Application of MIDIS for Rainfall on Grid Modelling

on the Sunshine Coast

Document Information

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Executive Summary

This document summarises the proposed method of applying rainfall losses to the Median Intensity Duration Independent Storm (MIDIS) to allow for changes to fraction impervious values. This method has been adopted for use by Sunshine Coast Council (SCC) for Master Drainage Studies (MDS) in order to help determine the potential impact of development when using rainfall on grid techniques. MDS investigations using the standard DIS or MIDIS method with rainfall on grid have resulted in negligible differences in peak flows with varying levels of impervious area. The modified MIDIS method allows for changes to be made directly to the input rainfall, in order to represent changes to catchment rainfall losses. This document should be read as an addendum to *Application of Design Temporal Patterns on the Sunshine Coast* (SCC, 2018), which summarises the methods proposed by SCC to simplify the use of Australian Rainfall and Runoff (ARR) Ensemble Temporal Patterns.

This report provides an example of the modified MIDIS methodology applied for a small urban catchment on the Sunshine Coast. The report also demonstrates a preferred method of incorporating the effects of catchment wide On-Site Detention (OSD).

A comparison of the MIDIS with full ARR ensemble approach was conducted. The results demonstrated an acceptable agreement between peak water levels and flows.

Contents

Glossary

AEP	Annual Exceedance Probability
ARF	Areal Reduction Factor
ARR	Australian Rainfall and Runoff
AVM	Average Variability Method (Temporal Pattern)
DCIA	Directly Connected Impervious Area
DIS	Duration Independent Storm, a temporal pattern derived from the IFD.
EIA	Effective Impervious Area
EIFA	Effective Impervious Flow Area
ICIA	Indirectly Connected Impervious Area
IFD	Intensity Frequency Duration design rainfall
FFA	Flood Frequency Analysis
MDS	Master Drainage Study
MIDIS	Medium Intensity Duration Independent Storm (Temporal Pattern)
MIS	Medium Intensity Storm (Temporal Pattern)
OSD	Onsite Detention
QUDM	Queensland Urban Drainage Manual
SCC	Sunshine Coast Council
TIA	Total Impervious Area
TIN	Triangulated Irregular Network
ToC	Time of Concentration, the duration of rainfall associated with peak discharge
TTPP	Travel Time Peak to Peak
URBS	Unified River Basin Simulator rainfall runoff routing model.

Introduction

In 2016, Australian Rainfall and Runoff (ARR) guidelines introduced and recommended the application of an ensemble temporal pattern approach that involved the analysis of 10 temporal patterns for each duration considered in a traditional critical duration analysis.

SCC has historically applied a Duration Independent Storm (DIS) methodology as a pragmatic approach to simplify the determination of design flood surface levels for a catchment and for development impact assessment. In order to account for the recommendations of ARR, the Median Intensity Storm (MIS) and Median Intensity Duration Independent Storm (MIDIS) methodologies were developed. Details of these methodologies are outlined in *Application of Design Temporal Patterns on the Sunshine Coast* (SCC, 2018). The MIS derives peak sub-duration rainfall depths for a duration of interest and then constructs a synthetic temporal pattern from the sub-duration rainfall depths using a DIS methodology. Using intensities derived from the ensemble temporal patterns reduces the peakiness of the MIS pattern relative to the DIS, and has the potential to improve the realism of the resultant hydrograph. The MIDIS calculates the maximum envelope of all MIS temporal pattern sub-duration depths and then applies the DIS methodology, allowing one temporal pattern to be used for each Annual Exceedance Probability (AEP) analysed.

The ability of MIDIS to use one temporal pattern for each AEP allows for practical and efficient modelling. This is particularly useful in larger catchments or development assessment where several critical durations may be relevant, or the effects of storage as well as conveyance capacity need to be considered.

Enhancement of the MIDIS method was required, specifically for rainfall on grid modelling, as this form of modelling has less sophisticated hydrology. It was necessary for the rainfall inputs to be modified to account for changes associated with increasing urbanisation. It was also necessary to develop a rainfall on grid modelling method that would account for how increased urbanisation accelerated runoff response time.

The recent release of Book 9 of ARR discussed the limitations of rainfall on grid methodologies when compared to traditional 1D/2D models, which use a separate hydrology model to calculate inflows. Rainfall on grid models can often underestimate peak flows due to terrain interception losses. They can also have difficulty with reflecting changes to catchment behaviour arising from urbanisation, which can be easier to represent in hydrology models.

The methodology that has been developed, where effective impervious area flows are distributed directly to the main flow paths (derived by filtering rainfall on grid results), should help to address these concerns with rainfall on grid modelling. This methodology could also be applied to standard ARR ensemble temporal patterns. Rainfall on grid modelling is particularly useful when complex flow paths and drainage behaviour in urban areas needs to be defined, and SCC encourages its continued use when appropriate.

SCC is committed to the application of industry recognised best practice principals in the preparation of flood models and planning scheme policies and guidelines. This report considers the practical application of ARR (2016) ensemble temporal patterns on the Sunshine Coast, particularly when using rainfall on grid modelling. The proposed method simplifies the required analysis and ensures that the impact of development can be quantified.

This document should be read as an addendum to *Application of Design Temporal Patterns on the Sunshine Coast* (SCC, 2018).

1. Runoff Volume Changes with Urbanisation

1.1. Rainfall Losses

The ARR Data Hub provides initial and continuing storm losses and pre-burst losses. The resultant burst loss is the storm loss minus the pre-burst, as shown in Figure 1.

$$IL_{burst} = IL_{storm} – \text{Pre-burst}$$

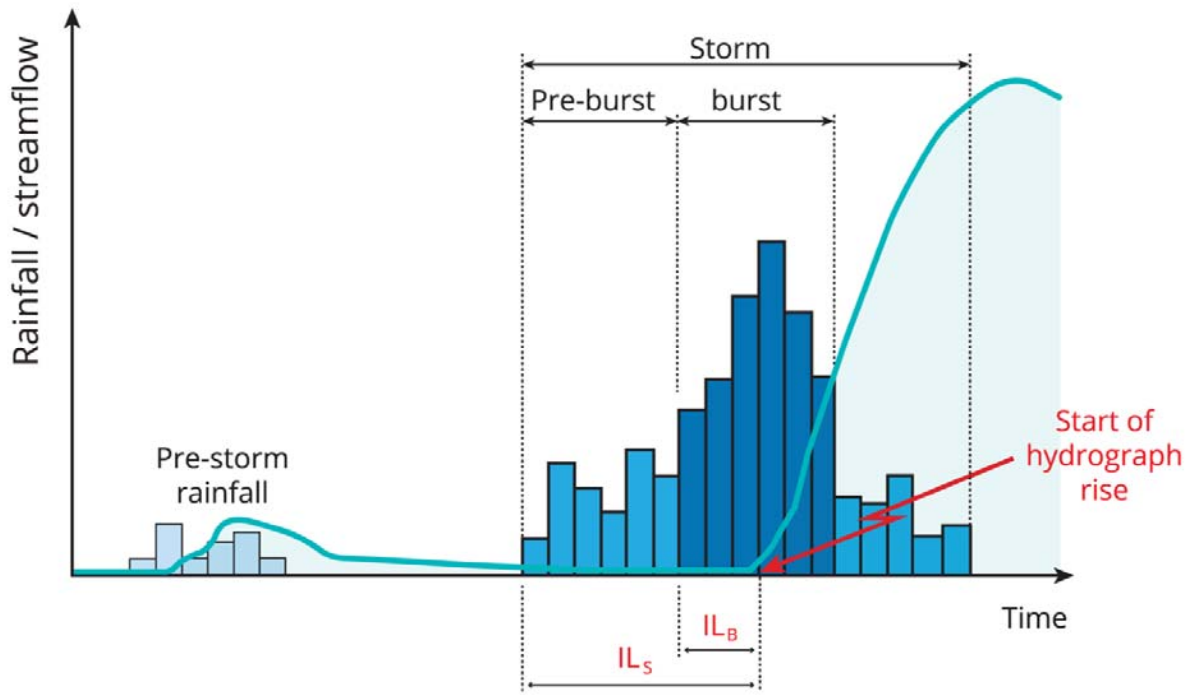

Figure 1 Storm Losses (Figure 5.3.5, ARR 2016)

The ARR Data Hub pre-burst losses are supplied for storms with a minimum duration of 1 hour. There is no clear guidance in ARR as to how 1 hour storm losses should be applied to storms of shorter duration. The original MIDIS methodology applied the 1 hour media pre-burst losses directly to storm durations less than 1 hour. If burst losses were negative (due to high pre-burst loss values), then no losses were applied to that storm duration.

The rainfall losses derived by ARR Data Hub are for use in rural areas only, and are not to be applied to urban areas. A method for determining suitable rainfall losses to use in urban areas, and how this should be applied to the MIDIS was therefore required.

1.2. Effective Impervious Area

Not all impervious area is directly connected to the stormwater drainage network, as shown in Figure 2. The areas that are directly connected, such as rooves and roads, are known as directly connected impervious area (DCIA). Indirectly connected areas, such as garages and driveways, are known as indirectly connected impervious area (ICIA). DCIA and ICIA combined is the total impervious area (TIA).

The effective impervious area (EIA) is the area which provides a rapid runoff response. The terms EIA and DCIA were often considered interchangeable, but ARR research has found that EIA is approximately 70 percent of DCIA. This could be due to blockages and overflows of connections to the stormwater drainage network. The relationship between TIA and EIA is important in determining how much runoff volume will be generated during a storm event. ARR recommends an

EIA/TIA ratio of between 55 and 65 percent. Use of TIA to estimate runoff volume is considered to be overly conservative.

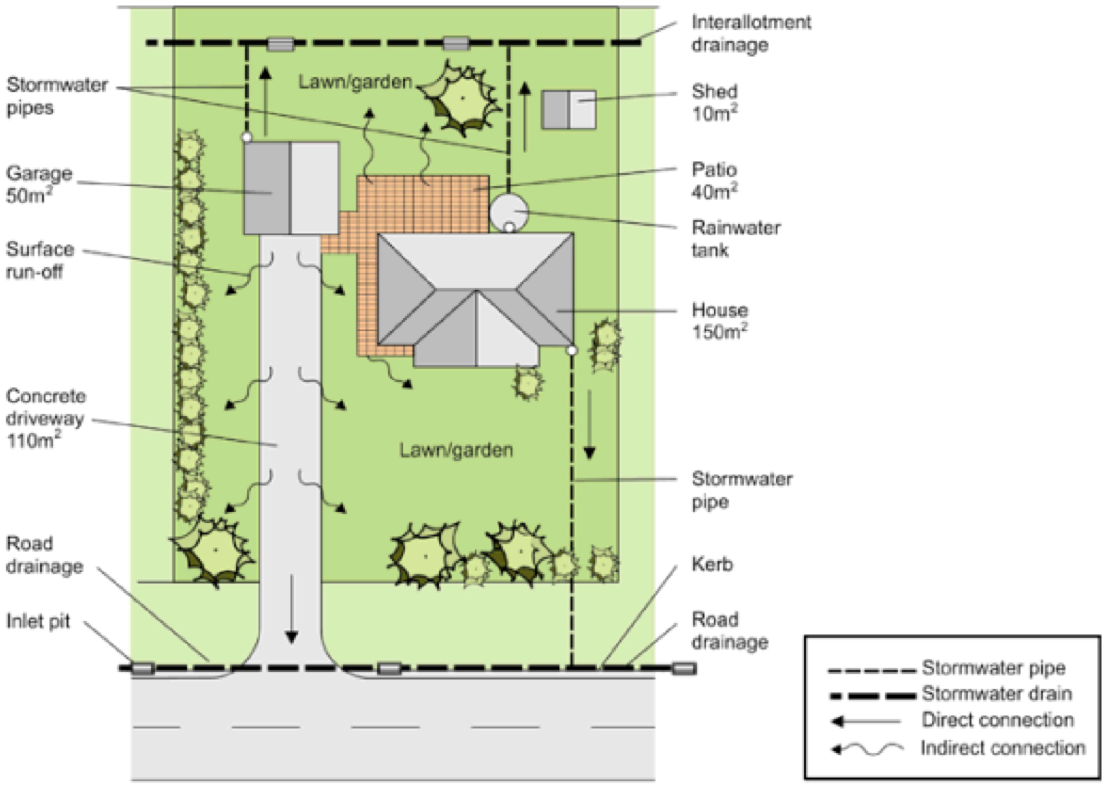

Figure 2 Effective Impervious Area (Sydney Catchment Authority, 2012)

The EIA/TIA relationship recommended for use by ARR was developed from regression analysis of gauged runoff and rainfall data from 8 catchments in Australia. The catchments were characterised by low to medium density urban areas, and are not considered to be typical of the higher density developments currently being constructed on the Sunshine Coast. The sole Queensland catchment was not used in the final ARR analysis due to the questionable reliability of the data.

International studies which incorporated catchments with higher fraction impervious values recommended a power EIA/TIA relationship rather than linear EIA/TIA relationship, such as:

Equation 1: $EIA = 0.15TIA^{1.41}$ (Alley and Veenhuis, 1983)

Given the lack of available data used by ARR, and that catchments with more impervious surfaces are likely to have more directly connected drainage, with less opportunity for infiltration, a modified power relationship has been proposed for use. The modified EIA/TIA relationship is provided in Equation 2 below:

Equation 2: $EIA = 0.25TIA^{1.25}$

The EIA and TIA terms in Equation 1 and 2 are expressed in percentages.

The Phillips et al (2014) data used in ARR is plotted in Figure 3 and compared to different methods of estimating EIA. The proposed power relationship in Equation 2 is considered to provide a reasonable fit to available Australian data and a more realistic estimation of the behaviour of highly impervious catchments. For example, a catchment with a TIA of 90 percent would have an EIA of 69.3 percent using Equation 2. If the linear ARR relationship was adopted the EIA value would be 49.5 to 58.5 percent.

ARR determined that EIA was around 70 percent of DCIA, based on low to medium density urban catchment. This is similarly expected to be a larger percentage for higher density developments.

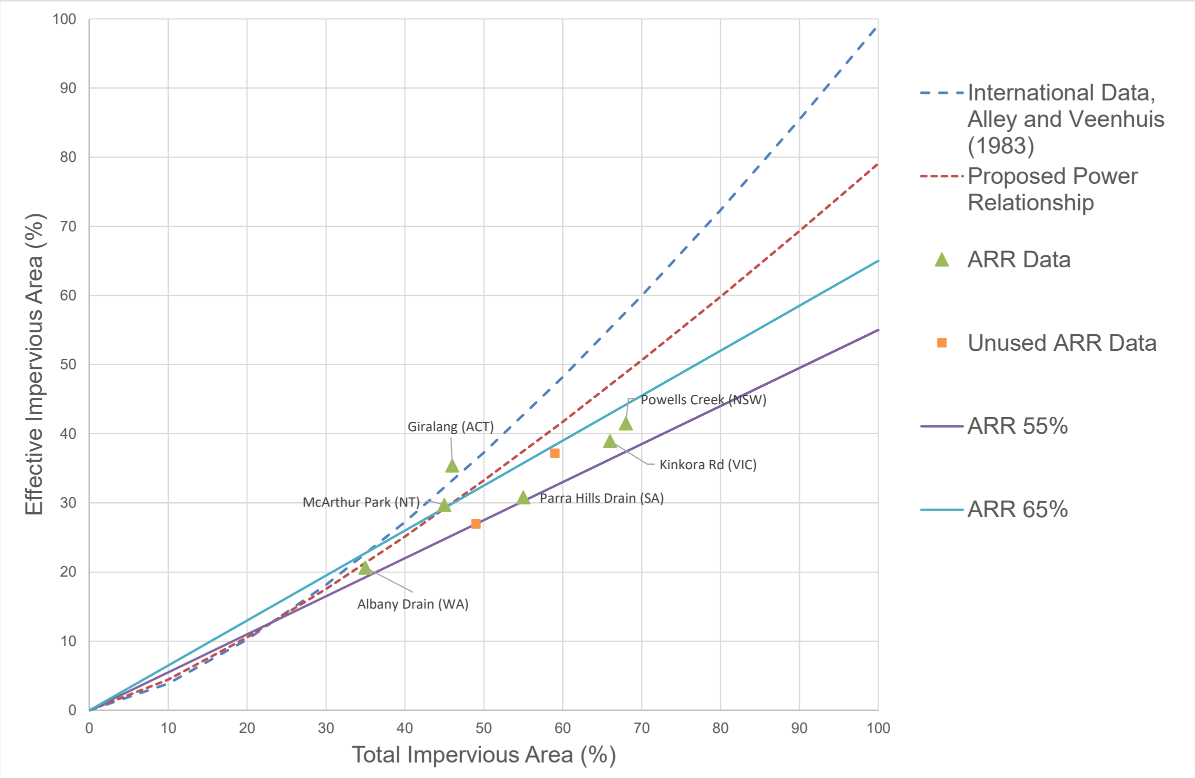

Figure 3 Proposed EIA/TIA Relationship compared to ARR Data

The EIA/TIA relationship should only be applied to catchment wide inflows. When designing the stormwater infrastructure and detention requirements for development of a particular site, the TIA value for that site should be used, so that internal infrastructure is not undersized. The actual TIA of the site should also be used in site specific flood impact modelling

1.3. Modified MIDIS

Altering the storm losses in the original MIDIS resulted in inconsistent relationships with peak rainfall intensity. This was due to where the peak in the ensemble patterns occurred. The initial losses typically only effected patterns which had their peaks towards the start of the burst. However, a slight increase in initial loss could start to impact on storms which had their peaks towards the end of the burst, significantly altering the resultant median peak rainfall intensity.

A method of applying more even losses to the ensemble patterns was therefore required in order for a linear relationship between peak rainfall intensity and rainfall losses to be established. This would also provide a more even relationship for different percent impervious values.

The original MIDIS was modified so that for durations less than 1 hour the initial burst loss was interpolated to zero, rather than being equal to the 1 hour initial burst loss. This reduced the magnitude of the initial loss for shorter storms, and so the potential differences between different loss values was minimised, smoothing the behaviour of the MIDIS.

Figure 4 compares the 1% AEP peak rainfall intensities using the two methods, with changes to TIA and initial losses. A linear relationship between TIA and losses was assumed, ranging from

0% losses for the fully impervious scenario and 100% losses for the fully pervious scenario. The relationship between EIA and TIA, as outlined in Section 1.2, should be considered separately.

Figure 4 demonstrates the inconsistent relationship that assuming a constant 1 hour initial burst loss resulted in. There were significant differences in peak rainfall intensity between the 27 and 40mm initial loss scenario if TIA was less than 50%, but negligible difference if the TIA was greater than 50%. Using interpolated losses for shorter duration storms smoothed this relationship.

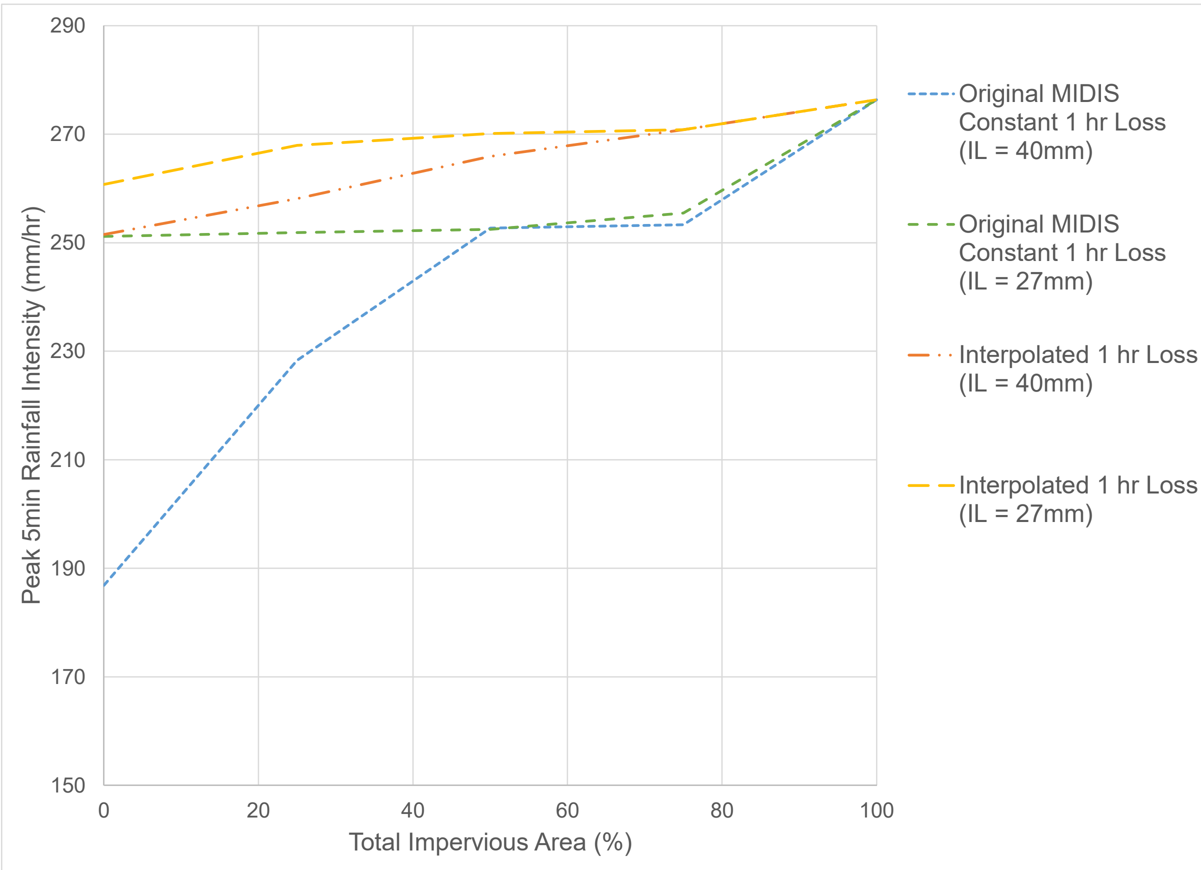

Figure 4 1% AEP Peak Rainfall Intensity with Varying Initial Losses and Initial Loss Method

As a reduced initial loss for shorter duration storms increased the peakiness of the MIDIS and reduced the difference between fully impervious and pervious scenarios, the minimum storm duration used in the formation of the MIDIS was increased to 15 minutes and a factor of 0.85 was applied to the peak 5 minute intensity.

The resultant peak rainfall intensities, compared to the original MIDIS are provided in Figure 5. This figure again demonstrates that there is a smoother relationship with changing TIA with the modified MIDIS. The peak rainfall intensities have been reduced, so that they align better with the original MIDIS, which did not take into account changes to fraction impervious.

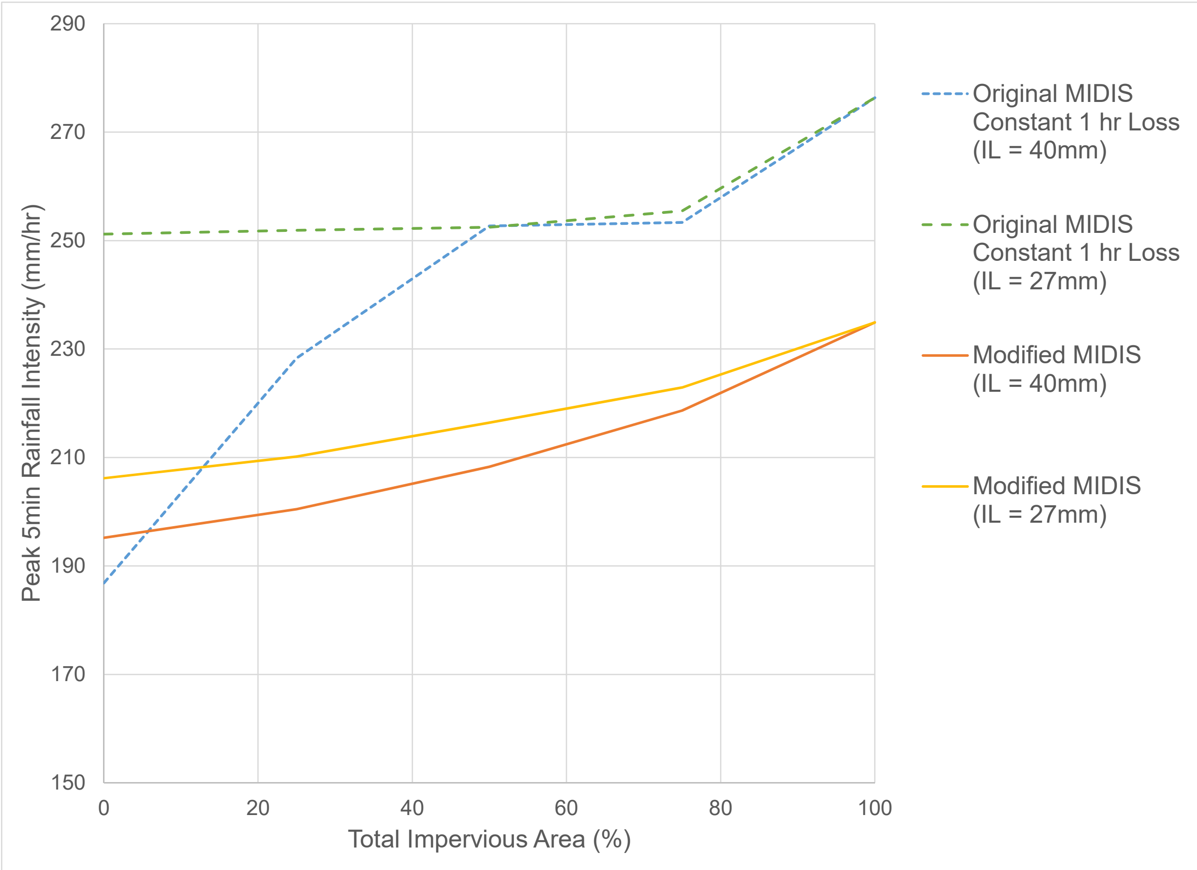

Figure 5 1% AEP Peak Rainfall Intensity Comparison with Modified MIDIS

The resultant 1% AEP peak sub-duration rainfall depths are provided in

Table 1 for 40mm initial loss and 2.4mm/h continuing loss. The original MIDIS peak depths are also provided for comparison purposes.

Table 2 shows the peak depth comparison with 27mm initial loss and 2.7mm/h continuing loss. These two loss scenarios were chosen as they were the values provided by ARR Data Hub for the same location in Nambour over a period of a few months. The ARR Data Hub losses used in the second column assumed that for durations less than 1 hour the burst losses were interpolated to zero.

As demonstrated by Table 1 and 2, the peak rainfall intensities are less sensitive to the initial loss assumption.

Table 1 Sub-duration 1% AEP Peak Depth Comparison, 40mm IL and 2.4mm/h CL

Duration (h)	**1% AEP Peak Sub-duration Rainfall Depth (mm)**				
	Design IFD / DIS	**Design IFD Minus ARR Data Hub Losses**	**Original Constant Loss MIDIS 40mm IL 2.4mm/h CL**	**Modified Interpolated Loss MIDIS 40mm IL 2.4mm/h CL**	**Modified MIDIS No Losses**
0.083	27.0	24.2	15.6	16.3	19.6
0.167	42.5	37.0	27.8	31.1	35.1
0.25	53.6	45.3	36.3	40.6	44.4
0.5	76.8	60.2	54.1	54.1	64.9
1	107.0	73.7	87.5	87.5	95.5
2	149.0	122.9	127.4	127.4	132.9
3	181.0	173.8	167.5	167.5	177.1
6	257.0	242.6	213.7	213.7	228.1
9	317.1	295.5	272.3	272.3	293.9
12	368.0	339.2	306.0	306.0	334.8
24	522.0	464.4	425.7	425.7	494.9
36	625.9	539.5	497.1	497.1	589.1
48	712.0	596.8	561.1	561.1	680.1
72	825.0	652.2	629.8	629.8	825.0

Table 2 Sub-duration 1% AEP Peak Depth Comparison, 27mm IL and 2.7mm/h CL

Duration (h)	**1% AEP Peak Sub-duration Rainfall Depth (mm)**				
	Design IFD / DIS	**Design IFD Minus ARR Data Hub Losses**	**Original Constant Loss MIDIS 27mm IL 2.7mm/h CL**	**Modified Interpolated Loss MIDIS 27mm IL 2.7mm/h CL**	**Modified MIDIS No Losses**
0.083	27.0	25.3	20.9	17.2	19.6
0.167	42.5	39.1	34.4	32.4	35.1
0.25	53.6	48.5	39.4	41.4	44.4
0.5	76.8	66.5	58.9	58.9	64.9
1	107.0	86.4	91.8	91.8	95.5
2	149.0	135.3	127.2	127.2	132.9
3	181.0	172.9	166.3	166.3	177.1
6	257.0	240.8	211.9	211.9	228.1
9	317.1	292.8	269.6	269.6	293.9
12	368.0	335.6	302.4	302.4	334.8
24	522.0	457.2	418.5	418.5	494.9
36	625.9	528.7	486.3	486.3	589.1
48	712.0	582.4	545.8	545.8	680.1
72	825.0	630.6	601.9	601.9	825.0

The resultant hyetographs for the peak 6 hours of the modified MIDIS are shown below in Figure 6. An initial loss of 40mm and continuing loss of 2.4mm/h was assumed for the fully pervious hyetograph. An initial loss of 1mm and continuing loss of 0mm/h was assumed for the fully impervious hyetograph.

Close inspection of some of the time steps leading up to the peak that the pervious intensities are slightly higher than the impervious rainfall intensity. This is due to the non-linear variation in maximum medians between different durations used to set up the MIDIS. For example, as shown in Table 1 the difference in peak rainfall is 3.3mm for the peak 5 minutes, 4mm for the peak 10 minutes and 3.8mm for the peak 15 minutes. The total peak rainfall for each sub-duration is always higher in the impervious hyetograph than it is in the pervious hyetograph. The negative differences were typically more pronounced in the original MIDIS. The negative differences have not been observed to result in model anomalies. However, as this could potentially occur, the pervious hyetograph has been reduced to the impervious hyetograph for the affected time steps. The resultant sub-duration depths are shown in Table 3. The resultant corrected MIDIS hyetographs are shown in Figure 7.

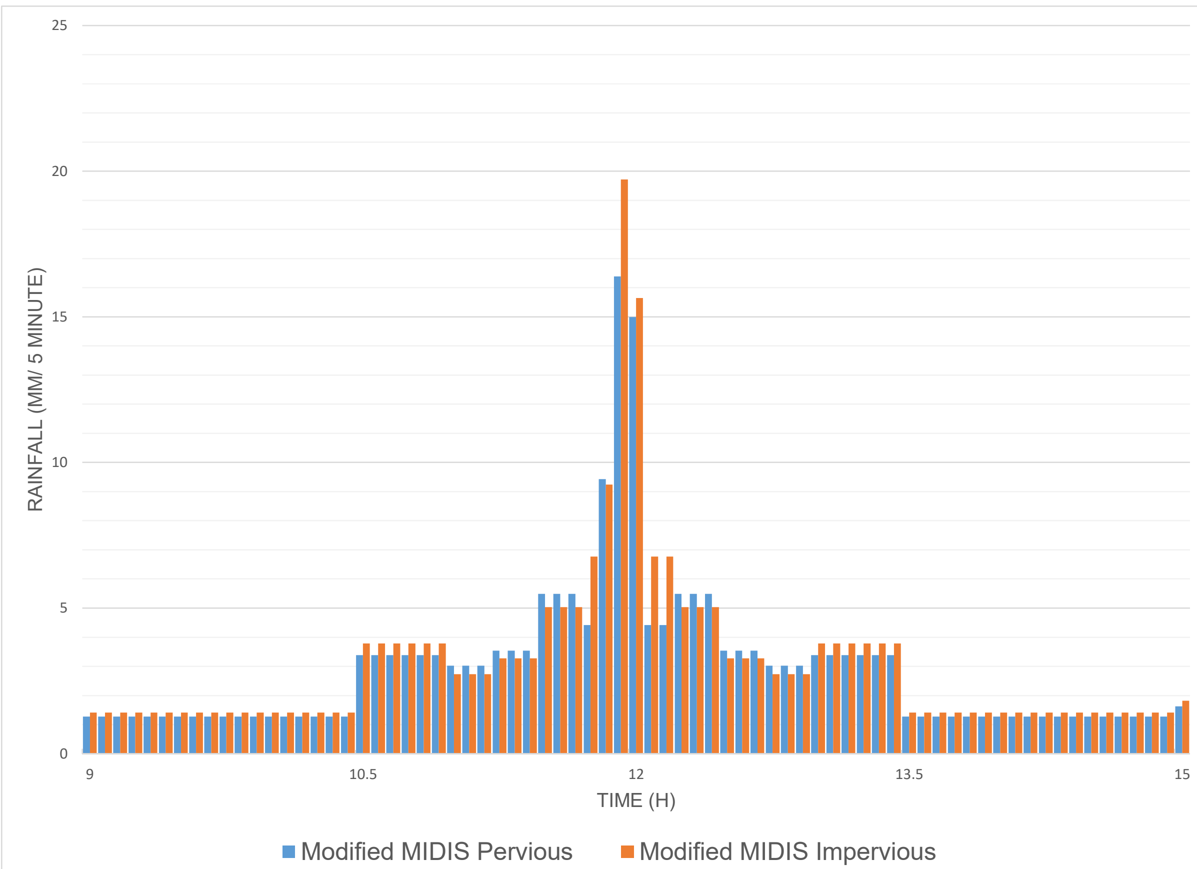

Figure 6 MIDIS hyetographs without correction

Table 3 Pervious Sub-duration 1% AEP Peak Depth Comparison, 40mm IL and 2.4mm/h CL

Duration (h)	1% AEP Peak Sub-duration Rainfall Depth (mm)				
	Design IFD / DIS	**Design IFD Minus ARR Data Hub Losses**	**Original Constant Loss MIDIS 40mm IL 2.4mm/h CL**	**Modified Interpolated Loss MIDIS 40mm IL 2.4mm/h CL**	**New MIDIS 40mm IL 2.4mm/h CL**
0.083	27.0	24.2	15.6	16.3	16.3
0.167	42.5	37.0	27.8	31.1	31.1
0.25	53.6	45.3	36.3	40.6	40.4
0.5	76.8	60.2	54.1	54.1	54.0
1	107.0	73.7	87.5	87.5	84.5
2	149.0	122.9	127.4	127.4	121.6
3	181.0	173.8	167.5	167.5	161.3
6	257.0	242.6	213.7	213.7	207.5
9	317.1	295.5	272.3	272.3	266.2
12	368.0	339.2	306.0	306.0	299.8
24	522.0	464.4	425.7	425.7	419.6
36	625.9	539.5	497.1	497.1	491.0
48	712.0	596.8	561.1	561.1	555.0
72	825.0	652.2	629.8	629.8	623.7

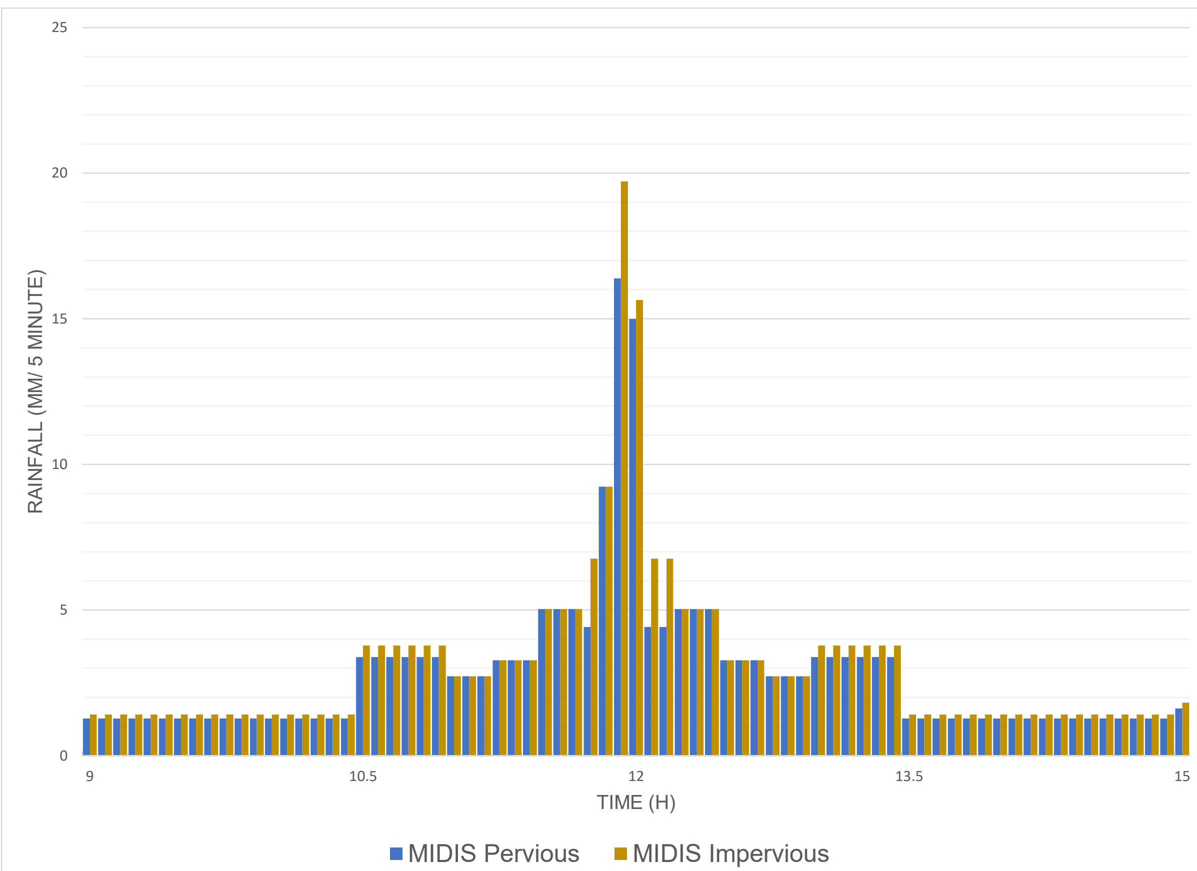

Figure 7 MIDIS hyetographs with correction

2. Runoff Response Time Changes with Urbanisation

2.1. Existing Rainfall on Grid Methods

The MIDIS method will be used by SCC for Master Drainage Studies (MDS) in order to help determine the potential impact of development. The MIDIS with no losses will be used on effective impervious areas, the area of which should be calculated using Equation 2.

Equation 2: $EIA = 0.25TIA^{1.25}$

Previous MDS investigations using the standard DIS or MIDIS method with rainfall on grid have resulted in negligible differences in peak flows with changing levels of development. As the hyetograph is centrally peaked, changing the initial or continuing losses with standard DIS or MIDIS did not significantly alter the peak rainfall intensities. Other methods of representing changes to development, such as altering the topography to remove reduce depression storage, or changing roughness values, were observed to have unintended consequences such as re-direction of flow, or reduction in peak water surface levels.

With the use of modified MIDIS hyetographs, the increase in runoff intensity and volume resulting from changes to development will be able to be directly captured.

2.2. Effective Impervious Flow Areas

A method to better represent the changes to effective impervious area in MDS investigations was also developed. This method, known as the Effective Impervious Flow Area (EIFA) method aims to direct rainfall falling on effective impervious areas directly to defined flow paths, speeding up the catchment response time. This method will be more representative of internal allotment drainage, which directs roof and pavement runoff to the kerb. The remaining pervious surface and non-effective impervious surface rainfall will be applied across the balance of the catchment.

This EIFA method will allow for more concentrated inflows while maintaining the advantage of rainfall on grid modelling. This should minimise issues usually observed with standard rainfall on grid modelling approaches, as discussed in Chapter 6 of Book 9 of ARR (Geoscience Australia, 2019).

A typical method of defining appropriate overland flow paths, to which effective impervious areas will be directly drained to, is provided in Appendix A.

After the overland flow paths have been defined, the model will be refined to include underground drainage and sub-catchments.

The rainfall on grid modelling process that is proposed to be used for future MDS investigations is outlined below:

Step 1. Use the MIDIS spreadsheet to create suitable hyetographs for 0% and 100% impervious catchments for all AEPs. Use initial and continuing losses as specified by ARR Data Hub for the 0% impervious hyetographs. For the 100% impervious area use 1mm and 0mm/h initial and continuing losses.

Step 2. Run the whole catchment model with the 1% AEP 100% impervious hyetograph. The model should not include any underground drainage or blocked out buildings. No pre-filtering of results should be conducted in TUFLOW, i.e. the entire active model area should have results output.

Step 3. Filter the resultant 1% AEP flow paths based on SCC Method (refer Appendix A). Modify SCC default parameters if required for your study area. These flow paths will be used in the next steps to define where effective impervious areas will drain to.

Step 4. Divide model extent into sub-catchments based on terrain, land use zones and the flow paths determined in Step 3. If a land use zone does not contain an overland flow path, combine it with the neighbouring catchment that it drains to or extend the sub-catchment to a suitable inflow point. Name each sub-catchment. Roads are to be included in the same sub-catchment as the surrounding land use.

Step 5. Use the overland flow path extent determined in Step 3 to determine the region of each sub-catchment where effective impervious areas should drain to. They will be referred to as effective impervious flow areas. The remainder of the sub-catchment will have the pervious surface and non-effective impervious surface area drained to it. They will be referred to as pervious flow areas. For example, in ArcGIS the sub-catchments would be divided using the Split Polygons command based on the overland flow path extent layer. If the split creates multiple regions in a sub-catchment these should be merged so that each sub-catchment contains only two regions covering the entire sub-catchment – the effective impervious inflow region and remaining pervious inflow region. For example, the highlighted region in the Figure 8 is the merged pervious inflow regions for sub-catchment G. The split sub-catchments should be renamed so that impervious and pervious regions are evident.

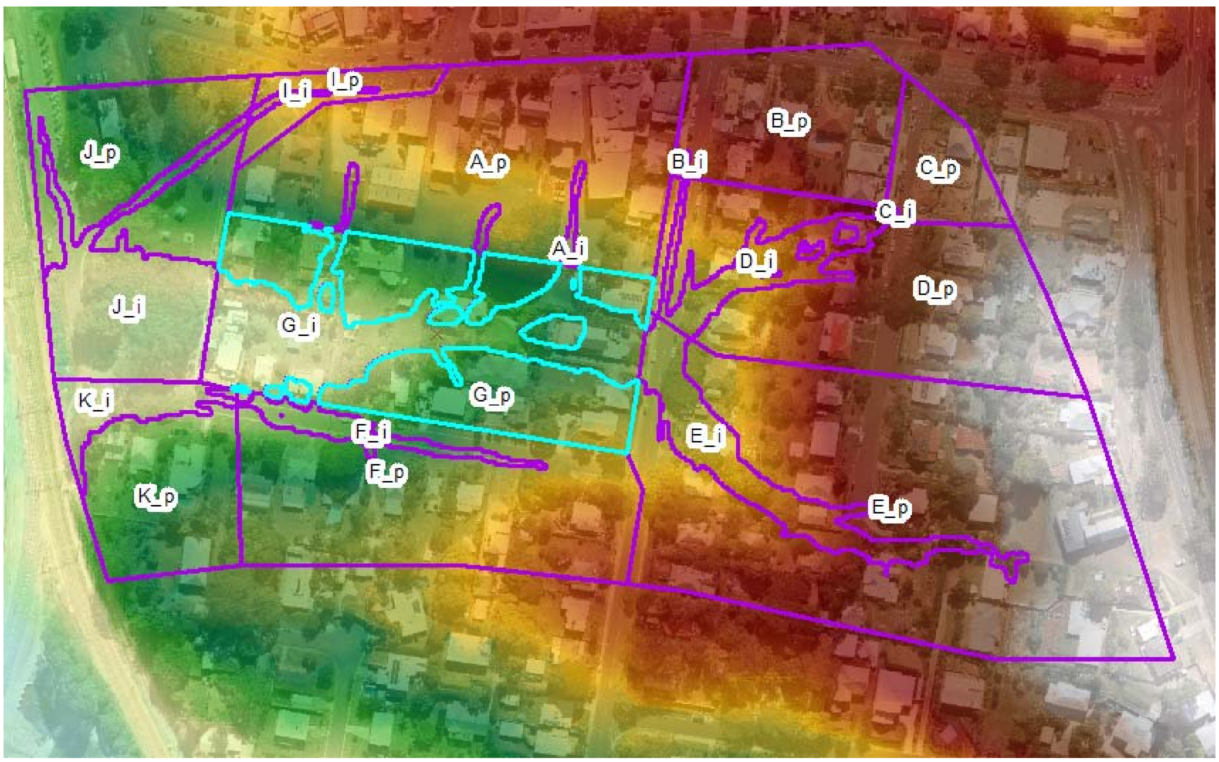

Figure 8 Split Sub-catchments Examples

Step 6. The areas of each sub-catchment region should be determined and the regions should be converted to 2d_sa_rf polygons in TUFLOW. The Catchment_Area parameter (area is in m²) in the 2d_sa_rf layer should be modified so that it relates to the effective impervious or remaining area (pervious and non-effective impervious) of each sub-catchment, not the actual area of the polygon. For example, for catchment E, which has a total area of 27,900 m², the actual area of E_i in the image above is 3,330 m², but based on a 40% total impervious value it will be defined as having an effective impervious area of 25.1%, or 7,020 m². Similarly E_p will reduce from 24,570 m² to 20,880 m². The exception to this rule is if the filtered overland flow path area is greater than the effective imperious area in a sub-catchment. In this case, the actual area of the polygons will be used to define the inflow area.

Step 7. The bc_dbase should reference the fully pervious or fully impervious rainfall hyetographs (calculated in Step 1) as appropriate for each sub-catchment. No initial or continuing losses should be applied to the 2d_sa_rf layer as these have already been included in the MIDIS. "Read GIS SA RF ALL" should be specified in the TUFLOW boundary file to ensure that rainfall is distributed evenly to all cells, similar to direct rainfall modelling.

Step 8. Add pipes and pits to model. Buildings are not to be blocked out unless they are known flow blockages. Increased roughness should be used over buildings. This will help ensure that false flow blockages are not created.

Step 9. The pre-development scenario should be based on actual % impervious values as defined by aerial photography, and then this should be converted to effective impervious area based on Equation 2.

Step 10. For the post-development scenario, the 2d_sa_rf layer will be modified so that the % impervious values as specified by SCC's Planning Scheme will be used to define the Catchment_Area parameter (unless this is less than the pre-development scenario). The % impervious values should then be converted to effective impervious area. This will increase the area directly connected to the main flow path, which should reduce the catchment response time and increase peak flow rates. The pervious catchment area will similarly be reduced. The actual area of each sub-catchment will be equal to the total effective impervious and pervious flow areas for the pre and post-development scenarios.

Step 11. Keep the roughness values the same within the effective impervious flow area in the pre and post-development scenarios, unless specific known changes are being made. Roughness changes may be required in areas beyond this extent to reflect the reduced roughness values resulting from development. This should further reduce catchment response time. No additional rainfall losses should be applied in TUFLOW.

Step 12. For mitigation scenarios that modify the location or extent of existing overland flow paths, ensure that the equivalent area is directly drained to the modified flow path.

This methodology was tested on a small 11.6 hectare urban catchment on the Sunshine Coast using a 24 hour long MIDIS. For this test case the railway and road embankment were removed so that conveyance rather than storage would be dominant. The roughness values of the pre-development scenario were modified until good agreement with the SCC Peak Flow Estimation Method (SCC, 2018) was reached. No changes to the roughness values were made for the post-development scenario. The proposed rainfall on grid method resulted in increases in peak flows and reductions in travel time of the peak, due to an increase in catchment imperviousness. The results are summarised in Table 4. The travel time of the peak was calculated as the difference between the time of peak flow and the time of peak rainfall (TTPP). Due to the small size of the study area, the use of rainfall on grid modelling, the direct connection of effective impervious area and the antecedent rainfall prior to the peak, the TTPP is less than 5 minutes.

If necessary, additional Manning's n roughness changes beyond the extent of the EIFA could be made in order to better replicate the impact of development.

Table 4 MIDIS EIFA Rainfall on Grid Results Comparison

Scenario	% TIA	1% AEP Peak Flow (m^3/s)		Catchment Response (min)	
		SCC Peak Flow Estimation Method	**MIDIS EIFA Rainfall on Grid Method**	**SCC Peak Flow Estimation Method Time of Concentration**	**MIDIS Rainfall on Grid Method TTPP**
Pre Development	50.5	5.93	5.94	19	3
Post Development	77.0	6.47	6.30	16	2
% Increase		9.1	6.1		

The length of the MIDIS pattern used can be shortened to reduce simulation times. A rule of thumb is that the storm length should be at least 10 times the time of concentration calculated using the SCC Peak Inflow Estimation Method. Checks should be conducted the peak water surface level within the model extent are identified.

A sensitivity analysis was conducted on the impact of the MIDIS duration. The 3 hour compared to the 24 hour MIDIS results are shown below. As this figure demonstrates, for this conveyance dominated network, the differences in peak water level were negligible.

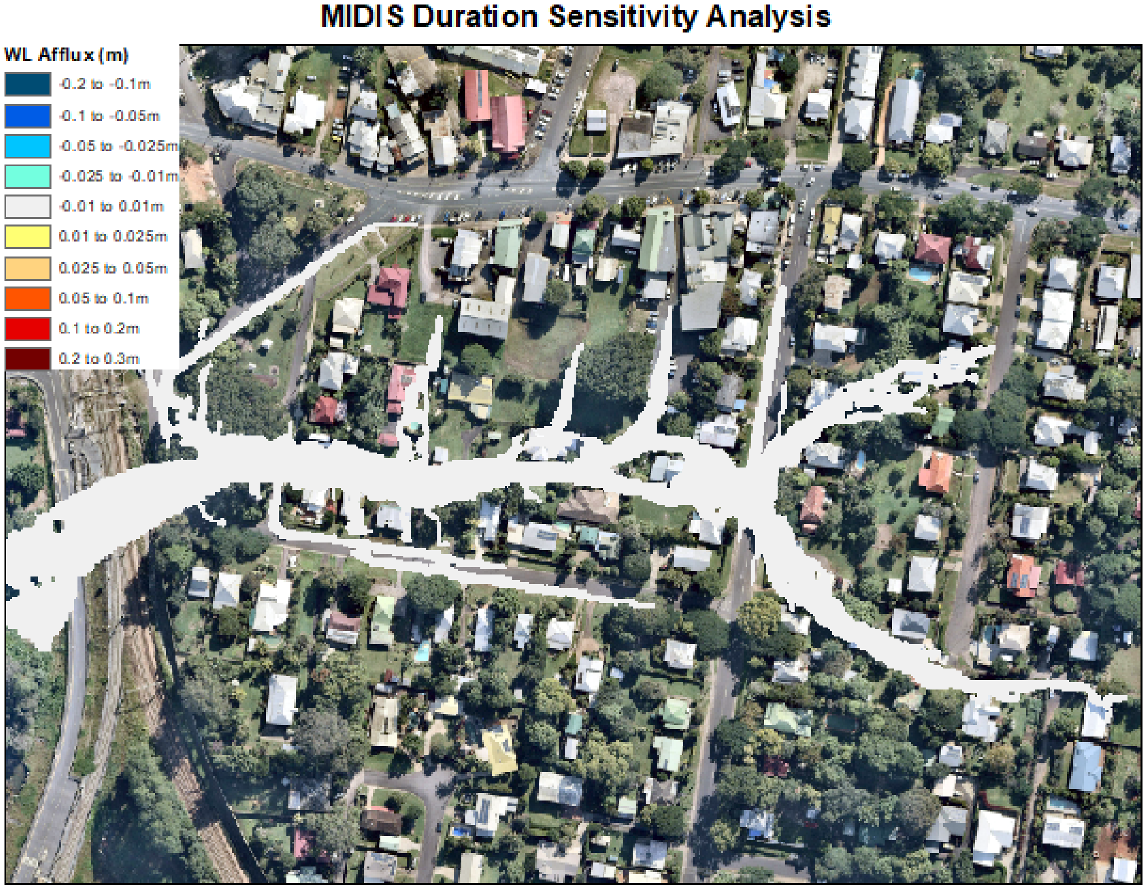

Figure 9 MIDIS Duration Sensitivity Analysis

2.3. Catchment Volume Checks

The flow volumes entering and leaving the model should be checked to ensure that the model has been properly primed. If there are numerous local trapped depressions in the topography, flows can be captured, overestimating the losses that would occur, and reducing the resultant peak flow rates.

If the total volume of flow leaving the model is within 5% of the total volume entering the model, the model is suitable for use. If the difference is greater than 5%, a restart file should be used. The restart file should adequately fill all local trapped depressions, and should help to ensure that rainfall losses are not overestimated.

2.4. Lumped Inflows

Where lumped inflows are used in hydraulic modelling for external catchments greater than 2 hectares, a separate hydrology model should be set up for these areas. The results of the hydrology model should be compared to the results obtained using the SCC Peak Flow Estimation Method (SCC, 2018), and adjustments should be made until suitable agreement is reached.

Where lumped inflows are used for catchment areas less than 2 hectares, separate 2d_sa_rf inflow regions will be required for each catchment, representing the effective impervious and pervious areas.

2.5. Peak Flow Checks

Care should be taken with the selection of comparison flow line locations when conducting checks with the SCC Peak Flow Estimation Method. For locations which are storage rather than conveyance dominated, or if located downstream of a detention basin, peak flows can be significantly reduced.

The test case was modified to reinstate the railway and road embankment. Due to the storage provided upstream of the embankment, the 1% AEP peak flow at the comparison point reduced from 5.95m^3/s to 2.75m^3/s.

3. ARR2016 Ensemble Sensitivity Analysis

3.1. Rainfall Losses

As discussed previously, ARR did not give specific guidance to the initial burst losses that should be used for storms with a duration of less than 1 hour. The recent release of Book 9 of ARR suggests that the 1 hour pre-burst rainfall should be used with burst rainfall ensembles of durations less than 1 hour (Table 9.6.5, Geoscience Australia, 2019).

There are multiple methods currently being used by the industry. The two most common rainfall loss methods were therefore analysed:

- Interpolated to zero 1 hour burst losses
- Constant 1 hour burst losses (ARR Book 9 approach)

For durations longer than 1 hour the same losses were assumed in both methods.

The interpolated loss approach means that less rainfall will be removed for shorter duration storms, resulting in higher rainfall intensities and more runoff. The constant loss approach often removes the majority of the burst rainfall for shorter duration storms, resulting in lower rainfall intensities and less runoff for these storm durations.

The interpolated loss approach is applied to the 1 hour burst loss. Methods that interpolate the 1 hour pre-burst to zero should be avoided as these can result in burst losses higher than the 1 hour burst loss, removing the majority of the burst rainfall for short duration events.

3.2. Scenarios and Ensembles Analysed

The same pre-development and post-development scenarios set up for the MIDIS EIFA method were analysed. No changes to roughness values were made. The only difference was the rainfall hyetographs referenced for the impervious and pervious inflow areas. The EIFA methodology was also adopted for the ARR ensemble analysis, based on the inflow boundaries that were previously developed using the MIDIS.

For pervious areas an initial storm loss of 40mm and continuing loss of 2.4mm/h was applied. For impervious areas an initial storm loss of 1mm and continuing loss of 0mm/h was applied.

The median pre-burst depths from ARR Data Hub for different durations were used to set up the hyetographs.

All ensemble patterns were modelled for durations ranging from 10 minutes to 6 hours. This resulted in a total of 110 storms for each scenario and AEP. The median for each storm duration was then used to determine the maximum of the medians.

This approach ensured that the maximum median (Rank 6) water surface level was identified for the entire study area.

3.3. Peak Flow Results

The peak flows that resulted in the maximum median (Rank 6) and maximum mean peak flow at the downstream end of the model have been identified in Table 5.

As this table shows, the interpolated loss approach resulted in the 10 minute storm duration being critical for this small catchment. The resultant peak flows were considerably higher than those calculated using the SCC Peak Flow Estimation Method and the MIDIS EIFA results. This is due to the relatively small burst losses used for short duration events resulting from the interpolated loss method. There was no difference in critical storm duration between the pre and post-development scenarios. The same temporal pattern resulted in the median for both scenarios. The percentage difference in peak flow was less than the MIDIS method using the median, and similar when using the mean.

Table 5 ARR Ensembles Peak Flow Comparison

Scenario	% TIA	1% AEP Peak Flow (m^3/s)					
		SCC Peak Flow Estimation Method	MIDIS EIFA Rainfall on Grid Method	ARR Ensembles Maximum Mean		ARR Ensembles Maximum Median	
				Interpolated Loss Approach	Constant Loss Approach	Interpolated Loss Approach	Constant Loss Approach
Pre Development	50.5	5.93	5.95	7.00 (10min)	5.39 (30min)	7.07 (10min, TP7)	5.55 (30min, TP7)
Post Development	77.0	6.47	6.31	7.42 (10min)	5.87 (30min)	7.37 (10min, TP7)	5.87 (15min, TP2)
% Increase		9.1	6.1	6.0	8.9	4.2	5.8

** TP – ARR Temporal Pattern Number*

With the maximum mean, the constant loss approach resulted in the 30 minute storm being critical for the pre and post-development scenarios. The difference in peak flows between the scenarios was the closest to the SCC Peak Flow Estimation Method of all the modelling approaches.

With the maximum median, the constant loss approach resulted in the 30 minute storm being critical for the pre-development scenario and the 15 minute storm being critical for the post-development scenario at the downstream end of the model. For the 30 minute storm duration in the post-development scenario, the median peak flow was only increased from 5.55 to 5.77m^3/s, and a different temporal pattern (TP8) was the median. This demonstrates that it is important to model a range of storm durations and temporal patterns when analysing the impact of development using ARR ensembles.

With the constant loss approach the resultant peak flows were less than those calculated using the SCC Peak Flow Estimation Method and the MIDIS EIFA results. This is due to the high burst losses used for short duration events.

The difference in the resultant peak water surface levels between the peak mean and medians was typically less than 5mm.

Based on the peak flow comparison, the MIDIS EIFA method resulted in a good compromise between the two loss methods, and provides a less complicated method of assessment. The peak flows and water levels for small catchments are highly sensitive to the loss method used in the ARR ensemble derivation.

3.4. Peak Water Level Results

The difference in peak water levels between different scenarios and different approaches was analysed. The maximum median was used for the ARR ensemble results.

The difference in peak water levels between the two development scenarios for the three different modelling approaches is shown in Figures 10, 11 and 12. As shown by these figures, the results are most similar in the MIDIS and ARR constant loss approach. There was minimal increase in peak water levels using the ARR interpolated loss approach.

The difference between modelling approaches for the pre-development scenario was also analysed. Figure 13 shows that the MIDIS resulted in peak water levels that were typically around 15 to 40mm lower than the ARR interpolated loss approach.

Figure 14 shows that the MIDIS resulted in peak water levels that were typically around 5 to 20mm higher than the ARR constant loss approach.

The differences in peak water surface levels between different ARR scenarios using the mean rather than the median was also reviewed. This water surface profile was calculated using TUFLOW utilities, and is the maximum of the average peak water surface levels for each duration. The extent of impacts was slightly more extensive than those shown in Figures 11 and 12.

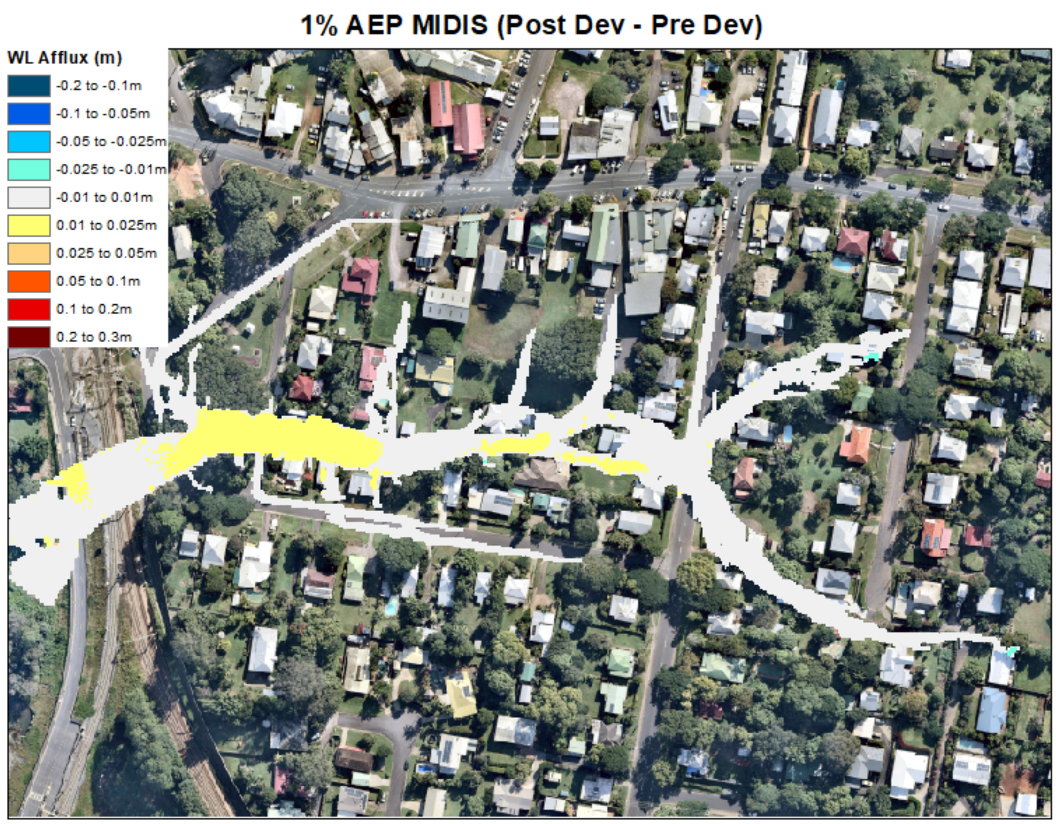

Figure 10 MIDIS - Post Development Peak Water Level Afflux

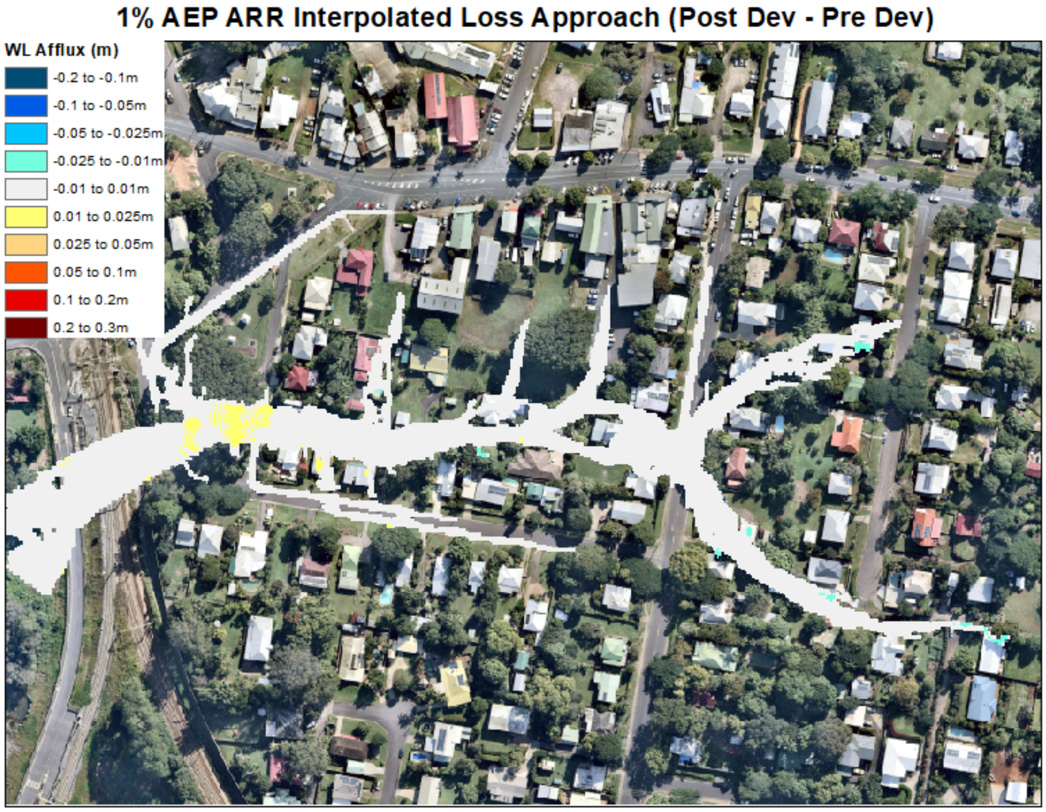

Figure 11 ARR Interpolated Loss Approach – Post Development Peak Water Level Afflux

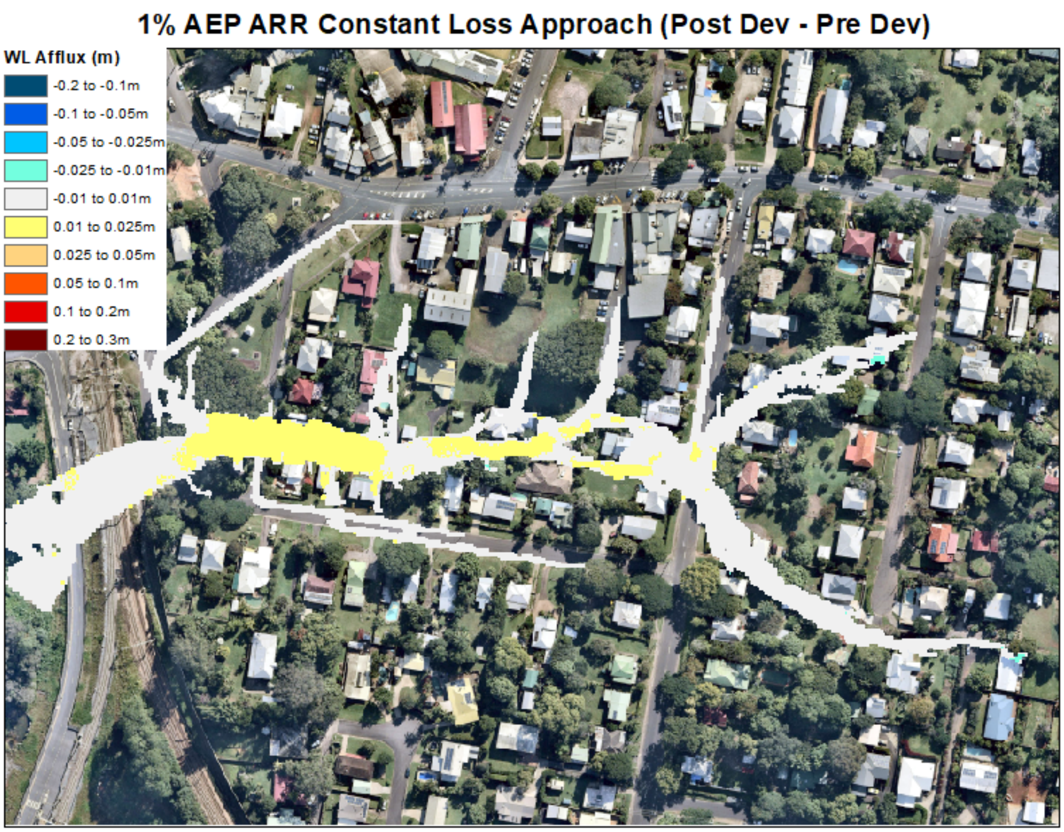

Figure 12 ARR Constant Loss Approach – Post Development Peak Water Level Afflux

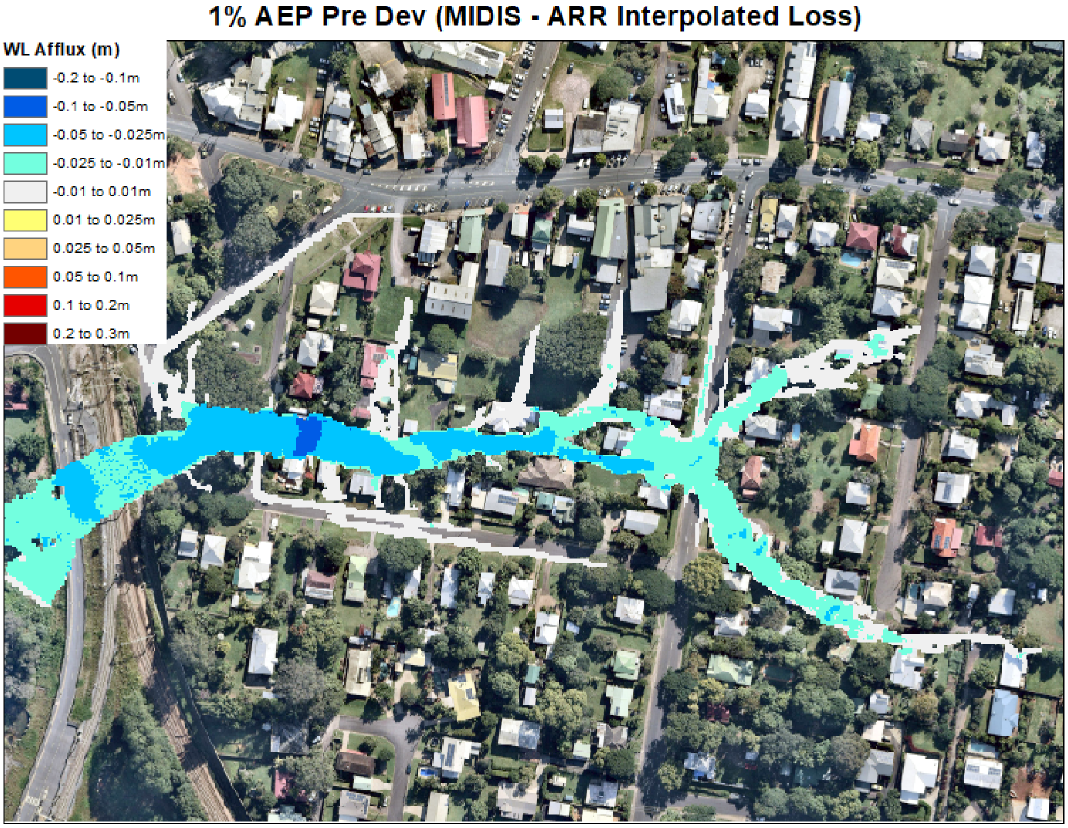

Figure 13 MIDIS results compared to ARR Interpolated Loss Approach

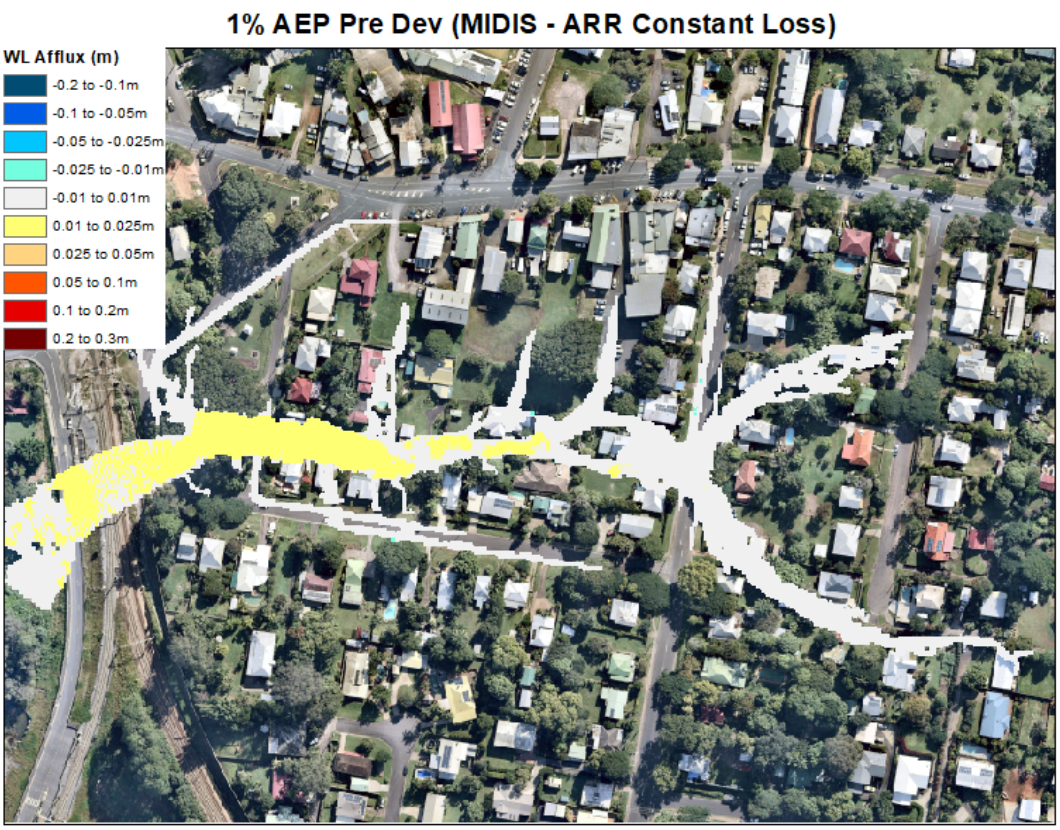

Figure 14 MIDIS results compared to ARR Constant Loss Approach

3.5. Storage Dominated Networks

The test scenario with the embankment in place was analysed using the ARR ensembles using the constant loss approach.

The results showed that the event that resulted in the maximum median peak water levels at the downstream section of the model changed from the 30 minute TP7 to the 3 hour TP3 or TP6. This confirms the importance of running multiple storm durations and temporal patterns when conducting the ARR ensemble analysis.

It should also be recognised that the event that results in the maximum median peak flow in a hydrologic analysis is not always the event that provides the maximum median peak water level in the hydraulic analysis.

The MIDIS EIFA results were compared to the ARR constant loss approach results with the embankment in place. The peak water levels were within -10 to 15mm of each other, as shown below in Figure 15. This demonstrates that the MIDIS EIFA method provides a good representation of peak water levels when either conveyance or storage is dominant.

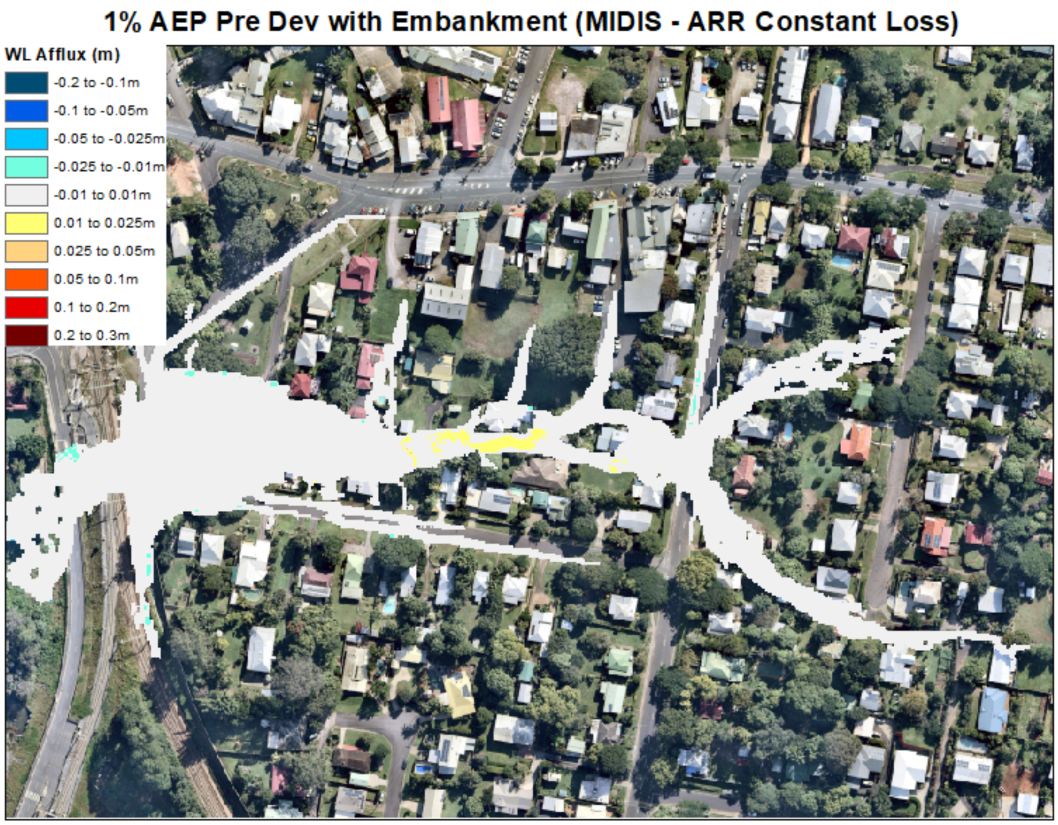

Figure 15 MIDIS results compared to ARR Constant Loss Approach in Storage Dominated Scenario

3.6. ARR Ensemble Sensitivity Analysis Conclusions

The results demonstrate that the MIDIS peak water level results compare relatively well to both the ARR ensemble maximum median and both the ARR ensemble maximum mean. It also provides a good compromise between the two ARR ensemble loss methods. The interpolated loss method results in higher peak flows and water levels, but does not sufficiently model the impact of development. The constant loss method can slightly underestimate peak water levels and flows, particularly for small catchments, due to the high initial loss values used. However, it does model well the impact of development. The MIDIS approach results in peak water levels and flows within the range of the two ARR loss methods and sufficiently models the impact of development.

The peak water levels and flows obtained using the ARR ensembles are highly sensitive to the loss approach used. They are not as sensitive to whether the mean or median is adopted.

The maximum mean rather than the maximum median is recommended for use in flood impact modelling. However, if this is not able to be easily calculated, the median is sufficient.

In order to ensure that the correct peak water surface is derived for all development scenarios for all parts of the catchment, the full ARR ensemble for sufficient durations is recommended to be modelled hydraulically.

The ARR interpolated burst loss approach is not recommended for use as it does not sufficiently account for the increase in impervious area.

The MIDIS EIFA approach is considered to provide a good representation of peak water levels and flows when compared to ARR ensemble analysis in both conveyance and storage dominated systems. Given that it requires significantly less computational effort and allows for simplified assessment of results, it is considered to be a sensible method for practical and efficient flood modelling.

4. Catchment Wide On-Site Detention Modelling

Another challenge of catchment wide rainfall on grid modelling is how to incorporate the effect of on-site detention (OSD). OSD aims to attenuate the peak flows back to pre-development levels, but the total volume of flow being discharged will still be increased (unless stormwater harvesting or other measures to increase infiltration, which are encouraged by SCC, are incorporated on site). The peaks after detention will also generally occur more quickly than in the pre-development scenario due to the increase in effective impervious area.

Previous methods of rainfall on grid modelling have used the following techniques to incorporate on-site detention:

1. Using pre-development hyetographs
2. Providing conceptual on-site detention at critical locations.

The first method does not account for the increased volume of runoff. The second method relies on subjective and complex model set up and requires numerous assumptions to be made, e.g. the size of OSD outlets and the location of OSD.

The proposed catchment wide OSD rainfall on grid modelling method is to use the pre-development inflows, but add additional flow, equivalent to the rainfall losses, to the effective impervious flow area. The additional inflow will ensure that the post-development total flow volume is maintained. By directing the additional inflow to the effective impervious flow area the TTPP may also be slightly reduced.

The area of the 2d_sa_rf polygons representing the remaining losses will be difference in effective impervious area between the pre and post-development scenarios.

The catchment wide OSD rainfall on grid modelling process is outlined in the following steps:

Step 1. Convert the impervious hyetograph total minus the pervious hyetograph total to a constant rate hyetograph. For example, if the difference in total rainfall between your impervious and pervious areas is 48mm over 24 hours, this will become a hyetograph with a rate of 2mm/hr or 0.1667mm/5 minutes. The result will be referred to as the remaining loss (RL) hyetograph.

Step 2. Copy the 2d_sa_rf effective impervious flow area regions to a new layer with RL in the title. Rename each region with an appropriate identifier, e.g. E_rl. In the bc_dbase add these new inflow polygons and ensure that they reference the RL hyetograph.

Step 3. Calculate the Catchment_Area parameter for each RL inflow region. It will be the difference between the post-development and the pre-development effective impervious area. Delete any regions that have zero area. There will now be three inflow regions for each sub-catchment with OSD (e.g. E_i, E_p and E_rl). The combined area of the three regions will be greater than the actual area of the sub-catchment.

Step 4. If no changes to inflow locations have been made, modify your boundary control file so that the OSD scenario uses the pre-development 2d_sa_rf layers and the RL 2d_sa_rf layer.

Step 5. If there have been changes to the inflow locations in the post-development scenario, use these modified inflow locations but change the Catchment_Area parameters so that the pre-development values are used. Modify your boundary control file so that the OSD scenario uses this new 2d_sa_rf layer and the RL 2d_sa_rf layer.

The results with OSD are shown in Table 6. As this table demonstrates, the peak flows from the OSD scenario are similar to the pre-development case, and the volume of flow is almost equal to the post-development scenario (the slight difference is most likely due to the adaptive time step used in HPC modelling).

Table 6 OSD Rainfall on Grid Results Comparison

Scenario	1% AEP Peak Flow (m^3/s)	Total Flow Volume (m^3)	TTPP (min)
Pre Development	5.94	55,390	3
Post Development	6.30	57,107	2
With On-site Detention	5.97	57,122	3

The catchment wide OSD rainfall on grid modelling approach does not calculate how much detention storage is required. It is assumed that this will be calculated separately, or reference made to the *Flooding and Stormwater Management Guidelines* (SCC, 2018).

The catchment wide OSD rainfall on grid modelling approach also does not connect runoff directly to the stormwater drainage network, which may be required. Alternative methods of directing flow to the 1D network may be necessary.

This catchment wide OSD approach should not be used for sizing site specific OSD.

There may be situations, for example when existing drainage is deficient and upgrades are unfeasible, where over-attenuation with OSD is required, rather than the returning peak flows to the pre-development scenario. For this situation the following steps should be taken:

Step 1. Copy the pre-development 2d_sa_rf layers and rename pre-existing. If there have been changes to the inflow locations in the post-development scenario, use the post-development 2d_sa_rf as the base for this new layer.

Step 2. Based on the new target effective impervious area, recalculate the impervious and pervious catchment areas in this new layer.

Step 3. Convert the impervious hyetograph total minus the pervious hyetograph total to a constant rate hyetograph. For example, if the difference in total rainfall between your impervious and pervious areas is 48mm over 24 hours, this will become a hyetograph with a rate of 2mm/hr or 0.1667mm/5 minutes. The result will be referred to as the remaining loss (RL) hyetograph.

Step 4. Copy the 2d_sa_rf effective impervious flow area regions to a new layer with RL and **pre-existing** in the title. Rename each region with an appropriate identifier, e.g. E_rl. In the bc_dbase add these new inflow polygons and ensure that they reference the RL hyetograph.

Step 5. Calculate the Catchment_Area parameter for each RL inflow region. It will be the difference between the post-development and the **pre-existing** effective impervious area. Delete any regions that have zero area. There will now be three inflow regions for each sub-catchment with OSD (e.g. E_i, E_p and E_rl). The combined area of the three regions will be greater than the actual area of the sub-catchment.

Step 6. Modify your boundary control file so that the OSD scenario uses the new **pre-existing** 2d_sa_rf layers and the new RL 2d_sa_rf layer.

5. Site Specific Modelling

This MIDIS EIFA methodology has been developed for use in MDSs, which have a catchment wide focus. The additional work required to set up EIFA layers may not be appropriate for all types of impact assessment or flood modelling.

If the MIDIS EIFA methodology is used for smaller scale analysis, where local internal drainage sizing and/or a flood impact analysis is necessary, the following points should be considered:

- The SCC default filter parameters may need to be modified to ensure that overland flow paths through and around the site are captured in sufficient detail.
- EIFA extents for external catchments draining into the site should be limited to upstream of the site boundary.
- TIA rather than EIA should be used for the site.
- Pervious and impervious areas within the site could be delineated, with appropriate MIDIS hyetographs applied.
- The inflows used within the site should be representative of site drainage for the pre and post-development scenarios. Ground areas should use rainfall on grid. Roof drainage should be directed to a suitable inflow point/s, with consideration given to the capacity of the roof drainage system.
- Roughness values within the site should be representative of post and pre-development scenarios.
- The catchment wide OSD approach described in Section 4 should not be used to model the impact of OSD. Specific OSD details should be included in the flood model. The outlets can be sized using MIDIS.
- If detention volumes less than the deemed-to-comply OSD solutions (refer Table 4 or Figure 10 of the *Flooding and Stormwater Management Guidelines* (SCC, 2018)) are proposed, the full ARR ensemble analysis will also be required to be modelled. The ARR constant loss approach and maximum means should be used in the analysis.

If the MIDIS EIFA methodology is used for larger urban subdivisions, where local street drainage sizing and/or a flood impact analysis is necessary, the following points should be considered:

- The SCC default filter parameters may need to be modified to ensure that overland flow paths through and around the site are captured in sufficient detail for both the pre and post-development scenarios.
- EIFA extents for external catchments draining into the site should be limited to upstream of the site boundary. The EIFAs within the site should be sub-divided based on site boundaries, so that the impact of development can be easily quantified. No EIFAs associated with site drainage should be located outside of the site boundaries.
- TIA rather than EIA should be used for the development to ensure drainage is conservatively sized.
- The inflows used within the site should be representative of site drainage for the pre and post-development scenarios. The EIFA extents for the post-development scenario may need to be recalculated with the design TIN in place.
- Roughness values within the site should be representative of post and pre-development scenarios.
- The catchment wide OSD approach should not be used to model OSD unless deemed-to-comply OSD is provided for individual internal lots.

- Detention basin outlet details can be sized using the MIDIS methodology if the volume is equal to or greater than the initial sizing recommended in Figure 10 of the *Flooding and Stormwater Management Guidelines* (SCC, 2018).
- If detention volumes less than the deemed-to-comply OSD solutions (refer Table 4 or Figure 10 of the *Flooding and Stormwater Management Guidelines* (SCC, 2018)) are proposed, the full ARR ensemble analysis will also be required to be modelled. The ARR constant loss approach and maximum means should be used in the analysis.

If conducting flood or stormwater modelling that does not use separate hyetographs for pervious and impervious areas, then a MIDIS hyetograph based on the equivalent percentage impervious for the pre and post-development scenarios should be used. Loss methods available within hydrology models are not suitable. Council can provide a spreadsheet which will create suitable hyetographs based on ARR Data Hub and BoM IFD inputs.

6. Conclusion

It has been concluded that:

- The modified MIDIS technique allows for rainfall losses resulting from changes in impervious area to be applied to the MIDIS.
- No additional rainfall losses are to be applied when using the modified MIDIS method.
- The proposed power relationship for determining effective impervious area results in less losses for highly impervious land uses than the linear method recommended by ARR. The data used to establish the ARR relationship did not include highly impervious catchments.
- The modified MIDIS method allows for rainfall on grid methods to better capture the potential impact of development.
- The EIFA rainfall on grid methodology permits the representation of directly connected impervious surfaces to be incorporated into catchment wide drainage investigations.
- The EIFA rainfall on grid methodology helps to ensure that depression interception losses, which can be an issue with rainfall on grid modelling, are minimised.
- The proposed EIFA rainfall on grid methodology requires modifications for site specific analysis.
- The resultant peak flows using the MIDIS EIFA methodology compare well to peak flows estimated by using the SCC Method.
- The proposed OSD rainfall on grid methodology allows the impact of OSD to be readily incorporated into catchment wide studies, maintaining pre-development peak flows and post-development flow volumes.
- The peak flows and water levels for small catchments are highly sensitive to the loss method used in the full ARR ensemble analysis. The MIDIS results fell within the range of results observed using different loss methods.
- The MIDIS EIFA approach is considered to provide a good representation of peak water levels and flows when compared to ARR ensemble analysis, for both conveyance and storage dominated systems. Given that it requires significantly less computational effort and allows for simplified assessment of results, it is considered to be a sensible modelling approach that supports practical and efficient flood modelling.
- If OSD volumes less than the deemed-to-comply OSD solutions are adopted then the full ARR ensemble analysis for sufficient durations will be required to be modelled.
- If the ARR ensemble approach is required to be used, then the constant 1 hour burst loss approach should be assumed. The full storm ensemble for sufficient durations is recommended to be analysed in order to identify the peak in pre and post-development scenarios. The ARR ensemble maximum mean rather than the maximum median is recommended for use in flood impact modelling. However, if this is not able to be easily calculated, the median is sufficient.

7. Recommendations

The following recommendations are made:

- That for hydrodynamic modelling of small catchments when using rainfall on grid modelling, the MIDIS EIFA approach should be adopted within the Sunshine Coast Council Local Government Area, as it is a practical method and provides appropriate results.

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Appendix A Rainfall on Grid Filtering Method

Rainfall on Grid Output Filtering

September 2018

This fact sheet describes the steps that should be taken to convert the output from “rainfall on grid” modelling to a more suitable format. This method has been adopted by Sunshine Coast Council to map overland flow paths throughout the region.

Rainfall on grid modelling has many advantages, including the ability to automatically determine local overland flow paths. However, due to the nature of the model input, the entire study area can be shown to be inundated, and ponding of isolated pockets can occur. This reduces the practical value of the model output. Filtering is therefore required in order to make the data more usable.

Filter Process

Sunshine Coast Council has trialled various filters over a number of study areas, with and without underground drainage. The aim of the output filtering was to:

- produce output that could identify the main overland flow paths;
- remove areas of shallow sheet flow;
- remove small, isolated ponded areas; and
- ensure that storage areas with reasonable depths were retained.

Simple filter methods, such as removing areas with depths below a certain value, are not appropriate. They often produce output that consists of disconnected ponding and/or missed critical flow paths.

The following filter is the result of Council’s investigations. It consists of the following steps:

Step 1. Remove areas where the depth is less than 0.01m AND the depth-velocity (dV) product is less than 0.125 m^2/s.

Step 2. Remove areas where the dV product is less than 0.02 m^2/s.

Step 3. Retain areas where depth is greater than 0.3 metres, even if the dV product is low.

Step 4. Remove islands less than 500m^2.

No pre-filtering of results should be conducted before the filtering tool is applied, i.e. the base output data used in filtering should cover the entire study area.

Results Example

An example of the resultant inundation extent after filtering has been applied is provided below in Figure 1.

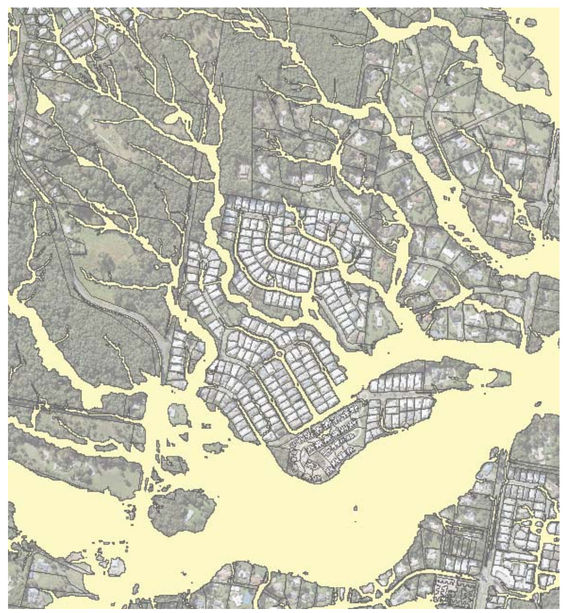

Figure 16 Example of Filter Output

This filtering method will be adopted as the Council default for processing rainfall on grid output data. However, it should be noted that individual studies, due to specific catchment characteristics, may require the default filtering method to be further refined in order to adequately identify flow paths.

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