in treating this would be considerably different to an urban catchment where the majority of phosphorus is associated with particulate matter. The user should therefore make an assessment of this when analysing MUSIC outputs and appropriate limitations noted.

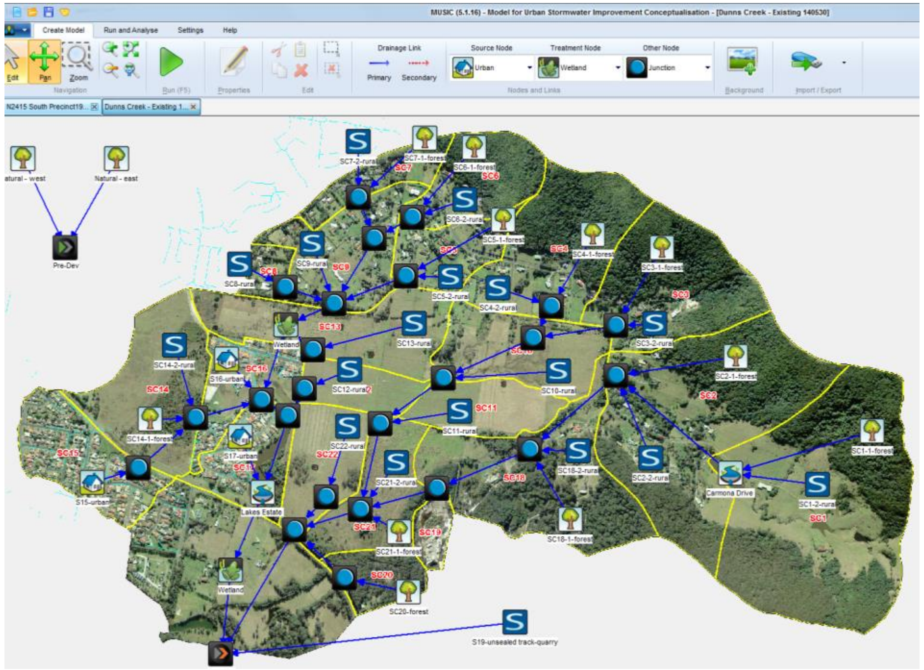


Figure 1-2 A MUSIC Model of a Peri-Urban Catchment

1.5 Developing a MUSIC Model

1.5.1 Small and Large Sites

The MUSIC modelling effort required is often linked to the scale of the area of interest under consideration, and where the modelling is being undertaken to assess the impacts of a proposed development on water quality, the potential risk of the development to the receiving environment.

Typically, local or state government authorities will develop separate criteria for small low risk developments that make up the bulk of development applications being assessed. Large or otherwise high risk developments may have a more comprehensive set of criteria to achieve.

1.5.2 Pre-development, Developed (untreated), Developed (treated) and Base Scenarios

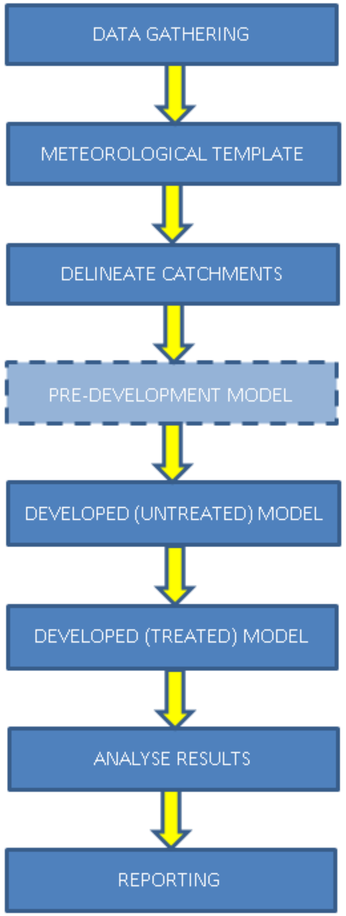
The pre-development scenario is defined for the purposes of these MUSIC modelling guidelines as the condition of the area of interest prior to any significant urban development occurring. Typically a pre-development condition will be represented by a forested, pasture, rural or agricultural land use condition where the imperviousness of the area of interest is low (typical effective impervious area less than 5%). The pre-development condition is typically only modelled in MUSIC when the relevant water quality targets are referenced to a site condition other than developed (untreated) condition.

The developed (untreated) scenario is defined for the purposes of these MUSIC modelling guidelines as the condition of the area of interest following completion of the proposed development **excluding** the influence of any stormwater treatment measures.

The developed (treated) scenario is defined for the purposes of these MUSIC modelling guidelines as the condition of the area of interest following completion of the proposed development **including** the influence of any additional stormwater treatment measures installed as a component of the development.

For most developments, the developed (treated) scenario is modelled and compared against targets established from either the pre-development or developed (untreated) scenario to confirm if the targets are achieved. The scenario against which the performance of the developed (treated) scenario is compared is referred to as the ‘base scenario’ in these guidelines.

Following a logical process when developing a MUSIC model helps to ensure consistency in the approach and make it easier to replicate in future applications. The following flow chart outlines the typical modelling process used for MUSIC modelling. The MUSIC modelling steps in this chart are explained in the subsequent chapters.



Policies, guidelines, rainfall, PET, aerial imagery, geographical data, land uses, survey, development plans, drainage plans etc.

Review / analyse rainfall and PET data.

Review data to confirm appropriate catchment / sub-catchments delineation.

Prepare pre-development model in circumstances where the base scenario is the site conditions prior to development.

Prepare a developed (untreated) model based on the development configuration in the area of interest.

Modify the developed (untreated) model to include treatment measures.

Analyse and compare the modelling results against targets established from the relevant policies and guidelines.

Prepare a report summarising the MUSIC modelling inputs, results and concept design.

2 Data Gathering

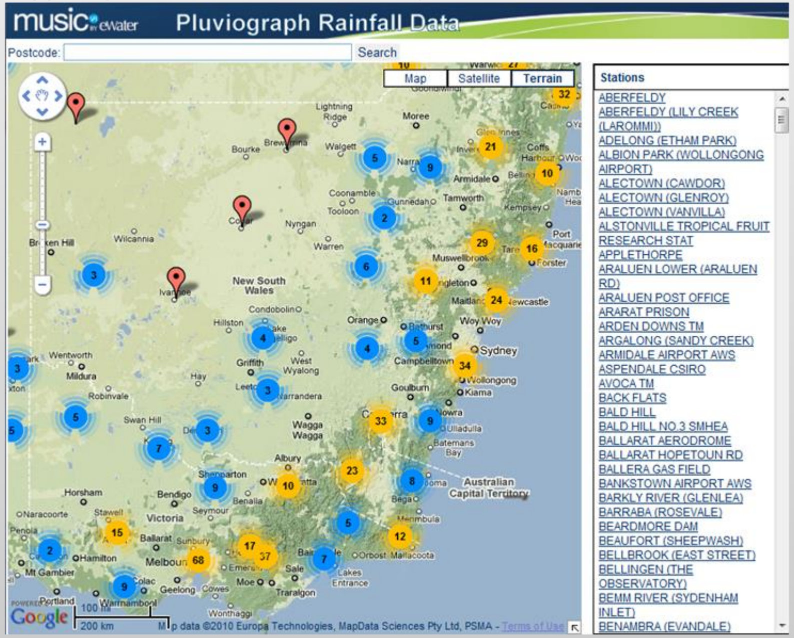
The initial step in preparing a MUSIC model involves identifying and gathering data required to develop the model inputs. There are a range of resources that can assist with developing the model inputs. Some key resource examples are summarised in Table 2-1.

Data gathering can often take more than time than initially envisaged. It is important that a modeller identifies the data requirements, extents and sources for a particular situation and initiates the data gathering well in advance of the intended model build period.

Table 2-1 Example Data Sources

Data	Example Source/s
Objectives and targets	State and Local Government policies/guidelines, Council LEP, Council DCP, WSUD policies, Water Quality Improvement Plans, Natural Resource Management Plans and Stormwater Management Plans.
Rainfall	MUSIC, eWater pluviograph rainfall data tool, Bureau of Meteorology and SILO (Qld Government).
Potential evapotranspiration	MUSIC, Climatic Atlas of Australia (Bureau of Meteorology) and SILO.
Sub-catchments	Digital elevation models, LiDAR data, GIS contour data, survey plans, development application plans, topographic maps, stormwater drainage plans, road design plans and long-sections, and aerial imagery.
Land uses and surface types	Aerial imagery, LEP, masterplan and development application plans.
Effective impervious area	Aerial imagery, LEP, masterplan, development application plans and stormwater drainage plans.

A pluviograph rainfall data tool is available through the MUSIC Version 5 and above support pages if you have access to premium support (for details, contact eWater).



ABERFELDY
ABERFELDY (LILY CREEK (LAROMMI))
ADELONG (ETHAM PARK)
ALBION PARK (WOLLONGONG AIRPORT)
ALECTOWN (CAWDOR)
ALECTOWN (GLENROY)
ALECTOWN (VANVILLA)
ALSTONVILLE TROPICAL FRUIT RESEARCH STAT
APPLETHORPE
ARALUEN LOWER (ARALUEN RD)
ARALUEN POST OFFICE
ARARAT PRISON
ARDEN DOWNS TM
ARGALONG (SANDY CREEK)
ARMIDALE AIRPORT AWS
ASPENDALE CSIRO
AVOCA TM
BACK FLATS
BALD HILL
BALD HILL NO.3 SMHEA
BALLARAT AERODROME
BALLARAT HOPETOUN RD
BALLERA GAS FIELD
BANKSTOWN AIRPORT AWS
BARKLY RIVER (GLENLEA)
BARRABA (ROSEVALE)
BEARDMORE DAM
BEAUFORT (SHEEPWASH)
BELLBROOK (EAST STREET)
BELLINGEN (THE OBSERVATORY)
BEMM RIVER (SYDENHAM INLET)
BENAMBRA (EVANDALE)

MUSIC Pluviograph data tool

The most suitable station can be selected then from the list available on the right, and when downloaded, this will be in a format suitable for direct use in MUSIC. Note that evapotranspiration values are not included with this data and therefore will need to be determined by consultation the National Climatic Atlas of Australia Evapotranspiration Maps (available from

3 Meteorological Template

MUSIC uses rainfall and areal potential evapotranspiration (PET) data to simulate runoff for each source node. The combined rainfall and PET input data is termed the meteorological template in MUSIC. Using the meteorological template build tool in MUSIC, the modeller creates an appropriate template for the site. The template forms the basis for simulating the hydrology of all source nodes in a particular MUSIC model. It is important to select representative rainfall and PET data for the site being modelled so that reasonable runoff estimates are achieved.

Example rainfall and PET data sets are supplied with the software, but for most applications additional data needs to be sourced. Although there are a number of organisations that can supply rainfall and PET data, the Bureau of Meteorology (BoM) is often the most accessible source. For users of MUSIC Version 5 and above that have premium support from eWater, access to additional continuous rainfall data are available for download using the pluviograph rainfall data tool (link available from the MUSIC support website). In some areas local government authorities have also established default meteorological templates.

As MUSIC is a continuous simulation model, it is necessary to ensure that a representation of the typical climate in a region is achieved through appropriate selection of data. The guidance provided below ensures that a reasonable amount of climate variability is represented, and as such the mean annual loads obtained from MUSIC models using the adopted meteorological data will represent wet, dry and average years. Therefore, it should not be necessary for data and results to be reported for individual selected years.

The BoM operates a large number of rainfall stations across NSW. The majority of these stations record daily rainfall, however, a proportion also continuously record rainfall and this data can be provided at smaller timesteps. Daily rainfall data are currently freely available from the BoM web-site. Sourcing of smaller time step rainfall data currently involves a data request to the BoM and a fee for supply of the data. Modellers should note that the BoM typically requires a week from the date of request to supply data.

For stormwater quality modelling in MUSIC, continuously recorded rainfall data at a six minute interval is typically required. BoM is also able to supply six minute interval rainfall data in the format required for MUSIC upon request. The number of continuously recording rainfall stations in NSW is relatively limited and typically the modeller will need to identify a rainfall station where data representative of their site is available. Often this will be the closest rainfall station, but not always.

The minimum continuous data period adopted for modelling will depend on the targets being addressed. For stormwater quality modelling only, a 5 year period may be sufficient, whilst for flow modelling a 10 year (minimum) to 20 year (ideal) data period should be sourced. Whilst the length of the data record is important, it is most critical that the data quality and data interval is appropriate for the particular modelling application.

No matter what rainfall data are sourced, the modeller should complete a number of checks to verify that the data is suitable for use in MUSIC and the modelling objectives. The following checks are recommended:

- Confirm that the data is available at the required timestep.
- Confirm that the data incorporates a continuous period of appropriate length.
- Confirm the continuous period has minimal missing or accumulated data.
- Confirm that the average annual rainfall is representative of the long-term average annual rainfall at the site.
- Confirm that the daily rainfall distribution is representative of long term conditions at the site (refer example graph in Figure 3-1 that compares long term daily rainfall totals with a shorter period selected for modelling)

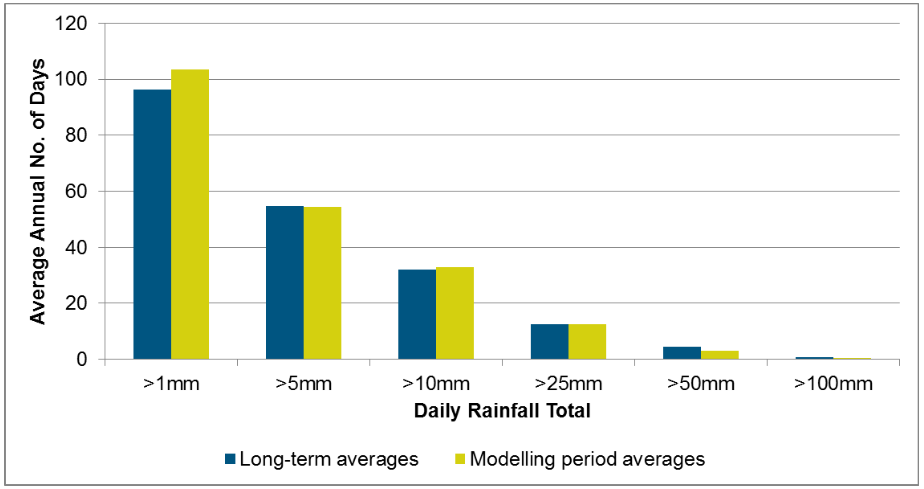
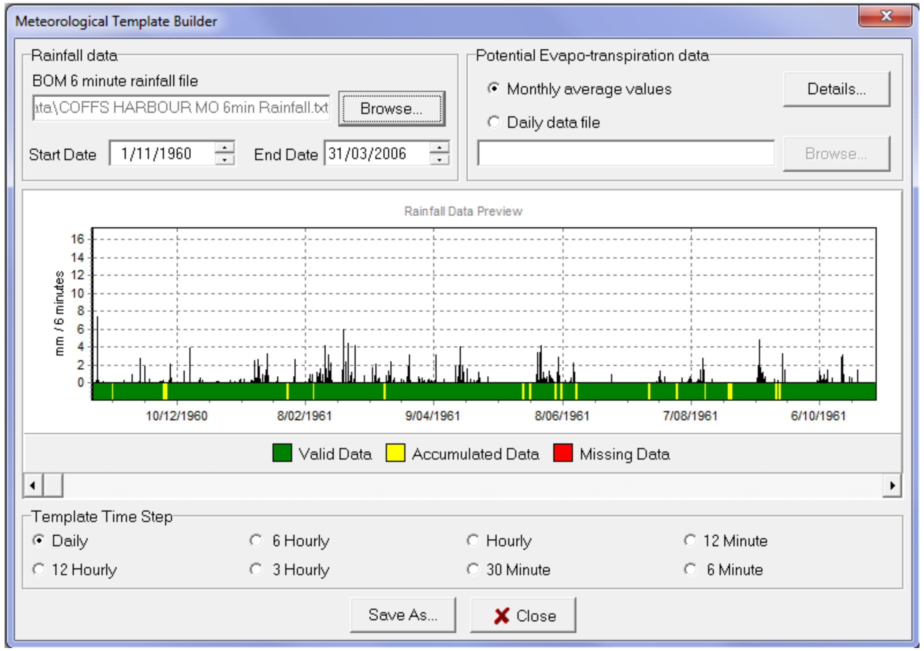


Figure 3-1 Daily Rainfall Total Comparison Example

MUSIC allows the viewing of the rainfall data (if in the appropriate BoM format) via the Meteorological template builder and areas of missing and accumulated data are shown as indicated in Figure 3-2.



Meteorological Template Builder

Rainfall data

BOM 6 minute rainfall file: ta\COFFS HARBOUR MO 6min Rainfall.txt

Start Date: 1/11/1960

End Date: 31/03/2006

Potential Evapo-transpiration data

● Monthly average values

○ Daily data file

Template Time Step

● Daily
○ 12 Hourly
○ 6 Hourly
○ 3 Hourly
○ Hourly
○ 30 Minute
○ 12 Minute
○ 6 Minute

Figure 3-2 Meteorological Template Builder

MUSIC requires the selection of monthly average or daily potential evapotranspiration (PET) data when setting up the meteorological template. For most modelling applications, the input of monthly average PET data will be sufficient. Monthly average PET data can typically be sourced from files supplied with MUSIC for nearby sites or from the *Climatic Atlas of Australia (Evapotranspiration*), available from BoM. Care is required to ensure that **areal** potential evapotranspiration rates are input to MUSIC (rather than pan evaporation, point evapotranspiration or actual evapotranspiration rates).

For some modelling applications (e.g. calibration to historical data), daily PET data can be important. Interpolated daily areal PET rates for sites within Australia can be sourced from the Queensland Government's SILO database.

To choose an appropriate timestep, the modeller should consider the size of sub-catchments and types of treatment measures being modelled. The timestep selected should reflect either the time of concentration of the smallest sub-catchment or the shortest residence time of any treatment measure. In most circumstances, a 6 minute timestep should be selected when modelling the performance of a treatment series.

4 Delineate Catchments

The extent of work required to delineate catchments will depend primarily on the size of the area of interest. For small development sites, delineation of a single catchment may be all that is required. For large urban release areas or drainage basin studies, a MUSIC model comprising more than 100 sub-catchments may be necessary to simulate the area of interest and intended treatment options appropriately.

As outlined in Table 2-1 there are a range of resources that can assist with delineating catchments. The modeller should consider their data requirements well in advance of delineating the catchments to ensure that the type and extent of data they source is appropriate for their particular needs.

The initial consideration when delineating catchments is to confirm the catchment outlet location that will form the reference point for analysis of the MUSIC model results. Where the area of interest drains in multiple directions, multiple outlet locations should be confirmed. A catchment boundary that encloses all areas that drain to the outlet/s should be delineated when developing MUSIC models (including catchments external to the area of interest).

Following delineation of the catchment boundary, the modeller should then consider if finer definition of sub-catchments is required. In most cases, sub-catchment delineation will be necessary to model the area of interest appropriately in MUSIC. It is recommended that the delineation of sub-catchments be considered in a particular area of interest where:

- There are multiple drainage outlets or flow paths from the area.
- The area incorporates a range of different land uses (e.g. forest, residential, industrial) or surface types (e.g. roofs, roads, landscaping) that have varying runoff and/or pollutant generation potential.
- The area will potentially be treated by installing measures at key locations or to manage runoff from particular surfaces (e.g. rainwater tanks to manage roof runoff). Consideration of the future treatment locations at this stage can assist with the sub-catchment break up.
- The area includes land that is unable to be treated.
- There are external upslope areas that flow into the area that are either to be diverted around future measures or drain to future measures and therefore need to be considered when estimating the hydrologic/pollutant loading for the measures.
- The area is to be evaluated against flow objectives that will require routing of flows to be considered.

Figure 4-1 Example Sub-catchment Boundaries

Definition of sub-catchments for the developed condition of an area of interest requires close consideration of existing infrastructure when defining sub-catchments. In particular, it is important to appreciate that the construction of roads and minor drainage systems can significantly alter natural drainage catchments by diverting overland flows.

Manual delineation of catchments utilising the best available data (e.g. contours, DEM, aerial imagery, drainage layouts etc.) is often the most accurate approach for smaller areas of interest. Where a digital terrain model (DTM) / digital elevation model (DEM) is available, stream definitions and catchment boundaries can be created using automated methods although, care is required when using automated methods to ensure that sub-catchments modified by roads and constructed drainage systems are accurately delineated.

Ideally the sub-catchments should be delineated within a geographical information system (GIS) or CAD environment. Once this is completed it can be beneficial to prepare a background image for use as an underlay in MUSIC for the model development. An example is shown in Figure 4-2 where MUSIC sub-catchments have been defined for a peri-urban catchment in coastal New South Wales.

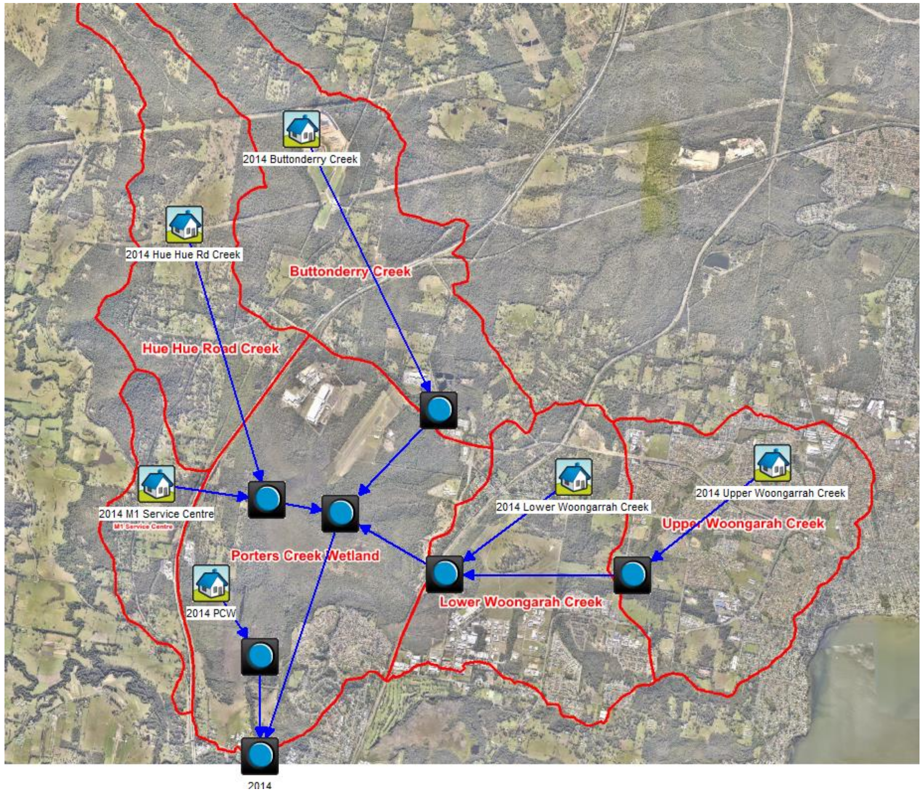


Figure 4-2 MUSIC Model with Background Image

5 Base Scenario Model

The base scenario model represents the area of interest in a condition that is to be compared with the developed (treated) scenario to determine if the established targets are achieved. In situations where the objective of the MUSIC modelling is to describe the situation for a particular scenario, preparation of a base scenario model may be all that is required.

Where load-based targets apply to future development in the area of interest, the base scenario model is often the area in a developed (untreated) condition. Where the targets are established from the existing, natural or otherwise pre-development condition of the area of interest, the base scenario model would be this pre-development condition.

The base scenario model defines the Source Nodes and the connection of these nodes using Drainage Links. The Source Nodes generate the runoff and pollutant loads within MUSIC. Creation of Source Nodes involves the definition of catchment/sub-catchment areas, catchment imperviousness, impervious area parameters, pervious area parameters and stormwater pollutant concentrations that are representative of the areas being modelled. In some circumstances, the base scenario model may also incorporate treatment measures that already exist in the area of interest.

The base scenario model preparation is an important step in MUSIC modelling. Selection of pervious area rainfall-runoff model parameters is particularly important when modelling the pre-development condition of an area of interest where the estimated effective impervious area percentage is <10%. Preparation of base scenario MUSIC models in these areas should be completed by experienced modellers with a good understanding of catchment hydrology in non-urban catchments.

The guidance in this section is divided into separate advice for preparing developed (untreated) and pre-development base scenario models.

5.1 Developed (untreated) Base Scenario

Currently in NSW, many authorities define the base scenario as the developed (untreated) scenario for the area of interest. Where the base scenario is the pre-development condition, the developed (untreated) scenario will obviously still need to be prepared as an intermediate step when preparing the developed (treated) scenario.

The catchment areas together with the rainfall data and pervious area parameters, define the runoff generated from the modelled catchment area. The definition of impervious area and pervious area parameters for developed (untreated) base scenario models is discussed below. Note that the guideline approach for estimating pervious area parameters for pre-development base scenarios differs somewhat from this approach (refer Section 5.2.2).

5.1.1 Catchment/Sub-Catchment Area

Each MUSIC Source Node requires catchment/sub-catchment areas and effective impervious area proportion to be defined. Delineation of catchment areas is discussed in Section 4.

5.1.2 Source Node Impervious Area Parameters

MUSIC requires the definition of two impervious area parameters:

- % effective impervious area (% impervious); and
- Rainfall threshold.

The % effective impervious area (EIA) is approximately equal to the % directly connected impervious area and is input as a percentage of the total surface area (TSA). EIA represents the impervious area that contributes to surface runoff observed at the outlet during days where the daily rainfall exceeds the rainfall threshold. It is essentially the proportion of impervious surfaces that are linked by a **continuous** series of impervious surfaces (e.g. roofs, road pavement, gutters, piped drainage, concrete channels) to the catchment/sub-catchment outlet.

Based on MUSIC calibration studies completed in NSW (BMT WBM, 2007), it was identified that in circumstances where the % effective impervious area exceeds 10% of the total catchment area, the adjustment of pervious area rainfall-runoff parameters had limited influence on improving runoff prediction. It is therefore critical for highly developed areas of interest (i.e. % EIA>10%) that the modeller accurately estimates the % EIA.

For small areas of interest (i.e. individual lots, small subdivisions), direct measurement of % EIA from sources including survey plans, engineering drawings, drainage plans, high resolution aerial imagery and a site visit will typically result in an accurate % EIA estimate. The modeller should seek to identify the location of inlets to piped drainage systems (or other impervious drainage systems) and then measure the impervious areas that drain directly to these inlets. Refer to the example in Figure 5-1.

Table 5-1 Example % EIA Calculations

Surface	Total Impervious Area (m^2)	Effective Impervious Area (m^2)
Roof	150	150
Driveway	110	55
Patio	40	8
Garage	50	50
Garden shed	10	0
Totals	***360***	***263***
Lot area	***600***	
%	***60%***	***44%***

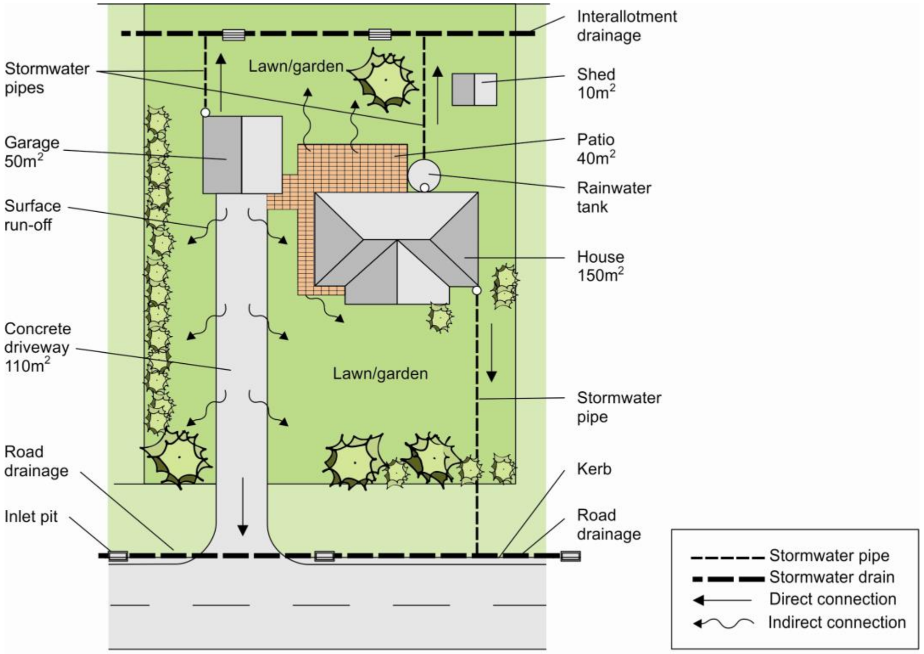


Figure 5-1 Estimating % EIA for Small Areas

If insufficient data is available on a small area of interest being modelled, it is suggested that the modeller review the EIA factors presented in Table 5-2 and confirm if these are appropriate for the specific development layout they are modelling.

Table 5-2 Estimating EIA for Small Areas - Typical Values

Surface types	EIA Factor*
Roof	1.0 x TSA
Sealed road pavement / shared access driveway	1.0 x TSA
Paved driveway for individual dwelling	0.5 x TSA
Paved landscaping (grading to drainage pits)	1.0 x TSA
Paved landscaping (grading to vegetated landscaping)	0.2 x TSA
Vegetated landscaping	0.05 x TSA
Public footway	0.5 x TSA
Unsealed road pavement	0.5 x TSA
Revegetated land	0.05 x TSA

* TSA = Total Surface Area

For large areas of interest (i.e. large subdivisions, urban release areas, local catchments), direct measurement of EIA will be time consuming, and often not possible due to limited detail on the final drainage system connectivity. For these areas, the final configuration of development and particularly individual lots is often unknown at the stage when initial MUSIC modelling is completed. In these circumstances, the modeller will need to make assumptions about the future EIA of the final constructed development.

The modeller should seek to confirm the likely total imperviousness of the development through discussions with local development planners and others. Where the area of interest is undeveloped and only land zoning data is available, suggested initial EIA estimates for future development are outlined in Table 5-3 for consideration. The modeller should confirm that these EIA factors are appropriate for the future land uses considering DCPs and other planning guidance that govern development in these areas.

Table 5-3 Typical EIA Proportions for MUSIC Models in NSW

Land Use Type	EIA Factor
Residential	0.60 x TIA
Commercial	0.80 x TIA
Industrial	0.90 x TIA
Rural residential	0.05 x TLA
Agriculture	0.00 x TLA
Forest	0.00 x TLA

TLA = Total Land-use Area; TIA = Total Impervious Area

The rainfall threshold represents the average daily rainfall depth that is capable of being adsorbed by impervious surfaces before runoff is generated. It is broadly equivalent to the concept of an initial loss applied in simulating individual flood events as a component of flood studies. Although, impervious surfaces may wet and dry multiple times a day (particularly hotter months).

MUSIC subtracts the rainfall threshold from the initial rainfall on each day, with all the following daily rainfall on impervious surfaces converted into surface runoff. The rainfall threshold storage is “emptied” each day ready to adsorb the same rainfall depth on the next wet day. Rainfall threshold values outlined in Table 5-4 are suggested for MUSIC modelling in NSW.

Table 5-4 Default Rainfall Threshold Values (RT)

	RT (mm)
Large Areas of Interest	
All land use zones	1.0
Small Areas of Interest	
Roofs	0.3
Sealed road pavement	1.5
Unsealed road pavement	1.5
Permeable pavement	1.2

5.1.3 Source Node Pervious Areas Parameters

In circumstances where the base scenario is a highly impervious development, the model results are unlikely to be significantly influenced by the selected pervious are rainfall-runoff parameters. For highly pervious catchments, selection of appropriate pervious area rainfall-runoff parameters is crucial for ensuring that the hydrology and dependent pollutant load estimates are reasonable.

To derive initial estimates of pervious area parameters for use in MUSIC, the field texture of the soil and average root zone depth are required (see Macleod, 2008). These are applied to estimate the soil storage capacity (the maximum water storage depth available in pervious areas) and field capacity (the maximum water storage in the soil prior to gravity recharge to groundwater) from Table 5-5. The values in Table 5-5 are based on a maximum root zone depth of 0.5 m as only a few vegetation types (e.g.

native forests) have deeper root zones. As a result, evapotranspiration is unlikely to be a significant influence below 0.5 m in most areas.

Where more than one soil texture is found extensively across the area of interest, the rainfall-runoff parameters for the soil texture that results in a lower estimate of flow volume for the base scenario should be adopted for the entire site. Soil texture should be determined from geotechnical soil investigations and classification of soils found in the upper 0.5m of the soil profile within the area of interest. Selection of appropriate soil storage capacity and field capacity for the developed scenario should also give consideration to likely soil modifications due to topsoil removal, cut/fill earthworks and soil compaction.

Table 5-5 should be consulted to determine the pervious area parameters based on the dominant soil type within the area of interest. It is suggested that the default MUSIC parameter values for initial storage (percentage of capacity) and initial depth (mm) be adopted for all soil types. It is recommended that Table 5-5 only be utilised for estimating pervious area parameters for developed base scenarios. In situations where the base scenario is a pre-development scenario with EIA < 10%, it is suggested that the approach outlined in Section 5.2.2 be applied to estimate reasonable rainfall-runoff parameters for pervious areas.

Table 5-5 Pervious Area Rainfall-Runoff Parameters* (Macleod, 2008)

Soil Texture	SSC (mm)	FC (mm)	Inf "a" (mm/d)	Inf "b"	DRR (%)	DBR (%)	DDSR (%)
Sand	175	74	360	0.5	100%	50%	0%
Loamy sand	139	69	360	0.5	100%	50%	0%
Clayey sand	107	75	250	1.3	60%	45%	0%
Sandy loam	98	70	250	1.3	60%	45%	0%
Loam	97	79	250	1.3	60%	45%	0%
Silty clay loam	100	87	250	1.3	60%	45%	0%
Sandy clay loam	108	73	250	1.3	60%	45%	0%
Clay loam	119	99	180	3.0	25%	25%	0%
Clay loam	133	89	180	3.0	25%	25%	0%
Silty clay loam	88	70	180	3.0	25%	25%	0%
Sandy clay	142	94	180	3.0	25%	25%	0%
Silty clay	54	51	180	3.0	25%	25%	0%
Light clay	98	73	135	4.0	10%	10%	0%
Light-medium	90	67	135	4.0	10%	10%	0%
Medium clay	94	70	135	4.0	10%	10%	0%
Medium-heavy	94	70	135	4.0	10%	10%	0%
Heavy clays	90	58	135	4.0	10%	10%	0%

*SSC = Soil storage capacity, FC = Field capacity, Inf "a" = Infiltration capacity co-efficient a, Inf "b"=Infiltration capacity exponent b, DRR=Daily Recharge Rate, DBR=Daily Baseflow Rate, DDSR=Daily Deep Seepage Rate.

5.1.4 Stormwater Pollutant Parameters

MUSIC currently incorporates five source node types (urban, agricultural, forest, user defined and imported data). Typically, the urban source node should be used to represent all urban land uses, including low/medium/high density residential, rural residential, open space areas, commercial and industrial areas.

The stormwater pollutant concentration parameters suggested for base flow and storm flow are presented in Table 5-6 and Table 5-7. Equivalent land use zonings and surface types for each development category are shown in Table 5-8. The base flow parameters are applied to groundwater flow, whilst the storm flow parameters are applied to surface runoff. In all cases, the stochastic generation option for pollutant generation should be selected.

The base flow and storm flow parameters should be selected based on whether the area of interest is a small or large. Similarly to estimating EIA, small areas of interest (i.e. individual lots, small subdivisions) can be relatively efficiently divided into the component surfaces for modelling and different concentration parameters applied to individual surfaces. This is particularly relevant when the ratio of roof to road area is high, and focused treatment of the road surfaces is likely to yield a higher benefit than treating roof surface runoff.

Within large areas of interest (i.e. large subdivisions, urban release areas, local catchments), runoff quality typically will become more homogenous with increasing area. Consequently definition of concentration parameters based on individual surfaces becomes less justifiable. For these larger areas, it is suggested that stormwater pollutant concentration parameters based on land uses/land zones be adopted.

In circumstances where sufficient site-based runoff quality monitoring has been completed, or data is available from similar sites, selection of alternative parameters may be justifiable. Where a modeller proposes to adopt different values to those presented in Table 5-6 and Table 5-7, appropriate statistical analysis shall be completed and the analysis discussed in the report.

For modelling purposes, land use/zonings and surface types should be translated into MUSIC source nodes according to Table 5-8, using the parameters provided in subsequent sections relevant to the recommended source node types.

Table 5-6 Base Flow Concentration Parameters (mg/L-log10) for NSW (adapted from Fletcher et al, 2004)

	TSS		TP		TN	
	Mean	Std. dev	Mean	Std. dev	Mean	Std. dev
Large Areas of Interest						
Residential	1.20	0.17	-0.85	0.19	0.11	0.12
Business	1.20	0.17	-0.85	0.19	0.11	0.12
Industrial	1.20	0.17	-0.85	0.19	0.11	0.12
Rural	1.15	0.17	-1.22	0.19	-0.05	0.12
Agricultural	1.30	0.13	-1.05	0.13	0.04	0.13
Eroding gullies	1.20	0.17	-0.85	0.19	0.11	0.12
Quarries	1.20	0.17	-0.85	0.19	0.11	0.12
Re-vegetated land	1.15	0.17	-1.22	0.19	-0.05	0.12
Forest	0.78	0.13	-1.22	0.13	-0.52	0.13
Small Areas of Interest						
Roofs	n/a	n/a	n/a	n/a	n/a	n/a
Sealed road pavement	1.20	0.17	-0.85	0.19	0.11	0.12
Unsealed road pavement	1.20	0.17	-0.85	0.19	0.11	0.12
Landscaped areas	1.20	0.17	-0.85	0.19	0.11	0.12

Table 5-7 Storm Flow Concentration Parameters for NSW (mg/L-log10) for NSW (adapted from Fletcher et al, 2004)

	TSS		TP		TN	
	Mean	Std. dev	Mean	Std. dev	Mean	Std. dev
Large Areas of Interest						
Residential	2.15	0.32	-0.60	0.25	0.30	0.19
Business	2.15	0.32	-0.60	0.25	0.30	0.19
Industrial	2.15	0.32	-0.60	0.25	0.30	0.19
Rural	1.95	0.32	-0.66	0.25	0.30	0.19
Agricultural	2.15	0.31	-0.22	0.30	0.48	0.26
Eroding gullies	3.00	0.32	-0.30	0.25	0.34	0.19
Quarries	3.00	0.32	-0.30	0.25	0.34	0.19
Re-vegetated land	1.95	0.32	-0.66	0.25	0.30	0.19
Forest	1.60	0.20	-1.10	0.22	-0.05	0.24
Small Areas of Interest						
Roofs	1.30	0.32	-0.89	0.25	0.30	0.19
Sealed road pavement	2.43	0.32	-0.30	0.25	0.34	0.19
Unsealed road pavement	3.00	0.32	-0.30	0.25	0.34	0.19
Landscaped areas	2.15	0.32	-0.60	0.25	0.30	0.19

Table 5-8 Stormwater Concentration Parameters for Standard Instrument Zonings

Standard Instrument Zoning or Surface Type	Suggested MUSIC Land Use
Large Areas of Interest	
Residential - R1, R2, R3	Residential
Residential – R4	Business
Residential – R5	Rural
Business – B1, B2, B3, B4, B4, B8	Business
Business – B5, B6, B7	Industrial
Industrial – IN1, IN2, IN3, IN4	Industrial
Special purposes – SP1, SP2	Industrial
Special purposes – SP3	Business
Recreation – RE1	Residential
Recreation – RE2	Business
Environmental Protection -E1, E2	Forest
Environmental Protection – E3, E4	Rural
Rural – RU1	Quarries
Rural – RU2, RU3, RU4	Agricultural
Rural – RU5	Business
Rural – RU6	Rural
Waterways – W1	Forest
Waterways – W2, W3	Business

Where part of a rural development is proposed to be re-vegetated and fenced off from livestock, the concentration parameters for the post-development model should be the 're-vegetated land' parameters given in Table 5-6 and Table 5-7. Parameters for 'forest' areas should not be used for re-vegetated land as it typically takes more than 15 years for a re-vegetated site to return to the equivalent water quality functioning and performance of a "fully forested" state (SCA, 2012).

5.2 Pre-Development Base Scenario

5.2.1 Impervious Area Parameters

The pre-development base scenario will often be a highly pervious forested, agricultural or rural residential land use. The effective impervious area in these types of catchments will typically be low. Estimates of EIA should be based upon a review of aerial imagery and consideration of the factors summarised in Table 5-3.

The rainfall threshold values presented in Table 5-4 are applicable to pre-development base scenarios where there is effective impervious areas present in the area of interest.

5.2.2 Pervious Area Parameters

5.2.2.1 MUSIC Calibration

This section of the guidelines assumes that a modeller completing MUSIC calibration has a good understanding of hydrology and the water cycle processes involved. MUSIC calibration to observed stream flows in highly pervious catchments should be completed by experienced modellers.

The rainfall-runoff parameters outlined in Table 5-5 consider soil texture and root zone depth only. Whilst soil texture and root zone depth are key factors influencing catchment hydrology, there is a range of variables that influence (to varying degrees) how much rainfall becomes runoff in a highly pervious catchment. Some of these variables include:

- Surface depressions;
- Natural water storages;
- Vegetation interception, coverage and species;
- Terrain;
- Geomorphology;
- Geology; and
- Rainfall patterns and climate.

It is particularly important that modellers deriving rainfall-runoff parameters for ungauged highly pervious catchments are able to interpret the physical characteristics of the catchment, and evaluate how these characteristics are likely to impact on hydrology.

In circumstances where the estimation of pre-development hydrology in highly pervious catchments is required, selection of pervious area rainfall-runoff parameters based on soil texture and root zone depth alone may oversimplify the pre-development hydrology. In these circumstances, calibration utilising concurrent stream flow and rainfall data for similar catchments, or adopting parameters based on calibration of similar gauged local catchments, may be required.

Whilst selection of pervious area parameters for highly impervious catchments based on soil texture and root zone depth only is likely to result in some error, the magnitude of the error is unlikely to significantly influence the model results. For pre-development scenarios with low effective impervious areas (typically EIA less than 10%), surface runoff and base flow from the pervious surfaces may be the dominant processes for transporting pollutants to a receiving environment. The estimated runoff in these situations is often highly sensitive to the selected pervious area rainfall-runoff parameters. In these circumstances the pervious area parameters outlined in Table 5-5 may be useful as a first estimate, but some modification through a model calibration exercise is often warranted to achieve a good representation of the catchment hydrology.

5.2.2.2 MUSIC Calibration to Observed Stream Flows

In circumstances where derivation of local pervious area parameters within MUSIC is critical, model calibration utilising concurrent stream flow and catchment average rainfall is typically undertaken. Often there are no long term stream gauges in the catchment incorporating the area of interest. Calibration is typically completed for a nearby representative gauged catchment, with the resultant calibrated parameters then applied to the area of interest.

Sourcing and preparing the stream flow and rainfall data is a critical step in developing the calibration model. The modeller should ensure that checks are completed to confirm that the stream flow and rainfall data is of a suitable quality and representative of the catchment prior to use. Poor quality data will limit the confidence in the calibration results. Ideally a calibration period exceeding 20 years should be utilised.

Is it suggested that MUSIC calibration run flow outputs be analysed by plotting observed monthly flow volume totals against MUSIC estimated totals. It is likely that calibration based on weekly or daily totals will be difficult to achieve due to the relative simplicity of the hydrologic model algorithms in MUSIC. It is recommended that the calibration be assessed based on objective functions such as the Nash-Sutcliffe coefficient of efficiency (E) (refer example in Figure 5-2). It is suggested that an ‘E’ exceeding 0.80 would be representative of a good calibration fit.

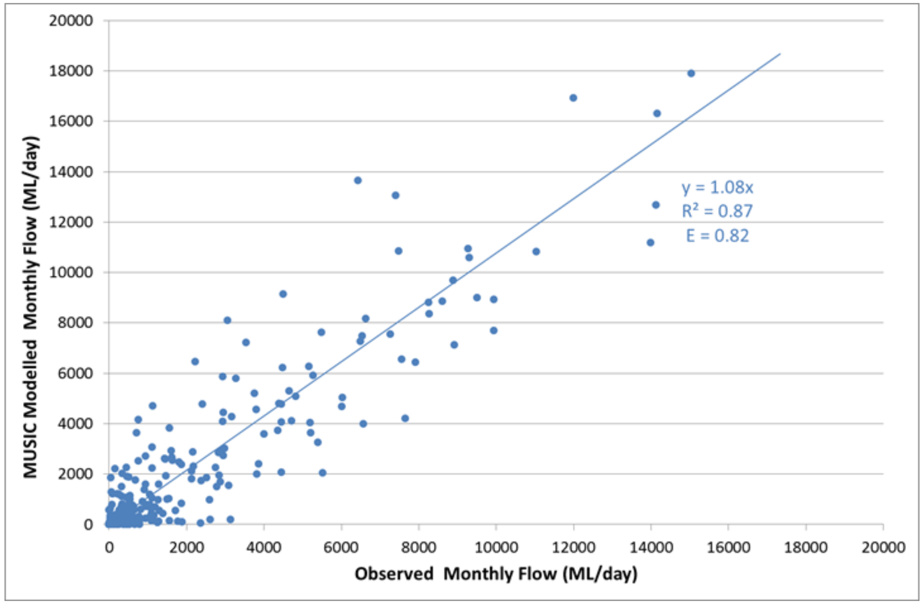


Figure 5-2 Example Monthly Flow Total Calibration Plot

5.2.2.3 Simplified MUSIC Calibration to Water Balance Estimates

In many situations local catchments with long-term good quality stream flow records may not be available to assist with model calibration. In these circumstances derivation of pervious area parameters based on an estimated typical water balance for the catchment may be required. A suggested approach to identify reasonable parameters in these circumstances is:

- Estimate the average annual rainfall for the area of interest.
- Estimate the average annual runoff fraction based on Figure 5-3 or similar.
- Estimate an appropriate base flow index for watercourses in the local area.
- Calculate the average annual runoff split between surface runoff and base flow based on the adopted base flow index.
- Estimate the average annual evapotranspiration for the area of interest.

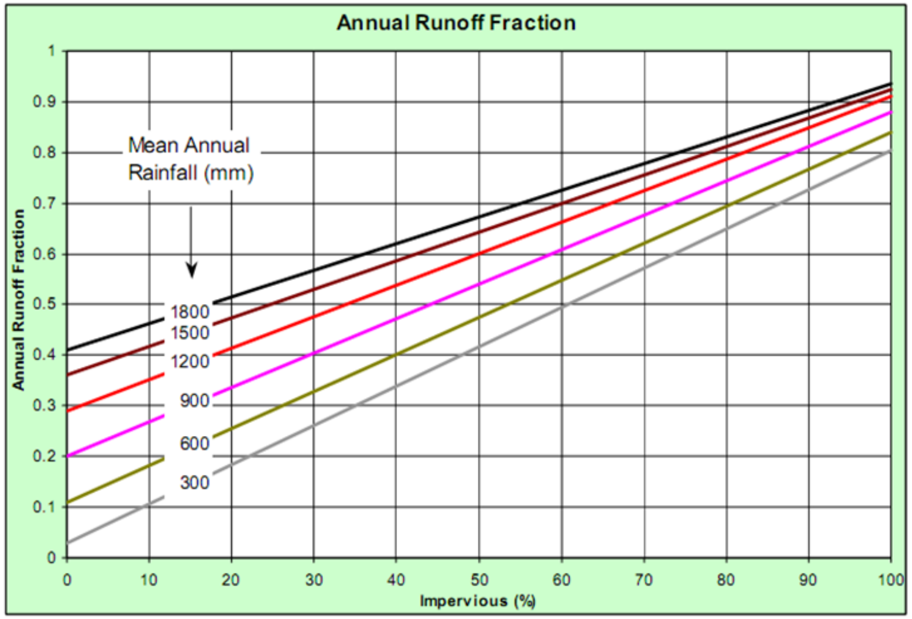


Figure 5-3 Annual Runoff Fraction (Fletcher et al, 2004)

The above approach will identify water balance targets that can be applied to estimate appropriate pervious area rainfall-runoff parameters for an area of interest. Iterations of the pervious area rainfall-runoff parameters can then be undertaken to achieve the water balance targets. The following approach is suggested to achieve the water balance targets:

- Prepare an appropriate meteorological template for the area of interest.

- Determine initial rainfall-runoff model parameters based on the soil texture within the area of interest (refer Table 5-5).
- Create a 100% pervious one node MUSIC model with a catchment area that results in 100ML of rainfall being generated (This is so node water balance outputs are effectively presented at a % of 100% rainfall).
- Run MUSIC and compare model results with the water balance estimates listed under the Statistics >> Node Water Balance menu.
- Complete model iterations following adjustment of the pervious area rainfall-runoff parameters until the water balance estimates area achieved.

A suggested order to modify the rainfall-runoff parameters is shown in Table 5-9. Parameters with the same order should be modified concurrently and proportionally.

Table 5-9 Order For Adjusting Rainfall-Runoff Parameters

Parameter	Parameter Description	Order
Soil Storage Capacity (mm)	The maximum water depth that can be retained within the soil. If the stored water depth exceeds this capacity any additional rainfall becomes surface runoff.	1
Initial Storage (% of capacity)	The initial water depth in the soil at the commencement of the model run.	-
Field Capacity (mm)	The maximum water depth in the soil storage prior to any recharge of groundwater occurring. Water is only 'lost' from this storage through evapotranspiration.	1
Infiltration Capacity Coefficient – a	The maximum daily infiltration rate into the soil when the water depth in the soil is zero.	3
Infiltration Capacity Exponent – b	An exponential decay parameter that is applied to modify the Infiltration Capacity Coefficient – a based on the current water depth in the soil.	3
Initial Depth (mm)	The initial groundwater depth at the commencement of the model run.	-
Daily Recharge Rate (%)	The proportion of water stored in the soil between the field capacity and soil storage capacity that is recharged to groundwater each day.	4
Daily Baseflow Rate (%)	The proportion of the current groundwater storage that contributes to base flow each day.	2
Daily Deep Seepage Rate (%)	The proportion of stored groundwater depth that is directed to deep drainage and does not contribute to either surface runoff or base flow observed at the catchment outlet.	-

5.3 Drainage Links

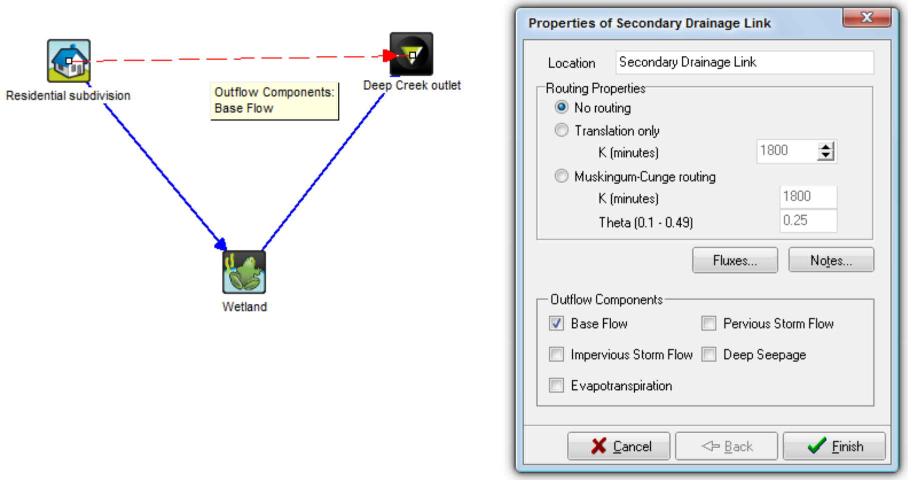
5.3.1 Primary and Secondary Drainage Links

Drainage links join source, treatment, junction and receiving nodes. They model the transfer of flows from one node to another. There are two types of drainage links applied within MUSIC, primary drainage links and secondary drainage links.

Primary drainage links typically define the surface runoff flow direction from impervious and pervious surfaces. Primary drainage links typically represent concentrated drainage flow paths including pipes, drainage swales, open channels or watercourses. Secondary drainage links are typically applied to transfer base flow, deep seepage and evapotranspiration where the flow direction differs to that of the primary drainage link.

Note that whilst secondary drainage links can be applied to re-direct water balance elements in an alternative direction to the primary flow path, all flows (and associated pollutants) should be re-combined or summed when assessing the performance of the system against targets. This is to ensure that the overall mass balance of models being compared is equal.

An example of the use of primary and secondary links is shown in Figure 5-4. In this example, surface runoff from a small residential subdivision drains through a piped drainage system to a constructed wetland. Base flow is modelled to flow as groundwater, bypass in the constructed wetland prior to seeping into the receiving creek.



Location: Secondary Drainage Link

Routing Properties
● No routing
○ Translation only
K (minutes) 1800
○ Muskingum-Cunge routing
K (minutes) 1800
Theta (0.1 - 0.49) 0.25

Outflow Components
☑ Base Flow
☐ Pervious Storm Flow
☐ Impervious Storm Flow
☐ Deep Seepage
☐ Evapotranspiration

Figure 5-4 Secondary Drainage Link Example

5.3.2 Flow Routing

Incorporating consideration of flow routing within a MUSIC model is particularly important when the model is being applied to evaluate the performance of a treatment series against flow targets. Flow routing along the drainage links is typically applied in circumstances where the time of concentration for the area of interest exceeds the model time step. Flow routing assists to ensure that flow rates estimated in MUSIC are not exaggerated at particular locations within the model network. There are three options for hydrologic routing along a link in MUSIC, no routing, translation only and Muskingum-Cunge routing.

The no routing option is appropriate where there is minimal flow travel time between all source nodes and the receiving node. Generally this option is only appropriate for small sites, or where the time of concentration for the area of interest is smaller than the model timestep. This option will typically result in flow rates being overestimated when applied to larger areas (assuming a six-minute model timestep).

The translation only routing option is typically applied for larger areas of interest where the flow travel time from different parts of the catchment varies significantly. The translation time K, is simply the time in minutes for stormwater to flow from one end of a link to the other. It is assumed that no attenuation of the flow occurs along the link with estimated flow rates at the upstream end of the link transferred to the downstream end but delayed by K. Although no attenuation occurs along individual links, translation of flows from different parts of the catchment by different periods ultimately results in attenuation of modelled flows at the outlet.

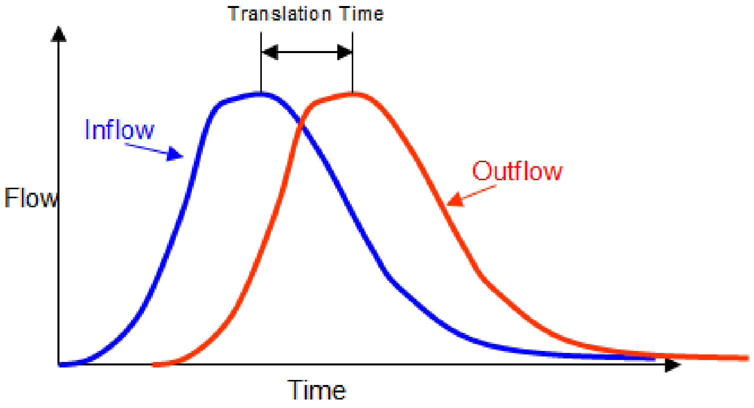
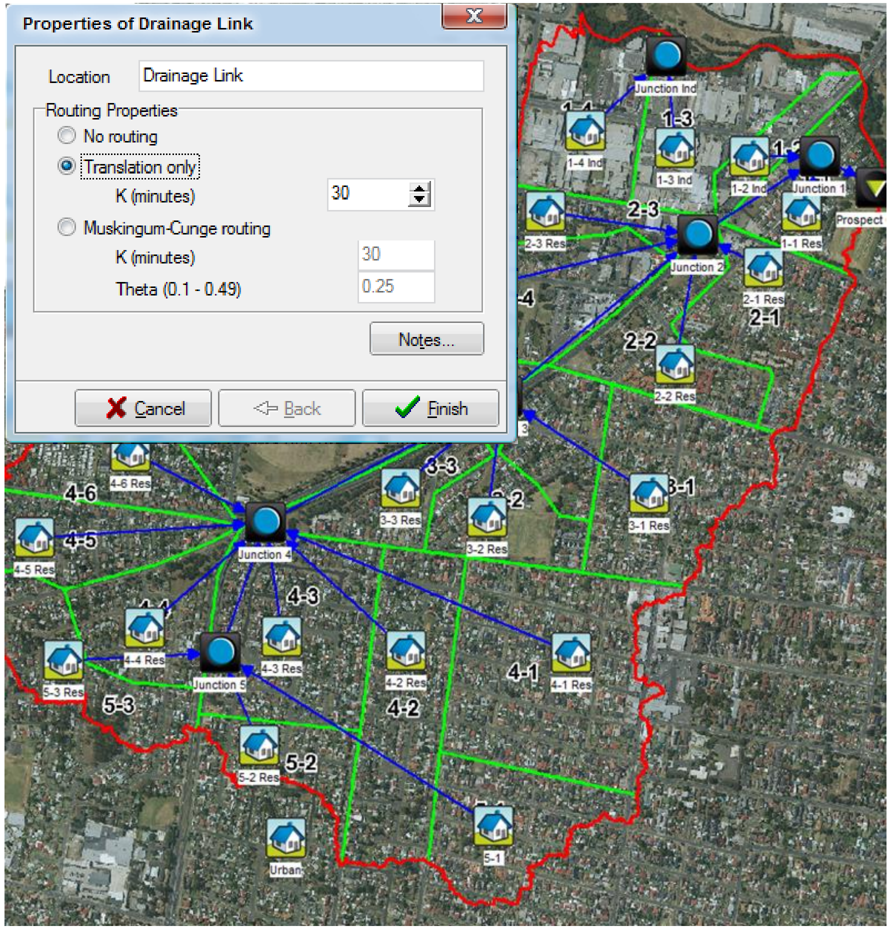


Figure 5-5 Hydrograph Translation Only (BCC, 2005)

K can be estimated by calculating flow travel times along the drainage network using appropriate estimates of flow velocities. For a developed scenario, it is suggested that K be based on flow velocities within the drainage network during the 1 year ARI event. The catchment can be divided into bands of equivalent travel time (band intervals based on the model timestep) to the catchment outlet and source nodes defined based on areas with equivalent travel time to the outlet. Areas with equivalent travel time can then be connected to a common junction node linked to a downstream node with the appropriate translation time applied to the link. Refer to example model network shown in Figure 5-6.

For a pre-development scenario, it is suggested that K be based on estimates of typical overland and natural watercourse flow velocities using standard techniques outlined in Australian Rainfall and Runoff (ARR). Based on these flow velocities, the pre-development catchment can similarly be divided into bands based on the model timestep. Typically the number of bands will be greater for the pre-development scenario due to a longer travel time to the catchment outlet.



Properties of Drainage Link

Location: Drainage Link

Routing Properties
○ No routing
● Translation only
K (minutes): 30
○ Muskingum-Cunge routing
K (minutes): 30
Theta (0.1 - 0.49): 0.25

Figure 5-6 Translation Only Routing Example

The Muskingum-Cunge routing option allows for storage within the drainage link. The volume of storage in the link is related to Theta (θ). θ is a factor applied to account for flow storage along the link (refer Figure 5-7, θ shown as X).

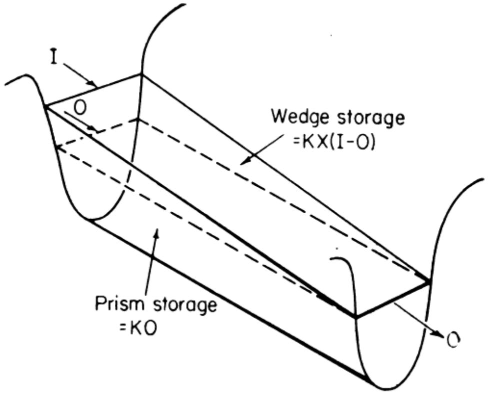


Figure 5-7 Muskingum-Cunge Routing (BCC, 2005)

θ is a dimensionless weighting factor that has a value between 0 and 0.5, and is generally between 0.1 and 0.3 for natural channels (Linsley et al, 1992). θ represents the relative weighting of the inflow and outflow when approximating the volume of water storage within the reach. When θ has a value of zero, the volume of water in storage is purely a function of the outflow alone. A value of 0.5 indicates that the inflow and outflow have an equal weighting in determining the volume in storage.

θ affects the attenuation of the flood wave as it travels along the reach. A value of θ = 0.5 produces no attenuation and the flood wave is purely translated by a time value equal to K. Attenuation will increase, and consequently outflow rates will decrease further, as θ is reduced below 0.5.

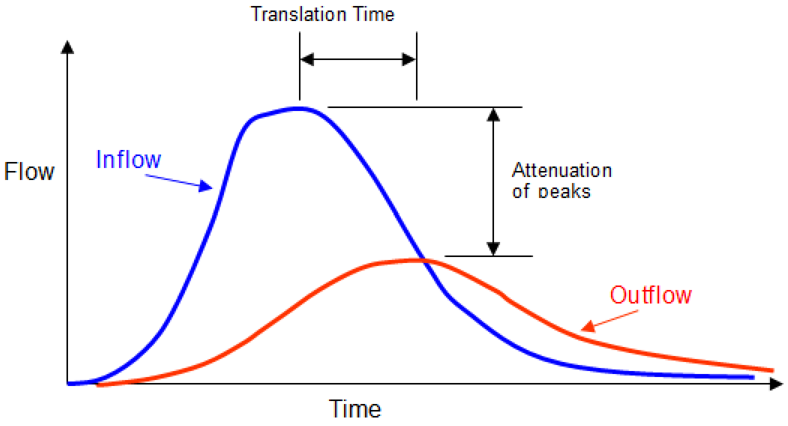


Figure 5-8 Flow Attenuation (BCC, 2005)

It is important to note that the methodology adopted in MUSIC assumes that the values of K and θ remain constant within a reach throughout the simulation. In some applications these parameters may be a function of the discharge in the reach, in which case the routing routine adopted in MUSIC may not accurately predict the attenuation and translation of the flood wave through the reach.

MUSIC currently does not allow for storage routing within source nodes. When calibrating MUSIC models it may be necessary to consider adopting a lower θ along drainage links as a means of accounting for flow routing at the source nodes. Typically θ will be higher for a developed scenario than a pre-development scenario (less attenuation).

6 Developed (treated) Scenario

This scenario represents the area of interest in its final developed state with a stormwater treatment series installed. The MUSIC modelling results for this scenario are typically compared against the base scenario results to determine if the targets are achieved.

6.1 Source Node Configuration Examples

Examples of approaches that could be considered by a modeller when configuring a post development scenario in MUSIC are discussed in the following sections.

6.1.1 Individual Lot

Simulation of an individual lot in MUSIC can be achieved using a one-node model that represents the average conditions of the land use being simulated (e.g. rural residential or urban residential). This approach is best applied when the proposed treatment measures will treat runoff from all the combined surfaces. When a measure is being proposed to treat runoff from a specific surface then this scenario can be modelled by dividing the lot into different surfaces (according to their flow paths) as shown in Figure 6-1 (which shows splitting of a lot according to roof and other areas), Figure 6-2 (which splits the roof area according to the proportion draining to a rainwater tank) and Figure 6-3 (which shows how rainwater tanks may be incorporated within a commercial lot).

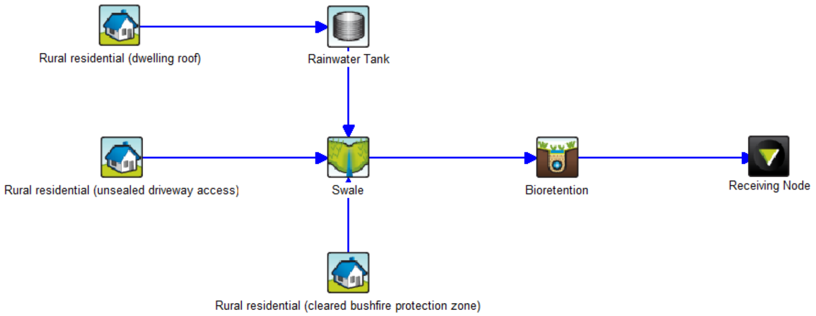


Figure 6-1 Rural Residential Lot (Treatment of Areas Modified by Development Only)

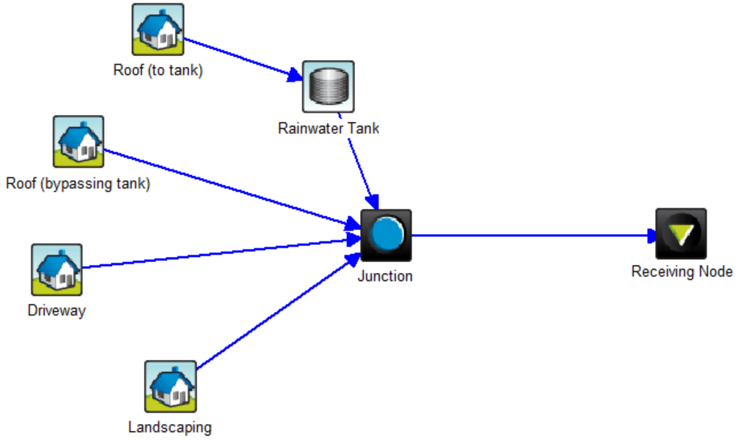


Figure 6-2 Residential Dwelling Lot (Individual Surfaces)

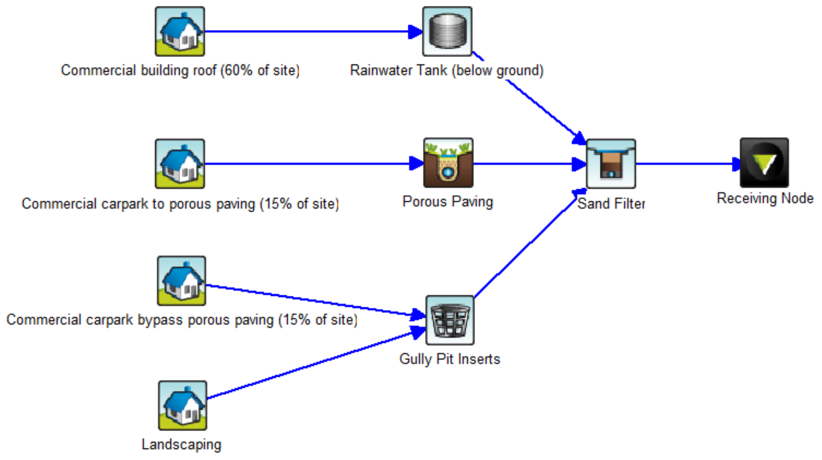


Figure 6-3 Business Lot (Individual Surfaces)

6.1.2 Multiple Lots

To simplify large areas of interest, the modeller should look to combine areas with similar characteristics such as a large residential subdivision comprising similar lots. The individual lots could be aggregated, or "lumped" such that the source node used represents a number of lots with similar characteristics. The imperviousness used in this case should reflect the aggregated lots (i.e. it will need to reflect different driveway and external building configurations in addition to varying roof areas). The size of the treatment measures estimated using this modelling approach can then be divided proportionally across the modelled area based on the number of lots or smaller sub-catchment areas. The example in Figure 6-4 shows surfaces within an area of interest being modelled by lumping 10 lots into a single source node for each of surface types required. The rainwater tank node in MUSIC can now be used to represent multiple rainwater tanks in a single treatment node.

Where the model is also being used to evaluate flows it will be an important consideration to only lump areas that have a similar flow travel time to the outlet.

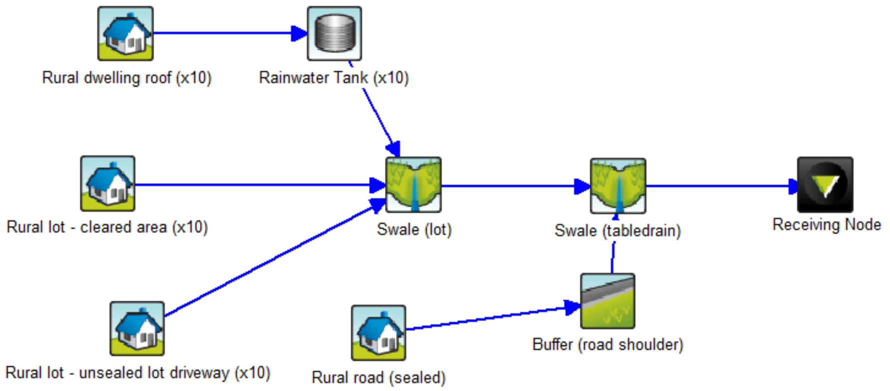


Figure 6-4 Rural Residential Subdivision (Lumping of Lots Based On Surface Types)

In circumstances where the treatment measures are to be positioned outside the lots, in road reserves or public open spaces it may be possible to divide the site according to the total area draining to each specific location throughout the catchment.

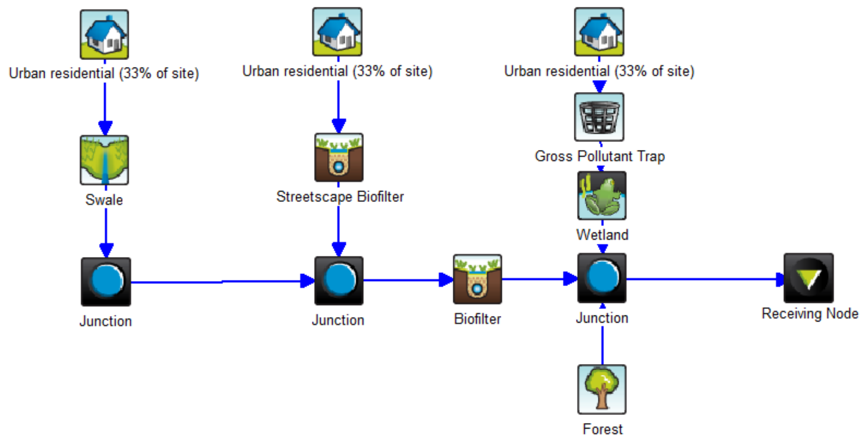


Figure 6-5 Urban Residential Subdivision (Lumping of Development Area Based on Sub-catchments)

Where the model is being used to evaluate flow rates it will be an important consideration to only lump areas that have a similar travel time to the outlet.

6.1.3 Large Scale

In circumstances where the treatment nodes are concentrated near the catchment/site outlet, simplifying the catchment into broad land uses is likely to provide a reasonable modelling approach.

Where the model is also being used to evaluate flows it will be an important consideration to only lump areas that have a similar flow travel time to the outlet.

This large scale approach is shown in Figure 2-10.

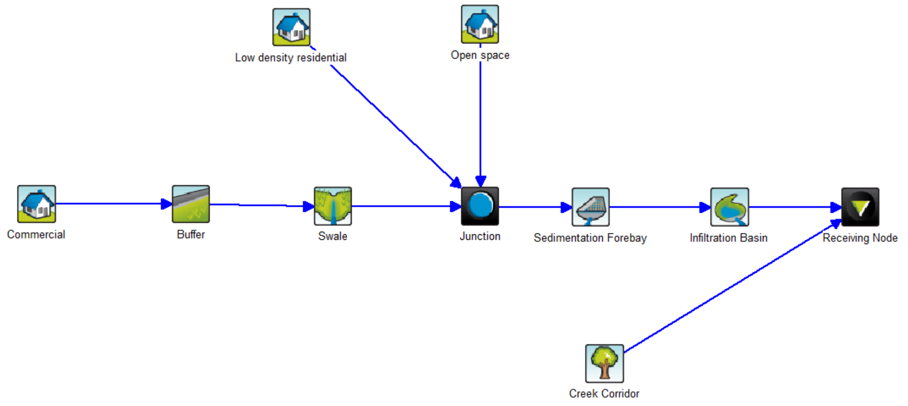


Figure 6-6 Urban Subdivision (Lumping Based on Land Use)

6.2 Catchment/Sub-Catchment Area

Catchments/sub-catchments defined for the base scenario often need to be sub-divided further when the base scenario model is to be compared with the developed (with treatment) scenario model. For example, when modelling an individual lot scale development, the base scenario model may simply comprise a one node model which is all that is required to quantify the stormwater loads from the base scenario site. For the post development scenario, the one node model will often need to be subdivided further to reflect parts of the lot that drain to different treatment measures (e.g. roof areas may drain to a rainwater tank, whilst flow from carparking areas may be directed to a raingarden). EIA for the sub-catchments will also need to be re-calculated.

Each MUSIC Source Node requires catchment/sub-catchment areas and effective impervious area proportion to be defined. Delineation of catchment areas is discussed in Section 4.

6.3 Impervious and Pervious Area Parameters

Impervious and pervious parameters defined for the base scenario should typically be adopted for most developed scenarios. Only developments where modification of the characteristics of the impervious or pervious surfaces at the source is likely to significantly alter surface runoff volumes or pollutant loads should consider any adjustment to the parameters for the post development scenario. An example of this may be conversion of an impervious roof to a green roof.

6.4 Stormwater Pollutant Concentration Parameters

Refer to Section 6.4 for definition of stormwater pollutant concentration parameters for the developed (treated) scenario.

6.5 Treatment Measures

Treatment measures are incorporated into the developed (treated) scenario model to reduce the pollutant loads and concentrations from the development. The following sections provide guidance on input parameter values applied to simulate the performance of the various treatment measures. Note, this is not intended to be a comprehensive guide. Further guidance is available in a range of documents, such as the MUSIC User Manual, as shown in the References section.

The treatment measures have been categorised into primary treatment (P), secondary treatment (S) or tertiary treatment measures (T) depending on their main treatment function.

6.5.1 Rainwater Tanks (P)

Rainwater tanks should be simulated considering the physical constraints of the roof drainage system. Where the tank is located above ground gravity drainage of the entire roof area to the tank may be impractical where the Council will not approve charged property drainage systems. Where the tank charged systems are allowable or the tank is located underground, draining of the entire roof area to the tank may be feasible. Example configurations of these situations are shown in Figure 2-18 and Figure 2-19.

In the rural setting, it is common for the entire roof area to drain to a rainwater tank positioned above ground. Whilst in an urban setting, some allowance for a proportion of the roof area to bypass the tank should be considered (particularly when modelling large catchments involving lumping multiple tanks).

The MUSIC modeller should confirm for their particular catchment (and Council area) a reasonable proportion of the roof area that can feasibly be drained to a rainwater tank, and what proportion would bypass. In the majority of greenfield development it is expected that the potential roof area draining to the tank may be close to 100%, although practically an assumption of 75% of roof areas connected is considered to be more appropriate. However in a retrofit context, a significantly lower roof connectivity may be more likely due to site constraints.

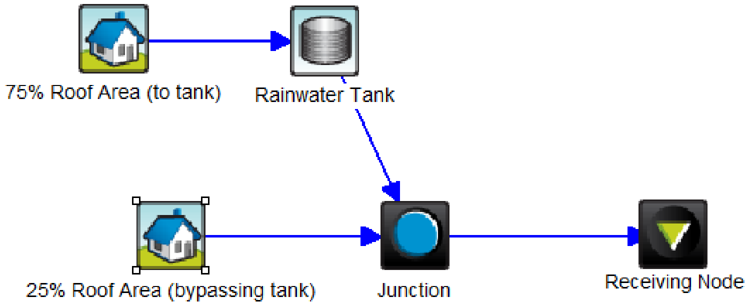


Figure 6-7 Rainwater Tank – % Roof Area Bypassing the Tank

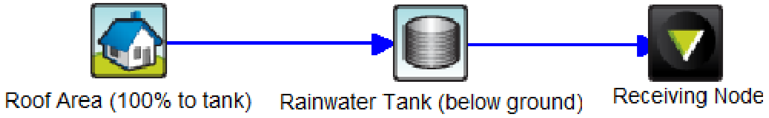


Figure 6-8 Rainwater Tank – All Roof Area to the Tank

In configuring the rainwater tank, several parameters are required by the MUSIC model. The representation of a rainwater tank in MUSIC is shown in the following concept diagram.

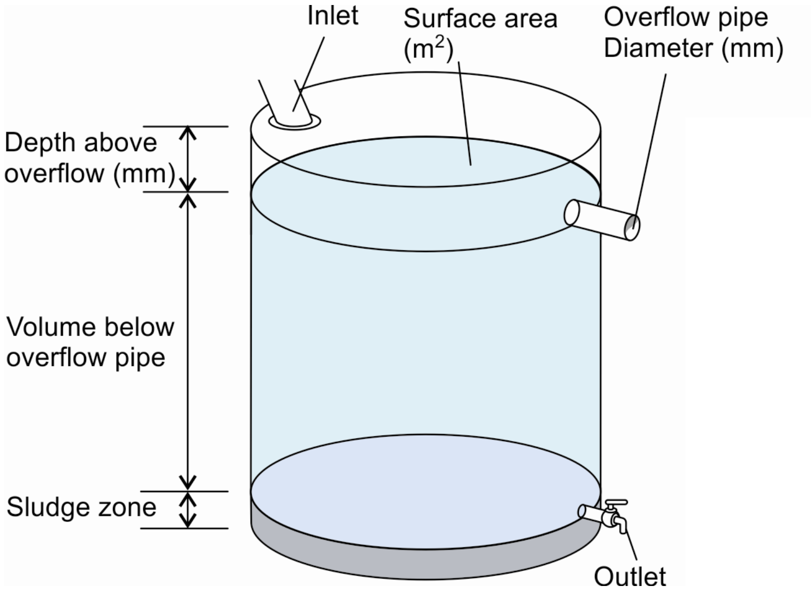


Figure 6-9 MUSIC Rainwater Tank Configuration

Residential demands can be estimated considering the values presented in Table 6-1 and Table 6-2, and non-residential demands estimated considering values in Table 6-3. Note that the values within these tables are based on estimates provided by Sydney Water Corporation (SWC) for the Sydney Metropolitan Area. SWC has advised that the estimates are provided for information only and may contain inaccuracies. Local water demand data should be sourced wherever possible. Modellers should confirm that these estimates are appropriate for their particular area and development prior to applying within MUSIC.

Where data is available on potable water demands in the area being modelled, it may also be necessary to determine indoor demands as these may vary according to local regulations. If this data is not available, the estimates suggested in Table 6-1 and Table 6-2 could be considered. Note that the outdoor demands shown in Table 6-1 and Table 6-2 represent urban residential demands. If additional outdoor demand (i.e. irrigation) is identified for rural residential development these demand estimates may be increased provided information is provided to support the estimates.

Table 6-1 Typical Water Demands for Single Dwellings (derived from data provided by Sydney Water, 2015)

Water Use	Single dwellings (litres/day/dwelling)					
	Number of occupants					
	1	2	3	3.05	4	5
Indoor Uses						
Toilets	27	54	80	82	107	134
Toilets + Washing Machine	58	115	173	176	231	289
Toilets + Washing Machine + Hot Water	106	212	318	324	425	531
All uses	162	325	487	495	649	812
Outdoor Uses						
All uses	151	151	151	151	151	151

Table 6-2 Typical Water Demands for Multi-residential Dwellings (derived from data provided by Sydney Water, 2015)

Water Use	**Multi-residential dwellings (litres/day/dwelling)**				
	Number of occupants				
	1	2	2.35	3	4
Indoor Uses					
Toilets	27	54	63	81	108
Toilets + Washing Machine	53	105	124	158	210
Toilets + Washing Machine + Hot Water	101	202	238	304	405
All uses	157	315	370	472	629
Outdoor Uses					
All uses	88	88	88	88	88

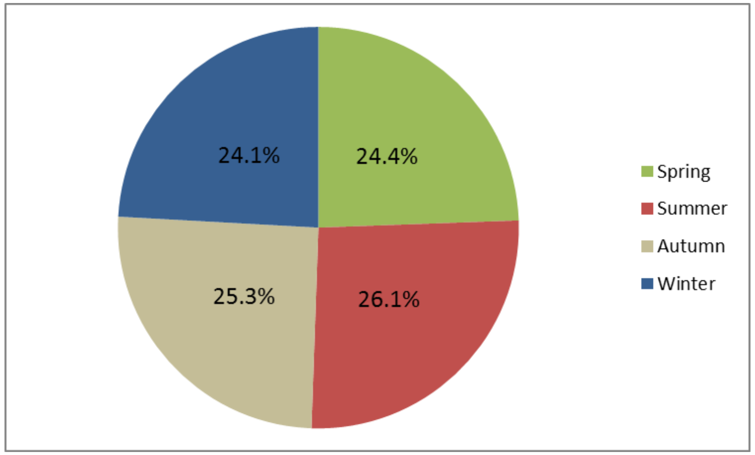


Figure 6-10 Average Seasonal Distribution of Residential Water Use (Sydney Water, 2015)

Key points - Rainwater Tanks:

- The roof area draining to a tank should be realistic considering downpipe locations, reasonable roof gutter gradients and the relevant land use.
- Low flow bypass should be 0 m3/s. For rainwater tanks, first flush diversion is included within the rainfall threshold for roofs shown in Table 5-4.
- High flow bypass should be estimated based on the roof gutter capacity and the tank inlet capacity. The lesser of these two controls should be

used. Note, 0.005m3/s per dwelling is considered reasonable for a typical detached residential dwelling.

- A maximum of 80% of the physical rainwater tank volume should be adopted for modelling. This allows for 10% of the tank volume to be allocated to sediment storage and 10% allowance for an air gap above the overflow pipe. In circumstances where rainwater tanks are to used for on-site detention (OSD), the proportion of the tank available for harvesting below the OSD outlet may be significantly lower than 80% and this should be allowed for in the model.
- External re-use should be modelled using the annual demand scaled by daily PET-Rain option in the re-use box.
- Internal re-use should be modelled as an average daily demand.
- Urban residential sites - internal uses include toilet flushing, washing machine and hot water.
- Rural residential sites (no mains water service) – all internal uses
- Other land uses – determine demands based on a case-by-case situation.

6.5.2 Detention Tanks and Detention Basins (P)

A number of highly urbanised Council LGA's have a requirement to provide on-site detention in development sites to reduce (or as a minimum not increase) discharges to an overburdened drainage system. Whilst MUSIC is not an appropriate model for the sizing and concept design of on-site detention storages, MUSIC can be used to estimate the impacts of on-site detention on runoff quality and frequent flows resulting from temporary detention of stormwater in these tanks.

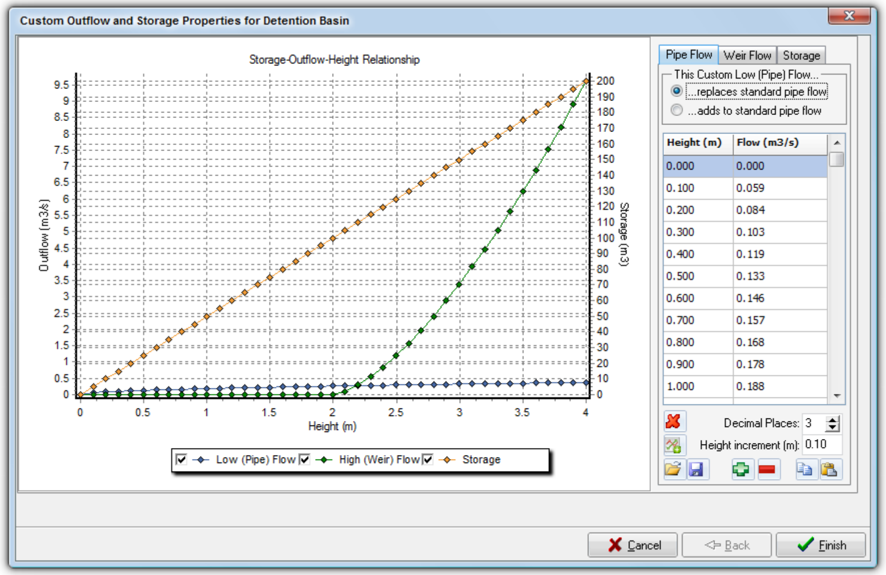
For locations where dedicated on-site stormwater detention is required, the rainwater tank node in MUSIC can be used to simulate this. The rainwater tank should be parameterised with the depth above the overflow pipe set to the storage depth of the tank above the on-site detention outlet, and the volume below the overflow set to 0. No reuse should be specified from the tank.

In some circumstances a BASIX rainwater tank may be required in addition to an on-site detention tank. For this situation, two rainwater tanks in series can be configured. The first rainwater tank would be modelled with water demands and a storage volume below the overflow to suit BASIX requirements. The second tank in the series would be simulated as an on-site detention tank as outlined above.

A detention basin is modelled similarly to a sedimentation basin in MUSIC and applies the same K, C* and C** values when undertaking the treatment calculations. The only difference is that a detention basin is assumed to be a dry detention basin and therefore this treatment node does include an option to define a permanent pool. If a wet detention basin is proposed, then the pond or sedimentation basin nodes should be applied (whichever is most appropriate).

Typically this node would be applied to evaluate how frequent flows would be routed through the detention basin. If the node represents a detention basin designed for flood mitigation purposes, the basin will potentially have minimal influence on more frequent flows. If the detention basin is designed to manage more frequent flows within the stream forming flow range, there is potential that the basin may have a significant influence.

The key component of the detention basin node is the definition of pipe flows, weir flows and storage that specifies how flows are routed through the basin storage.



This Custom Low (Pipe) Flow...
● ...replaces standard pipe flow
○ ...adds to standard pipe flow

Height (m)	Flow (m3/s)
0.000	0.000
0.100	0.059
0.200	0.084
0.300	0.103
0.400	0.119
0.500	0.133
0.600	0.146
0.700	0.157
0.800	0.168
0.900	0.178
1.000	0.188

Decimal Places: 3
Height increment (m): 0.10

Figure 6-11 Detention Basin Node Outflow and Storage Definition

Key points – Stormwater Detention Tanks / Basins

- To simulate detention tanks/basins appropriately, it is important that appropriate hydraulic calculations are completed to define the stage / discharge relationship for the pipe and weir flow discharge. Typically the assistance of a civil or hydraulics engineer will be required to perform the hydraulic calculations necessary to ensure that the flow estimates are reasonable.

- The stage / storage relationship should typically be based on a conceptual design of the detention tank/basin to enable reasonable estimates of storage at particular depths to be ascertained.
- The modeller has the option to define the tank/basin outflows in isolation or combined with the default pipe and weir outflows calculated by MUSIC. In most circumstances, it is suggested that when defining custom flows the modeller should select the option to replace standard outflow to avoid confusion or doubling up on discharges.

6.5.3 Buffer Strips (P)

Buffer strips are essentially grassed or otherwise vegetated areas formed to filter sheet flow runoff from the impervious proportion of a source node. Buffers are provided primarily to remove coarse matter that may otherwise overload a downstream measure. A typical application of this treatment node would be where road pavement runoff is allowed to flow across a vegetated roadside strip prior to draining into a roadside swale or bioretention system.

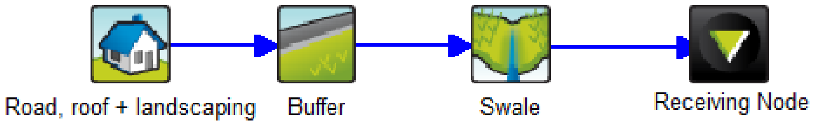


Figure 6-12 Example of Buffers Strip Node Application

Key points – Buffer Strips

- Only effective immediately downstream of a source node that incorporates impervious area.
- Only appropriate for simulating situations where flow is not concentrated. If flow is concentrated, model this situation using the swale treatment node.
- Ensure the percentage of upstream area buffered is based on the **impervious area only**. For example, if the source node represents the combination of equivalent road (100% impervious), roof (100% impervious) and grassed (0% impervious) areas and if only the road is to be buffered, 50% would be the adopted figure (i.e. 33% / 66%).
- Allowance for seepage loss should only be considered where it can be demonstrated that it is unlikely that infiltrated runoff would contribute to flow at a downstream location (e.g. interflow, seepage into drainage pipes or groundwater recharge to sandy soils).

- In most circumstances, the maximum seepage loss rate should be no greater than the average PET rate in order to represent the loss of water due to evapotranspiration from the buffer strip.
- A buffer zone immediately adjacent to an outlet from a stormwater drainage system discharging into existing natural vegetation should be simulated as a wide swale. Refer to Section 6.5.10 for further guidance.

6.5.4 Gross Pollutant Traps (P)

Gross pollutant traps (GPTs) are typically provided to remove litter, organic debris and coarse sediment that may otherwise overload measures provided to manage fine particulates and nutrients. GPTs may also be installed as a standalone measure at specific hotspots where gross pollutants are a concern (e.g. commercial areas).

GPTs are often modelled at the sub-catchment scale in MUSIC as pre-treatment for a constructed wetland or bioretention system. Lot scale systems for particular development types may include screening measures such as leaf diverters (for rainwater tanks) or stormwater pits with inclined outlet screens (for infiltration measures) to minimise the potential for the treatment mechanism of the device to be impeded. Stormwater pits with flush grates can also be effectively at removing gross pollutants with a least dimension of 20 mm.

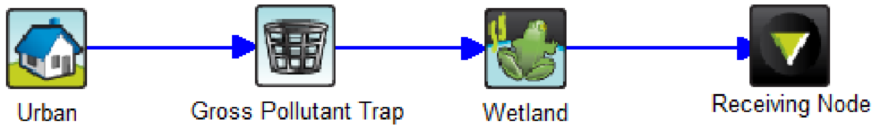


Figure 6-13 Example of GPT Node Application

Where a gross pollutant trap is required, it should be selected or designed to achieve the minimum performance criteria outlined in Table 6-3. If alternative performance data is to be relied upon to estimate the performance of a gross pollutant trap, this data must be from an independent source and not simply based on proprietor-supplied data. The source document (not just the reference) for the data shall be included with the MUSIC model report so as to enable a review.

Where a GPT is to be implemented only for gross pollutant capture (e.g. a trash rack), then only the gross pollutant removal component as shown in Table 6-3 shall be used (i.e. no sediment or nutrient removal is to be attributed to the device). If a proprietary device is an oil and sediment separator, no gross pollutant removal is to be attributed to the device, nor should it be used for this purpose.

Table 6-3 GPT treatment node inputs (adapted from Alison et al 1998)

	Inlet properties	
Low flow bypass	0	
High flow bypass	Define based on 10% of the total flow volume bypassing the GPT.	
Transfer Function Properties		
	Input (mg/L)	**Output (mg/L)**
TSS	0	0
	75	75
	1000	350
TP	0.00	0.00
	0.50	0.50
	1.00	0.85
TN	0.0	0.0
	0.5	0.5
	5.0	4.3
Gross pollutants	0	0
	15	1.5

6.5.5 Proprietary Primary/Secondary Treatment Devices (P/S)

Most proprietary stormwater treatment devices fit into one of the following categories:

(i) Pit inserts – source control measures installed in stormwater pits to catch gross pollutants and coarse sediment

(ii) In-line gross pollutant traps – devices installed along a stormwater drainage line to filter stormwater to remove gross pollutants and coarse sediment

(iii) End-of-line gross pollutant traps – devices installed at the end of a piped drainage system to filter stormwater to remove gross pollutants and coarse sediment

(iv) Oil and sediment separators – source control measures installed to capture oil, coarse sediment and some fine sediment.

(v) Media filtration devices source control measures installed to capture fine sediment, some fine particulate pollutants and, depending on the nature of the media, may also absorb dissolved pollutants including nutrients.

(vi) Nets and in-stream measures – devices installed in a watercourse or at the end of a stormwater pipe to catch large and floating gross pollutants

For proprietary stormwater treatment devices that fit into categories (i), (ii) and (iii) listed above it is suggested that the treatment performance values shown in Table 6 3 be adopted. If alternative performance values are adopted, independent testing data shall be provided with the report to support their use. The performance of category (vi) proprietary devices should not be simulated in MUSIC.

Proprietary devices that correspond to category (iv) and (v) above should not be used as GPTs. Where such devices are modelled as a part of the treatment series, a GPT should be located upstream of the device. The treatment performance values for total suspended solids, total phosphorus and total nitrogen outlined in Table 6-3 can be adopted, however, where alternative performance values are adopted independent testing data shall be provided with the report to support their use.

Proprietary devices that correspond to category (iv) are specialised devices that should be used where oil and sediment are key pollutants, such as petrol service stations. They can be modelled as a single standalone device or, in some circumstances, may incorporate an upstream GPT in the form of a pit insert or inline GPT. Oil cannot be modelled in MUSIC.

Where alternative (higher) performance values for category (v) devices are proposed to be adopted, independent testing data that demonstrates the performance of these devices at capturing the typical composition of stormwater pollutants (i.e. typical proportions of particulate and dissolved pollutants) shall be provided in the report.

Key points – GPTs

- GPTs are sometimes used as a standalone measure for commercial developments with potentially high litter loads but invariably additional treatment measures will be required to achieve the targets.
- GPTs can be used as a pre-treatment measure for sites where large sub-catchment scale measures are proposed, such as bioretention basins or constructed wetlands.
- GPTs are generally not needed at the lot and street scale level where stormwater quality is generally managed using measures such as rainwater tanks, buffer strips, grassed swales and raingardens. Other appropriate pre-treatment options such as inlet basins, that perform similar functions to gross pollutant traps, may be used to reduce future maintenance.
- The high flow bypass shall be set at a flow rate that results in a maximum of 90% of the modelled flow volume passing through the GPT. The flow rate at which this occurs can be established by modifying the inflows using a generic treatment node to establish the flow rate at which the 10% of flow bypasses. Spreadsheet analysis of the inflow time series can also establish this flow. The generic treatment node can then be replaced by a GPT node with the assessed flow rate. Note that for design purposes the high flow bypass for a gross pollutant trap node should be set at the 3 month ARI flow (approximately equivalent to 50 percent of the 1 year ARI

flow in Sydney). If an alternate treatable flow rate is proposed, this should be justified in the report.

- All MUSIC models must specify the type and size of GPT modelled.

6.5.6 Sedimentation Basins (P)

Sedimentation basins are primarily used to target the removal of coarse and medium sediment from stormwater. Sedimentation basins may also be designed to function as a GPT if an appropriate trash rack or similar device is incorporated into their design. Sedimentation basins are measures that can be utilised during the construction and post development phases for a site. It is important to note the key differences between these two phases. A sedimentation basin is represented conceptually in MUSIC as shown below.

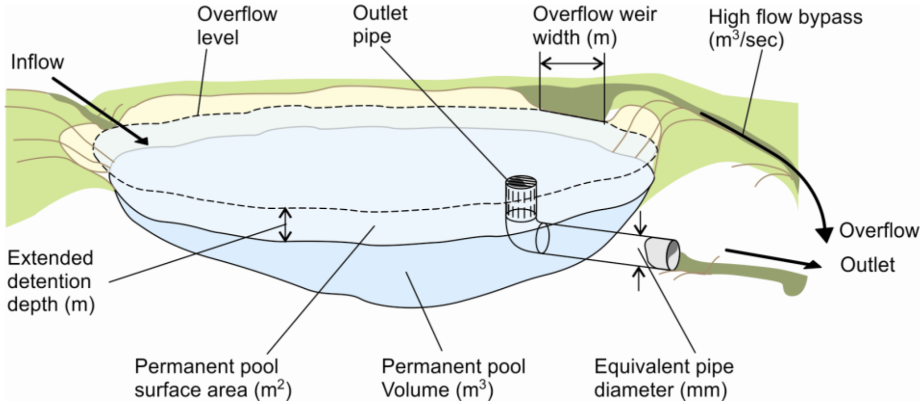


Figure 6-14 Conceptual Sedimentation Basin Configuration

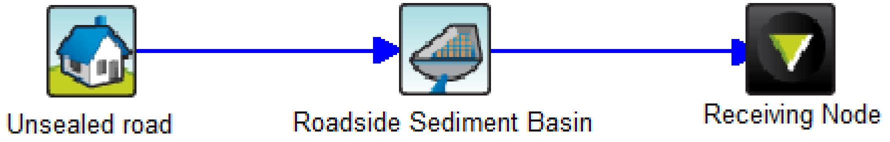


Figure 6-15 Example of Sedimentation Basin Node Application

During construction, sedimentation basins are provided to intercept and enable settling of coarse and/or fine sediment particles generated from erosion of exposed surfaces during construction. Construction phase sedimentation basins should be sized using the approaches outlined in 'Managing Urban Stormwater: Soils and Construction – Volume 1' the "Blue Book" (Landcom, 2004). Construction phase sedimentation basins should not be simulated in MUSIC.

Construction phase sedimentation basins are often planned to be converted to a post development stormwater management measure such as a wetland. For the post-development phase the sedimentation pond treatment node should only be used to simulate sites where unvegetated and exposed soil forms a significant part of post-development conditions, for example quarries, landscape supply developments, unsealed roads, intensive horticulture or erosion gullies.

Key points – Sedimentation Basins

- Construction-phase sedimentation basins shall be sized using the methods in 'Managing Urban Stormwater: Soils and Construction – Volume 1' (Landcom, 2004).
- Post development phase sedimentation basins should be modelled to remove the coarser range of TSS particles.
- Only use sedimentation basins in sites where unvegetated areas with exposed soils are part of the post-development site conditions (such as quarries, landscape supply developments, unsealed roads, intensive horticulture or erosion gullies).
- MUSIC assumes that the extended detention storage has vertical sides. If the measure being modelled will not have vertical sides, an estimate of the average surface area needs to be calculated. If the system modelled has a trapezoid-shaped extended detention storage, the surface area should be calculated as the detention depth when it is at 50% of the maximum extended detention depth.
- The k and C* for sedimentation basins in areas that are un-vegetated (such as quarries, landscape supply developments, unsealed roads, intensive horticulture or erosion gullies) shall be adjusted to 15,000 and 90mg/L respectively.
- A maximum notional detention time of 8 hours should be adopted for modelling a sedimentation basin (assuming an average settling zone depth of 1m) to target coarser particles. If a longer detention time is desirable, an alternative treatment measure incorporating vegetation should be modelled. This will ensure that captured nutrients associated with finer material can be removed biologically. Increasing the detention time of a sedimentation basin may simply result in other water quality issues such as excessive algal growth.
- The high flow bypass shall be set at a flow rate that results in a maximum of 90% of the modelled flow volume passing through the measure. The flow rate at which this occurs can be established by modifying the inflows using a generic treatment node to establish the flow rate at which the 10% of flow bypasses.

6.5.7 Mitre Drains (P)

Mitre drains (also called turnout or tailout drains) are common along unsealed roads and tracks in rural areas. They intercept concentrated flow moving down a swale or table drain and fan it out onto a level vegetated area as sheet flow. The lower velocity of the sheet flow causes coarser sediment to drop out and associated vegetation filters finer sediments. Further filtering occurs as the stormwater passes through the vegetation at the end of, or after, the mitre drain.

Mitre drains provide a small reduction in phosphorus levels but negligible reduction in nitrogen levels. These measures are invariably positioned adjacent to a roadside runoff discharge point. Figure 6-17 shows the typical configuration of mitre drains.

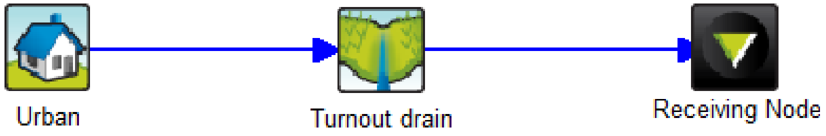


Figure 6-16 Example of Mitre Drain Application in MUSIC

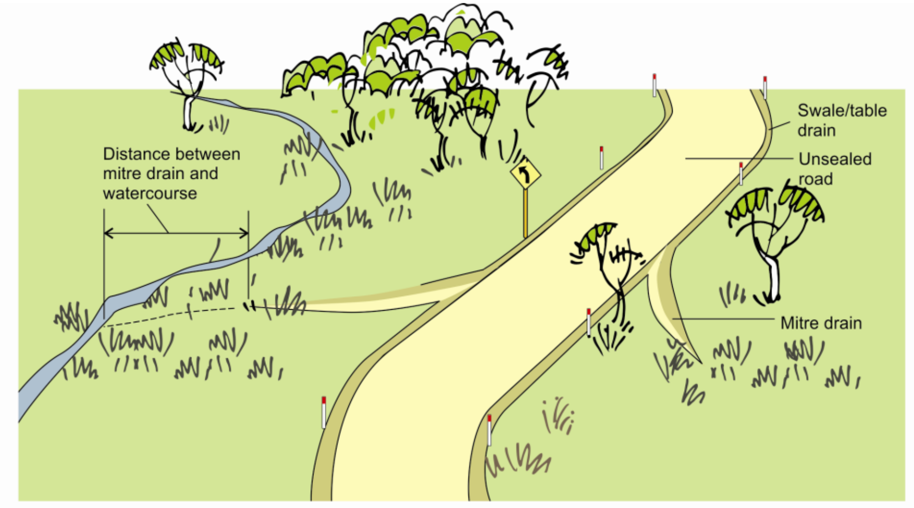


Figure 6-17 Typical Mitre Drain

These measures are typically positioned adjacent to a discharge point into the receiving environment.

Key points – Mitre Drains

- Mitre drains should not be used in urban areas.
- The swale treatment node should be used to model mitre drains. The distance (up to a maximum of 20 m) from the downslope end of the mitre drain to either the nearest watercourse (gully, creek or drainage depression), or to a flat surface, is taken as the length of a wide swale.
- The dimensions of the swale representing each mitre drain should be limited to a length of 20 m, a base width of 0.5 m, a depth of 0.3 m, and a slope of 1 to 3% (depending on the site).
- Mitre drains should be modelled in multiples for each site sub-catchment and not individually. The average length of “swales” representing mitre drains (nominal top and base width of 1.5 m and 0.5 m, and depth of 0.3 m) should be multiplied by the number of mitre drains for the length of road.
- Mitre drain spacing is dependent on: steepness and length of slope, soil type and erodibility, rainfall and natural drainage line locations. A reasonable starting point for determining the maximum spacing of mitre drains is the following relationship:

  Maximum spacing = 300 ÷ % slope
- DECC’s ‘Soils and Construction Volume 2C: Unsealed Roads’ provides more detail for determining mitre drain spacing that can be utilised for modelling.

6.5.8 Infiltration Systems (S)

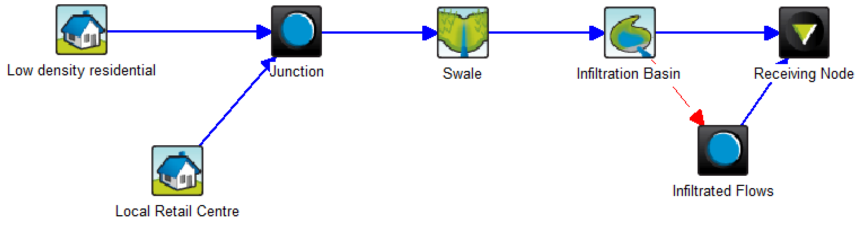


Figure 6-18 Example of Infiltration Node Application in MUSIC

Infiltration systems are increasingly being considered within Australia to assist with managing hydrologic objectives and they are one of the few treatment measures which can significantly reduce surface runoff volumes for smaller rainfall events, and therefore lead to reductions in overall flow frequencies from urbanised catchments. Whilst significant surface runoff reductions can be achieved, it is important to evaluate the impacts of infiltrating large volumes of stormwater on downslope developments or environments.

When modelling the infiltration of stormwater, it is important that a pre-treatment measure (e.g. biofiltration swale), is provided to treat runoff to an acceptable quality. Infiltration measures should not be applied to simulate the loss of large loads of stormwater pollutants. The focus of these measures should be on reducing surface runoff volumes following pre-treatment to remove the bulk of the stormwater pollutant load.

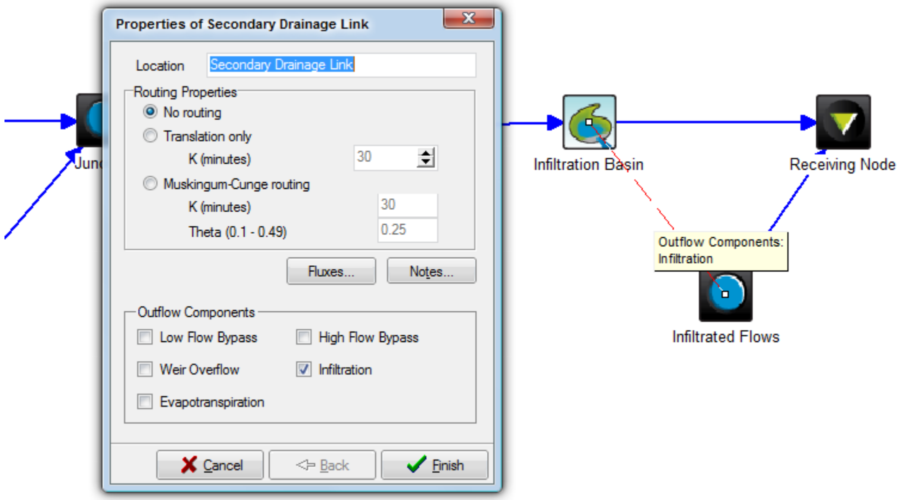
Prior to modelling infiltration for a particular site, it is recommended that the modeller becomes familiar with guidance outlined in the guideline document *WSUD: Basic Procedures for Source Control of Stormwater* (Argue, 2006). Care needs to be taken with adopting infiltration measures such that consideration is given to separation distances, soil characteristics (e.g. hydraulic conductivity) and potential for nuisance caused by seepage into adjacent or down slope properties. Table 6-4 provides some guidance on saturated hydraulic conductivities for particular soils (applied as an exfiltration rate for the infiltration system node) that may be suitable for use in MUSIC (noting that these are for homogeneous soils and steady-state conditions). Care also needs to be taken about the use of infiltration systems in soil types with high acidity and/or salinity, especially sodic soils and areas known to have high acid sulfate soil potential.

Table 6-4 Soil Hydraulic Conductivity (from ARQ 2005)

Soil Type	Minimum Hydraulic Conductivity (mm/hr)
Deep sands (confined or unconfined)	180
Sandy Clays	36
Medium Clay	3.6

Soil Type	Minimum Hydraulic Conductivity (mm/hr)
Heavy Clay	0.036
Constructed Clay	0.0004
Sandstone (overlain by shallow soil)	3.6

In previous versions of MUSIC, any flows that were exfiltrated from a system were deemed to be lost from the water balance and any associated pollutants were assumed to be also lost with them. In practice though, such water, if not sufficiently treated, can contaminate groundwater environments and examples such as the sandy aquifers of the Central Coast of NSW have shown those impacts being released to downstream waterways. In order to account for infiltrated water and any associated pollutants, in the most recent versions of MUSIC, the Secondary Drainage Link should be used to direct infiltrated water to a separate junction node and this then directed to the receiving node. This is indicated in the figure above, but also shown in terms of configuring the secondary link in the diagram below.



Properties of Secondary Drainage Link

Location: Secondary Drainage Link

Routing Properties
- ● No routing
- ○ Translation only
  - K (minutes): 30
- ○ Muskingum-Cunge routing
  - K (minutes): 30
  - Theta (0.1 - 0.49): 0.25

Outflow Components
- ☐ Low Flow Bypass
- ☐ High Flow Bypass
- ☐ Weir Overflow
- ☑ Infiltration
- ☐ Evapotranspiration

Outflow Components: Infiltration

Figure 6-19 Secondary Drainage Link Configuration

6.5.9 Permeable Paving (S)

Permeable paving is a paving material specifically designed to allow runoff to drain through an open pavement and infiltrate to the underlying base-course. Water typically drains through the sand and gravel of the basecourse and is collected by a subsoil drain. Particulates and some dissolved pollutants are removed by being filtered and absorbed by the filter media. Using porous paving instead of conventional paving reduces the amount of directly connected impervious area and reduces the volume of untreated runoff reaching the outlet.

Permeable paving is usually provided at the lot scale for surfaces including driveways. Most permeable paving is generally unsuitable for roads with high heavy-vehicle traffic loads. High sediment loads can also clog the paving and reduce its effectiveness.

Porous or pervious pavers or concrete should be treated the same as permeable paving provided it is laid on an appropriate depth of basecourse that acts as a filter and is constructed with an underdrain. The 'open' area, which represents the filter area, will vary according to the nature of the porous material and ranges from about 10 percent for porous asphalt, porous concrete pavers or porous concrete to an upper value of 40 percent for resin-bound pavers or surfaces. A conservative value based on the product specifications should be adopted for modelling.

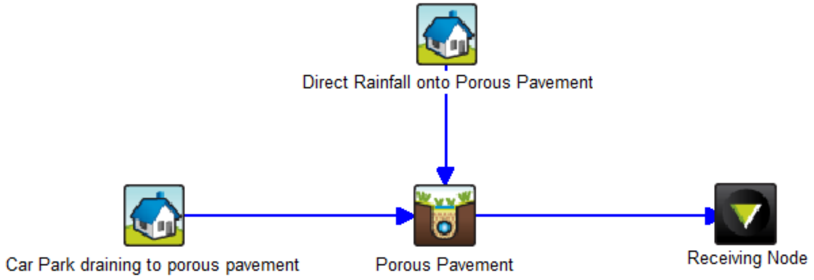


Figure 6-20 Example of Permeable Paving Application in MUSIC

Permeable paving can be utilised to promote a variety of water management objectives, including:

- Reduced peak stormwater discharges from paved areas;
- Increased groundwater recharge;
- Ability to store stormwater;
- Improved stormwater quality; and
- Reduced area of land dedicated solely for stormwater management.

Key points – Permeable Paving

- Permeable paving should be modelled using the media filtration node.

- The ‘open’ or permeable part of the permeable pavement (not the total surface area) should be input as the filter area. This should be estimated from the product specifications. The ‘open’ space for porous pavers or pavement should be based on a conservative value derived from product specifications.
- The catchment draining to the permeable paving should be separated into 2 or more nodes. One node should represent the surface flow to the paving and the other the direct rainfall on the paving. For the source node representing the actual area of the pavement, adopt 100% impervious and adopt the rainfall threshold presented in Table 5-4.
- Determine the saturated hydraulic conductivity to represent the smallest median aggregate (D50) in the permeable paving base and sub-base layers. This value should be factored by 0.4 to allow for a reduction in permeability over the life of the pavement. If the permeable paving is slightly depressed, allow for this by including a small extended detention depth.
- The filter depth should represent the total depth of the basecourse (and sub-base course if applicable), but should not include the transition and drainage layers which are usually coarser material that provides negligible treatment capacity.
- It will generally be preferable to drain the filtered runoff away from the pavement subgrade. For this situation assume that the depth below underdrain is 0% and that the seepage loss is zero.

6.5.10 Vegetated Swales (S)

Vegetated swales are typically trapezoidal shaped open channels provided to convey and filter stormwater runoff through vegetation to remove coarse sediment and total suspended solids. The modelled performance of this measure largely depends on the assumed operational vegetation height and the gradient/length of the swale.

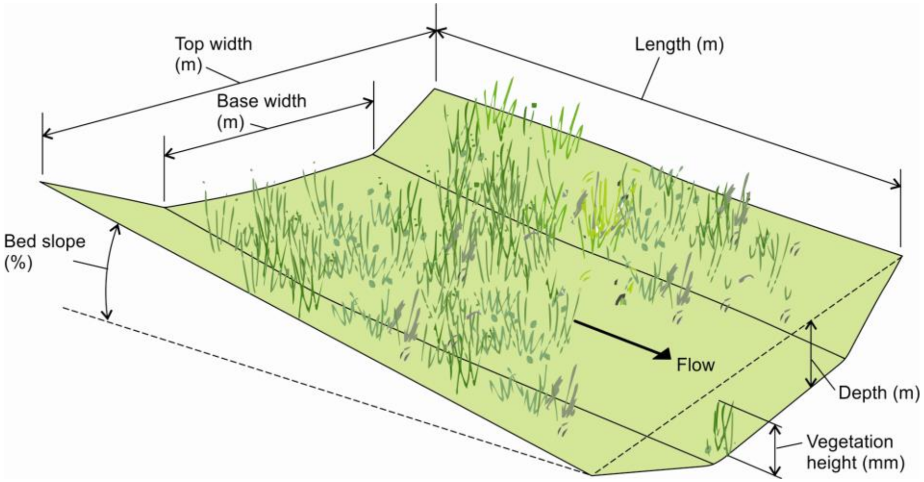


Figure 6-21 Conceptual Swale

The swale length should be selected to reflect the physical configuration of the development. It is important to consider whether the swales should be modelled in series or parallel. Where the constructed swale will be relatively long and linear with individual lot drainage entering it, the swale should be modelled in separate sections in series representing the individual lot flows into the swale. Figure 6-22 shows the configuration of this approach.

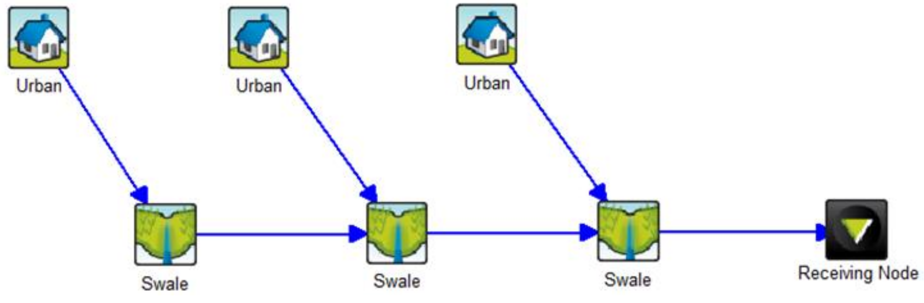


Figure 6-22 Vegetated Swales in Series

Where a swale has drainage inlets positioned at intervals along its full length, then the modelling approach shown in Figure 6-22 is not appropriate. In these circumstances, the source node catchment area for each section of swale should be estimated based on the proposed location of drainage inlets and the model configured to only treat specific sources nodes in specific sections of the swale. The configuration of this approach is shown in Figure 6-23.

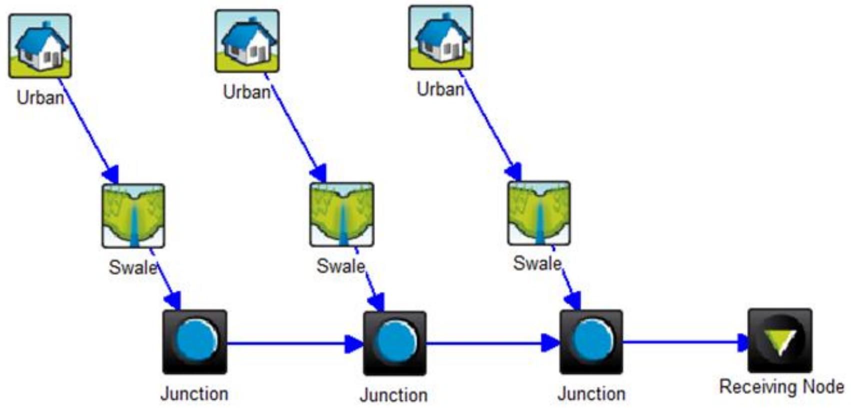


Figure 6-23 Vegetated Swales in Parallel

Key points – Vegetated Swales

- Do not model table drains where drainage is the main function as grassed swales.
- Confirm Council’s engineering standards to define appropriate swale characteristics (particularly within residential areas).
- The background concentration (C*) for a swale is relatively high, so ensure that swales are correctly positioned in the treatment series so that modelled concentrations do not increase after passing through them.
- Consider if the swales are best modelled as a series of segments or as parallel measures.

- In most circumstances the low flow bypass should be set to 0m3/s. This should only be modified where it is clear that runoff draining to the swale would bypass during low flow events (e.g. into a low flow pipe under the swale).
- An average slope for swales with varying gradients should be estimated using the equal area method. The longitudinal bed slope should be within the 1 to 4% range. For gradients of 1-2%, swales with sub-soil drainage may be appropriate.
- If the swale is of a non-linear shape (e.g. curved profile), the modeller should select top and base widths that best represent the swale dimensions.
- Swale depths in most road reserves should optimally be between 0.15 and 0.30 m to achieve suitable side slopes. For local streets swales should be modelled with a depth closer to 0.15 m where it can be demonstrated that the swale has sufficient flow capacity to minimize the chance of nuisance flooding, however, swale depths closer to 0.30 m are generally best. Swale depths outside the road reserve (for example in open space areas) may be deeper if it is safe and practical to implement.
- Vegetation height should be realistic for available species. For swales in rural areas, model the height at two-thirds of the swale depth up to a maximum of 0.25 m. For grassed swales in urban areas, where residents are likely to mow regularly, decrease modelled vegetation height to about 0.05 m.
- Seepage loss should not be modelled. The exfiltration rate parameter should be set to 0 mm/hr unless it can be demonstrated that infiltrated runoff would not contribute to observed flows downstream either through surface runoff, seepage into drainage lines, interflow or base flow.

6.5.11 Media Filtration Measures (S)

The media filtration node has been set up to account for filtration systems (proprietary and non-proprietary) which operate in such a way that they are not properly represented by other MUSIC treatment nodes outlined in this manual. A typical configuration is shown below.

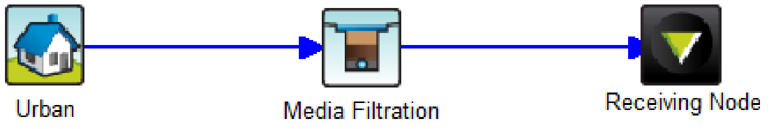


Figure 6-24 Example of a Media Filtration Node in MUSIC

Media filtration measures operate in a similar manner to bioretention systems with the exception that stormwater passes through a filter media (typically media may include combinations of sand, gravel, perlite, zeolite, granulated activated carbon etc.) that has no vegetation. Media filters typically do not incorporate vegetation because the filter media does not typically have sufficient field capacity to retain moisture to support plant growth. They are also often installed underground and this further limits plant growth potential.

Key points – Media Filtration

- For all media filters, the extended detention depth should represent the depth available above the filter media for temporary storage prior to filtration (should be based on the level of the overflow/bypass weir).
- For all media filters, the overflow weir should be designed to control and discharge the peak design ARI flow relevant to the minor drainage system.
- For all media filters, the saturated hydraulic conductivity should be based upon the smallest D50 of the media layers in the filter. The saturated hydraulic conductivity should be factored by 0.4 for media filters where access to the filter media for maintenance is limited.
- The modeller should consider the different input considerations for media filters that have either below ground or above ground extended detention storages.
- Where the extended detention storage is below ground, the filter area is typically equivalent to the surface area.
- Where the extended detention storage is above ground, the surface area input where the extended detention storage is above ground should be the surface area at approximately 2/3 of the proposed maximum extended detention depth and the depth below underdrain pipe should not be greater than 50mm.
- The exfiltration rate should be set to 0mm/hr for all underground media filters. For media filters exposed to sunlight, the exfiltration rate should be no greater than the average PET rate in order to represent the loss of water due to evapotranspiration.
- In circumstance where proprietary media filters are proposed, the modelled reduction efficiencies should be justified by rigorous scientific testing and results published in a credible engineering/scientific journal.

6.5.12 Ponds (S)

A pond is essentially a sedimentation basin with a permanent water storage. These measures typically have an average depth greater than 1.5m to minimise the growth of emergent plant species and are primarily incorporated into a development configuration for aesthetics. MUSIC adopts a default vegetation coverage of 10% for ponds which essentially represents a predominantly open water pond with fringing vegetation. A pond is represented conceptually in MUSIC identically to sedimentation basins.

Figure 6-25 Example of Pond Node Application

Key points – Ponds

- The use of ponds in urban areas is generally not a preferred stormwater management option, as other water quality issues such as algal blooms can happen in ponds that typically have limited vegetation coverage. Additional biological treatment for these issues can outweigh the other water quality benefit that ponds provide.
- A trash rack (modelled as a GPT) should be incorporated into the treatment series when a pond is proposed in urban areas to remove coarse sediment and gross pollutants. Preferably, ponds should only target the removal of medium to coarse grained particles. The hydraulic residence time should be appropriate to minimise the capture of fine grained particles and nutrients that can lead to high maintenance requirements where there is not enough aquatic vegetation to prevent issues like algal growth.
- The pond node should be used to model farm dams in rural areas where they are used to treat runoff and sediment from unsealed roads. Locate ponds to capture runoff from roadside swales, which will also remove coarse sediments and gross pollutants.
- If a pond spillway or high-flow bypass is to be located near the inlet, model the pond treatment measure as a constructed wetland and adjust the C* and k parameters to the values for a pond. This is because the overflow from a typical pond is normally assumed to be located at the downstream end of the pond. Spills from the pond are assumed to be partially treated, which is not true if the high-flow bypass is near the inlet.
- Similarly to a sedimentation basin, the notional detention time within a pond should not exceed 8 hours to target coarser particles. If a longer detention time is desirable, an alternative treatment measure incorporating vegetation should be modelled. This will ensure that captured nutrients associated with finer material can be removed biologically. Increasing the detention time of a pond may simply result in other water quality issues such as excessive algal growth.

6.5.13 Constructed Wetlands (T)

Constructed wetlands are artificial systems that mimic functions of natural wetlands in reducing fine particulate sediments and associated pollutants such as nutrients, metals and toxicants, including those in soluble forms. They are simulated in MUSIC as surface wetlands with permanent or ephemeral water bodies in the upstream inlet (sediment) pond and main wetland (macrophyte) zone. The diagram below shows how they are conceptually represented within MUSIC.

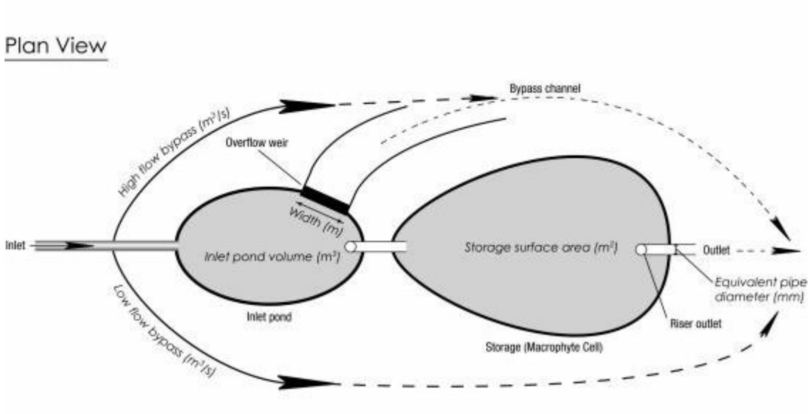


Figure 6-26 Conceptual Constructed Wetland

Constructed wetlands have a higher proportion of shallow water zones than ponds, and aquatic vegetation is distributed more widely across the wetland (in ponds vegetation is mainly limited to the edges of the pond). Constructed wetlands may have low flow and high flow bypasses. The low and high flow bypasses are located upstream of the inlet to the inlet pond (or wetland storage inlet when no inlet pond is provided). The wetland storage includes an overflow weir that operates when the water level exceeds the extended detention depth.

A pre-treatment device such as a gross pollutant trap is typically required to reduce gross pollutants and coarse sediments from entering the wetland to maintain functionality, reduce maintenance and prolong the life of the system.

If a gross pollutant trap is not provided, the wetland should be modelled and designed with an inlet pond for pre-treatment.

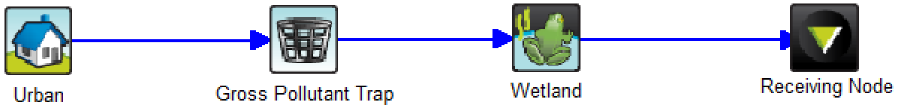


Figure 6-27 Example of Constructed Wetland Node Application

Key points – Constructed Wetlands

- In situations where a GPT is not provided for pre-treatment, a constructed wetland should be modelled with an inlet pond. Similarly to a sedimentation basin, the notional detention time within the inlet pond should not exceed 8 hours to target coarser particles. Increasing the detention time of an inlet pond may simply result in other water quality issues such as excessive algal growth.
- The high flow bypass should be designed to be located prior to the inlet to the main storage and macrophyte zone. The high flow bypass shall be set at a flow rate that results in a maximum of 90% of the modelled flow volume passing through the constructed wetland. The flow rate at which this occurs can be established by modifying the inflows using a generic treatment node to establish the flow rate at which the 10% of flow bypasses. Spreadsheet analysis of the inflow time series can also establish this flow. Note that for design purposes the high flow bypass for

a gross pollutant trap node should be set at the 3 month ARI flow (equivalent to 50 percent of the 1 year ARI flow in Sydney). If an alternate high flow bypass rate is proposed, this should be justified in the report.

- If the high flow bypass will be located at the outlet the measure should be modelled as a pond and k and C* parameters in the pond node adjusted to be equivalent to the corresponding wetland parameters.
- Water depths in excess of the extended detention depth discharge from the wetland via the overflow weir. The treatment of discharges via the overflow weir is dependent on whether the wetland system being modelled includes an inlet pond for pre-treatment of stormwater. If an inlet pond has been specified, the discharge over the overflow weir is considered to have undergone pre-treatment and to have bypassed the macrophyte zone of the wetland; otherwise, discharge over the overflow weir is considered as not being treated and will adopt the pollutant concentrations of the inflow.
- Calculate the surface area input for this treatment node when the water level is approximately half of the extended detention depth. This assumes trapezoidal banks for the wetland. If the wetland is surrounded by vertical or near vertical walls, the surface area will probably be almost equivalent to the surface area when the permanent storage is full.
- A fixed default 50% coverage of vegetation applies to the constructed wetland node. If less vegetation is proposed, the constructed wetland node k and C* values should be modified to the pond node values to represent a lower level of treatment.
- Extended detention should typically not exceed 0.5 m unless it can be demonstrated that a higher depth is achievable without flooding impacts.
- The permanent pool in the constructed wetland should not exceed the surface area (at permanent pool level) multiplied by 1m unless more detailed information is provided of the wetland configuration.
- The seepage loss rate should be 0mm/hr unless it can be demonstrated that infiltrated runoff would not contribute to observed flows downstream either through surface runoff, seepage into drainage lines, interflow or groundwater.
- The evaporative loss should be the default value of 125% of PET.
- The notional detention time in the wetland storage should typically be between 48 to 72 hours to ensure optimal treatment of nutrient species. The value can be set by adjusting the equivalent pipe diameter, as this is simply a way of controlling the nominal outlet size.

6.5.14 Bioretention Measures (T)

Bioretention measures include measures such as tree pit filters, raingardens, bioretention swales and bioretention basins. Tree pit filters are typically located in highly impervious areas to treat relatively small catchments. Raingardens are typically small basins distributed within lots, the road reserve or open space areas to capture and treat flow at a specific location. Bioretention swales are typically provided within medians or footpaths within the road reserve and these may also provide a minor flow conveyance function. Bioretention basins are typically large basins provided in large open space areas to manage stormwater quality at the sub-catchment scale. These measures can be represented as one node in MUSIC as shown in the following diagrams.

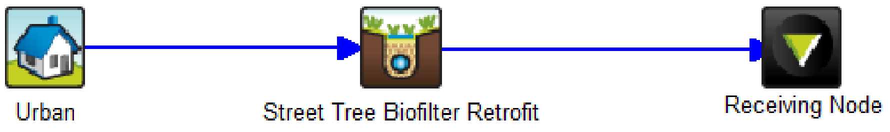


Figure 6-28 Example of Bioretention Node Application

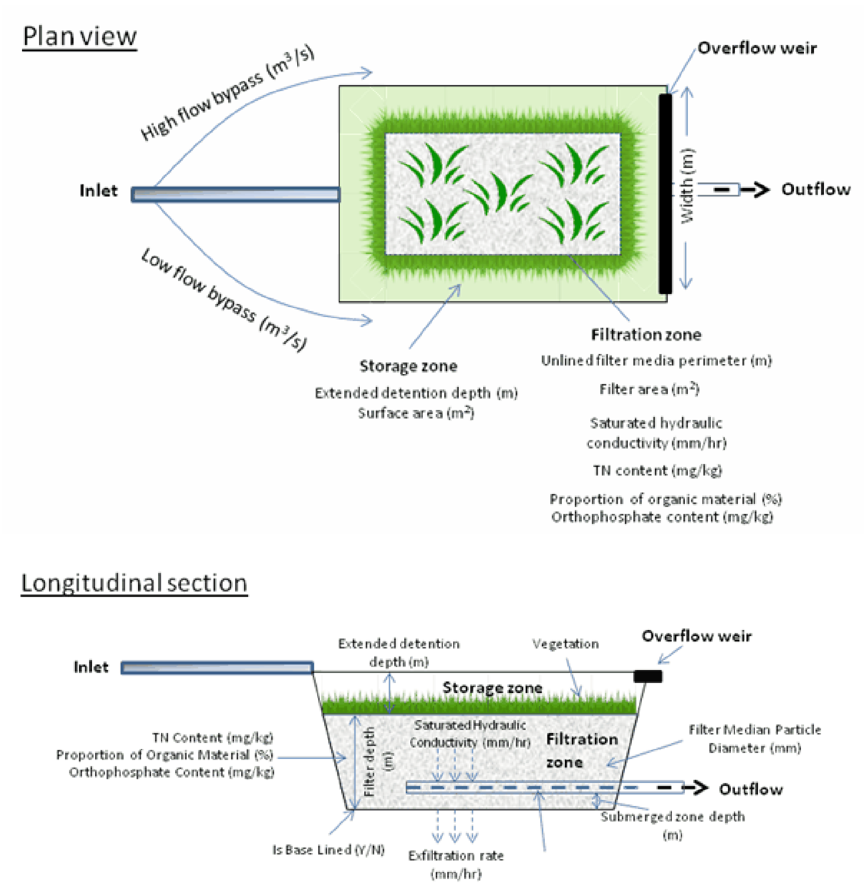


Figure 6-29 Conceptual View of Bioretention Measure

MUSIC versions beyond v4 include significant revisions to the bioretention node to reflect studies undertaken by the Facility for Advancing Water Biofiltration (FAWB). This has also resulted in significant changes to the parameters needed to model these measures in MUSIC. The key parameters which have changed are related to the filter media properties and any exfiltration. These parameters are summarised below:

- **Filter area (m2):** The filter area depends on the scenario and is set as the area of the bioretention filter media.
- **Unlined filter media perimeter (m):** The parameters for an unlined filter media perimeter depend on the scenario. Where an exfiltration rate of 0 mm/hr is used, set the unlined perimeter to 0.01 (nominally zero). If the unlined perimeter is not known, a useful general rule to use is four times the square root of the surface area.
- **Saturated hydraulic conductivity (mm/hr):** It is usually best to use a sandy loam as the filter media for bioretention measures, with an effective particle diameter of around 0.45 mm and a saturated hydraulic conductivity of 200 mm/hr. Given compaction and the accumulation of fine sediment particles in the filter media over time, the hydraulic conductivity value adopted for modelling should be set at 50% of the saturated hydraulic conductivity (that is 100 mm/hr instead of 200 mm/hr.
- **Filter depth (m2):** The recommended bioretention filter depth is 0.4 to 1.0 m. The depth will depend on the inlet and outlet levels and the species of plants being used. For particularly flat sites where street scale raingardens are to be provided, it may be possible to limit the filter depth to 0.3 m. For any filter media depth more than 0.8 m, the planting of deep-rooted plants such as trees is necessary. If a filter media depth of more than 0.8 m is proposed, obtain expert advice from a landscape architect or ecologist to provide adequate justification for plant selection. Do not model the depth of the intermediate transition layer or the drainage layer as part of the filter media depth.
- **TN content in the filter media (mg/kg):** Where the total nitrogen content in the filter media is unknown, use a value of 400 mg per kg. The total nitrogen content is the amount of nitrogen available within the filter media consistent with the FAWB (2009a) Guidelines.
- **Orthophosphate content of filter media (mg/kg):** Where the orthophosphate content of the filter media is unknown, use a value of 40 mg per kg. This is the amount of phosphorus available within the filter media defined by testing consistent with the FAWB (2009a) Guidelines.
- **Lining properties:** Is the base of the bioretention measure lined?: When demonstrating compliance with water quality objectives, it is necessary to tick “Yes” to indicate that the base is lined and then set the exfiltration rate (mm/hr) to zero.
- **Vegetation properties:** Plant types have a significant impact on reducing nutrient loads. Root morphology and associated physiochemical processes are key factors (Read et al., 2009). Bioretention measures perform best with deep-rooting plants and they should be modelled using

the option ‘Vegetated with Effective Nutrient Removal Plants’. If the vegetation in the bioretention measure is proposed to be turf, for example, use the ‘Vegetated with Ineffective Nutrient Removal Plants’ option.

- **Overflow weir width (m):** The length of the overflow weir controls the discharge rate when the water level in the bioretention measure exceeds the top of extended detention. An undersized overflow weir results in water backing up, effectively adding additional extended detention. For modelling purposes only, it is recommended that the overflow weir width (m) initially be set at the surface area (m2) divided by 10 m (with a minimum width of 10m).
- **Exfiltration rate (mm/hr):** If a bioretention measure is modelled with exfiltration, the pollutant loads in the water lost to exfiltration are included in the reduction of pollutant loads achieved across the treatment node (as shown by the mean annual loads and treatment train effectiveness statistics). Objectives for reducing stormwater pollutants relate to all runoff leaving the site, including that exfiltrating to groundwater. Where an exfiltration rate is set greater than 0 mm/hr, sum all losses at any node that has exfiltration (using the node water balance statistics option at each node) and add them to the total pollutant loads reported leaving the site when demonstrating compliance with stormwater pollutant reduction targets.

If exfiltration is modelled the rate must be justified through in-situ soil testing. The applicant must suitably demonstrate that in-situ soils will not be compacted during earthworks.

When a bioretention measure is constructed in highly permeable sandy or gravelly soils, lining of the sides of the bioretention filter media should be modelled. Lining is required to ensure that that stormwater is properly treated through the filter before it enters the receiving environment, i.e. exfiltration should only occur either at the level of the drainage layer or through the base of the bioretention measure and not by ‘short-circuiting’ through the sides of the filter.

Underdrain present?: Usually the ‘yes’ option as bioretention measures in are generally configured with collection pipes.

Submerged zone with carbon present?: If the measure is proposed to include a submerged (or saturated) zone this option should be ticked. Submerged zones improve the potential for denitrification in bioretention measures, and also provide moisture storage for plants, and are typically between 0.2 and 0.4 m. Where practical, a submerged zone should be included below the underdrain.

Key points – Bioretention Measures

- The high flow bypass shall be set at a flow rate that results in a maximum of 90% of the modelled flow volume passing through the measure. The flow rate at which this occurs can be established by modifying the inflows using a generic treatment node to establish the flow rate at which the 10% of flow bypasses. Spreadsheet analysis of the inflow time series can also establish this flow. The generic treatment node can then be replaced by a bioretention node with the assessed high flow bypass rate.

- The extended detention depth for areas outside lots and road reserves (e.g. open space areas) may be deeper than 0.30m, although this must be clearly demonstrated as being achievable, safe to the community and the vegetation appropriate for inundation at greater depths for prolonged periods.
- For raingardens or bioretention basins, the longitudinal gradient is likely to be close to 0% across the measure, whilst a bioretention swale may have a gradient typically up to 2% and consequently the storage depth along the swale will vary. This should be accounted for when estimating the extended detention depth.
- Bioretention swales should be limited to locations where a longitudinal gradient <4% is achievable.
- MUSIC currently assumes that the extended detention storage has vertical sides. If the proposed system does not have vertical sides the surface area needs to be determined. For a trapezoid-shaped extended detention storage, the surface area should be calculated at half of the maximum extended detention depth.
- The filter area should not be greater than 50% of the surface area unless specific calculations are provided to indicate otherwise.
- Bioretention system should be modelled in areas where the performance of the measure would be impeded by shallow rock or groundwater.
- Choosing plants for a bioretention system is critical to ensure best performance in terms of removing nutrients and maintaining saturated hydraulic conductivity. Effective nutrient removal plants include deep rooted indigenous species such as *Carex, Melaleuca, Juncus, Goodenia and Ficinia* (FAWB, 2009b). Where non-indigenous shallow rooted turf grass species form the biofilter vegetation these should be modelled as ineffective nutrient removal plants.
- The vertical structure of the bioretention media particularly the transition layer (consisting of medium to coarse sand) below the filter media is important to prevent filter media from washing into the drainage layer. The drainage layer conveys filtered water to and holds the perforated collection pipe, and typically consists of fine 5 mm gravel.
- For measures where the filtered flow is to be collected in a sub-soil drain near the base of the bioretention filter and directed to a constructed drainage system, the modeller should confirm that the sub-soil drain is not below the base of the stormwater pit that the subsoil drain would connect into.

- Where bioretention systems are located downstream of a large source area, pre-treatment, such as a buffer strip or gross pollutant trap, should be installed to reduce the risk of clogging filter media and to prolong the life of the system.
- Determine an appropriate soil media considering the Facility for Advancing Water Biofiltration (FAWB) “Stormwater Biofiltration Systems Adoption Guideline”.

7 Analyse Results

7.1 Pollutant Load Targets

For locations in NSW where load based targets have been established to assess the performance of a stormwater management strategy, the modeller simply needs to establish the Treatment Train Effectiveness from the developed (treated) scenario MUSIC model for all outlets from the area of interest (typically all are connected to a receiving node) and compare this effectiveness with the targets.

In situations where the base scenario is the pre-development scenario, the Treatment Train Effectiveness from developed (treated) scenario would be compared with that scenario to confirm that the loads would not increase above pre-development conditions.

7.2 Pollutant Concentration Targets

Where concentration based targets are required to be achieved, the modeller should ensure that flows of 0 m3/s are removed from the analysis. To accomplish this, the “flow based subsample threshold” within the assessment options should be used. The selection of this parameter can significantly affect the concentration results reported, however for consistency, the modeller should set the low flow threshold to 0 such that any results when no outflows are occurring are removed. The statistical analysis (mean, median, 10th and 90th percentiles) will then represent only those times when base flow or storm event flow occurs.

While no quantitative effort has yet been published on the uncertainty of MUSIC models, usually the uncertainty, variations and assumptions associated with the representation of a stormwater treatment series in MUSIC are significant, compared to that which is finally delivered on the ground. This means that a calculation of numerical uncertainty would have little value in expressing the true uncertainty of the ability of the model to represent that which is to finally occur. In presenting an assessment of the accuracy of the model if it did exactly represent the final adopted strategy, a value of 10% uncertainty in the model outputs was suggested as being reasonable when preparing stormwater treatment curves used in Fletcher et al 2004.

7.3 Stream Erosion Index

The Stream Erosion Index (SEI) is a stormwater flow target adopted by a number of authorities in NSW. The SEI aims to assist with protecting streams from increased erosion potential resulting from urban development. The SEI is the ratio of the developed catchment stormwater volume exceeding the ‘stream forming flow’ to the pre-development catchment stormwater volume exceeding the ‘stream forming flow’.

The stream forming flow (or critical flow) is typically taken as a proportion of the 2 year ARI pre-development flow. It varies between streams primarily based on the stream bed/bank soils and underlying geology. Increased frequency and duration of elevated flows as a result of increased catchment imperviousness can more rapidly erode sediment at the bank toe, destabilising the bed and banks, and ultimately leading to increased stream erosion.

Ideally stream forming flows should be assessed considering the stream hydraulics to enable estimates of stream power to be completed. Whilst this is ideal, physical surveying of the stream to determine cross-sections and bed slope characteristics would be required and this data is often unavailable when assessments are completed. To overcome the lack of physical data, the SEI was derived to focus on the hydrologic inputs to the stream as a measure of stream erosion potential.

MUSIC can be used to estimate the SEI for a particular development. There are five steps in estimating the SEI:

(1) Confirm the relevant critical flow for the receiving watercourse.

(2) Analyse data from a representative stream flow gauge site to confirm calibration targets.

(3) Prepare a calibrated pre-development MUSIC model.

(4) Prepare developed and develop (treated) MUSIC models.

(5) Calculate the SEI and compare with targets.

A suggested approach for estimating the SEI for a particular area of interest/development site is summarised below.

7.3.1 Confirm Critical Flow

The weakest soil type at or near the toe of the stream bank is often critical in controlling the degree and rate of channel expansion. Bedrock controlled, clay-lined streams are typically more stable and such streams typically expand to a lesser degree than more erodible sand-lined streams (EarthTech, 2005).

The critical flow for a waterway is defined as the flow threshold below which minimal erosion is expected to occur within the waterway. This has been estimated as a percentage of the pre-development 2 year ARI flow (EarthTech, 2005).

Examples of stream forming flows relevant to streams in coastal NSW catchments with different dominant bed and bank soils are summarised in Table 7-1. Appropriate targets for particular streams should be confirmed by a field inspection and/or soil sampling of bed and bank materials.

Table 7-1 Example Critical Flows (adapted from EarthTech, 2005)

Stream Bed and Bank Soil Type	Critical Flow
Sands	10% of 2 year ARI pre-development flow
Silts	10% of 2 year ARI pre-development flow
Silty clays	25% of 2 year ARI pre-development flow
Medium-heavy clays	50% of 2 year ARI pre-development flow

7.3.2 Analyse Reference Stream Gauge Data

An initial step is to confirm a suitable continuously recording stream gauge to calibrate MUSIC rainfall-runoff parameters to. Stream flow data also assists with determining appropriate routing parameters for the links. This reference stream gauge ideally will have similar catchment area, terrain, soils and rainfall distribution to the catchment the area of interest is located within. The catchment should also have minimal urban development and impervious areas.

The flow record should be sourced for the stream gauge and the data reviewed to confirm that the flow data quality is suitable for further analysis. Typically the data should be extracted at a small time step (ideally 6 minute) to assist with identifying peak discharges. Following confirmation of the data quality, the following analysis should be completed:

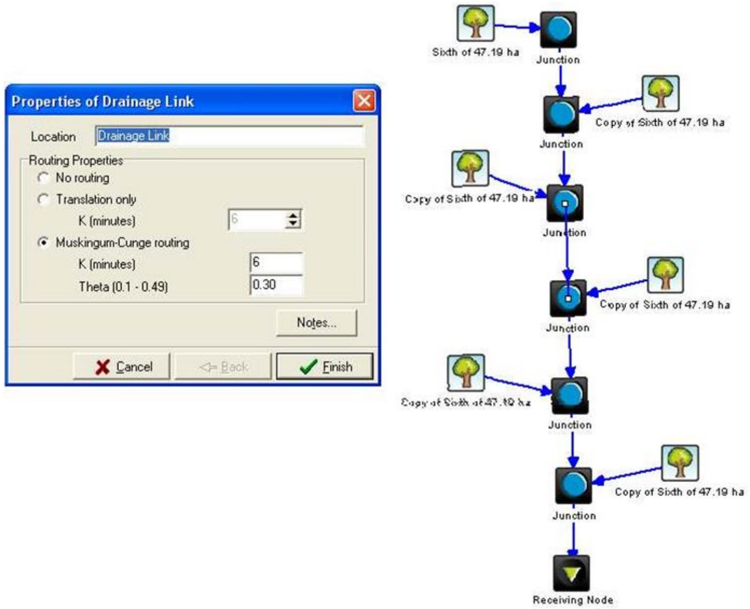
- Annual or partial flood frequency analysis (depending on the length of the flow record) to estimate the 2 year ARI flow; and
- Estimate the percentage of long-term flow volume that exceeds the 2 year ARI flow.

The result of this analysis forms the basis for calibration of the pre-development MUSIC model.

7.3.3 Calibrate Pre-Development Model

A calibrated MUSIC model based on the reference stream gauge site should be developed by an experienced MUSIC modeller in accordance with the approach outlined in Section 5.2.2.2.

The calibrated rainfall-runoff model parameters form the basis for developing a pre-development model for the site. The area of interest should be divided into a series of sub-catchments joined by links (refer Table 7-1). Flow routing should be applied to the links to simulate the relative timing of the contributions of each sub-catchment within the area of interest.



Properties of Drainage Link

Location: Drainage Link

Routing Properties
- ○ No routing
- ○ Translation only
  - K (minutes): 6
- ● Muskingum-Cunge routing
  - K (minutes): 6
  - Theta (0.1 - 0.49): 0.30

Figure 7-1 Pre-development Model Routing

The model should then be run and flows output at 6-minute intervals from the receiving node. Flood frequency analysis can be performed based on these flow outputs to confirm the 2 year ARI pre-development flow for the area of interest. An estimate of the 2 year ARI pre-development flow should be completed using alternative flow estimation methods (e.g. event based hydrologic model and/or probabilistic rational method) and the MUSIC estimated flow compared with these values. Where the MUSIC estimated peak discharge differs significantly to the other modelled values, the link routing and/or sub-catchment distribution should be adjusted and the 2 year ARI discharge re-evaluated until the estimated discharges are similar.

The percentage of flow volume exceeding the MUSIC estimated 2 year ARI flow should then be determined using the Generic Treatment Node. This percentage can be checked against the estimates from the analysis of the reference stream gauge to confirm that the modelled percentage is similar to that observed.

7.3.4 Prepare Developed (Treated) Model

The calibrated pre-development model is then modified to incorporate modified source nodes to reflect the developed conditions of the area of interest. The developed model is run and flows output from the receiving node. Flood frequency analysis should then be performed to confirm the 2 year ARI developed flow for the area of interest. An estimate of the 2 year ARI developed flow should be completed using alternative flow estimation methods (e.g. event based hydrologic model and/or probabilistic rational method) and the MUSIC estimated flow compared with these values. Where the MUSIC estimated peak discharge differs significantly to the other modelled values, the link routing and/or sub-catchment distribution should be adjusted and the 2 year ARI developed discharge re-evaluated until the estimated discharges are similar.

The developed model can then be modified to incorporate treatment measures. The modelled flows for the pre-development and developed (treated) models can then be compared to calculate the SEI in accordance with Section 7.3.5.

7.3.5 Calculate SEI

One approach to calculating the SEI is outlined below.

Initially, position a Generic Treatment Node between the last Source Node and Receiving Node in the pre-development model. Similarly, position a Generic Treatment Node in the developed (treated) model between the last measure in the treatment series and the Receiving Node (refer Figure 7-2).

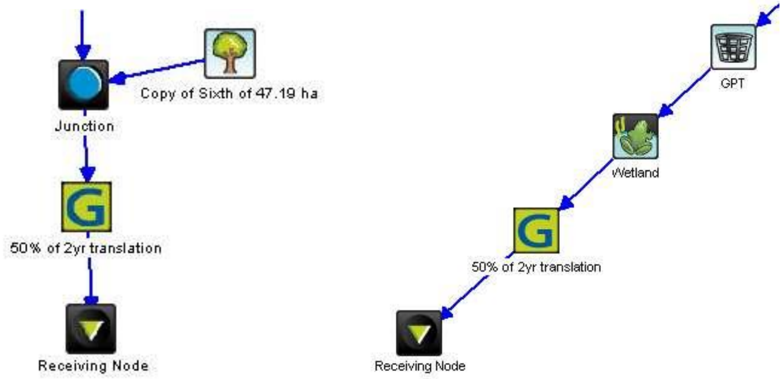


Figure 7-2 Generic Treatment Node – Pre-development (LHS) and Developed (RHS)

Configure the Generic Treatment Node to transform modelled flows below the critical flow to zero, i.e.:

$$Q_{out} = 0 \quad \text{if} \quad Q_{in} < Q_2.x\%$$

$$Q_{out} = Q_{in} - \frac{Q_2}{x\%} \text{if} \quad Q_{in} = Q_{in} > Q_2.x\%$$

Where x% is the percentage of the 2 year ARI peak flow that equates to critical flow.

The Generic Treatment Node should be configured the same for the pre-development and developed (treated) models. The flows transformed to zero represent the flows that are considered to have low stream erosion potential.

The models can then be run and the mean annual flow volume exceeding the critical flow determined from the mean annual flow statistics results at the Receiving Node for the pre-development and developed (treated) models.

The SEI is calculated by dividing the sum of the transformed mean annual flow volumes for the developed (treated) scenario by the equivalent flow volume sum for the pre-development condition.

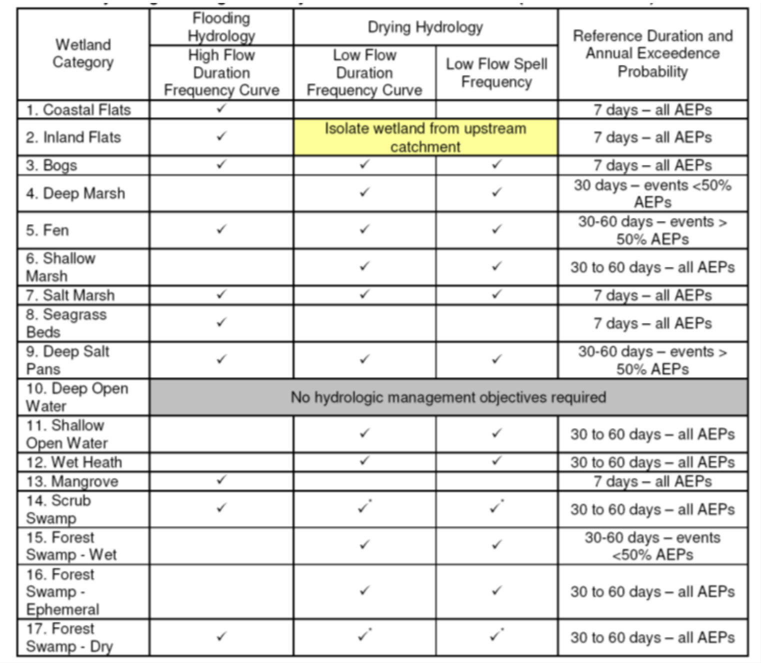
$$SEI = \frac{\sum(Q_{post} - Q_2.x\%)}{\sum(Q_{pre} - Q_2.x\%)}$$

The calculated SEI can then be checked against the targets.

7.4 Wetland Flow Regimes

A study completed in the Hunter and Central Coast Region of NSW (HCCREMS 2007) identified wetland types and proposed hydrologic management objectives for each (see Table 7-1).

Table 7-2 Wetland Hydrologic Management Objectives (HCCREMS, 2007)



Wetland Category	Flooding Hydrology	Drying Hydrology		Reference Duration and Annual Exceedence Probability
	High Flow Duration Frequency Curve	Low Flow Duration Frequency Curve	Low Flow Spell Frequency	
1. Coastal Flats	✓			7 days – all AEPs
2. Inland Flats	✓	Isolate wetland from upstream catchment		7 days – all AEPs
3. Bogs	✓	✓	✓	7 days – all AEPs
4. Deep Marsh		✓	✓	30 days – events <50% AEPs
5. Fen	✓	✓	✓	30-60 days – events > 50% AEPs
6. Shallow Marsh		✓	✓	30 to 60 days – all AEPs
7. Salt Marsh	✓	✓	✓	7 days – all AEPs
8. Seagrass Beds	✓			7 days – all AEPs
9. Deep Salt Pans	✓	✓	✓	30-60 days – events > 50% AEPs
10. Deep Open Water	No hydrologic management objectives required			
11. Shallow Open Water		✓	✓	30 to 60 days – all AEPs
12. Wet Heath		✓	✓	30 to 60 days – all AEPs
13. Mangrove	✓			7 days – all AEPs
14. Scrub Swamp	✓	✓	✓	30 to 60 days – all AEPs
15. Forest Swamp - Wet		✓	✓	30-60 days – events <50% AEPs
16. Forest Swamp - Ephemeral		✓	✓	30 to 60 days – all AEPs
17. Forest Swamp - Dry	✓	✓	✓	30 to 60 days – all AEPs

Whilst generally specific to that region, these objectives provide an indication of the hydrologic requirements of similar wetlands in NSW.

For brackish/freshwater coastal wetlands in NSW that are most susceptible to impacts from increased catchment runoff (e.g. deep marsh, shallow marsh, wet heath, scrub swamp, forest swamp), the following targets are often applied to this range of wetlands:

- Preserve the targeted 30 day low flow duration frequency curve for the dry season (period where PET exceeds rainfall)
- Preserve the targeted 30 day high flow duration frequency curve (entire year)
- Preserve the targeted low flow spells frequency curve for the dry season.

Inland and elevated freshwater wetlands typically have key targets to protect these wetlands from shorter duration flows. Although, many of these wetlands are also isolated from the impacts of urban runoff. Typical targets for these types of wetlands include:

- Preserve the targeted 7 day low flow duration frequency curve for the dry season (period where PET exceeds rainfall)
- Preserve the targeted 7 day high flow duration frequency curve (entire year)
- Preserve the targeted low flow spells frequency curve for the dry season.

Avoiding the discharge of catchment runoff into wetland categories not typically exposed to concentrated freshwater flows is often a preferable outcome (e.g. salt marsh, seagrass beds, mangroves, coastal flats).

The modelling approach for evaluating hydrologic regimes typically comprises:

- Identify a suitable representative rainfall data period (ideally more than 20 years of six minute timestep rainfall data. Daily data may also be sufficient for hydrologic modelling only (not for runoff quality modelling) depending on the types of treatment measures proposed.
- Prepare a calibrated pre-development (or other targeted condition) MUSIC model.
- Prepare developed and developed (treated) MUSIC models.
- Calculate moving average daily flow totals from the model output in a spreadsheet (e.g. 7 day, 30 day, 60 day averages).
- Complete annual series flood frequency analysis on the moving average totals.
- Calculate low flow spells from the flow output.
- Plot resulting curves and compare with targeted conditions.

Examples of the hydrologic curves showing minimum (low flow) and maximum (high flow) 30 day flow duration curves, and low flow spells analysis outcomes are shown in Figure 7-3, Figure 7-4 and Figure 7-5 respectively.

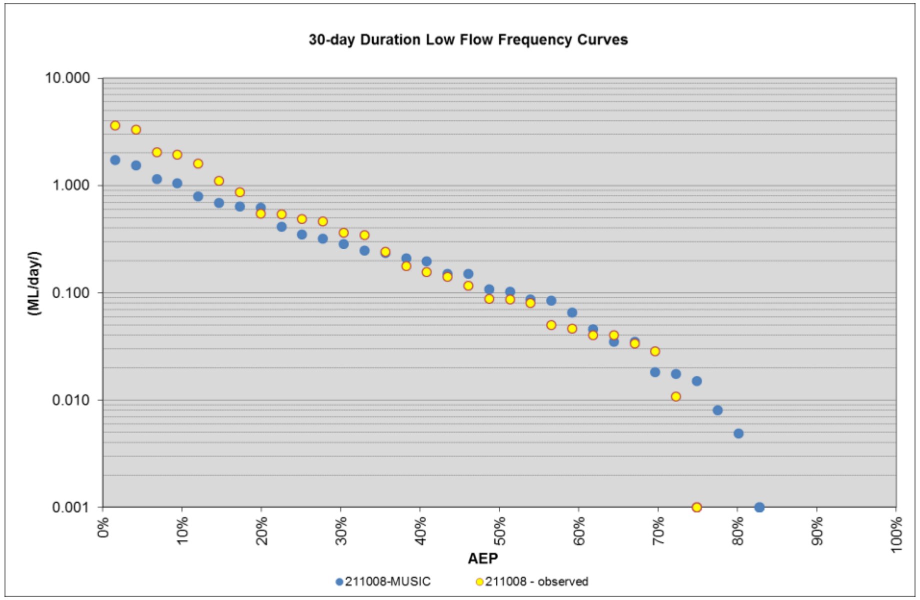


Figure 7-3 Example 30-day Low Flow Frequency Curves

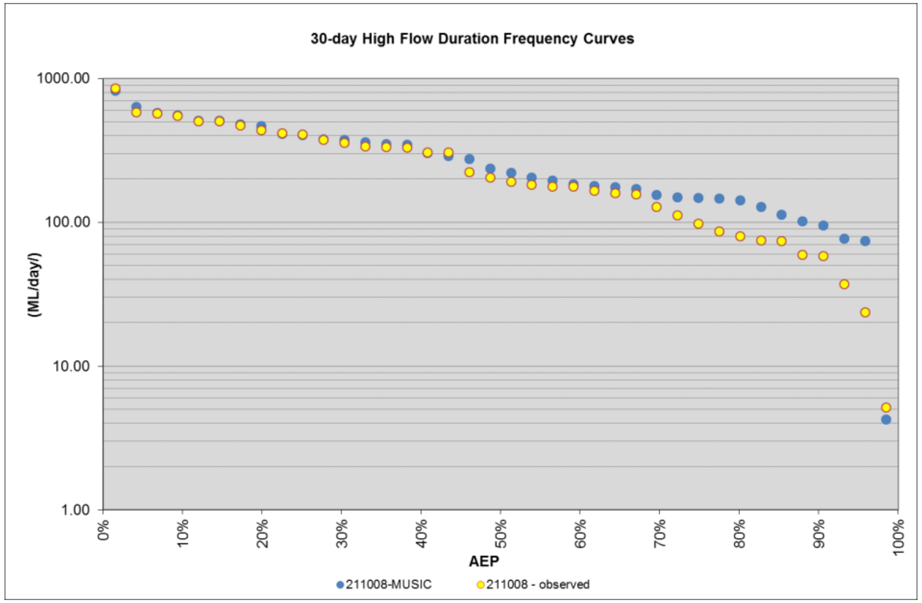


Figure 7-4 Example 30-day High Flow Frequency Curves

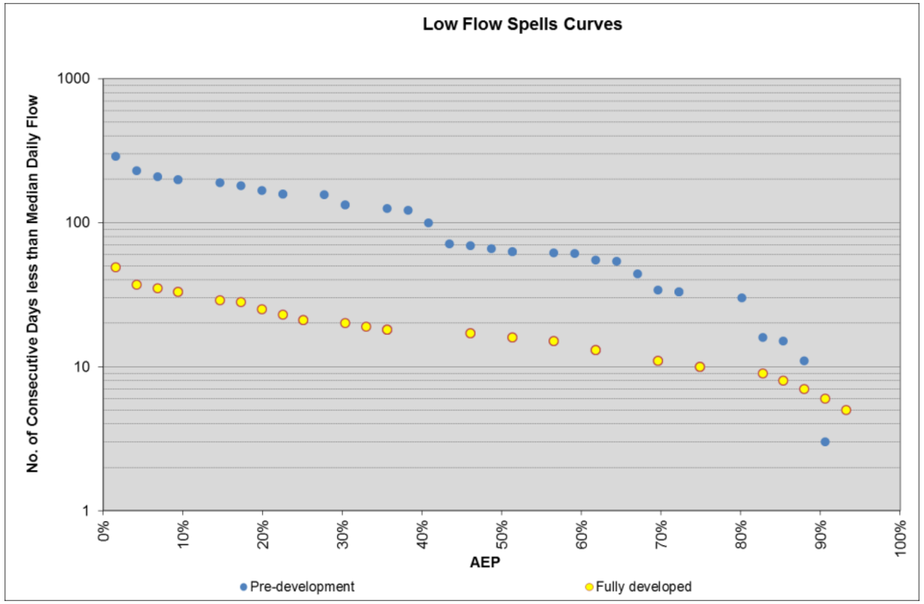


Figure 7-5 Example Low Flow Spells Curves

Further guidance on this is provided in the assessment of hydrologic objectives (HCCREMS 2007) and the modeller is referred to those documents on developing suitable strategies and modelling them within MUSIC where wetland hydrologic objectives are to be achieved.

7.5 Lifecycle Costs

Where MUSIC modelling is being completed to support a development application or for future catchment planning, life cycle cost analysis should be completed. The overall life cycle costs for all elements in the treatment train and split these into Total Acquisition, Typical Annual Maintenance and Renewal/Adaptation Costs. In the majority of cases, a specific decommissioning cost should not be included and this should be set to the same value as the Typical Annual Maintenance cost.

The user should treat the current life cycle costs as indicative only as the data used to develop the algorithms for this module are now dated. The modeller should source current costs where available to ensure that estimates are realistic. Whilst the current costs in MUSIC are indicative, they may be of assistance for broad planning of maintenance resources and expenditure for future contributed assets.

8 Reporting

In order to provide a degree of confidence that the proposed MUSIC modelling suitably reflects that which is to be implemented within an area of interest / development site, the modeller shall prepare a report outlining the modelling undertaken and provide justification for any assumptions made.

The MUSIC modelling report typically forms one component of a stormwater management plan, water cycle management plan, integrated water cycle management plan or similar report. These guidelines outline specific considerations for inclusion in the MUSIC modelling section of a report that addresses stormwater quality and quantity objectives and targets. Additional guidelines should be sourced when reporting on the following water management elements not addressed by MUSIC modelling:

- Flood management
- Stormwater drainage
- Stormwater detention
- Sewage management
- Potable water conservation.

The MUSIC modelling report should consider and address the following information and issues.

8.1 Site Description

A general outline of the existing site/catchment conditions and future development/catchment conditions should be provided. This description should include details such as:

- Property details including locality, lot, deposited plan number and area
- General description of the existing development and site configuration
- General description of the final form of future development (e.g. changed land uses, lots, roads, footways, carparking, landscaping, parks, cycleways etc.).

This section should ideally include scaled plan figures outlining the existing and future condition of the site/catchment.

Where figures are not included outlining a proposed development, reference to a specific plan drawing (including drawing reference number, date, issue version etc.) included as a component of rezoning/subdivision/development application should be provided. This is to ensure that the MUSIC modelling is based upon the latest version of a proposed development.

8.2 Principles, Objectives and Targets

The report shall summarise the relevant water management principles, objectives and targets identified during the data gathering phase.

The report shall summarise how the qualitative principles and objectives are addressed by the proposed stormwater management measures. This section should also provide a statement confirming that the proposed stormwater management measures would achieve the quantitative targets relevant to the site.

8.3 Site Analysis

The report shall provide a summary of the physical site characteristics that influence the feasibility and effectiveness of stormwater treatment measures. The purpose of this section is to ensure that modelled stormwater treatment measures are compatible with the site constraints and opportunities.

Common physical site characteristics that influence the selection of stormwater treatment measures include:

- Flooding – flood extents and characteristics for major flooding events should be identified to ensure stormwater treatment measures are positioned outside of significant flow paths;
- Terrain – location of steep/flat areas unsuitable for particular measures and any proposed site regrading areas;
- Drainage – existing drainage infrastructure including the influence of constructed roads, swales and drainage systems on natural flow paths;
- Water quality – availability of runoff or receiving environment water quality data;
- Soils, groundwater and geology – soil types/landscapes, salinity, depth to groundwater and bedrock, groundwater flow direction;
- Riparian corridors and sensitive water bodies – location and extent of riparian corridors and defined boundaries for sensitive water bodies;
- Aquatic and terrestrial ecology – location of sensitive aquatic and terrestrial habitats and their sensitivity to hydrologic/water quality changes;
- Existing services and infrastructure – location and depth of telecommunications, water supply, sewerage, electricity, gas, oil etc; and
- Receiving environments – initial environment that accepts stormwater from the site.

Depending on the scale of the site being considered, other urban design criteria (e.g. landscaping, visual, bushfire, heritage, archaeology, acoustics, transport etc.) may also require consideration.

The site analysis should confirm the potential risks to the receiving environments if mitigations measures are not provided. Any review of background reports/data and additional site investigations undertaken to inform the site analysis shall be referenced and described in this section.

The site analysis should also include consideration of the future development and identify how the future development would impact on the existing physical site characteristics. Potential adverse impacts should be mitigated by the stormwater management strategy.

8.4 Stormwater Management Strategy

The site analysis outlines the opportunities and constraints that apply to the selection of stormwater treatment measures for the site. Prior to undertaking MUSIC modelling, it is important that an appropriate treatment series is identified for the site based on the opportunities and constraints.

This section of the report forms the link between the site analysis and MUSIC modelling for the developed scenario. It should outline the rationale and justification behind the treatment series selected for modelling. This section will effective justify that the modelled treatment measures are effective and feasible for the site. Key considerations are outlined below.

The proposed treatment measures will have a sufficient life span and will not present an inordinate maintenance burden to those responsible for on-going management.

The proposed treatment measures can be practically implemented within the development and locations maximise the area of impervious surface receiving treatment. It shall be demonstrated that there is adequate land allocated to construct the stormwater treatment measures including consideration of the site analysis outcomes (particularly terrain and riparian corridors).

It is important to note that the NSW Office of Water currently does not permit the construction of stormwater quality management measures along watercourses. It is therefore important that the stormwater management strategy and associated MUSIC modelling demonstrates how stormwater quality would be treated appropriately before it discharges into a riparian corridor.

8.5 MUSIC Modelling Summary

The report shall summarise the following:

- Input data sources;
- Meteorological template data adopted and analysis completed to select appropriate data;
- Description of the base scenario model development;
- Description of the developed and developed (treated) models;
- MUSIC modelling results;
- Lifecycle cost analysis; and
- Analysis of the MUSIC modelling results against the targets.

8.5.1 Input Data Sources

The report shall confirm the sources of input data. This section of the report should also outline any limitations of the sourced data. Analysis of the input data should be included within the relevant sections of the report.

8.5.2 Meteorological Data

The report should outline details of the adopted rainfall and potential evapotranspiration data for the site and summarise the analysis and checks completed by the modeller to confirm that the data is appropriate for the site.

8.5.3 Base Scenario Model

The report shall confirm the base scenario selected (pre-development or other historical developed condition).

The report shall confirm the sub-catchments defined taking into close consideration how the site drains. A particularly important consideration will be how pre-development or developed infrastructure impacts on natural flow paths. The sub-catchments adopted shall be shown on a scaled drawing of the site. The sub-catchments defined shall include external areas where these areas drain through the site.

The report shall confirm the land uses / surface types and associated rainfall-runoff and stormwater quality concentration parameters adopted for each source node representing each sub-catchment. The extents of each land use / surface type shall be clearly defined on the sub-catchment plan.

The report shall confirm the imperviousness adopted for each node. The report shall confirm any assumptions adopted in estimating the imperviousness.

The modelled sub-catchment areas, land uses and imperviousness shall be summarised in a table format in addition to the sub-catchment extents and land uses being defined on a plan. The plan shall also clearly identify the location of the site outlet/s where base scenario model results were compared with the post development model results.

8.5.4 Developed (treated) Model

The report shall confirm if there are any variations to the base scenario model sub-catchment extents due to site drainage modifications associated with the developed site configuration (including how constructed treatment measures may modify base scenario sub-catchments).

The modeller shall confirm that the total developed (treated) scenario modelled catchment area is equivalent to the base scenario modelled area.

The location and total footprint of the modelled measures shall be shown on a developed (treated) sub-catchment plan.

The report shall confirm any variation to the rainfall-runoff or stormwater quality concentration parameters adopted for each source node representing each sub-catchment. The extents of each land use / surface type shall be clearly defined on the sub-catchment plan (where these vary from the base scenario).

The report shall outline any changes to the imperviousness for each node. The report shall confirm any assumptions adopted in estimating the imperviousness.

The report should identify the proposed stormwater management measures that are appropriate for the site based on the site analysis outcomes, and the scale and nature of the development. It should also identify the location of these measures to ensure that the maximum volume of stormwater from the site is treated.

Appropriate treatment nodes for proposed stormwater management structures must be used for the developed (treated) scenario. The model must use design parameters for treatment nodes based on appropriate hydraulic sizing and treatment effectiveness.

The report shall detail the specific design elements of the proposed stormwater management measures, including the hydraulic basis for their sizing based on the size of the contributing catchment area and proposed land uses.

The report shall consider whether the proposed treatment measures can be practically implemented at the proposed location in the development site. It should also be demonstrated that there is adequate space to construct the treatment measures, and that they are appropriately located in the development so they will capture runoff from the modelled sub-catchment areas.

The treatment measures should not adversely impact upon, or be impacted on, by the operation of the site. The operation of the site must not affect the ability to maintain the treatment measures. Proposed street scale measures must be practical and acceptable considering use of the road reserve for other utility services.

The report shall confirm the design parameters adopted for modelling to ensure the proposed treatment measures are hydraulically sound with regard to size and function. It should indicate how design event/s will be conveyed through (or ideally bypass) the treatment measures where they are in the overall drainage network and confirm their detention times are appropriate for the performance required.

8.5.5 Lifecycle Cost Analysis

The report shall include a section on lifecycle cost analysis, where Councils require such cost-benefit analysis of stormwater management works that are to be dedicated to Council. In such a case the study should include the overall life cycle costs for all elements in the treatment series split into total acquisition, typical annual maintenance and renewal/adaptation costs. In most cases, a decommissioning cost should not be included and this should be set to the same value as the typical annual maintenance cost.

8.6 Analysis

A comparison of the base scenario and post development scenario results shall be provided demonstrating that the targets relevant to the site have been achieved.

Relevant graphs and tables shall be provided to demonstrate that targets have been achieved.

8.7 Other

The study must incorporate an overall conclusion that includes a specific conclusion about the nature, extent and duration of any stormwater quality and quantity impacts on any receiving waters and also a specific conclusion about the sustainable achievement of the targets at all stages of the proposed development.

The report needs to include a statement of all assumptions that have been adopted in the MUSIC model and the implications for achieving the targets. This may include notional dwelling sizes, imperviousness, water demands etc.

The report should clearly specify and justify any variations to the recommended parameters in these guidelines. A clear and strong justification shall be provided for the selection of different values.

It should identify the life span, ongoing management, maintenance and other cost requirements of proposed treatment measures to ensure that they will not be an inordinate and unrealistic maintenance burden on those responsible for on-going management.

Identify key assumptions relating to land use change such as the retention of existing native vegetation and regrowth, or the retention of existing erosion control works structures on site for ongoing water quality management.

An electronic copy of the MUSIC model shall be provided to the consent authority for assessment.

It must include or have attached a stormwater drainage plan that shows the location, size and nature of each stormwater treatment measure including a section view or relative levels (RLs). The drainage plan must reflect MUSIC model requirements and management measures.

It should also include a detailed list of all references used.

9 Glossary

BASIX BASIX or the Building Sustainability Index is a NSW Government online program that ensures new homes are designed to be water and energy efficient.

Biodiversity The variety of life forms, plants, animals and micro-organisms in a particular habitat or ecosystem including variation in their genetic makeup. Biodiversity is a measure of the health of an ecosystem.

Catchment A hydrological catchment or area of land where surface waters drain by a network of drainage lines and streams to a single outlet.

Sub-catchment A smaller component of a larger catchment where surface water drains to a single outlet.

Consent Authority A consent authority is the body responsible for approving (or otherwise) of all development applications that need to be submitted under the *Environmental Planning and Assessment Act 1979*. It is Council for most developments, but Regional Planning Panels, the Planning Assessment Commission and the Planning Minister are responsible for regionally significant and major infrastructure projects.

Denitrification The reduction of simple inorganic nitrogen compounds such as nitrates (NO3-) by heterotrophic denitrifying soil bacteria to gaseous nitrogen forms such as N2, which is returned to the atmosphere. Denitrification occurs in low oxygen or anoxic environments.

Development Development is the use or subdivision of land, erection of a building, work, including demolishing a building, and other matters controlled by an environmental planning instrument (see Part 5 S110 of the *Environmental Planning and Assessment Act 1979*).

Development Application An application for consent under Part 4 of the *Environmental Planning and Assessment Act 1979* to carry out development.

EP&A Act The *Environmental Planning and Assessment Act 1979* provides the planning framework for NSW. It covers environmental planning instruments including state environmental planning policies, local environmental plans, development control plans, assessment of major infrastructure and other projects by the Planning and Assessment Commission. It includes environmental assessment procedures for Part 4 developments that require consent, environmental assessment procedures for Part 5 developments and activities such as infrastructure by public authorities, and some activities, such as mining exploration, that do not require development consent.

Groundwater Water occurring in saturated layers of soil, sediment or porous rock below the land surface as aquifers. Aquifers in geological formations are permeable enough to allow water to move into them and enable discharge or extraction.

Gully Erosion Gully erosion is a highly visible form of soil erosion along drainage lines that is often associated with substantial soil and sediment loss, which can affect productivity and restrict land use. Gullies are relatively steep-sided eroded watercourses that experience ephemeral flows during heavy or extended rainfall. All gullies are considered to be watercourses.

MUSIC Model for Urban Stormwater Improvement Conceptualisation is a stormwater quality modelling tool that estimates stormwater flows and pollutant generation and the performance of stormwater treatments from proposed land development.

Nutrients Substances such as phosphorus and nitrogen that are essential for life, but which under excessive concentrations and loads may over-stimulate the growth of plants, algae and cyanobacteria (blue-green algae).

Pathogen A biological agent or organism such as a virus, bacterium, protozoan or other microorganism that causes disease or illness to its host.

Permeability The characteristic of a soil texture, structure and particle size that governs the rate at which water moves through it.

Riparian Zone Any land and associated vegetation immediately adjoining a creek or river, and areas around lakes and wetlands. Riparian also refers to anything connected with or immediately adjacent to the banks of a stream such as riparian access.

Rural Residential Development A subdivision and development of larger rural and agricultural land holdings into smaller lots for rural residential use.

Site The area of land on which a development is proposed to be carried out, which may include the whole or part of a lot, or lots.

Soil Depth The vertical depth of soil from the soil surface to parent rock material. This does not include the C horizon consisting of weathered rock.

SEPP A State Environmental Planning Policy is a legal planning instrument under the *Environmental Planning and Assessment Act 1979* that deals with environmental planning matters of particular importance, which may involve several local authorities.

Suspended Solids Means fine clay or silt particles suspended in the water as a result of the motion of water or as colloids, resulting in turbidity.

Waterbody A natural or artificial body of water, whether perennial or intermittent, fresh, brackish or saline, including a lake, wetland, river, stream, constructed waterway, canal, dam, lake or artificial wetland, but does not include a dry detention basin or other stormwater management structure that is only intended to hold water intermittently.

Watercourse Means any river, creek, stream, chain of ponds or gully, whether artificially modified or not, in which water usually flows, either continuously or intermittently, in a defined bed or channel.

Water Cycle Management Study A study that addresses the management of stormwater, wastewater, site and development specific pollutants or contaminants, and erosion and sediment control for a specific development proposal.

Wetland An area of land where soil is inundated or saturated with salt, fresh, or brackish water, either permanently, seasonally or periodically, and which is characterised by specialised vegetation and animal communities. A wetland is typically natural but may also be artificial.

10 References

Alison, R. A., Walker, T. A., Chiew, F. H. S., O'Neill, I. C. and McMahon, T. A. (1998), "From Roads to Rivers – Gross Pollutant Removal from Waterways", Technical report 98/6, Cooperative Research Centre for Catchment Hydrology, Melbourne, Victoria, 1998.

Blackham, D. And Wettenhall, G. (2010). Review of the stream erosion index for NSW. Report P109081_R01V03 by Alluvium and DesignFlow for Sydney Metropolitan Catchment Management Authority

BMT WBM (2007) "Rainfall Runoff Modelling Project", Prepared for NSW Department of Environment and Climate Change, BMT WBM Water and Environment - Newcastle, June 2007

BMT WBM (2008) "Reasonable Performance Levels for WSUD (working draft)", Prepared for NSW Department of Environment and Climate Change, BMT WBM Water and Environment - Newcastle, May 2008

Facility for Advancing Water Biofiltration, "Guidelines for Soil Filter Media in Bioretention Systems (Version 2.01), Facility for Advancing Water Biofiltration, Monash University, Melbourne, March 2008

Fletcher T, Duncan H, Poelsma P, Lloyd S, "Stormwater Flow and Quality and the Effectiveness of Non-Proprietary Stormwater Treatment Measures – A Review and Gap Analysis", CRC for Catchment Hydrology Technical Report 04/8, CRC for Catchment Hydrology, Monash University, Melbourne, December 2004.

Hunter and Central Coast Regional Environmental Management Strategy (2007), "Water Sensitive Urban Design Solutions for Catchments above Wetlands – Overview Report", May 2007.

Landcom, "The Blue Book – Soils and Construction, Volume 1, 4th Edition", Landcom, Sydney, 2006.

Macleod, A (2008) "MUSIC calibration based on soil conditions", in proceedings of Stormwater 2008, Stormwater Industry Assocation Regional Conference, Gold Coast, 2008.

Morse McVey and Associates (2006), "MUSIC Calibration Details for Soil Landscape Facets" Prepared for Sydney Catchment Authority.

Moreton Bay and Waterways Catchments Partnership, "Water Sensitive Urban Design Technical Design Guidelines for South East Queensland", Version 1, Moreton Bay and Waterways Catchments Partnership, Brisbane 2006.

MUSIC Version 3.01 User Guide, CRC for Catchment Hydrology, Monash University, Australia, 2005.

National Committee for Water Engineering, "Australian Runoff Quality – A National Guide to Water Sensitive Urban Design", Institute of Engineers Australia, Australia, 2005.

National Committee for Water Engineering, “Australian Rainfall and Runoff – A Guide to Flood Estimation”, Institute of Engineers Australia, Australia, 1999.

Sydney Catchment Authority (SCA) 2012, “Using MUSIC in Sydney’s Drinking Water Catchment, SCA, December 2012.

Wyong Shire Council 2008, “Draft DCP Chapter 97 – WSUD Technical Guideline No 1 – Appendix A Hydrologic Objectives”, prepared by EDAW for Wyong Shire Council, April 2008.

Wyong Shire Council 2008 (2), “Draft DCP Chapter 97 – WSUD Technical Guideline No 4 – Concept Design Tools, prepared by EDAW for Wyong Shire Council, April 2008

BMT WBM
Bangalow
6/20 Byron Street, Bangalow 2479
Tel +61 2 6687 0466 Fax +61 2 66870422
Email bmtwbm@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM
Brisbane
Level 8, 200 Creek Street, Brisbane 4000
PO Box 203, Spring Hill QLD 4004
Tel +61 7 3831 6744 Fax +61 7 3832 3627
Email bmtwbm@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM
Denver
8200 S. Akron Street, #B120
Centennial, Denver Colorado 80112 USA
Tel +1 303 792 9814 Fax +1 303 792 9742
Email denver@bmtwbm.com
Web www.bmtwbm.com

BMT WBM
London
International House, 1st Floor
St Katharine's Way, London E1W 1AY
Email london@bmtwbm.co.uk
Web www.bmtwbm.com

BMT WBM
Mackay
PO Box 4447, Mackay QLD 4740
Tel +61 7 4953 5144 Fax +61 7 4953 5132
Email mackay@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM
Melbourne
Level 5, 99 King Street, Melbourne 3000
PO Box 604, Collins Street West VIC 8007
Tel +61 3 8620 6100 Fax +61 3 8620 6105
Email melbourne@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM
Newcastle
126 Belford Street, Broadmeadow 2292
PO Box 266, Broadmeadow NSW 2292
Tel +61 2 4940 8882 Fax +61 2 4940 8887
Email newcastle@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM
Perth
Level 3, 20 Parkland Road, Osborne, WA 6017
PO Box 1027, Innaloo WA 6918
Tel +61 8 9328 2029 Fax +61 8 9486 7588
Email perth@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM
Sydney
Level 1, 256-258 Norton Street, Leichhardt 2040
PO Box 194, Leichhardt NSW 2040
Tel +61 2 8987 2900 Fax +61 2 8987 2999
Email sydney@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM
Vancouver
Suite 401, 611 Alexander Street
Vancouver British Columbia V6A 1E1 Canada
Tel +1 604 683 5777 Fax +1 604 608 3232
Email vancouver@bmtwbm.com
Web www.bmtwbm.com