THE BENEFITS OF CONTINOUS SIMULATION STORMWATER QUALITY MODELLING IN CHRISTCHURCH

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ABSTRACT

Continuous simulation water quality modelling uses long term continuous rainfall records and evapotranspiration input data to model runoff from urban catchments. Utilising long term rainfall records allows continuous models to better represent runoff by considering factors such as antecedent days between storm events, system storage and infiltration. Pollution runoff concentrations can be attributed to various land uses and surface types within the catchment which allows for estimated mean annual loads to be determined for urban stormwater runoff. A range of stormwater treatment devices can then be modelled to size stormwater treatment devices accordingly and undertake contaminant load modelling.

A water quality model of the Avon River catchment in Christchurch has been developed using eWater's existing Model for Urban Stormwater Improvement Conceptualisation (MUSIC) continuous simulation water quality model. The rainfall-runoff model has been calibrated to local climatic and catchment land use parameters for both directly connected impervious area (DCIA) and total impervious area (TIA). As the contaminant load rates are directly correlated with runoff, a good calibration is crucial to provide accurate outcomes for both contaminant load modelling and designing stormwater treatment devices.

This paper presents a summary of the rainfall-runoff model calibration results against both DCIA and TIA parameters and summarises the suitability of this model for use in Christchurch and other regions within New Zealand.

MUSIC has currently been used to size street-scale rain gardens in central Christchurch for the Ōtākaro An Accessible City project, to quantify the estimated reduction in Total Suspended Solid (TSS) load entering the Avon River from the Knights Drain catchment, assess the suitability of rainwater harvesting tanks for the King Edward Barracks development in Christchurch, and to undertake a comparative assessment of various stormwater facility configurations for the Curletts Stream catchment that were not sized to Council guidelines due to size constraints.

KEYWORDS

Continuous simulation, water quality, modelling, MUSIC, stormwater treatment.

PRESENTER PROFILE

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1 INTRODUCTION

Single event water quality models are often based on synthetic design storms which fail to consider varying rainfall patterns, evapotranspiration and groundwater interaction.

Stormwater treatment devices are typically sized in Christchurch using empirical equations based on a water quality volume (WQV) obtained from a first flush depth. This approach works well for individual devices sized in accordance with the Christchurch City Council (CCC) Waterways, Wetlands and Drainage Guide (WWDG) (CCC, 2003). This approach however does not easily quantify an estimated water quality benefit such as the mean annual load reduction of pollutants entering the receiving waterway or account for a number of stormwater treatment devices adopted within a treatment train configuration within the catchment.

Continuous simulation water quality modelling uses long term continuous rainfall records and evapotranspiration input data to model runoff from urban catchments. Utilising long term rainfall records allows continuous models to better represent runoff by considering factors such as antecedent days between storm events, system storage and infiltration. Pollution runoff concentrations can be attributed to various land uses and surface types within the catchment which allows for estimated mean annual loads to be determined for urban stormwater runoff. A range of stormwater treatment devices can then be modelled to size stormwater treatment devices accordingly and undertake contaminant load modelling for various pollutants.

A water quality model of the Avon River catchment in Christchurch has been developed using eWater's existing Model for Urban Stormwater Improvement Conceptualisation (MUSIC) continuous simulation water quality model. The rainfall-runoff model has been calibrated to local climatic and catchment land use parameters for both directly connected impervious area (DCIA) and total impervious area (TIA). This paper presents a summary of the rainfall-runoff model calibration results against both DCIA and TIA catchment parameters.

The Canterbury Earthquake Sequence offered an opportunity to install a number of stormwater treatment devices within the city, such as street-scale rain gardens and tree pits. MUSIC provided an opportunity to size these stormwater treatment devices when the presence of numerous constraints made it difficult to size these devices for the WQV in accordance with the WWDG (CCC, 2003).

MUSIC has currently been used to size street-scale rain gardens and stormwater tree pits in central Christchurch for the Ōtākaro An Accessible City project, to quantify the estimated reduction in Total Suspended Solid (TSS) load entering the Avon River from the Knights Drain catchment, to assess the suitability of rainwater harvesting tanks for the King Edward Barracks Development in central Christchurch, and to undertake a comparative assessment of various stormwater treatment facility configurations for the Curletts Stream catchment that were not sized in accordance with the WWDG (CCC, 2003) due to a lack of space.

These project applications provide a number of examples which demonstrate the benefits of continuous simulation water quality modelling as an alternative approach and show how it can be used for contaminant load modelling and design stormwater treatment devices within New Zealand.

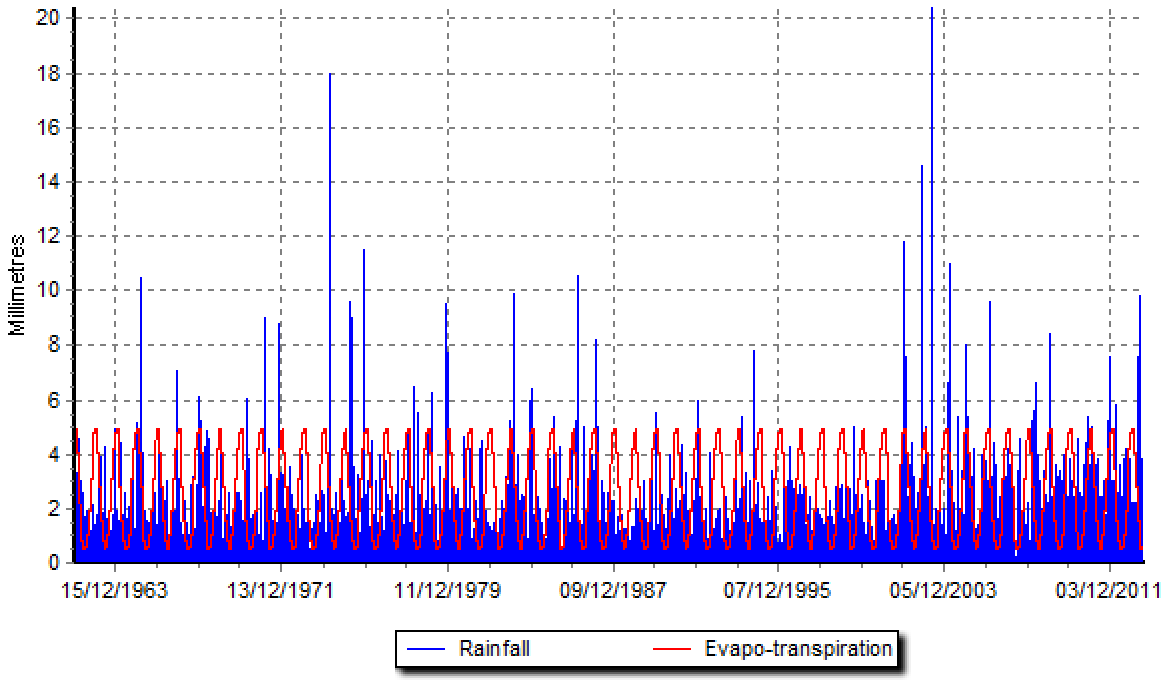
2 WHAT IS MUSIC

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is a water quality model which uses rainfall records and evapotranspiration input data to model runoff from catchments. The MUSIC model was developed from research undertaken at Monash University, the Cooperative Research Centre (CRC) for Catchment Hydrology and eWater.

MUSIC is used throughout Australia to size Low Impact Design (LID) devices and has been used successfully in numerous other countries. MUSIC has been successfully calibrated to local data in the United Kingdom where it is also being used (eWater, 2013). Therefore the benefit of adopting this model is that it has been successfully implemented, has a proven track record and has an extensive amount of literature and research used in its development.

MUSIC uses a continuous rainfall record and evapotranspiration input data to model runoff from catchments by converting rainfall into runoff, and in doing so accounting for losses due to soil storage. Figure 1 shows the Christchurch Botanic Gardens Rainfall gauge in 30 minute intervals from January 1962 to December 2013 and the average monthly evapotranspiration data obtained from the National Institute of Water and Atmospheric Research (NIWA) for the Christchurch Aero 4843 station.

Figure 1: Christchurch Continuous Rainfall and Evapotranspiration Record



Pollutants are generated in MUSIC as rainfall is converted into runoff. During this conversion, pollution concentrations are attributed to runoff to represent the pollutants that would have been generated by surface wash off processes. The pollutants added to runoff also attribute pollutants likely to be generated by atmospheric washout. MUSIC uses Event Mean Concentration (EMC) data for various pollutants for different urban land uses.

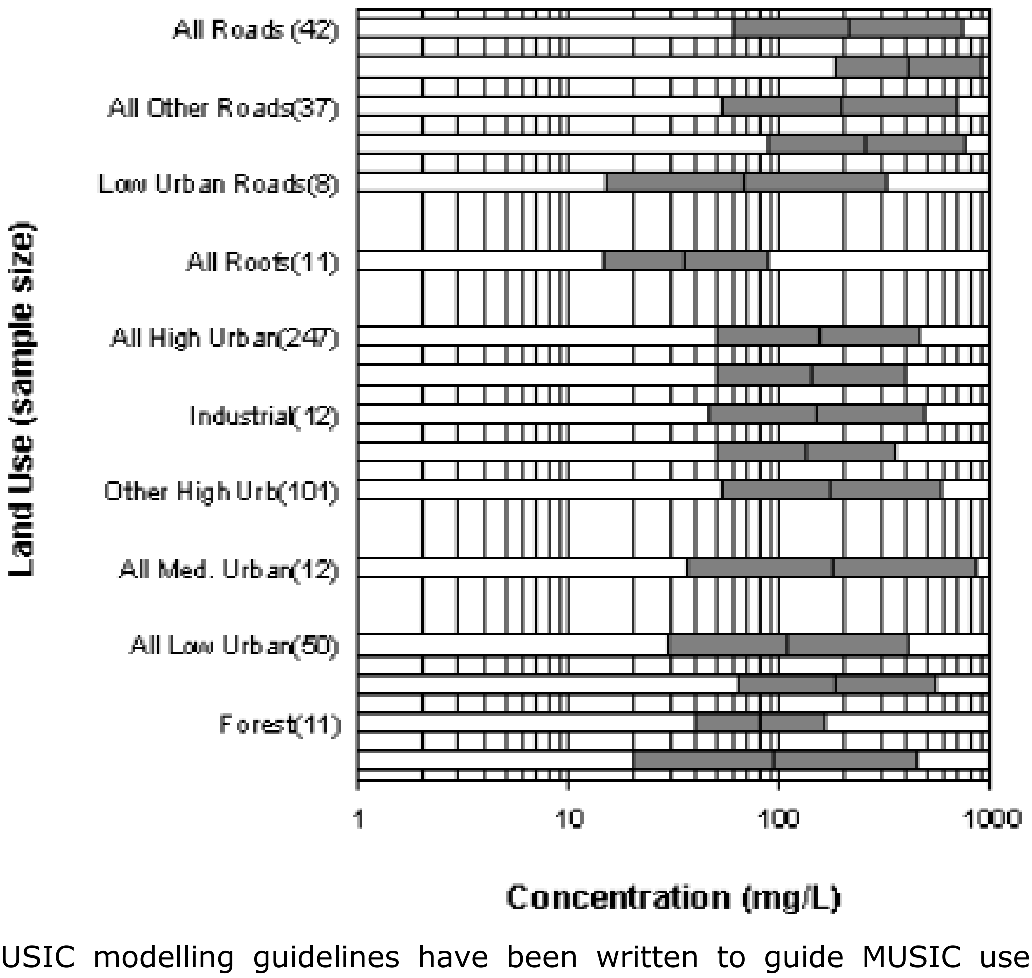
At this stage, Total Suspended Solids (TSS), Total Phosphorus (TP), Total Nitrogen (TN), Total Copper (TC), Biological Oxygen Demand (BOD) and gross pollutants are the only default pollutants included in MUSIC. However other pollutants including other heavy metals can be modelled with the MUSIC 'swap pollutant' function.

In Australia, the most comprehensive reference on the quality of runoff from different surfaces is: Duncan, H.P. (1999), *Urban Stormwater Quality: A Statistical Overview, Report 99/3*, Cooperative Research Centre for Catchment Hydrology, February 1999. Duncan (1999) reviewed over 500 studies reported in the international technical literature available up to 1997. The information collated for this report supports the Australian Runoff Quality (2006) chapter on Urban Stormwater Pollutant Characteristics, also by Duncan.

This information was refined slightly and updated to make specific recommendations for the use of this data in MUSIC modelling by Fletcher et al. in 2004: Tim Fletcher, Hugh Duncan, Peter Poelsma, and Sara Lloyd (2004). *Stormwater flow and quality, and the effectiveness of non-proprietary stormwater treatment measures — a review and gap analysis*. Technical Report 04/8. December 2004. Cooperative Research Centre for Catchment Hydrology.

Analysis by Duncan (1999) found event mean concentrations of TSS, TP and TN to be approximately log-normally distributed for a range of different urban land-use. The user may change the parameters of the log-normal distribution of each pollutant type, refer Figure 2. MUSIC allows the zoning surface type to be set (such as mixed, roof, sealed road, unsealed road, roading gullies, revegetated land, residential, commercial, industrial and rural residential) and then suitable EMC values are applied to match these zoning surface types.

Figure 2: TSS Concentrations (mean ± 1 standard deviation) versus Landuse (redrawn from Duncan, 1999)



Several MUSIC modelling guidelines have been written to guide MUSIC users on the appropriate selection of pollutant runoff parameters for MUSIC modelling. These guidelines provide EMC data for Total Suspended Solids (TSS), Total Nitrogen (TN), Total

Phosphorus (TP), gross pollutants and a number of metals such as Total Zinc, Total Lead, Total Copper, Total Nickel, Total Cadmium, Total Chromium and Total Iron.

MUSIC can then model a wide range of stormwater treatment devices to find the best way to capture and reuse stormwater runoff, remove its contaminants, and reduce the frequency of runoff. MUSIC helps to evaluate these treatment devices until the best combination of cost, hydrology and water quality improvement is achieved. However, MUSIC is not a detailed design tool. It does not contain the algorithms necessary for detailed sizing of structural stormwater quantity and/or quality facilities. MUSIC should be viewed as a conceptual design tool (eWater, 2013).

3 CALIBRATION OF MUSIC TO CHRISTCHURCH CONDITIONS

3.1 SUMMARY

MUSIC directly correlates contaminant loading with runoff, therefore to accurately size treatment devices and undertake contaminant load modelling it is critical that the model is calibrated to local climatic and catchment land use parameters. A sufficient record of rainfall and observed stream gauging record is required to calibrate the model.

The Avon River catchment was selected to calibrate the MUSIC model to local conditions. This catchment was selected due to a large proportion of Christchurch being located within this catchment and this catchment is representative of typical land use parameters in Christchurch.

A MUSIC model was also developed for the Okeover Stream and Bowenvale Stream catchments. The Okeover Stream model was developed due to the large quantity of historic rainfall and stream gauging data available for this catchment. The Bowenvale Stream catchment was developed to calibrate the MUSIC rainfall-runoff model parameters to a steeper Port Hills catchment. This paper only presents the results from the Avon River MUSIC model calibration.

For the Avon River catchment, the most suitable continuous rainfall record is the Christchurch Botanic Gardens site. This site has a 30 minute continuous record from January 1962 to present.

3.2 MODEL DEVELOPMENT

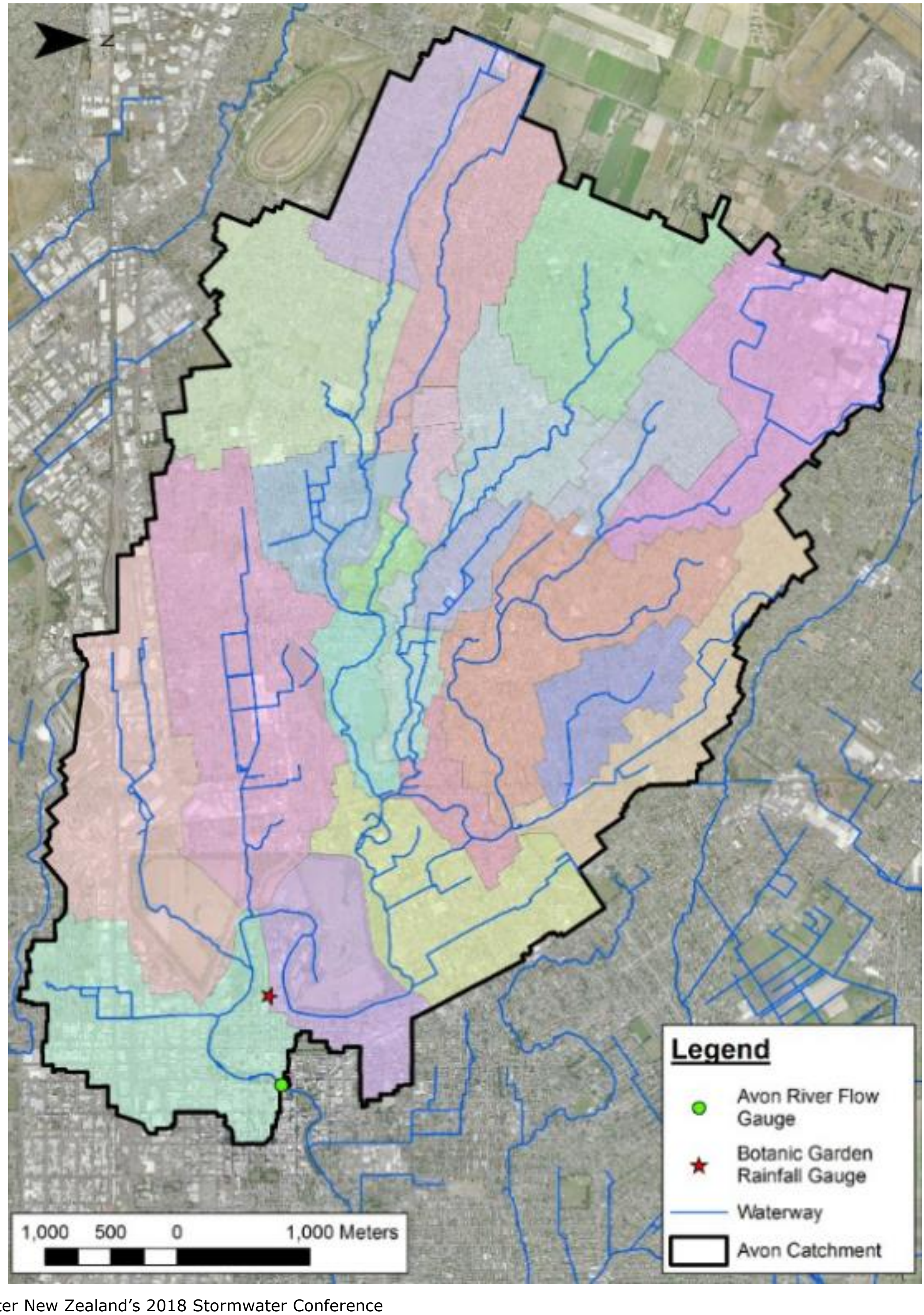
The Avon River catchment MUSIC model was developed using the following meteorological data and catchment land use information.

3.2.1 METEOROLOGICAL DATA

- Continuous rainfall data from the Christchurch Botanic Gardens site in 30 minute intervals from January 2004 to December 2010. This data range was found to be representative of the Christchurch long-term rainfall record and the smaller data set allowed for reduced model run time. Refer Figure 1 for historic rainfall record. The location of this rainfall gauge is presented on Figure 3.
- Average monthly evapotranspiration data obtained from NIWA for the Christchurch Aero 4843 station. Refer Figure 1 for historic monthly evapotranspiration data record.

- Avon River stream gauging data at the Environment Canterbury (ECan) 66602 site at Gloucester Street. This data was available in 30 minute intervals from July 1980 till present.

Figure 3: Avon River Catchment for MUSIC model Calibration



3.2.2 CATCHMENT LAND-USE DATA

- Catchment and subcatchment areas were determined by analysing post-earthquake LiDAR and Christchurch's stormwater network in GIS. Due to the size of the catchment, the catchment was broken down into twenty-two smaller sub-catchments. The total catchment boundary for the MUSIC model extends downstream to a stream gauging site located at Gloucester Street. Refer Figure 3.

- Impervious areas were calculated for each sub-catchment based on land-use composition. The land-use composition of the Avon River subcatchments were determined using the CCC land use zoning data available in GIS format. Refer to Figure 4 for the land use zoning for the Avon River catchment.

  There are two general approaches for calculating the impervious area within a catchment. The first approach is the Total Impervious Area (TIA) method. This covers all impervious areas within a catchment; such as roofs, roads, driveways and other external hardstand surfaces. The second approach is the Directly Connected Impervious Area (DCIA) method. This covers impervious surfaces that are directly connected to the CCC piped stormwater reticulation network; typically this includes roofs and road carriageways.

  The TIA and DCIA were calculated for each sub-catchment. MUSIC models have been developed for the Avon River catchment based on both TIA and DCIA parameters.

  The TIA impervious percentage for each land use category was determined based on published values in the WWDG (CCC, 2003). These values were checked against the actual TIA digitised from aerial photography for smaller sample areas.

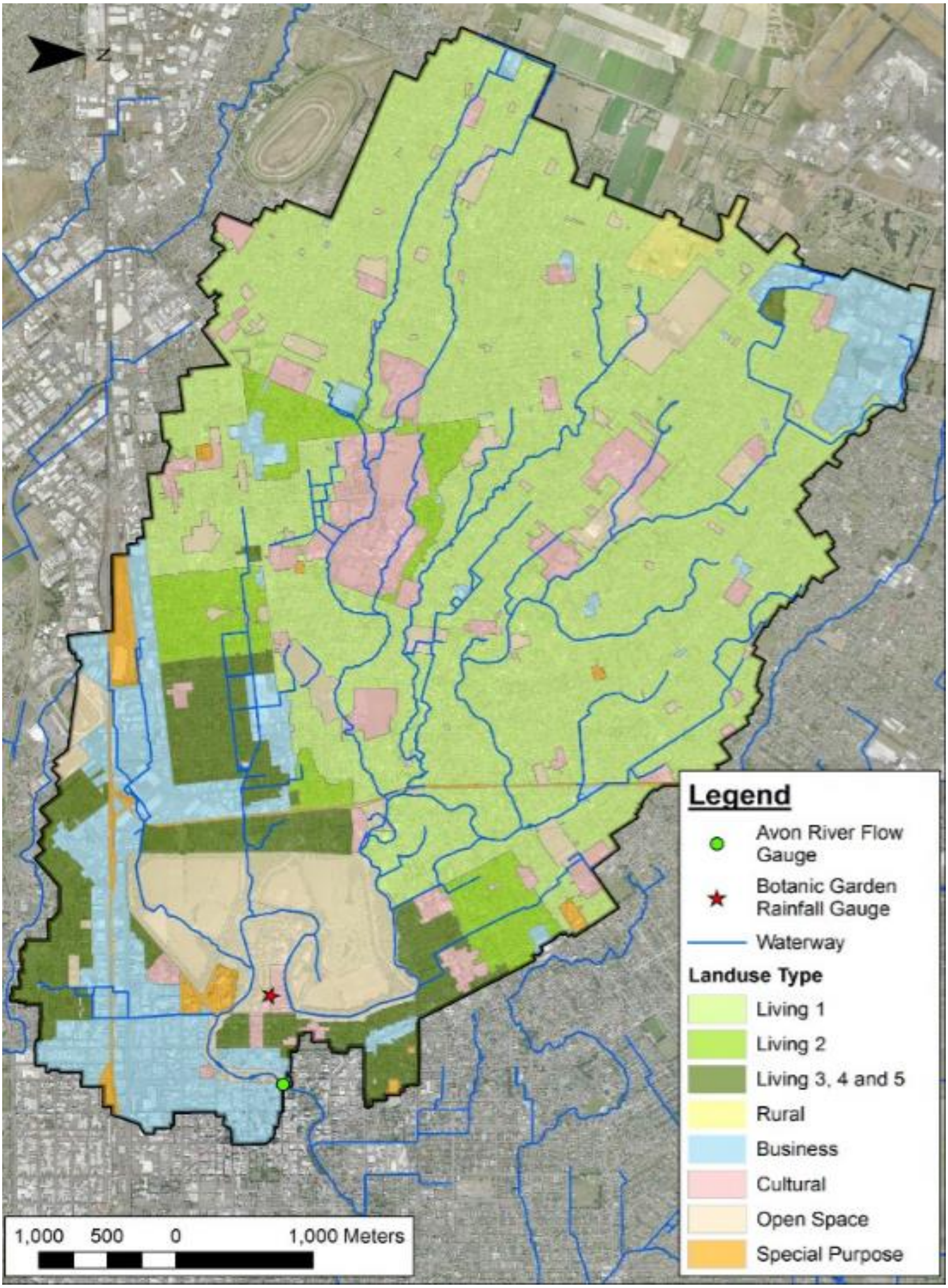
  The DCIA impervious percentage for each land use category was determined based on GIS layers of existing roof areas and external impervious percentages digitised from aerial photography for smaller sample areas throughout the catchment.

- Soil classifications for each sub-catchment were identified using Landcare Research's S-Map and the appropriate soil loss parameters were entered into MUSIC. Most of the Avon River catchment falls into poorly and imperfectly drained soil drainage categories.

- Baseflow has been included in the model. This baseflow record was derived from the historic stream gauging record with storm flows removed from the record.

- Lag times for waterways to represent the different response time of subcatchments within the Avon River catchment. These lag times were estimated based on stream velocities both measured on site and from hydraulic models.

Figure 4: Land use zoning within the Avon River Catchment



3.3 MODEL RESULTS

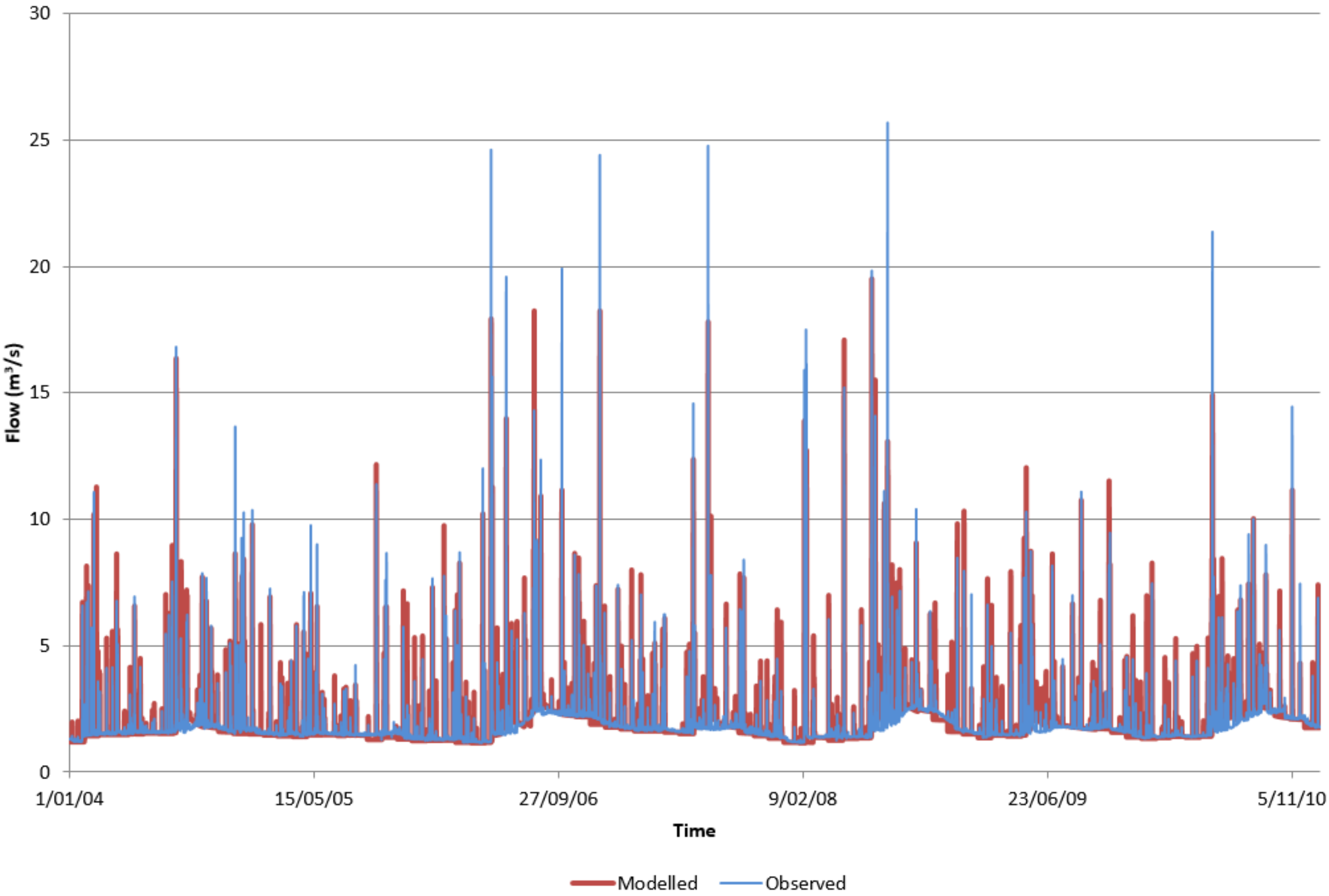
3.3.1 MODELLED VERSUS OBSERVED FLOWS

The Avon River MUSIC model was simulated for both TIA and DCIA subcatchment parameters. Modelled results were compared with the recordings from the stream gauge records from the Gloucester Street Bridge for both models.

The MUSIC model was initially run using default MUSIC soil loss parameters. These parameters were slightly modified to achieve a better model calibration.

Figures 5 and 7 present continuously modelled flow between January 2004 and December 2010 for both DCIA and TIA catchment parameters respectively. These figures present the modelled and observed flows in the Avon River at Gloucester Street. The observed flows have been obtained from the ECan 66602 stream gauge.

Figure 5: Avon River Modelled and Observed Flows for DCIA Parameters

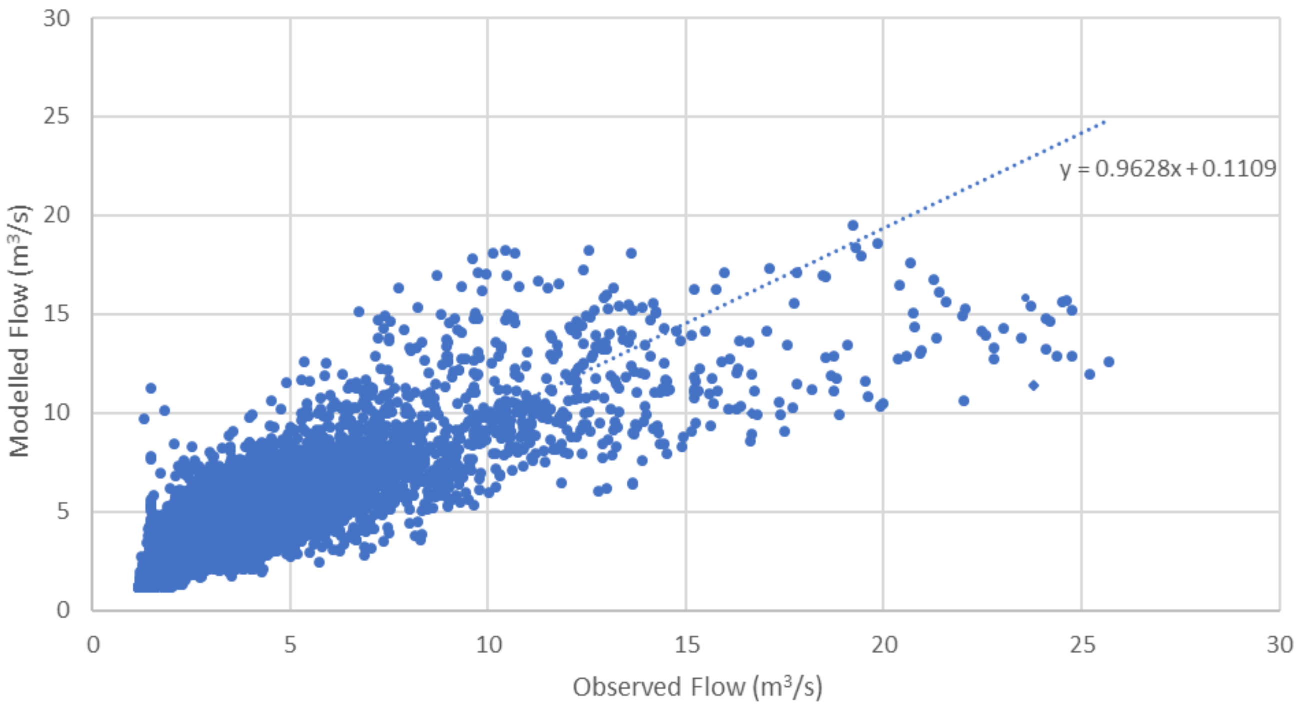


It can be seen from Figure 5 that with DCIA catchment parameters, the modelled and observed flows produce a close match for the more frequent storm events. For storm events with a peak flow greater than approximately 15 m^3/s the modelled flows are smaller than the observed flows for these events. Based on these results it can be seen that the smaller and more frequent water quality events are more accurately modelled using DCIA catchment parameters. The TIA catchment parameters produce a better match in larger flood events in which antecedent conditions result in runoff from all impervious and some pervious surfaces contributing to the peak flow.

The modelled results were analysed using graphical and statistical measures in accordance with Moriasi et al., 2007 *Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations*. The graphical analysis consisted of plotting a 1:1 relationship between the observed and modelled data, the data spread and trendline could then be assessed. The slope of the trendline indicates the relative relationship between modelled and observed values, while the y-intercept indicates the presence of a lag or lead between model predictions and the observed data. A slope of one and a y-intercept of zero indicate a perfect match between the modelled and observed data (Willmott, 1981). This process resulted in the following figures.

Figure 6 presents the modelled flow versus observed flow for DCIA catchment parameters.

Figure 6: Modelled Flow versus Observed Flow Data for DCIA Catchment Parameters



As with Figure 5, it can be seen from Figure 6 that the modelled flows with DCIA catchment parameters produce a good fit up to flows of approximately 15 m^3/s. Above this flow rate the model underestimates peak flows.

It can be seen from Figure 7 that with TIA catchment parameters, that the modelled and observed flows produce a better match for the larger storm events than the more frequent water quality events. For the smaller storm events the modelled flow is typically greater than the observed flow.

Figure 8 presents the modelled flow versus observed flow for TIA catchment parameters.

Figure 7: Avon River Modelled and Observed Flows for TIA Parameters

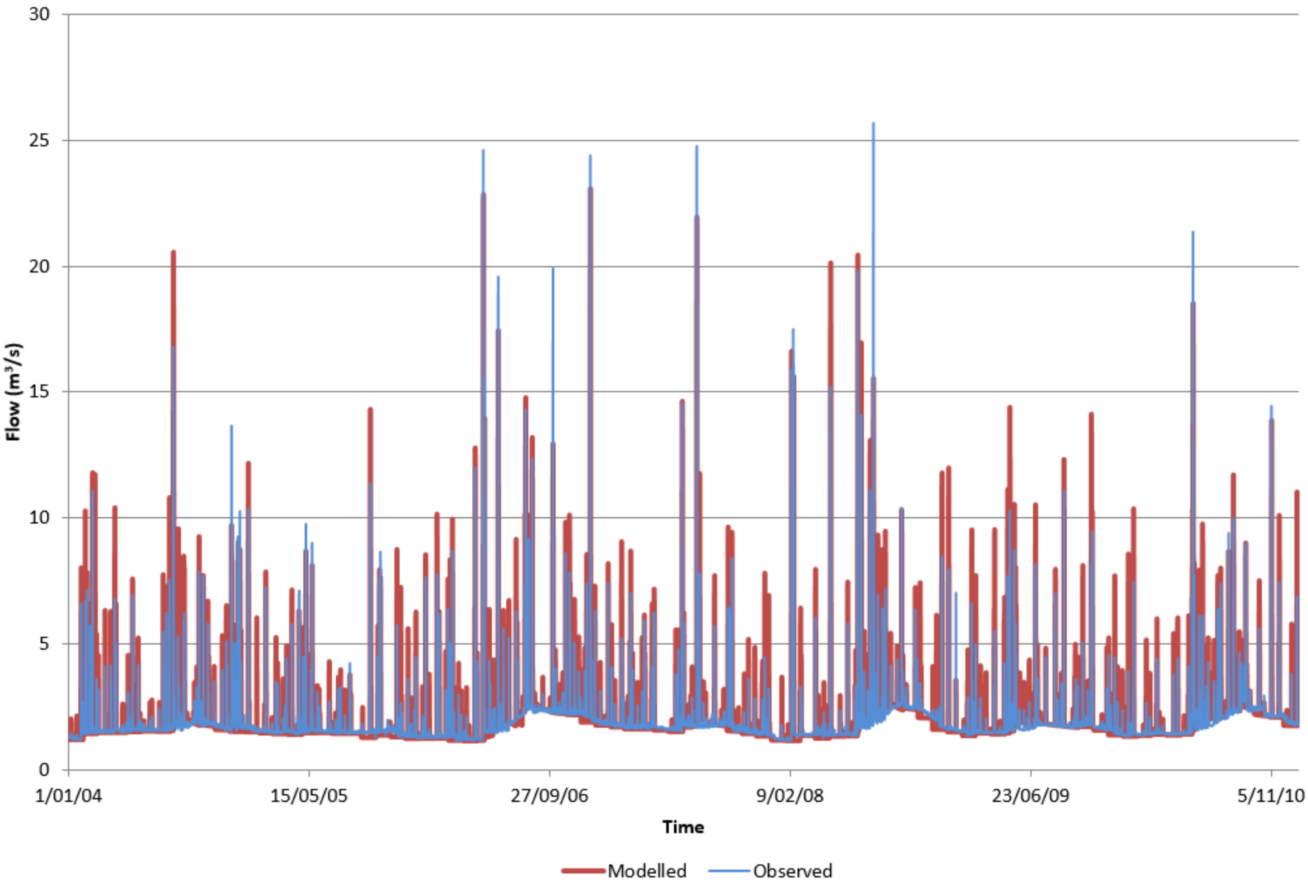
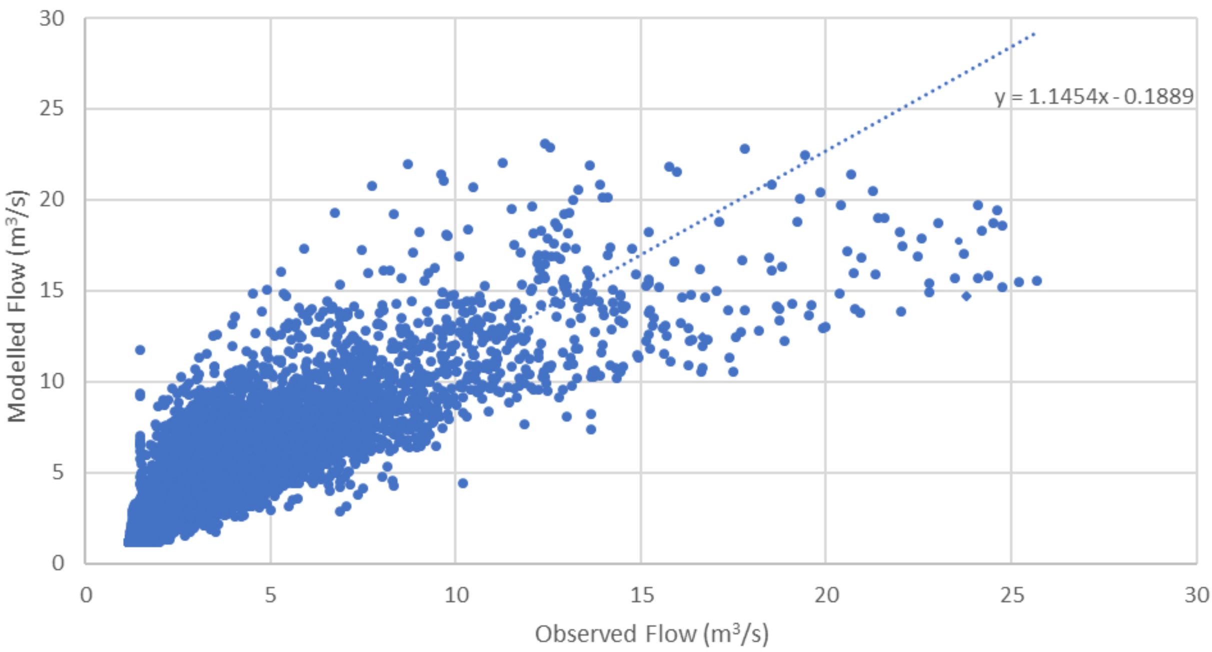


Figure 8: Modelled Flow versus Observed Flow Data for TIA Catchment Parameters



It can be seen from Figure 8 that the modelled flows with TIA catchment parameters tend to overestimate peak flows less than 15 m^3/s and produce a closer match for flows greater than this when compared to the DCIA results.

3.3.2 STATISTICAL EVALUATION OF MODELLING RESULTS

The modelled results were analysed using three different statistical methods as recommended in Moriasi et al., (2007). These statistical methods were chosen as they are commonly used to assess hydrological models both in New Zealand and internationally (NIWA, 2017). The statistical methods are as follows:

- Nach-Sutcliffe Efficiency (NSE).
- Percent bias (PBIAS).
- Root mean square error-observations Standard deviation Ratio (RSR).

The predictive power of a hydrological model can be assessed using the Nash-Sutcliffe model efficiency (NSE) coefficient. The NSE determines the magnitude of the "noise" (modelled data) compared to the measured data variance (observed data) (Nash and Sutcliffe, 1970). The NSE coefficient is determined using the following formula:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^{n}(Q_i^{obs} - Q^{mean})^2}\right] \quad (1)$$

Where Q^{sim} is the modelled discharge, Q^{obs} is the observed discharge and Q^{mean} the mean of the observed discharge. The NSE coefficient ranges from negative infinity to one and can be classified as follows:

- Negative infinity < NSE < 0, the mean of the observed data is a better predictor than the model.
- NSE = 0, the model predictions are as accurate as the mean of the observed data.
- NSE = 1, there is a perfect match between the mean of the observed data and the modelled results.

The Percent Bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than the observed equivalent (Gupta et al., 1999). The closer the PBIAS is to zero the more accurate the model simulation is. Positive values indicate a model's bias to underestimate and negative values indicate a bias to overestimate. The PBIAS can be calculated using the following equation:

$$PBIAS = \frac{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim}) * 100}{\sum_{i=1}^{n}(Q_i^{obs})} \quad (2)$$

RMSE-observation Standard deviation Ratio (RSR) standardises the Root Mean Square Error (RMSE) using the standard deviation of the observed data (Moriasi et al., 2007). The lower the RSR value, the lower the RMSE and the better the model performance. An RSR value of zero indicates a RMSE of zero and therefore no residual variation, a perfect fit between modelled and observed. The RSR is calculated using the following equation:

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim})^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}(Q_i^{obs} - Q^{mean})^2}\right]} \quad (3)$$

The TIA and DCIA results were analysed using the above statistical methods. Table 1 presents the results of the statistical analysis for both the DCIA and TIA catchment parameters.

Table 1: Summary of Statistical Analysis Results

Model Parameters	NSE	PBIAS	RSR	Overall Classification [1]
DCIA	0.76	-2.25	0.49	Very Good
TIA	0.63	-4.39	0.62	Satisfactory

1. *Classification as per Table 4. General performance ratings for recommended statistics for monthly time step (Moriasi et al., 2007).*

It can be seen from Table 1 that the DCIA parameters produce more accurate modelling results for all three statistical analysis methods. The DCIA catchment parameters produce a 'very good' statistical match and the TIA catchment parameters produce a 'satisfactory' statistical match.

4 PROJECT EXAMPLES

4.1 CURLETTS STREAM

Stormwater treatment measures are being designed by CCC for the Curletts Stream catchment as part of the CCC Land Drainage Recovery Programme (LDRP). The footprint of land in which the stormwater facility can be constructed is not large enough for a first flush basin (FFB) and conventional wetland sized to the WWDG (CCC, 2003) and therefore the final stormwater facility design needed to be sized for a lower first flush depth or comprise other treatment devices in the treatment train.

Water quality modelling was undertaken to help quantify the water quality benefits that could be achieved from a number of different stormwater treatment facility configurations constructed in the Curletts Stream catchment that have not been sized in accordance with the WWDG (CCC, 2003). This modelling was undertaken to estimate the mean annual load of TSS and Total Zinc (TZ) that may be discharged from the Curletts Stream catchment both before and after the proposed stormwater facility options have been constructed. This MUSIC modelling was undertaken using rainfall-runoff parameters from the Avon River model calibration and default EMC parameters for TSS and TZ.

MUSIC modelling was undertaken for the following stormwater facility configurations.

Table 2: Summary of Curletts Stream Stormwater Facility Options

Option	First Flush Volume (m^3)	First Flush Depth (mm)	Wetland Area (m^2)	Flow Rate through wetland (m^3/day)	Wetland Residence Time (hours)
1	50,800	25.8	26,500	12,700	9.4
2 / 2b	16,800	8.5	45,000	4,200	48.2

3 / 3b	27,000	13.7	37,400	6,750	24.9

It is noted that Option 1 has a FFB sized for a 25 mm first flush depth but has a wetland smaller than is required by the WWDG. Option 2 has a smaller FFB than is required by the WWDG but has a wetland sized to comply with the WWDG design requirements. Option 3 has a FFB and wetland with a smaller footprint than is required by the WWDG.

Option 2b and 3b have the same stormwater facility as Options 2 and 3 but have a StormFilter proprietary stormwater treatment device included to treat storm events with a first flush depth greater than that used to size the FFB and wetland and up to 25 mm first flush depth i.e. events that bypass the undersized FFB and/or wetland.

Another objective was to identify the StormFilter design flow (flow rate receiving stormwater treatment) for Option 2b and 3b to achieve both 75% and 85% TSS removal for the Curletts Stream catchment.

The model results for these three stormwater facility configurations are presented in Table 3.

Table 3: TSS Model results for Curletts Stream Stormwater Facility

Parameter	**Curletts Stream Stormwater Facility Scenario**		
	Option 1	**Option 2**	**Option 3**
	Large FFB with 25mm WQD, small wetland	**Small FFB with 8.5mm WQD, large wetland**	**Medium FFB with 13.7mm WQD, medium wetland**
TSS mean annual load from Curletts Stream catchment (kg/year)	217,000	217,000	217,000
Mean annual flow from Curletts Stream catchment (ML/year)	1,220	1,220	1,220
TSS removal efficiency by FFB	68.0%	49.1%	57.9%
TSS removal efficiency by wetland	78.9%	88.1%	86.0%
Mean annual flow bypassing proposed Stormwater Facility (ML/year)	160	550	378
TSS mean annual residual load entering Heathcote River (kg/year)	31,400	82,100	55,400
TSS removal efficiency (by Stormwater Facility)	**85.5%**	**62.2%**	**74.1%**

It can be seen from Table 3 that stormwater facility Option 1 achieves the highest TSS removal efficiency of 85.5%. Whilst this option has a smaller wetland than is required by the WWDG (CCC, 2003), it has a FFB sized to capture a 25 mm first flush depth which achieves a high TSS removal efficiency. This option also releases a larger flow rate and mean annual flow into the wetland for secondary treatment because this flow rate has been estimated as the first flush volume (FFV) divided by 4 in accordance with the WWDG (CCC, 2003) design requirements. The undersized wetland is estimated to still achieve a 78.9% TSS removal efficiency.

Option 2 achieves the lowest TSS removal efficiency of 62.2%. Whilst this option has a wetland sized to WWDG (CCC, 2003) design requirements, it has a small FFB and corresponding small flow rate (FFV/4) and mean annual flow entering the wetland for secondary treatment. The wetland achieves a high TSS removal efficiency of 88.1% but less flow enters the wetland for secondary treatment due to the lower flow rate entering the wetland from the undersized FFB. This option results in a larger mean annual flow bypassing the proposed stormwater facility without receiving any stormwater treatment.

Option 3 achieves a TSS removal efficiency of 74.1%. Stormwater treatment devices are commonly sized to capture 80% of stormwater runoff volumes in Christchurch and this design requirement is expected to capture at least 75% of TSS. Therefore Option 3 is expected to capture approximately 80% of stormwater runoff volumes.

This assessment was also undertaken for Total Zinc. The MUSIC model was used to estimate the design flow required for a StormFilter incorporated into Option 2 and Option 3 so these stormwater facility configurations achieve a pollutant removal efficiency equivalent to achieve both a 75% and 85% TSS removal efficiency for the Curletts Steam catchment.

4.2 KNIGHTS DRAIN

Stormwater facilities are being designed by CCC for the Knights Drain catchment as part of the CCC LDRP. For the Knights Drain catchment a number of options were investigated to provide both flood attenuation storage and water quality enhancement. The shortlisted options comprised a wet pond and a wet pond with conventional wetland.

A water quality assessment was undertaken to help quantify the water quality benefits that could be expected from constructing the proposed Knights Pond stormwater facility. This water quality modelling has been undertaken for a wet pond and wet pond with wetland configuration. The construction of this stormwater facility requires voluntary land acquisition and therefore it was important to quantify the water quality treatment benefits to assist Councilors to make an informed decision.

This modelling estimated that the wet pond only and wet pond with wetland options would result in a 57% and 84% reduction in TSS load entering the Avon River respectively. The mean annual load of TSS and residual TSS load after the stormwater facility has been constructed were used to estimate the volume of TSS load that would be captured prior to discharge into the Avon River.

4.3 AN ACCESSIBLE CITY / HE TAONE WĀTEA, CHRISTCHURCH

The Otakaro An Accessible City anchor project integrated street-scale stormwater treatment devices (rain gardens, bioretention tree pits and passively irrigated tree pits) into the public realm as part of the street renewal for the Manchester Street, Durham /Cambridge Terrace and Hospital Corner transport corridors in Christchurch.

The treatment devices for this project were designed prior to the completion of the CCC Rain Garden Design, Construction and Maintenance Manual (CCC, 2015) and Avon Stormwater Management Plan technical reports for rain gardens and stormwater tree pits that were developed by CCC.

It was not possible to include treatment devices sized to capture the first flush depth in accordance with the WWDG (CCC, 2003) due to the large number of existing utility services and street trees in these locations which limited the footprint available for stormwater treatment devices.

The MUSIC model was used to size these stormwater treatment devices for a minimum 75% TSS removal efficiency. This approach resulted in stormwater treatment devices that could be constructed within the public realm of these street rejuvenation projects.

Photograph 1 and 2: Accessible City Rain Garden on Manchester Street (left) and Cambridge Terrace (right)

4.4 KING EDWARDS BARRACKS

The viability of implementing rainwater harvesting tanks into the Ngai Tahu King Edward Barracks development in Christchurch was investigated using MUSIC.

The MUSIC model can incorporate monthly reuse demands from external irrigation and internal reuse such as toilet flushing. When a continuous rainfall record is modelled the percentage of reuse demand met can be estimated for different rainwater harvesting tank volumes. This approach allows the optimum rainwater harvesting tank volume to be identified that will achieve an acceptable reliability that is value for money for the client.

Figure 9 presents the mean monthly rainfall, mean monthly potential evapotranspiration (PET) data and difference between rainfall and PET data for Christchurch. The monthly variation in the adopted 0.5 m annual irrigation demand is also presented. A toilet flushing demand of 1.6 kL/day was adopted for work days.

It can be seen from Figure 9 that the mean monthly rainfall is relatively uniform throughout the year, but slightly lower in summer. The mean monthly PET is highest in summer when rainfall is lower and lowest in winter when rainfall is higher. This makes rainwater harvesting less viable when only adopted for external irrigation reuse. The relatively uniform rainfall throughout the year makes internal reuse more viable. A key consideration in the use of rainwater harvesting in Christchurch is that potable water is currently covered by rates and not charged based on usage.

Figure 10 presents the tank volume versus percentage of reuse demand met for a number of scenarios with different contributing catchment area and reuse demands. It can be seen from this figure that when only 50% of the roof area is captured that the percentage of reuse demand met is typically less than 60% and that the optimum tank volume is about 10 to 15 kL. Tank volumes larger than this do not result in a significant increase in reliability and therefore are not considered to be value for money. When 100% of the roof area is captured the percentage of reuse demand met increases to 65 – 85%.

Rainwater harvesting was not adopted for the King Edward Barracks site but this example shows how the viability of rainwater harvesting can be easily investigated using MUSIC and that an optimal tank volume can be selected based on the contributing catchment and adopted reuse demands.

Figure 9: Christchurch Monthly Climate Data

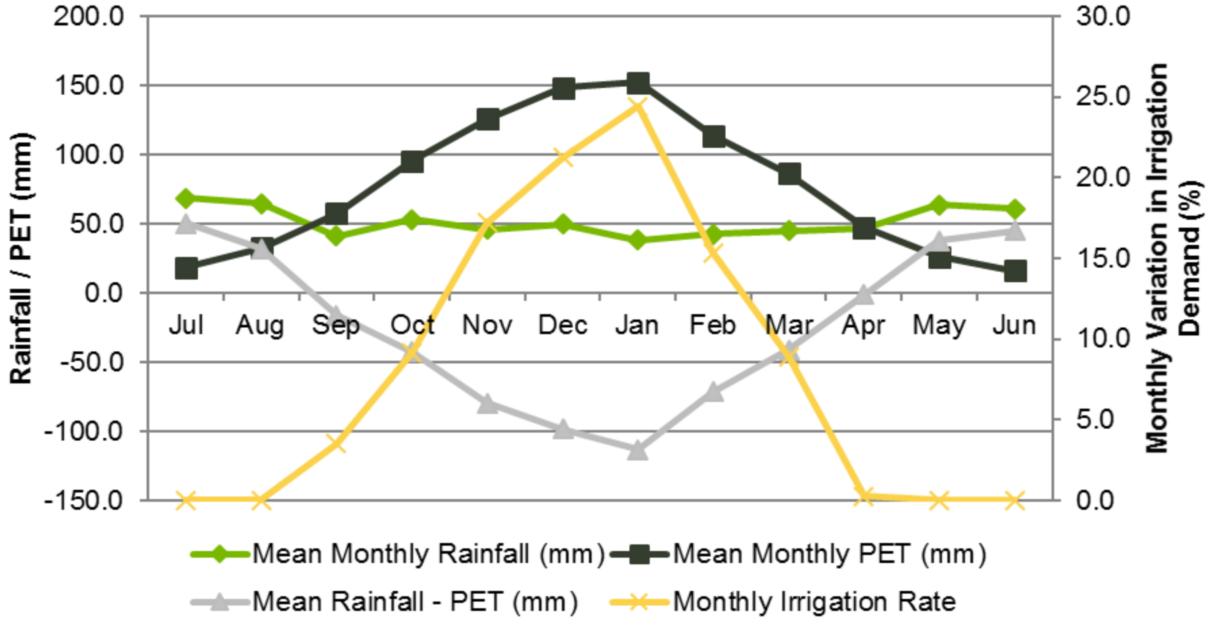
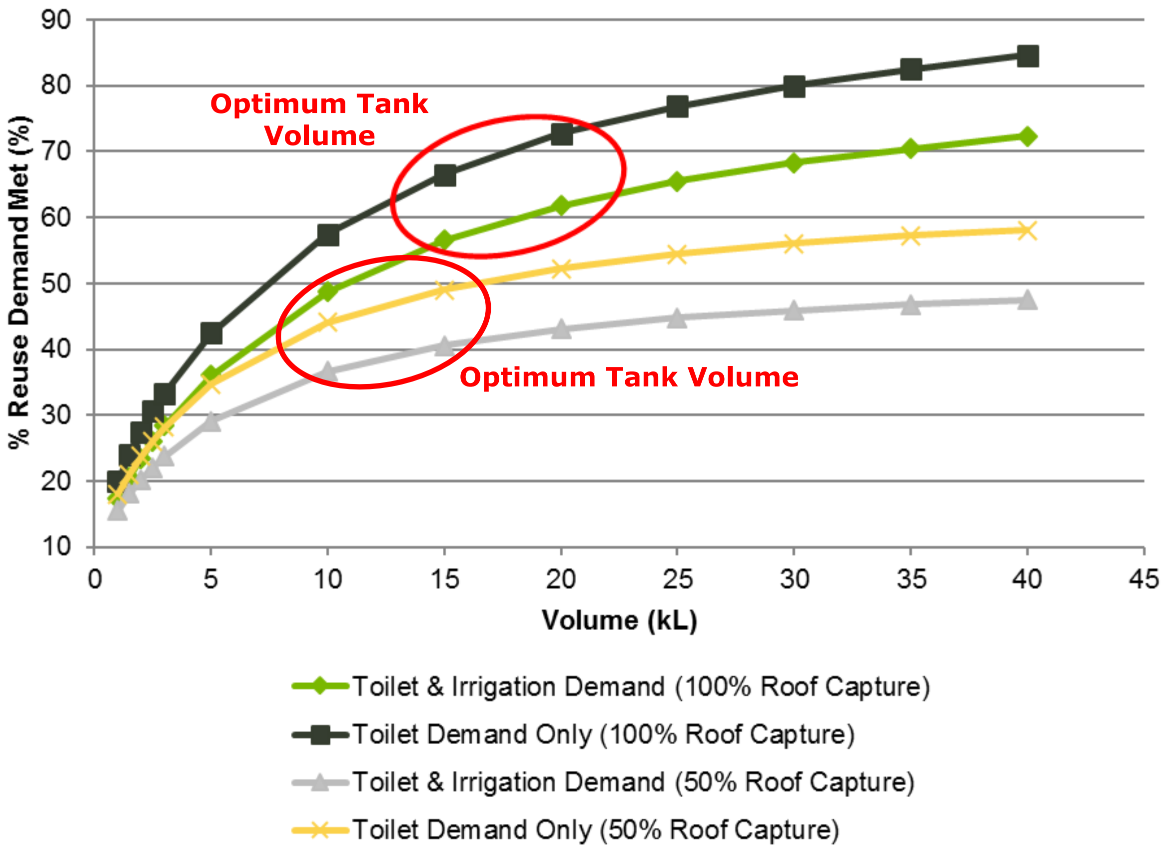


Figure 10: King Edwards Barracks Tank Curve



5 CONCLUSIONS

A MUSIC model was developed for the Avon River catchment based on both DCIA and TIA catchment parameters.

The Avon River catchment MUSIC model produced a very good calibration to DCIA catchment parameters for smaller storm events with a first flush depth typically less than 25 mm. These calibration results indicate that a MUSIC model developed in Christchurch using DCIA catchment parameters would provide an accurate estimate of contaminant loads when used for contaminant load modelling, and will appropriately size stormwater treatment devices to achieve a specified pollutant removal efficiency (such as 85% TSS).

As the contaminant load rates are directly correlated with runoff, a good calibration is crucial to provide accurate outcomes for both contaminant load modelling and designing stormwater treatment devices. As a result of the very good calibration of the rainfall runoff model, it can be expected that the concentration and mean annual loads estimated using MUSIC will also be of a high accuracy.

The project applications presented in this paper demonstrate the benefits of continuous simulation water quality modelling. This modelling can be used for contaminant load modelling, quantifying the water quality benefits of proposed stormwater treatment devices, and sizing a range of stormwater treatment devices either installed individually or within a complex treatment train of stormwater treatment devices within a catchment.

Other benefits of continuous simulation water quality models include estimating the mean annual flow from a catchment, the residual mean annual flow after stormwater treatment devices have been installed, changes in the frequency of stormwater runoff, and designing both rainwater and stormwater harvesting infrastructure.

Continuous simulation water quality modelling could be undertaken as an alternative approach that can be used for contaminant load modelling and to design stormwater treatment devices within New Zealand.

Further calibration is currently underway for the pollutant generation parameters in MUSIC based on local measurements for TSS and other heavy metals.

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