# Application of Design Temporal Patterns

on the Sunshine Coast

Document Information

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# Executive Summary

This document sets out a process to simplify the use of Ensemble Temporal Patterns as recommended in the Australian Rainfall and Runoff (ARR) 2016 guidelines particularly regarding their application within hydrodynamic models. These models are used to prepare and update design flood level surfaces and for the assessment of development proposals throughout the Sunshine Coast. The primary reason for the simplification is to reduce the significant number of hydrodynamic modelling days required to fully implement the ARR 2016 temporal pattern ensemble approach. This issue has been identified in the ARR 2016 guidelines.

The approach proposed by Sunshine Coast Council (SCC) is to adopt the ARR 2016 Ensemble Temporal Patterns, but to pre-process the patterns to a single all duration pattern for a prescribed AEP through a two-stage process. This pattern is named MIDIS or Median Intensity Duration Independent Storm. The first process is to derive Median Intensity Storm patterns (Carroll, 2017) for each duration based on the 10 ARR 2016 ensemble patterns. The second process is to derive an envelope pattern. Essentially the proposed methodology is a hybrid approach that captures many of the statistical attributes of the ARR 2016 patterns but retains the DIS pattern generation methodology as currently adopted by the Sunshine Coast Council. The approach proposed is considered a pragmatic implementation that incorporates substantial elements of the ARR 2016 guidelines.

The proposed methodology has been trialed for the Mooloolah catchment and demonstrated to provide similar results to those estimated using the ARR 2016 temporal pattern approach. Further there is no requirement to use proportional loss scaling factors as currently required using the DIS methodology, whose temporal pattern shape is peakier that the proposed hybrid approach.

# Contents

# Glossary

| | |
|---|---|
| AEP | Annual Exceedance Probability |
| ARF | Areal Reduction Factor |
| ARR | Australian Rainfall and Runoff |
| AVM | Average Variablity Method (Temporal Pattern) |
| DIS | Duration Independent Storm, a temporal pattern derived from the IFD. |
| IFD | Intensity Frequency Duration design rainfall |
| FFA | Flood Frequency Analysis |
| MIDIS | Medium Instensity Duration Independent Storm (Temporal Pattern) |
| MIS | Medium Intensity Storm (Temporal Pattern) |
| QUDM | Queensland Urban Drainage Manual |
| SCC | Sunshine Coast Council |
| ToC | Time of Concentration, the duration of rainfall associated with peak discharge |
| URBS | Unified River Basin Simulator rainfall runoff routing model. |

# Introduction

In 2016 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.

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, identifying the circumstances when understanding temporal variability through the use of ensemble patterns can better inform design, planning and impact assessment.

The analysis that supports this report is based upon modelling comparisons at the Mooloolah River gauge using an URBS model. This location was selected because significant effort was invested as part of the Council flood study (Cardno, 2015) to improve the rating curve to produce an accurate at-site flood frequency analysis from gauged data.  The modelling of this report adopts URBS parameters of 0.15 (Alpha), 3.0 (Beta) and 0.8 (m).

# 1 Ensemble Temporal Patterns

## 1.1 Comparison with Gauged Site Flood Frequency Analysis

The URBS hydrologic model provides for the analysis of ARR (2016) ensemble temporal patterns. Losses were adopted consistent with the advice from the ARR Datahub. These were 27mm initial loss and 2.7mm/hr continuing loss. Figure 1 shows excellent agreement between the median of the peak flows derived from ensemble temporal patterns and the Mooloolah River Gauge flood frequency analysis (FFA).

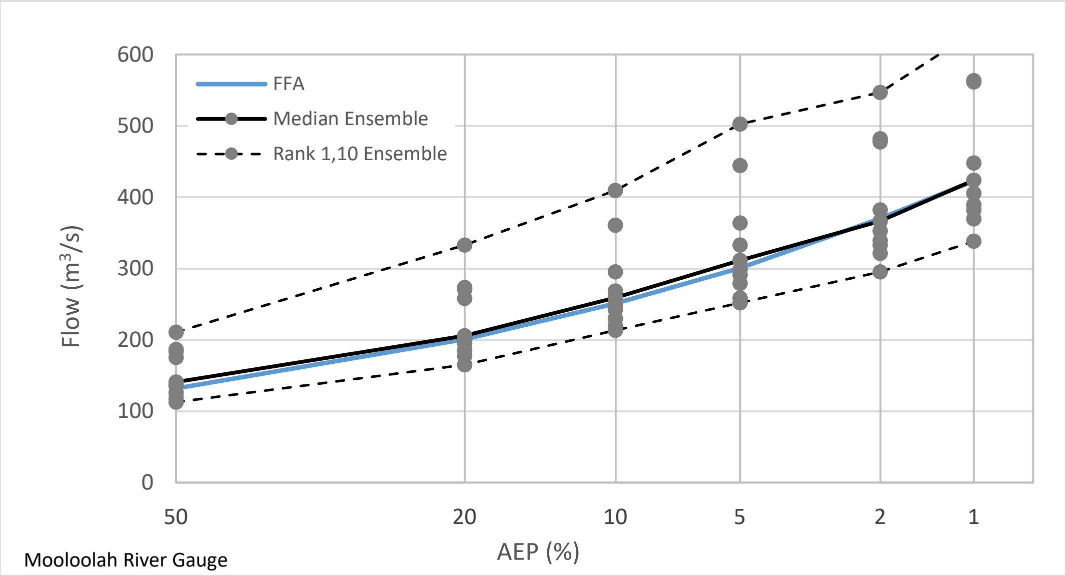


Figure 1 Comparison of the Mooloolah River FFA with Design Results derived using Ensemble Patterns

## 1.2 Hydrograph Selection for an AEP of Interest

Ensemble temporal patterns provide an ability to understand temporal variability, not just to gain an understanding of the uncertainty in the estmation of peak but also in understanding the possible hydrograph shapes and volumes for a given AEP of interest. Thus from the scatter of design results that come from an investigation of ensemble temporal patterns at differing AEPs and durations, a vertical slice through the scatter for a given AEP of interest will inform the uncertainty in the estimation of the peak and a horizontal slice through the scatter will identify the range of design events that have the same peak magnitude as the AEP neutral design event at the AEP of interest. This is shown in Figure 2.

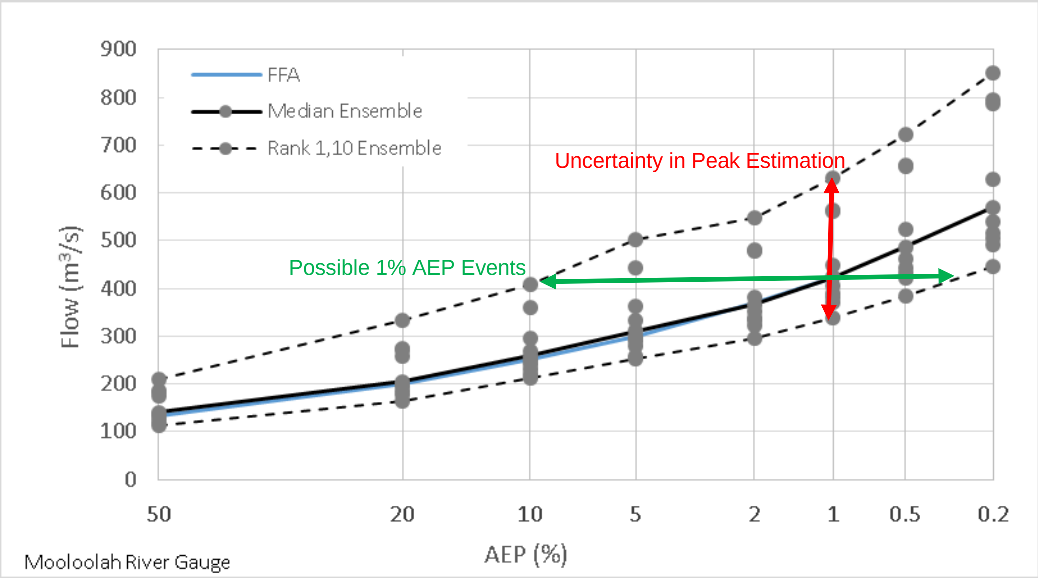


Figure 2 Comparison of the Mooloolah River FFA with Design Results derived using Ensemble Patterns

The 10 ensemble temporal patterns that are applied to design rainfall for an AEP of interest provide an understanding of the variability and uncertainty in the estimation of the peak. The peak flow from the rank 6 (lowest to highest) burst event approximates the median and average of the range of estimates. The critical duration is also determined from the rank 6 event. The purpose of the critical duration is to define the rainfall duration that produces the peak flow event. The associated hydrograph may not be appropriate for non-peak related purposes. That is, the critical duration is used to determine peak discharge, it is not necessarily appropriate for selecting a hydrograph for volume or duration of inundation analysis.

Figure 2 shows how plausible 1% AEP hydrographs can be identified. It shows that a 1% AEP discharge event can be produced from design rainfall probability events that range from 10% to 0.4% AEP, as a result of the variable intensity of the associated temporal patterns.  Appendix A provides results of all URBS runs for various combinations of duration, rainfall AEP and ensemble temporal pattern. Peak discharges within 1.5% [1]of the 1% AEP FFA discharge are highlighted. These combinations are all plausible 1% AEP peak discharge events.  Appendix A also provides individual figures of these hydrographs. Figure 3 plots them together.

[1] 1.5% threshold results in 10 events.

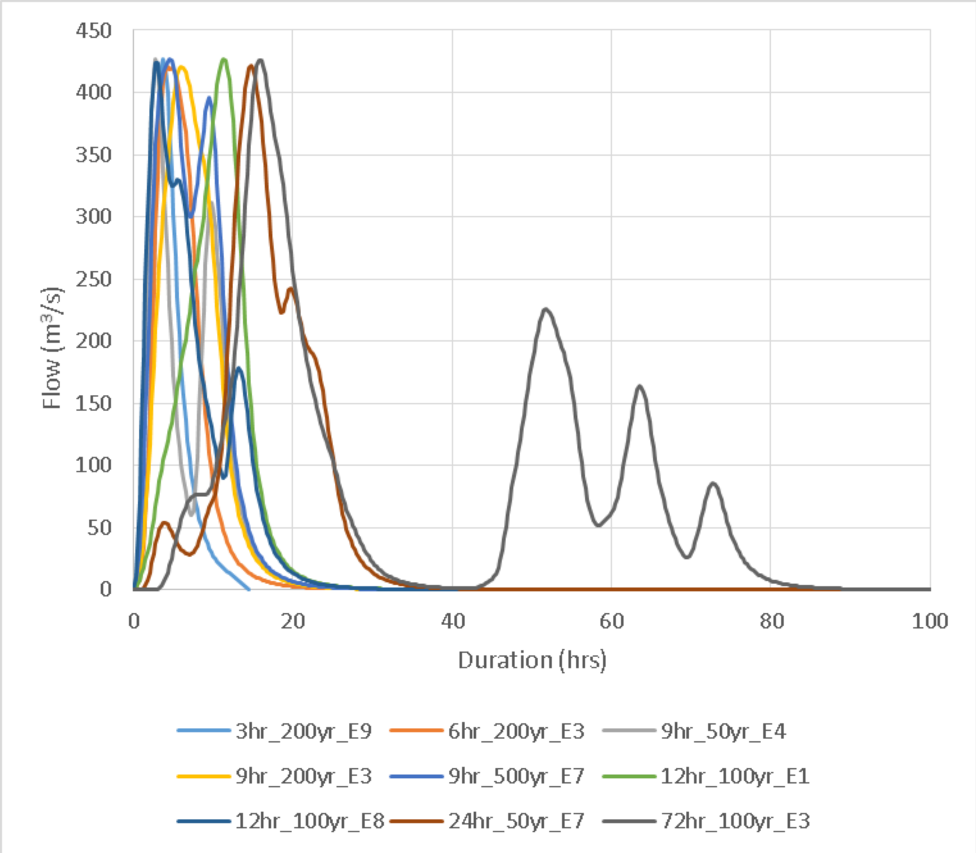


Figure 3 1% AEP Discharge Hydrographs from Ensemble Hydrographs

## 1.3 Duration of Inundation

Duration of inundation analyses are performed by considering the duration of time that a hydrograph is above a nominated threshold. The plausibile 1% AEP hydrographs have been analysed for a number of thresholds. Thresholds range from the 50% AEP to the 2% AEP.

The median, average, minimum and maximum duration statistics of the suite of event hydrographs are presented in Table 1

Table 1 Duration of Inundation Statistics from 10 Possible 1% AEP Events generated using Ensemble Patterns

| | 50% AEP | 20% AEP | 10% AEP | 5% AEP | 2% AEP |
|---|---|---|---|---|---|
| Median | 10.5 hrs | 8 hrs | 5.75 hrs | 4.5 hrs | 2.75 hrs |
| Average | 11.53 hrs | 7.85 hrs | 5.95 hrs | 4.7 hrs | 2.6 hrs |
| Minimum | 4.75 hrs | 3.5 hrs | 3 hrs | 2.5 hrs | 1.5 hrs |
| Maximum | 21.5 hrs | 11.25 hrs | 9 hrs | 7.75 hrs | 4.25 hrs |

## 1.4 Volume

Table 2 provides statistics for plausible 1% AEP hydrograph volumes generated using ensemble temporal patterns (as highlighted in Appendix A).

Table 2 Ensemble Hydrograph Volume Statistics

| | Volume ($m^3 \times 10^6$) |
|---|---|
| Average | 13.85 |
| Median | 12.61 |
| Minimum | 6.11 |
| Maximum | 27.4 |

## 1.5 Burst vs Storm Temporal Patterns

ARR Book 2, Chapter 5.4 states "*In many parts of Australia the pre-burst rainfall generally represents a very small amount of the event and generally does not contribute to the runoff response, so it can be treated in a relatively simply manner. However, in some parts of the country pre-burst rainfall can represent a significant part of the rainfall event and runoff response. Pre-burst can also be important in urban catchments with large directly connected impervious areas (Book 5). Storage strategies need to account for this additional runoff when sizing storage tanks and basins (Book 9).*"

ARR Book 2, Chapter 5.4 provides an indication of the quantum of preburst rainfall to burst rainfall. This is shown below in Figure 4. On the Sunshine Coast this quantum appears to be in the range of 12% to 27%.

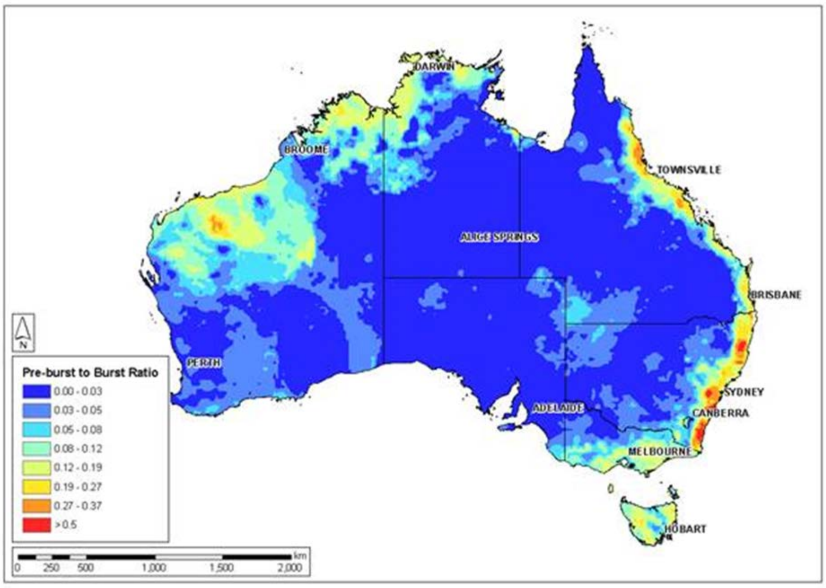


Figure 4 Preburst to Burst Ratio (Source: ARR Book 2, Chapter 5.4)

ARR Book 2, Chapter 5.2.3 also states *"practitioners have become concerned with using burst patterns where complete storm volume is important. Rigby and Bannigan (1996) suggest the entire burst approach needed to be reviewed and design storms needed to replace design bursts. For the Wollongong area Rigby and Bannigan (1996) demonstrated that historically most short duration events were embedded in longer duration events. They recommended that short duration events could be embedded in a 24 hour event of the same probability. They particularly cautioned against using bursts on catchments with significant natural or man-made storages. Phillips et al (1994) had found similar problems in the upper Parramatta River and suggested embedded storms were more realistic, and that basin storages would be underestimated with a burst approach unless the embedded nature of events was factored into the starting volumes. Rigby et al (2003) extended the earlier work to include guidance on using the embedded design storms. Roso and Rigby (2006) recommended a storm based approach be used when there are significant storages or diversions present in the catchment. Kuczera et al (2003), inspired by Rigby and Bannigan (1996), explored basin performance using a theoretical catchment at Observatory Hill, Sydney in a continuous simulation approach and found similar problems with peak flow being underestimated by a similar amount when storages were present. All of these studies were based on catchments less than 110 km*$^2$ *that are close to Sydney"*.

Most regional catchments of the Sunshine Coast have significant flood plain basins in the lower catchment that require a design storm approach to prime the storage of these basins in order to determine appropriate peak design levels for the lower catchment.

This analysis has applied burst rainfall to the ARR (2016) ensemble patterns using the built-in features of URBS. The analysis has also shown that the ARR (2016) ensemble patterns can have issues with embedded sub-duration busts existing within longer duration patterns and that this can cause problems for the accurate determination of critical duration. This is shown below in Figure 4, where it is evident that ensemble pattern E4 has a number of sub-duration bursts that exceed the design IFD values.

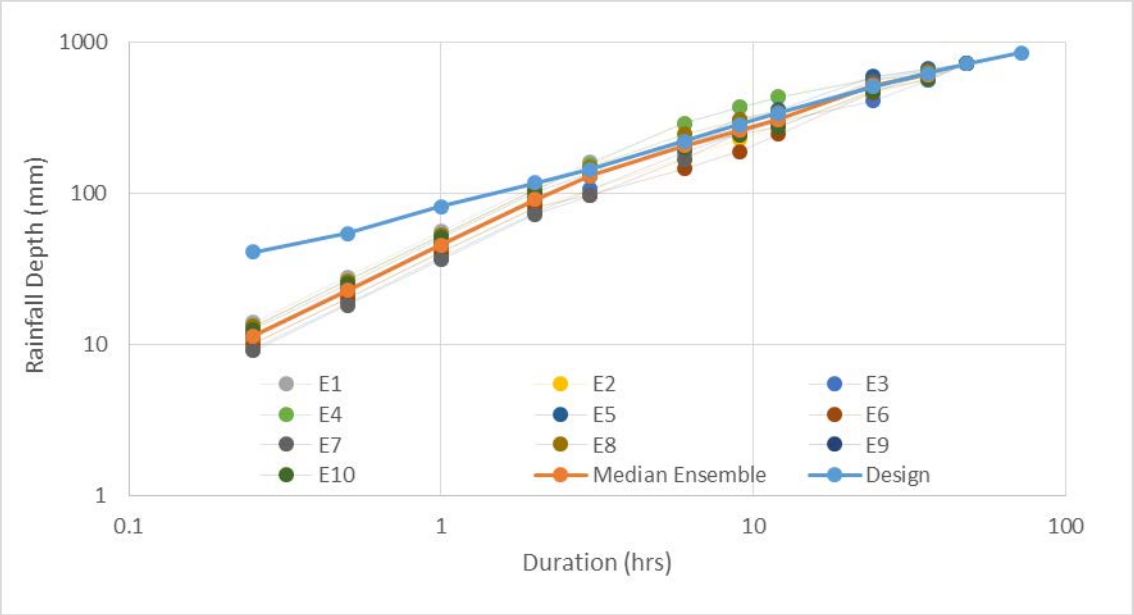


Figure 5 Sub-duration totals within 48hour temporal patterns

# 2 Issues with Application at Multiple Focal Point Locations

Sunshine Coast Council has a number of regional catchment models that are subject to regular change as a result of development. The community has an expectation that Council flood mapping will reasonably keep pace with development, with insurance being a key driver responsible for this expectation. These models determine subarea inflows using a hydrological model (URBS). Channel routing and peak level estimation occurs with detailed hydraulic models that have been created to provide appropriate accuracy within a 24 hour runtime.

To correctly and confidently apply a critical duration analysis approach for an entire catchment (rather than a point of interest) the modeller should consider critical durations that range from sub hourly to at least 24 hours (for most regional catchments on the Sunshine Coast). This could typically involve 10 temporal patterns. As it cannot be assumed that the hydrologic model will replicate the channel routing of the hydraulic model, especially in locations of tidal or backwater influence, the hydraulic model should be run for each duration in the critical duration analysis and the critical duration should be based on the peak level outcomes of the hydraulic model.

SCC typically analyses 10 current climate riverine AEPs and a further 3 future climate riverine AEPs. The total hydraulic model run time required to apply a critical duration analysis correctly then becomes 13 AEPs x 10 temporal patterns x 24hrs = 3,120 hours (130 days). The adoption of ensemble temporal patterns introduced in ARR (2016) extends this run time by a factor of 10 to 1300 days.

ARR Book 2 Chapter 5.9.2 recognises the issue of increased hydraulic model run-time that ensemble temporal patterns create. It offers two solutions:

- Limit the analysis of ensemble temporal patterns to the hydrologic model; or
- Reduce the resolution of the hydraulic model

SCC considers that neither of these solutions are optimal. As stated above, the hydrologic model often cannot replicate the results of the hydraulic model. Similarly, changing the resolution of the hydraulic model for design, affects the calibration of the hydraulic model and compromises confidence in the results of the hydraulic model. Additionally such a solution is not readily implemented in a hydraulic model which adopts a finite volume method of calculation.

The recently released second generation TUFLOW GPU product (HPC) can significantly reduce runtimes of a TUFLOW classic 1D/2D model. It should be noted that it may be necessary to recalibrate the HPC model to ensure equivalent model outcomes as the classic model. For some practitioners, with smaller hydraulic models, HPC may prove to deliver workable runtimes with an ensemble analysis or critical duration analysis approach, but in the case of SCC it will not, as the cumulative total of ensemble runtimes will still be excessive and because not all models are readily migrated to HPC.

In addition to runtime issues, the ensemble approach also has issues with different ensemble patterns yielding the median outcome at different focal locations. This makes analyses that require hydrograph continuity difficult. Such analyses include development impact assessment.

# 3 Simplified Methods

Historically Sunshine Coast Council has adopted the Duration Independent Storm (DIS) to simplify the estimation of design levels and for the assessment of development impacts. Figure 5 shows the 1% AEP hydrograph derived from the Mooloolah River URBS hydrologic model using the DIS temporal pattern. The temporal pattern and resultant hydrograph are purely synthetic and as suggested by ARR (2016) do not reflect the shape of a hydrograph produced from observed rainfall. Appendix B also provides an overview of how a DIS temporal pattern is calculated.

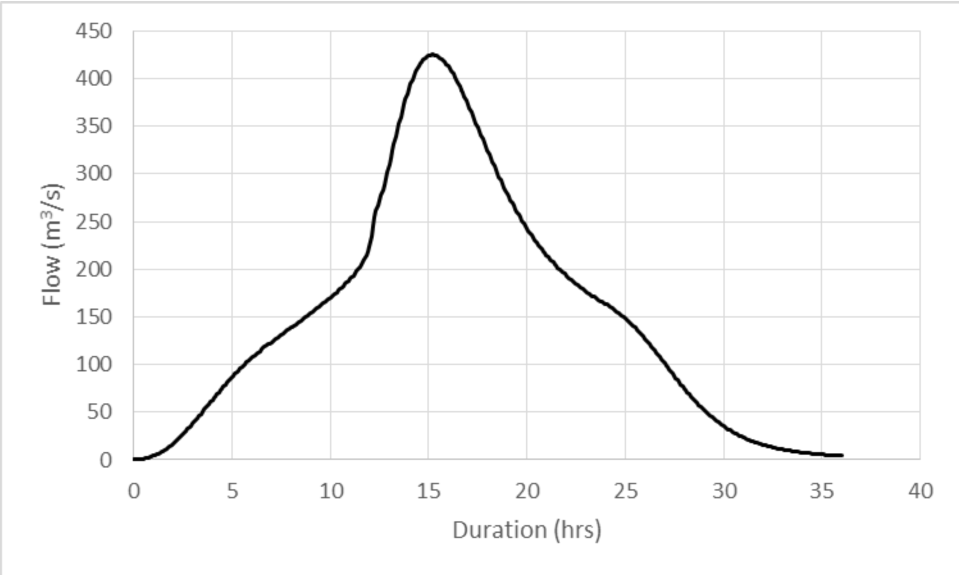


Figure 6 1% AEP Hydrograph from 24hr Duration Independent Storm Temporal Pattern

During the course of peer reviewing this report, Don Carroll proposed the concept of the Median Intensity Storm (MIS) as a pragmatic method to reduce hydraulic model complexity, deriving a single temporal pattern for each rainfall duration and allowing a traditional critical duration approach to be applied.

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. Further details are provided in Carroll, 2017. An Overview of how a MIS temporal pattern is calculated is provided in Appendix C.

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 author considered the MIS temporal patterns and whether they could be made duration independent. This was done by calculating the maximum envelope of all MIS temporal pattern sub-duration depths and then applying the DIS methodology. This method is named the Median Intensity Duration Independent Storm (MIDIS). Further details of how a MIDIS temporal pattern is calculated are in Appendix D.

The MIDIS was calculated for a number of storm durations, from 6 to 72 hours, and used to calculate 1% AEP event hydrographs. These are shown in Figure 6.

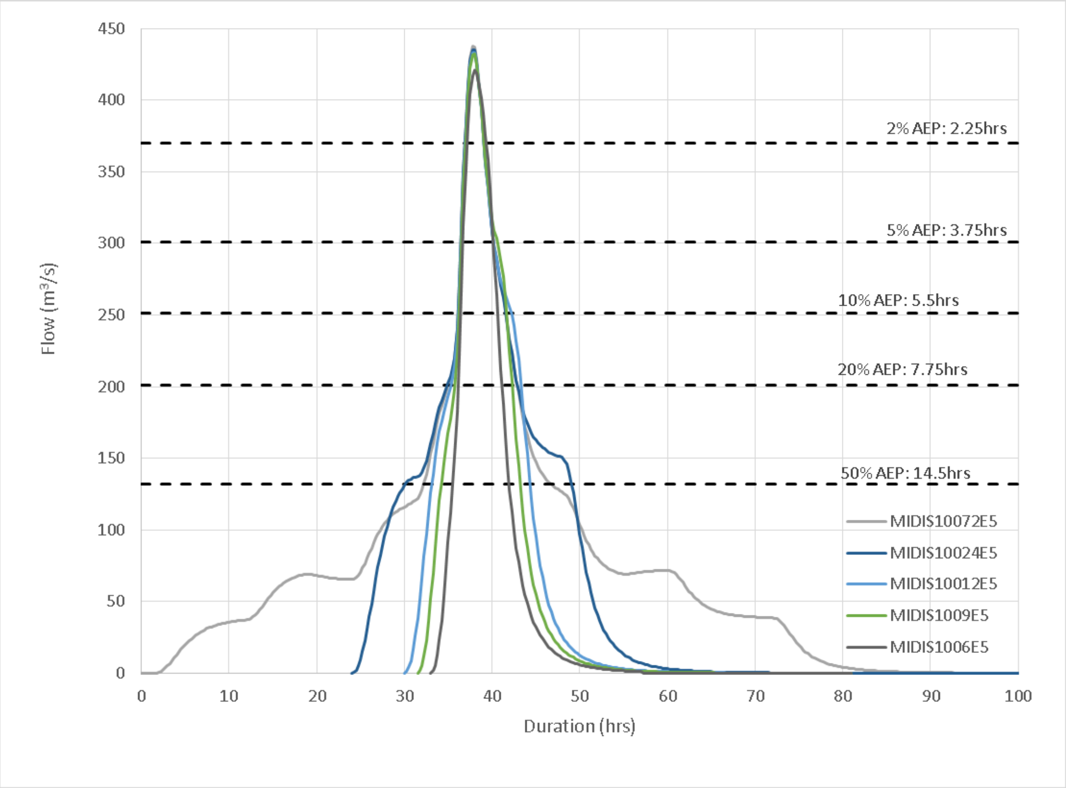


Figure 7 MIDIS 1% AEP Hydrographs for different storm durations

The peak flows from the various MIDIS storm durations were compared as part of a critical duration analysis that considered a number of other temporal pattern simplication methods including MIS, AVM, the Rank 6 ensemble peak flow and the average of the ensemble peak flows.

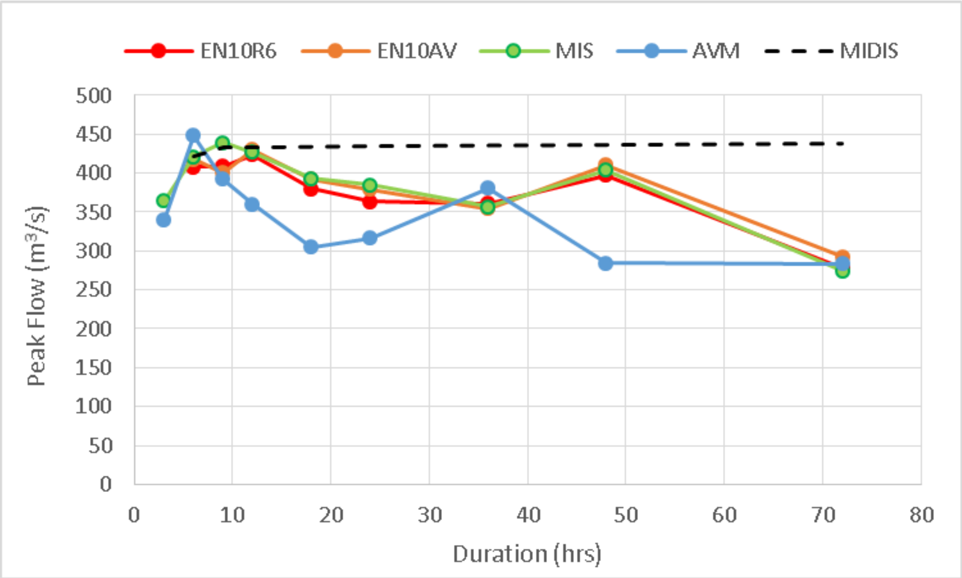


Figure 8 Critical Duration Analysis

Figure 7 shows that the peak derived from a MIDIS duration of 9 hours or longer can produce a peak flow that approximates the peak derived from the median or average of ensemble patterns.

## 3.1 Duration of Inundation

Table 3 provides duration of inundation estimates for the various MIDIS storm durations and compares them to the statistics of the plausible events generated using ensemble patterns for the 1% AEP.

At the location of the Mooloolah Gauge, the 12 hour MIDIS storm provides the best match to the average duration of inundation statistics of the plausible events. It is also evident that for the 20% AEP threshold and above, the longer duration MIDIS storm durations are equally good at matching the average duration of inundation statistics of the plausible events.

Table 3 Duration of Inundation Statistics of MIDIS 1% Events compared to statistics from 10 Possible Events generated using Ensemble Patterns

| | 50% AEP | 20% AEP | 10% AEP | 5% AEP | 2% AEP |
|---|---|---|---|---|---|
| Median | 10.5 hrs | 8 hrs | 5.75 hrs | 4.5 hrs | 2.75 hrs |
| **Average** | **11.53 hrs** | **7.85 hrs** | **5.95 hrs** | **4.7 hrs** | **2.6 hrs** |
| Minimum | 4.75 hrs | 3.5 hrs | 3 hrs | 2.5 hrs | 1.5 hrs |
| Maximum | 21.5 hrs | 11.25 hrs | 9 hrs | 7.75 hrs | 4.25 hrs |
| MIDIS 6hr Storm | 6.5 hrs | 5 hrs | 4.25 hrs | 3.5 hrs | 2.25 hrs |
| MIDIS 9hr Storm | 9 hrs | 6.5 hrs | 5.5 hrs | 4 hrs | 2.25 hrs |
| **MIDIS 12hr Storm** | **11.25 hrs** | **8 hrs** | **6 hrs** | **3.75 hrs** | **2.25 hrs** |
| MIDIS 24hr Storm | 19 hrs | 8 hrs | 5.5 hrs | 3.75 hrs | 2.25 hrs |
| MIDIS 72hr Storm | 14.5 hrs | 7.75 hrs | 5.5 hrs | 3.75 hrs | 2.25 hrs |

## 3.2 Volume

Table 4 provides volume estimates for the various MIDIS storm durations and compares them to the statistics of the plausible events generated using ensemble patterns for the 1% AEP.

At the location of the Mooloolah Gauge, the 12 hour MIDIS storm provides the best match to the median volume statistics of the plausible events.

Table 4 Ensemble Hydrograph Volume Statistics

| | Volume ($m^3 \times 10^6$) |
|---|---|
| **Average** | **13.85** |
| **Median** | **12.61** |
| Minimum | 6.11 |
| Maximum | 27.4 |
| MIDIS 6hr Storm | 8.47 |
| MIDIS 9hr Storm | 10.79 |
| **MIDIS 12hr Storm** | **12.59** |
| MIDIS 24hr Storm | 17.93 |
| MIDIS 72hr Storm | 25.93 |

Whilst the 12 hour duration provides the best match for the volume of the whole hydrograph, it is also clear from the duration of inundation comparison that the longer duration storms also provide a good match for the hydrograph volume above the 20% AEP threshold.

# 4 Multi Focal Location Analysis.

The Mooloolah River URBS model covers a total catchment area of 215.4 km$^2$, including the Currimundi Creek catchment. A number of focal locations were established within the model and critical duration analyses were undertaken at each location, changing the areal reduction factor (ARF) and temporal pattern with the area of the focal location. This was done using ARR ensemble, MIS and the average variability method (AVM) temporal patterns. Further details and results are provided in Appendix E.

Critical duration methods are readily applied to focal locations within a catchment but they do not preserve the AEP neutrality of the peak estimates at other locations within the catchment. Thus to determine a surface of design levels for large catchment, many focal locations need to be considered, with results at the critical duration from the hydrologic model being input to a hydraulic model as lumped inflows, for each focal location. A maximum envelope would then need to be derived from all hydraulic model results. This process is time consuming and onerous, both in the time it takes to run the hydraulic model but also in the post processing of the GIS results.

The MIDIS temporal pattern, with some adjustment for larger catchment multi-focal analysis offers a pragmatic approach that simplifies analysis to a single run of the hydraulic model for a given AEP of interest. This is done by calculation of outlet ARF's for a range of durations from 30 minutes to 72 hours, and then upscaling these ARF's by the inverse of the 72 hour ARF for durations up to and including 1 hour, upscaling ARFs between 1 hour and 12 hours by linearly interpolating the 72 hour ARF upscaling factor applied to the 1 hour and a factor of 1 applied to the 12 hour. No upscaling is applied for durations greater than 12 hours. The methodology for adjusting the MIDIS temporal pattern is demonstrated in Appendix F.

The MIDIS 72hr peak flow values shown in Appendix E have been derived using this adjustment and show average and median errors in the hydrologic model analysis that are similar to those using the ARR2016 guidelines and applying the rank 6 ensemble temporal pattern.

Whilst this method is primarily for producing a peak level surface for a catchment, it also has value for duration of inundation application where the threshold of interest is above the magnitude of the 20% AEP event. This was demonstrated previously in Section 3.1.

It is apparent that the hydrographs generated using a longer duration MIDIS temporal pattern do contain excess volume in the base of the hydrograph (flows that are below 45% of the peak, or 20% AEP event magnitude). This is evident in Figure 8.

For volumetric analysis, it may be possible to extract MIDIS hydrographs at locations of interest and filter these hydrographs to remove the excess volume. This is also shown in Figure 8. Table 5 shows the volume of the filtered 1% AEP hydrograph at the Mooloolah Gauge. It provides good agreement with the average and median statistics derived previously (in Section 1.4) from ensemble temporal pattern analysis. The filtering algorithm is provided in Appendix G, it is based upon the rising and falling slope of the hydrograph between flows that are 45% and 90% of the peak.

Table 5 Ensemble and Filtered MIDIS Hydrograph Volume Statistics

| | **Volume ($m^3 \times 10^6$)** |
|---|---|
| **Average** | **13.85** |
| **Median** | **12.61** |
| Minimum | 6.11 |
| Maximum | 27.4 |
| **Filtered MIDIS 72hr** | **12.77** |

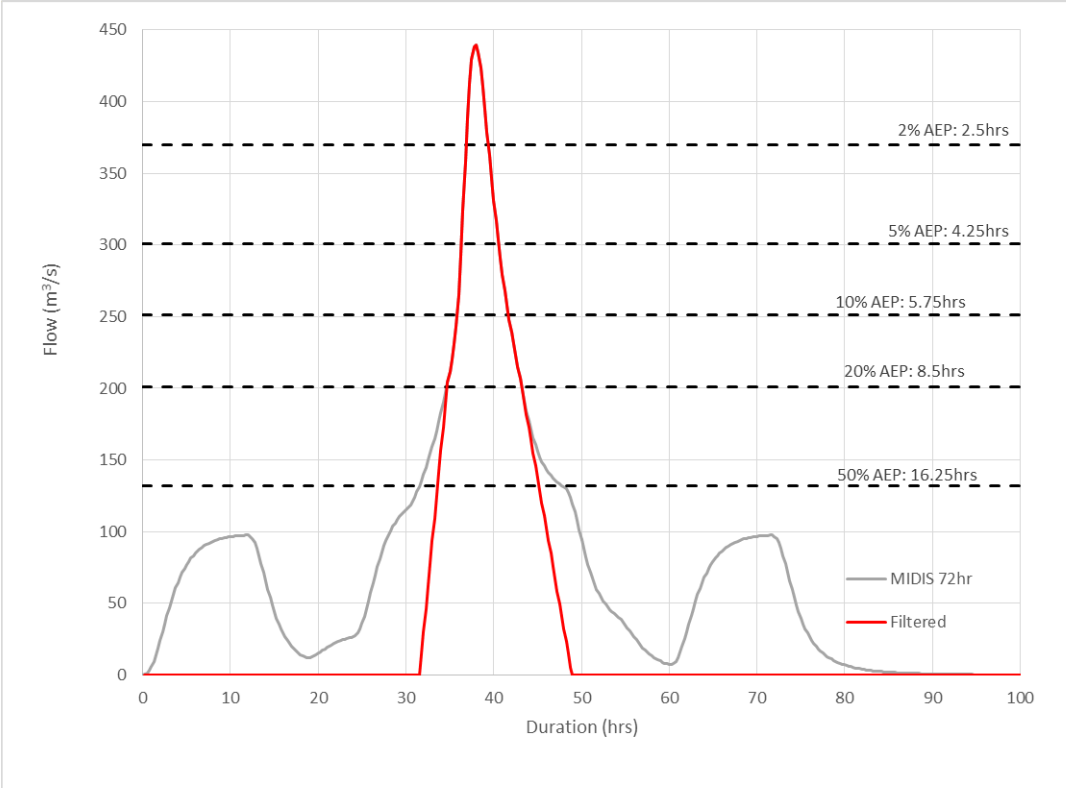


Figure 9 MIDIS Hydrograph Filtering

As stated previously, SCC has historically adopted the DIS temporal pattern as a pragmatic approach for estimating peak surface design levels throughout a catchment as well as for development impact assessment. The application of the DIS has required a proportional loss methodology, calibrated by fitting to flood frequency analysis. This loss approach assists with removing some of the peakiness from the temporal pattern. Figure 9 compares the DIS and MIDIS temporal patterns. It is apparent that the agreement is good, although the DIS is a slightly narrower hydrograph.  As the MIDIS uses ensemble temporal patterns and a continuing loss methodology consistent with the ARR datahub it is considered preferable for future adoption on the Sunshine Coast, however the DIS remains appropriate for use within existing adopted hydraulic models, until such time as the hydrology can be updated.

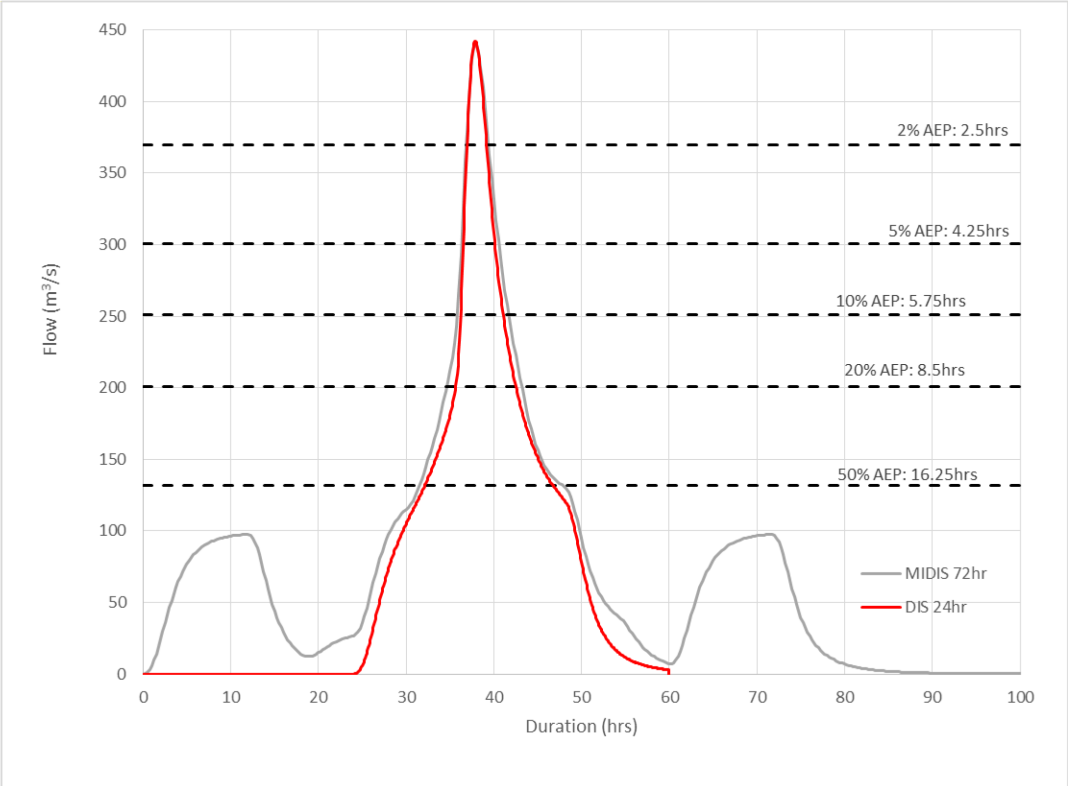


Figure 10 MIDIS vs DIS Hydrograph

# 5 Time of Concentration and Critical Duration

Historically some practitioners have avoided critical duration analysis by assuming that the critical duration can be estimated from a Time of Concentration (ToC) formula. SCC (2017) provides a definition of ToC that is based on preserving the AEP neutrality of design rainfall and flood frequency. It also provides a ToC formula for use on the Sunshine Coast as part of a rational method application. At the Mooloolah Gauge the ToC is 4.1 hours.

Figure 7 provides a critical duration analysis. Dependant on the temporal pattern the critical duration is 6 (AVM), 9 (MIS) or 12 (Ensemble Average and Rank 6) hours.

It is evident from the observed critical durations that the ToC is always shorter. ToC should never be used as a proxy for critical duration.

# 6 Conclusions

It has been concluded that:

- The MIS temporal pattern offers a simplification to the ARR ensemble approach. Testing on the Mooloolooah River Catchment has shown that the MIS temporal pattern estimates a peak flow equivalent to the average of peaks from hydrographs generated using East Coast North Temporal Pattern Ensembles.
- The MIDIS temporal pattern is appropriate for determination of peak design flood levels when a spatial layer of peak levels is required for a large catchment.
- The MIDIS and DIS approaches compare favourably when the DIS is applied with calibrated proportional losses. The DIS is therefore appropriate for continued use within existing hydraulic models, although it is desirable to update the hydrology to apply MIDIS temporal patterns as this is considered to better align with temporal pattern and loss guidance of ARR.
- The MIDIS temporal pattern is less peaky than the DIS and does not require proportional loss scaling factors to be applied as is required for the DIS.
- Ensemble patterns are appropriate for providing guidance on temporal and volume variability of design hydrographs at a single focal point. It is recommended that ensemble hydrographs be selected from combinations of duration, AEP rainfall and ensemble temporal pattern that have a peak discharge equivalent to the rank 6 peak flow ensemble event for the AEP of interest. This is likely to only be practical for analysis involving a hydrologic model or a smaller hydraulic model (using a GPU computational method).
- Median and average statistics of ensemble pattern hydrographs indicate that a MIDIS hydrograph provides an appropriate proxy for duration of inundation investigations, when the threshold of interest is above the 20% AEP event magnitude.
- Early testing of a process of filtering a MIDIS hydrograph has shown promise in producing a hydrograph volume that resembles median and average statistics of ensemble pattern hydrographs. This may prove useful for situations when the excess volume in the base of the MIDIS hydrograph is problematic.
- Volume and duration of inundation investigations should have an awareness of the variability that ensemble (and real world) temporal patterns provide. The outcomes of these investigations should consider the consequences of real world event volumes and durations of inundation being in the range of half to double that of design estimates.
- Ensemble patterns should not be limited to the critical duration for applications other than determination of peak discharge. The determination of a true critical duration can be compromised by embedded bursts within longer duration temporal patterns.
- Critical Duration is not Time of Concentration and cannot be estimated from a ToC formula.

# 7 Recommendations

The following recommendations are made:

- That for hydrodynamic modelling, particularly for large regional catchments, the MIDIS methodology with ARF adjustment is to be preferred over the current DIS approach and should replace the latter as models are progressively updated.
- That for hydrodynamic modelling of smaller catchments, the practioner has the flexibility to adopt design results derived from MIS or the MIDIS temporal pattern methodologies, but the MIDIS should always be checked.
- That for analyses that only require hydrological modelling[2], the ensemble temporal pattern approach as recommended by ARR 2016 be adopted.

[2] Excluding situations where deemed to comply solutions of the Flooding and Stormwater Guidelines 2018 apply for low risk detention and waterway stability.

# 8 References


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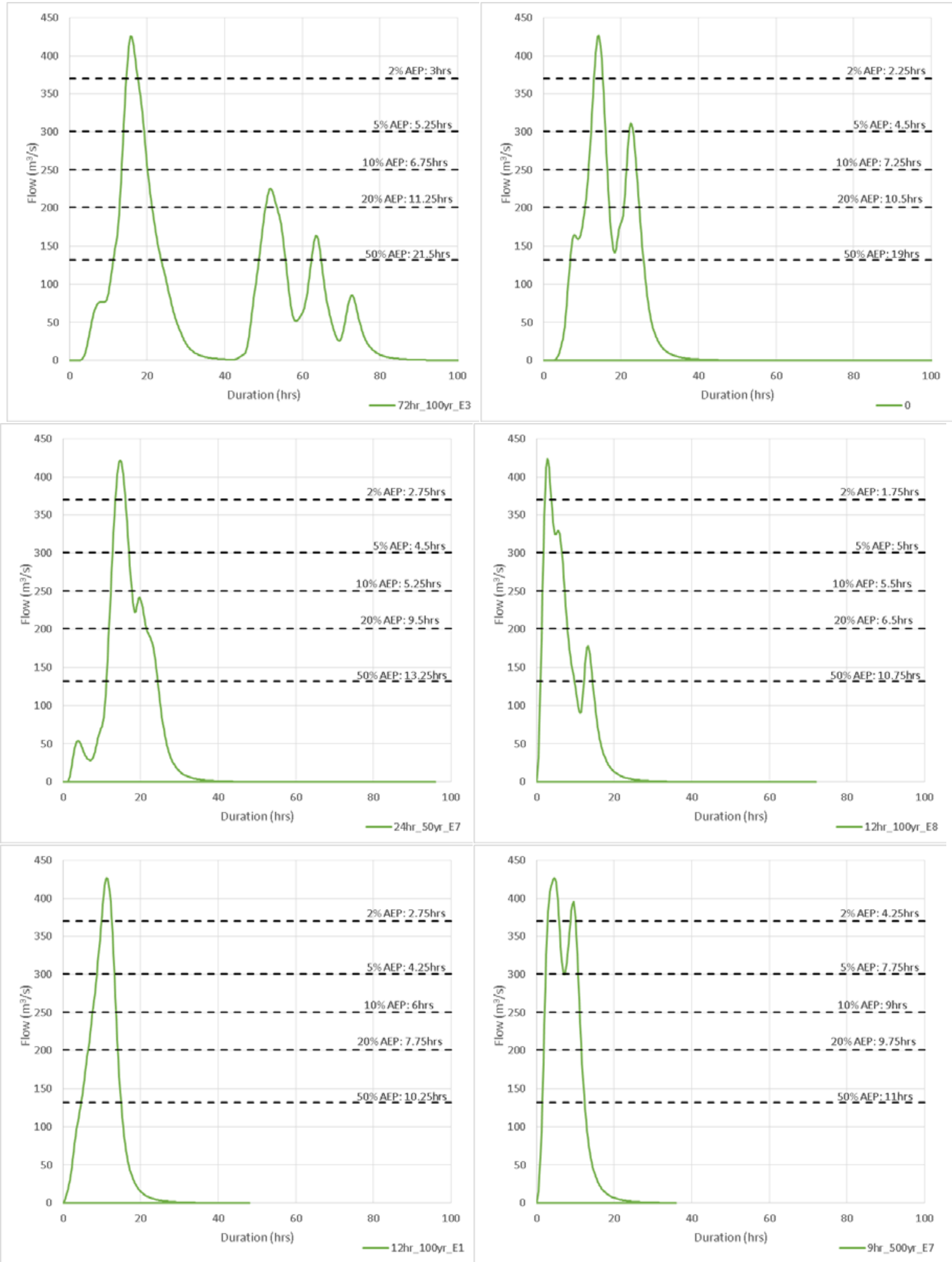
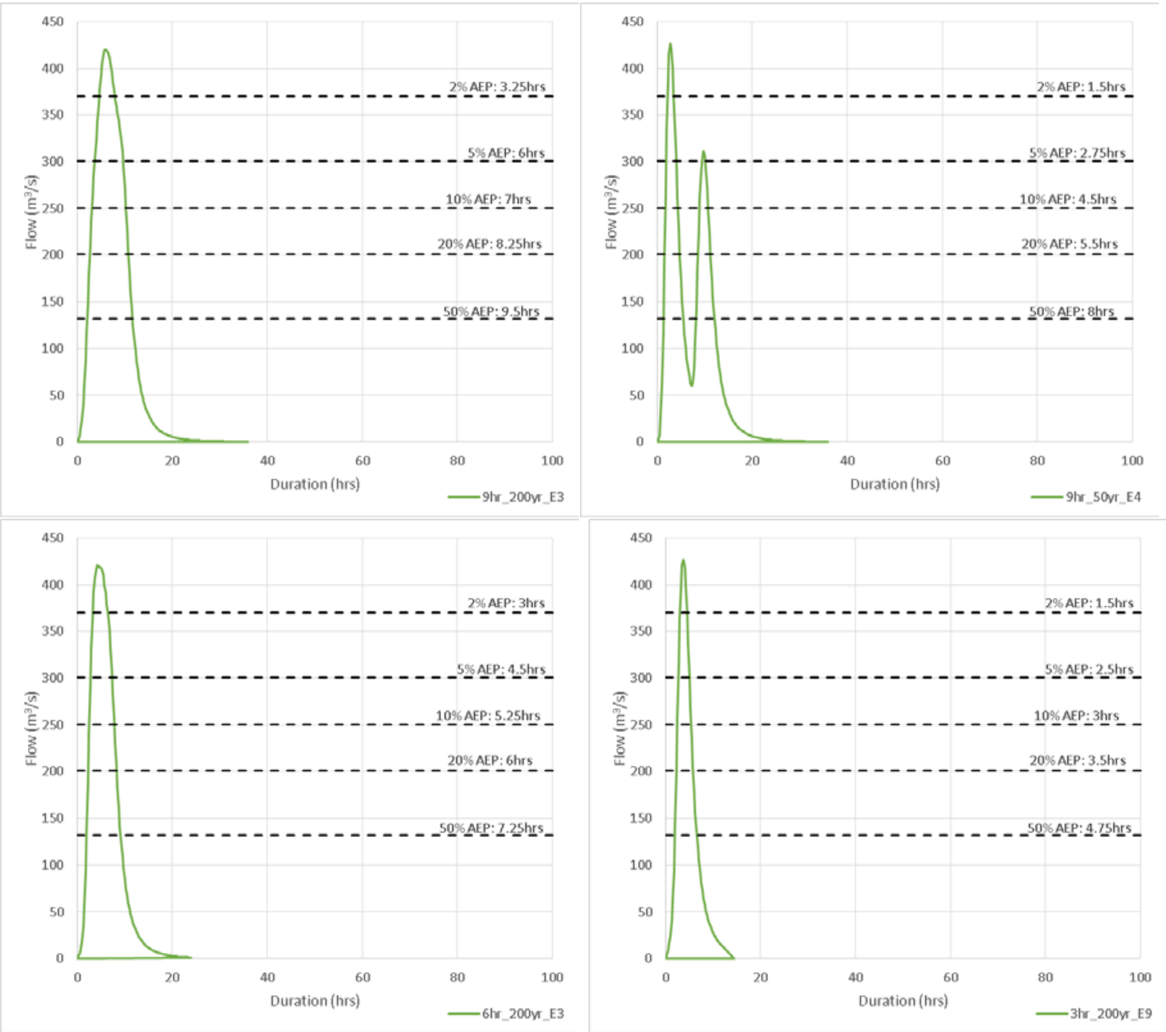
# Appendix A URBS Results using Ensemble Temporal Patterns

| Duration (hrs) | AEP (1:Y) | E0 | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | E9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 50 | 314.89 | 283 | 325.04 | 308.97 | 302.91 | 303.69 | 303.83 | 295.36 | 306.76 | 333.67 |
| 3 | 100 | 358.08 | 321.36 | 369.72 | 351.5 | 344.61 | 345.64 | 345.9 | 335.69 | 349.11 | 379.79 |
| 3 | 200 | 402.19 | 360.5 | 415.99 | 394.97 | 387.22 | 388.54 | 388.93 | 376.85 | 392.39 | **426.97** |
| 3 | 500 | 463.65 | 414.71 | 480.09 | 454.96 | 446.01 | 447.76 | 448.35 | 433.57 | 452.15 | 492.17 |
| 6 | 50 | 430.73 | 332.94 | 355.58 | 321.3 | 347.35 | 339.41 | 445.93 | 406.92 | 295.51 | 360.76 |
| 6 | 100 | 495.39 | 382.09 | 407.98 | 369.74 | 398.6 | 389.51 | 512.46 | 468.07 | 338.62 | 414.32 |
| 6 | 200 | 565.24 | 434 | 463.32 | **421.09** | 452.74 | 442.43 | 582.9 | 533.15 | 384.06 | 470.96 |
| 6 | 500 | 662.97 | 505.98 | 540.16 | 492.59 | 527.79 | 515.79 | 680.83 | 624.1 | 446.94 | 549.61 |
| 9 | 50 | 356.92 | 315.45 | 311.28 | 319.15 | **427.27** | 353.76 | 461.43 | 274.93 | 289.91 | 355.21 |
| 9 | 100 | 413.42 | 363.67 | 358.1 | 367.96 | 494.12 | 408.89 | 533.06 | 317.61 | 336.17 | 409.95 |
| 9 | 200 | 474.36 | 415.41 | 408.18 | **420.28** | 566.39 | 468.39 | 610.27 | 363.42 | 386.12 | 468.7 |
| 9 | 500 | 559.48 | 487.29 | 477.54 | 492.9 | 667.64 | 551.61 | 719.16 | **427.1** | 455.98 | 550.35 |
| 12 | 50 | 352.86 | 371.39 | 303.81 | 283.74 | 479.45 | 260.51 | 292.79 | 546.96 | 366.47 | 472.96 |
| 12 | 100 | 405.68 | **427.18** | 349.83 | 327.18 | 553.88 | 301.06 | 339.27 | 631.32 | **423.89** | 544.74 |
| 12 | 200 | 462.72 | 487.47 | 399.55 | 374.18 | 635.04 | 344.96 | 389.83 | 723.24 | 486.5 | 622.54 |
| 12 | 500 | 541.29 | 570.55 | 468.02 | 439.06 | 747.91 | 405.55 | 459.97 | 851.08 | 573.59 | 730.1 |
| 18 | 50 | 296.03 | 254.4 | 278.49 | 335.81 | 439.57 | 458.57 | 289.88 | 328 | 390.36 | 310.88 |
| 18 | 100 | 342.69 | 295.89 | 324.32 | 389.24 | 510.16 | 531.33 | 336.5 | 379.93 | 451 | 360.46 |
| 18 | 200 | 392.89 | 340.66 | 373.94 | 446.83 | 586.66 | 609.91 | 386.82 | 435.88 | 516.28 | 413.93 |
| 18 | 500 | 462.31 | 402.74 | 442.96 | 526.61 | 693.22 | 718.99 | 456.65 | 513.34 | 606.59 | 488.02 |
| 24 | 50 | 309.19 | 271.75 | 367.81 | 441.41 | 337.68 | 268.76 | 254.86 | **421.61** | 272.14 | 311.65 |
| 24 | 100 | 360.87 | 317.24 | **426.83** | 513.51 | 392.15 | 313.34 | 297.89 | 488.97 | 316.12 | 363.74 |
| 24 | 200 | 399.92 | 351.28 | 470.95 | 567.57 | 432.87 | 346.71 | 330.22 | 539.32 | 348.99 | 402.85 |
| 24 | 500 | 466.92 | 409.43 | 546.21 | 660.03 | 502.34 | 403.7 | 386.07 | 625.19 | 405.03 | 469.83 |
| 36 | 50 | 307.99 | 487.88 | 329.37 | 372.79 | 307.99 | 313.64 | 246.09 | 244.03 | 202.19 | 216.17 |
| 36 | 100 | 361.12 | 567.8 | 385.34 | 435.24 | 360.02 | 365.63 | 288.68 | 287.03 | 236.92 | 253.17 |
| 36 | 200 | 413.47 | 646.41 | 441.03 | 496.68 | 411.17 | 416.65 | 330.59 | 329.48 | 271.02 | 289.49 |
| 36 | 500 | 492.67 | 764.32 | 525.5 | 588.9 | 487.84 | 493.01 | 393.76 | 393.39 | 322.05 | 343.87 |
| 48 | 50 | 295.94 | 275.32 | 481.92 | 233.17 | 477.43 | 382.32 | 298.55 | 226.25 | 337.74 | 485.62 |
| 48 | 100 | 349.48 | 323.56 | 563.71 | 274.32 | 561.66 | 448.13 | 350.53 | 267.26 | 397.16 | 569.03 |
| 48 | 200 | 410.48 | 378.27 | 656.59 | 320.96 | 657.91 | 522.84 | 409.46 | 313.85 | 464.66 | 663.98 |
| 48 | 500 | 497.25 | 455.7 | 788.15 | 386.91 | 795.15 | 628.64 | 492.8 | 379.88 | 560.36 | 798.86 |
| 72 | 50 | 235.05 | 232.1 | 196.97 | 360.07 | 134.61 | 237.31 | 231.25 | 197.09 | 381.92 | 263.77 |
| 72 | 100 | 279.04 | 275.47 | 234.44 | **425.94** | 161.75 | 281 | 274.25 | 234.79 | 450.09 | 312.44 |
| 72 | 200 | 330.56 | 326.12 | 278.21 | 503.14 | 193.44 | 331.92 | 324.53 | 278.98 | 529.73 | 369.24 |
| 72 | 500 | 401.38 | 395.87 | 338.31 | 609.2 | 236.88 | 401.8 | 393.51 | 339.73 | 639.08 | 447.14 |

Yellow cells highlight events with a peak flow within 1.5% of the 1% AEP event magnitude.


2% AEP: 3hrs
5% AEP: 5.25hrs
10% AEP: 6.75hrs
20% AEP: 11.25hrs
50% AEP: 21.5hrs
Flow (m³/s)
Duration (hrs)
72hr_100yr_E3
2% AEP: 2.25hrs
5% AEP: 4.5hrs
10% AEP: 7.25hrs
20% AEP: 10.5hrs
50% AEP: 19hrs
Flow (m³/s)
Duration (hrs)
0
2% AEP: 2.75hrs
5% AEP: 4.5hrs
10% AEP: 5.25hrs
20% AEP: 9.5hrs
50% AEP: 13.25hrs
Flow (m³/s)
Duration (hrs)
24hr_50yr_E7
2% AEP: 1.75hrs
5% AEP: 5hrs
10% AEP: 5.5hrs
20% AEP: 6.5hrs
50% AEP: 10.75hrs
Flow (m³/s)
Duration (hrs)
12hr_100yr_E8
2% AEP: 2.75hrs
5% AEP: 4.25hrs
10% AEP: 6hrs
20% AEP: 7.75hrs
50% AEP: 10.25hrs
Flow (m³/s)
Duration (hrs)
12hr_100yr_E1
2% AEP: 4.25hrs
5% AEP: 7.75hrs
10% AEP: 9hrs
20% AEP: 9.75hrs
50% AEP: 11hrs
Flow (m³/s)
Duration (hrs)
9hr_500yr_E7




## *Statistics of 10 1% AEP Events derived from Ensemble Patterns*

| | 50% AEP | 20% AEP | 10% AEP | 5% AEP | 2% AEP |
|---|---|---|---|---|---|
| Median | 10.5 hrs | 8 hrs | 5.75 hrs | 4.5 hrs | 2.75 hrs |
| Average | 11.53 hrs | 7.85 hrs | 5.95 hrs | 4.7 hrs | 2.6 hrs |
| Minimum | 4.75 hrs | 3.5 hrs | 3 hrs | 2.5 hrs | 1.5 hrs |
| Maximum | 21.5 hrs | 11.25 hrs | 9 hrs | 7.75 hrs | 8.25 hrs |

# Appendix B Duration Independent Storm (DIS)

The DIS temporal pattern is a temporal pattern derived from IFD design rainfall, preserving all sub-duration rainfall intensities up to 24hrs. A sample DIS temporal pattern for the Mooloolah River gauge catchment is shown in Figure 10 as a percentage of the 24hr duration rainfall depth. Figure 11 shows this temporal pattern applied to the 1% AEP design rainfall depths in 5 minutely intervals.

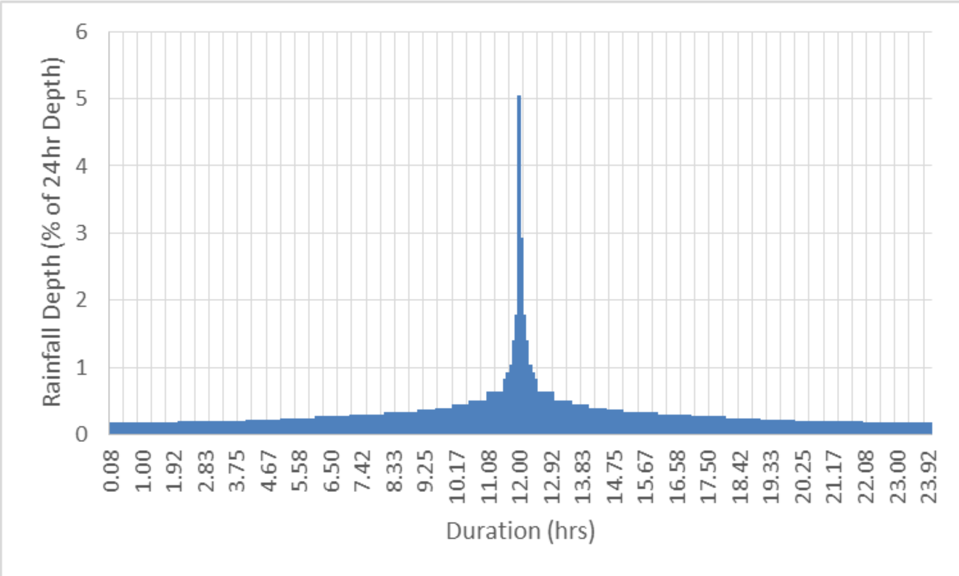



Figure 11 Duration Independent Storm Temporal Pattern (% of 24hr Rainfall Depth)

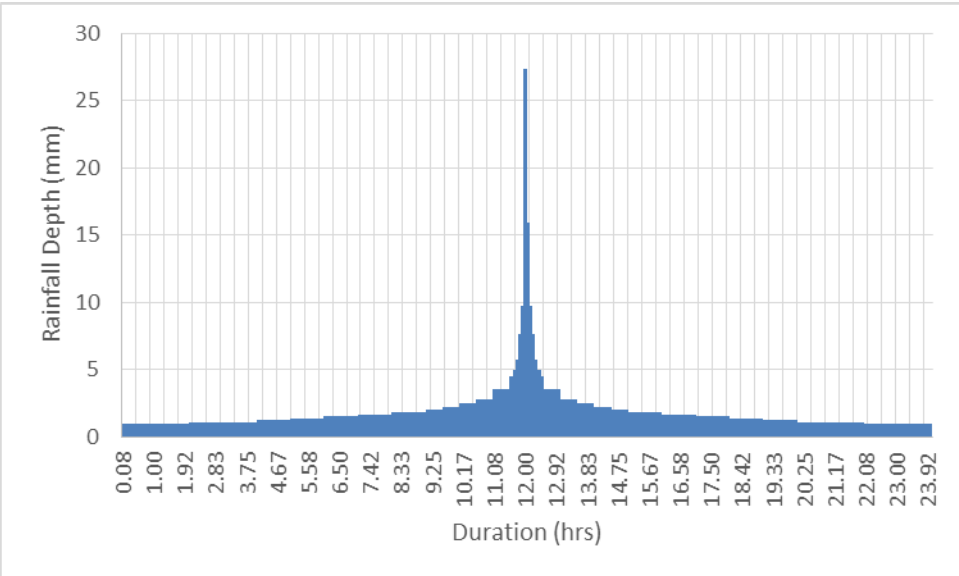



Figure 12 24hr Duration Independent Storm Temporal Pattern (Rainfall Depth)

Figure 12 shows how the DIS temporal pattern in calculated. This is done by starting with the 5 minutely design rainfall. The pattern is expanded to 10 minutes by adding the difference between the 10 and 5 minute design rainfall. The pattern is expanded to 20 minutes by adding half the difference between of the 20 and 10 minute design rainfall symmetrically on either side of the temporal pattern. This is continued for all durations up to 24hrs.

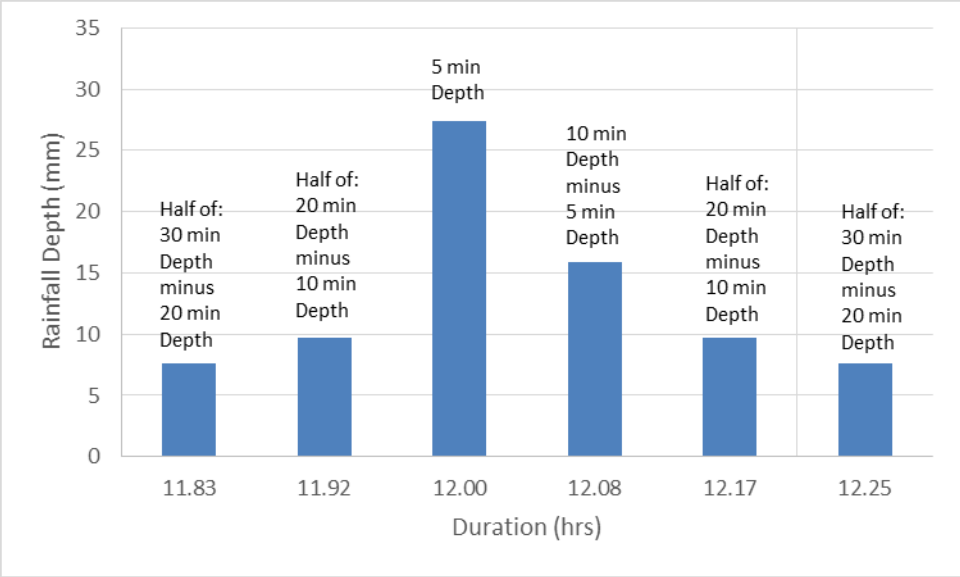



Figure 13 Demonstrating the calculation of a Duration Independent Storm Temporal Pattern

# Appendix C Median Intensity Storm (MIS)

The MIS temporal pattern is a temporal pattern derived from the 10 ensemble rainfall temporal patterns of ARR 2016, with sub-duration intensities calculated for each of these temporal patterns and a median intensity from these 10 patterns calculated for each sub-duration. A synthetic temporal patten is then calculated using a DIS methodology, but using the median sub-duration intensities rather than design IFD information.

Example

The example below calculates a MIS 24hr temporal pattern from a 24hr duration design rainfall depth of 549mm.

1. Calcuate Ensemble Temporal Pattern rainfall depths by applying the appropriate areal and regional ensemble patterns for the catchment. In this case East Coast North, for a catchment area less that 100 $km^2$.

Ensemble Temporal Patterns

| Time(hrs) | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | E9 | E10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.25 | *2.43* | *2.94* | *0.44* | *7.99* | *1.92* | *3.05* | *9.98* | *0.29* | *4.31* | *9.46* |
| 0.5 | *2.43* | *2.94* | *0.44* | *7.99* | *1.92* | *3.05* | *9.98* | *0.29* | *4.31* | *9.46* |
| 0.75 | *2.43* | *2.94* | *0.44* | *7.99* | *1.92* | *3.05* | *9.98* | *0.29* | *4.31* | *9.46* |
| 1 | 2.43 | 2.94 | 0.44 | 7.99 | 1.92 | 3.05 | 9.98 | 0.29 | 4.31 | 9.46 |
| 1.25 | *6.23* | *4.67* | *0.03* | *13.81* | *2.79* | *4.74* | *12.82* | *6.40* | *2.42* | *5.35* |
| 1.5 | *6.23* | *4.67* | *0.03* | *13.81* | *2.79* | *4.74* | *12.82* | *6.40* | *2.42* | *5.35* |
| 1.75 | *6.23* | *4.67* | *0.03* | *13.81* | *2.79* | *4.74* | *12.82* | *6.40* | *2.42* | *5.35* |
| 2 | 6.23 | 4.67 | 0.03 | 13.81 | 2.79 | 4.74 | 12.82 | 6.40 | 2.42 | 5.35 |
| 2.25 | *1.54* | *3.58* | *1.08* | *6.40* | *4.12* | *8.51* | *10.38* | *2.44* | *3.68* | *6.14* |
| 2.5 | *1.54* | *3.58* | *1.08* | *6.40* | *4.12* | *8.51* | *10.38* | *2.44* | *3.68* | *6.14* |
| 2.75 | *1.54* | *3.58* | *1.08* | *6.40* | *4.12* | *8.51* | *10.38* | *2.44* | *3.68* | *6.14* |
| 3 | 1.54 | 3.58 | 1.08 | 6.40 | 4.12 | 8.51 | 10.38 | 2.44 | 3.68 | 6.14 |
| 3.25 | *3.18* | *3.31* | *3.35* | *1.39* | *4.52* | *7.77* | *3.97* | *0.92* | *3.28* | *4.39* |
| 3.5 | *3.18* | *3.31* | *3.35* | *1.39* | *4.52* | *7.77* | *3.97* | *0.92* | *3.28* | *4.39* |
| 3.75 | *3.18* | *3.31* | *3.35* | *1.39* | *4.52* | *7.77* | *3.97* | *0.92* | *3.28* | *4.39* |
| 4 | 3.18 | 3.31 | 3.35 | 1.39 | 4.52 | 7.77 | 3.97 | 0.92 | 3.28 | 4.39 |
| 4.25 | *5.89* | *4.50* | *2.72* | *1.62* | *5.56* | *4.74* | *6.30* | *0.30* | *3.82* | *1.32* |
| 4.5 | *5.89* | *4.50* | *2.72* | *1.62* | *5.56* | *4.74* | *6.30* | *0.30* | *3.82* | *1.32* |
| 4.75 | *5.89* | *4.50* | *2.72* | *1.62* | *5.56* | *4.74* | *6.30* | *0.30* | *3.82* | *1.32* |
| 5 | 5.89 | 4.50 | 2.72 | 1.62 | 5.56 | 4.74 | 6.30 | 0.30 | 3.82 | 1.32 |
| 5.25 | *1.99* | *5.64* | *9.11* | *1.72* | *8.66* | *6.66* | *6.51* | *1.52* | *5.65* | *5.27* |
| 5.5 | *1.99* | *5.64* | *9.11* | *1.72* | *8.66* | *6.66* | *6.51* | *1.52* | *5.65* | *5.27* |
| 5.75 | *1.99* | *5.64* | *9.11* | *1.72* | *8.66* | *6.66* | *6.51* | *1.52* | *5.65* | *5.27* |
| 6 | 1.99 | 5.64 | 9.11 | 1.72 | 8.66 | 6.66 | 6.51 | 1.52 | 5.65 | 5.27 |
| 6.25 | *17.84* | *10.18* | *6.05* | *0.78* | *6.71* | *1.00* | *5.78* | *1.67* | *4.38* | *9.69* |
| 6.5 | *17.84* | *10.18* | *6.05* | *0.78* | *6.71* | *1.00* | *5.78* | *1.67* | *4.38* | *9.69* |
| 6.75 | *17.84* | *10.18* | *6.05* | *0.78* | *6.71* | *1.00* | *5.78* | *1.67* | *4.38* | *9.69* |
| 7 | 17.84 | 10.18 | 6.05 | 0.78 | 6.71 | 1.00 | 5.78 | 1.67 | 4.38 | 9.69 |
| 7.25 | *12.05* | *12.98* | *2.26* | *5.42* | *5.86* | *2.98* | *3.10* | *4.12* | *4.93* | *2.91* |
| 7.5 | *12.05* | *12.98* | *2.26* | *5.42* | *5.86* | *2.98* | *3.10* | *4.12* | *4.93* | *2.91* |
| 7.75 | *12.05* | *12.98* | *2.26* | *5.42* | *5.86* | *2.98* | *3.10* | *4.12* | *4.93* | *2.91* |
| 8 | 12.05 | 12.98 | 2.26 | 5.42 | 5.86 | 2.98 | 3.10 | 4.12 | 4.93 | 2.91 |
| 8.25 | *4.39* | *5.17* | *5.85* | *15.02* | *8.98* | *3.21* | *4.45* | *4.27* | *4.79* | *4.05* |
| 8.5 | *4.39* | *5.17* | *5.85* | *15.02* | *8.98* | *3.21* | *4.45* | *4.27* | *4.79* | *4.05* |
| 8.75 | *4.39* | *5.17* | *5.85* | *15.02* | *8.98* | *3.21* | *4.45* | *4.27* | *4.79* | *4.05* |
| 9 | 4.39 | 5.17 | 5.85 | 15.02 | 8.98 | 3.21 | 4.45 | 4.27 | 4.79 | 4.05 |

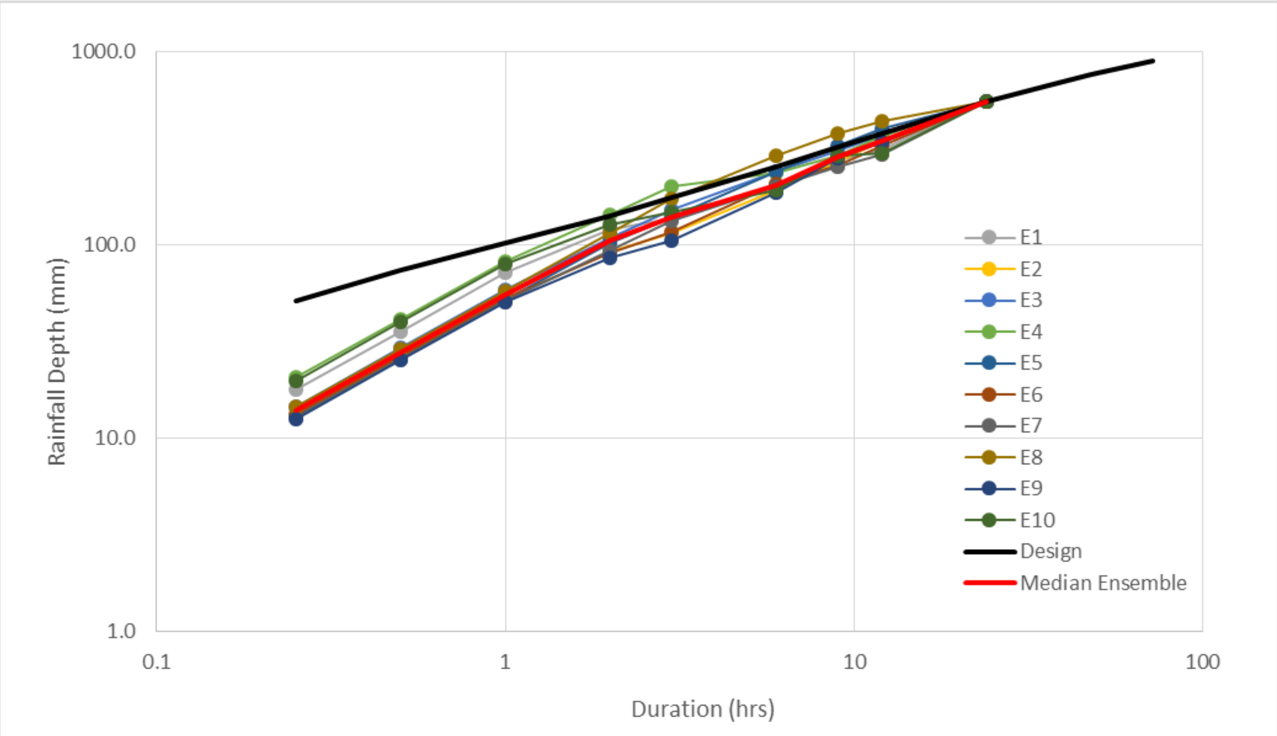
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 9.25 | *1.30* | *7.60* | *7.34* | *20.57* | *12.71* | *3.66* | *5.92* | *2.29* | *6.62* | *13.52* |
| 9.5 | *1.30* | *7.60* | *7.34* | *20.57* | *12.71* | *3.66* | *5.92* | *2.29* | *6.62* | *13.52* |
| 9.75 | *1.30* | *7.60* | *7.34* | *20.57* | *12.71* | *3.66* | *5.92* | *2.29* | *6.62* | *13.52* |
| 10 | 1.30 | 7.60 | 7.34 | 20.57 | 12.71 | 3.66 | 5.92 | 2.29 | 6.62 | 13.52 |
| 10.25 | *2.03* | *6.16* | *7.93* | *14.45* | *12.96* | *7.56* | *2.42* | *13.27* | *6.30* | *0.25* |
| 10.5 | *2.03* | *6.16* | *7.93* | *14.45* | *12.96* | *7.56* | *2.42* | *13.27* | *6.30* | *0.25* |
| 10.75 | *2.03* | *6.16* | *7.93* | *14.45* | *12.96* | *7.56* | *2.42* | *13.27* | *6.30* | *0.25* |
| 11 | 2.03 | 6.16 | 7.93 | 14.45 | 12.96 | 7.56 | 2.42 | 13.27 | 6.30 | 0.25 |
| 11.25 | *1.14* | *1.92* | *14.12* | *2.05* | *5.31* | *2.90* | *1.88* | *14.33* | *2.26* | *0.78* |
| 11.5 | *1.14* | *1.92* | *14.12* | *2.05* | *5.31* | *2.90* | *1.88* | *14.33* | *2.26* | *0.78* |
| 11.75 | *1.14* | *1.92* | *14.12* | *2.05* | *5.31* | *2.90* | *1.88* | *14.33* | *2.26* | *0.78* |
| 12 | 1.14 | 1.92 | 14.12 | 2.05 | 5.31 | 2.90 | 1.88 | 14.33 | 2.26 | 0.78 |
| 12.25 | *2.77* | *7.26* | *13.05* | *1.02* | *6.20* | *1.22* | *1.74* | *14.49* | *4.19* | *1.04* |
| 12.5 | *2.77* | *7.26* | *13.05* | *1.02* | *6.20* | *1.22* | *1.74* | *14.49* | *4.19* | *1.04* |
| 12.75 | *2.77* | *7.26* | *13.05* | *1.02* | *6.20* | *1.22* | *1.74* | *14.49* | *4.19* | *1.04* |
| 13 | 2.77 | 7.26 | 13.05 | 1.02 | 6.20 | 1.22 | 1.74 | 14.49 | 4.19 | 1.04 |
| 13.25 | *2.95* | *6.82* | *10.90* | *1.89* | *11.57* | *8.65* | *3.54* | *14.18* | *6.12* | *0.55* |
| 13.5 | *2.95* | *6.82* | *10.90* | *1.89* | *11.57* | *8.65* | *3.54* | *14.18* | *6.12* | *0.55* |
| 13.75 | *2.95* | *6.82* | *10.90* | *1.89* | *11.57* | *8.65* | *3.54* | *14.18* | *6.12* | *0.55* |
| 14 | 2.95 | 6.82 | 10.90 | 1.89 | 11.57 | 8.65 | 3.54 | 14.18 | 6.12 | 0.55 |
| 14.25 | *4.02* | *9.21* | *3.32* | *8.48* | *10.86* | *6.57* | *6.41* | *9.00* | *6.60* | *0.99* |
| 14.5 | *4.02* | *9.21* | *3.32* | *8.48* | *10.86* | *6.57* | *6.41* | *9.00* | *6.60* | *0.99* |
| 14.75 | *4.02* | *9.21* | *3.32* | *8.48* | *10.86* | *6.57* | *6.41* | *9.00* | *6.60* | *0.99* |
| 15 | 4.02 | 9.21 | 3.32 | 8.48 | 10.86 | 6.57 | 6.41 | 9.00 | 6.60 | 0.99 |
| 15.25 | *4.52* | *5.42* | *2.53* | *2.73* | *3.14* | *2.72* | *6.85* | *6.86* | *6.27* | *5.48* |
| 15.5 | *4.52* | *5.42* | *2.53* | *2.73* | *3.14* | *2.72* | *6.85* | *6.86* | *6.27* | *5.48* |
| 15.75 | *4.52* | *5.42* | *2.53* | *2.73* | *3.14* | *2.72* | *6.85* | *6.86* | *6.27* | *5.48* |
| 16 | 4.52 | 5.42 | 2.53 | 2.73 | 3.14 | 2.72 | 6.85 | 6.86 | 6.27 | 5.48 |
| 16.25 | *6.82* | *7.11* | *1.07* | *1.11* | *5.01* | *3.46* | *2.57* | *3.51* | *10.36* | *19.91* |
| 16.5 | *6.82* | *7.11* | *1.07* | *1.11* | *5.01* | *3.46* | *2.57* | *3.51* | *10.36* | *19.91* |
| 16.75 | *6.82* | *7.11* | *1.07* | *1.11* | *5.01* | *3.46* | *2.57* | *3.51* | *10.36* | *19.91* |
| 17 | 6.82 | 7.11 | 1.07 | 1.11 | 5.01 | 3.46 | 2.57 | 3.51 | 10.36 | 19.91 |
| 17.25 | *8.61* | *5.96* | *4.67* | *3.94* | *1.43* | *6.35* | *8.58* | *5.64* | *8.02* | *11.60* |
| 17.5 | *8.61* | *5.96* | *4.67* | *3.94* | *1.43* | *6.35* | *8.58* | *5.64* | *8.02* | *11.60* |
| 17.75 | *8.61* | *5.96* | *4.67* | *3.94* | *1.43* | *6.35* | *8.58* | *5.64* | *8.02* | *11.60* |
| 18 | 8.61 | 5.96 | 4.67 | 3.94 | 1.43 | 6.35 | 8.58 | 5.64 | 8.02 | 11.60 |
| 18.25 | *6.12* | *6.49* | *8.73* | *2.55* | *3.61* | *9.46* | *9.42* | *12.35* | *6.26* | *0.26* |
| 18.5 | *6.12* | *6.49* | *8.73* | *2.55* | *3.61* | *9.46* | *9.42* | *12.35* | *6.26* | *0.26* |
| 18.75 | *6.12* | *6.49* | *8.73* | *2.55* | *3.61* | *9.46* | *9.42* | *12.35* | *6.26* | *0.26* |
| 19 | 6.12 | 6.49 | 8.73 | 2.55 | 3.61 | 9.46 | 9.42 | 12.35 | 6.26 | 0.26 |
| 19.25 | *5.49* | *4.86* | *2.47* | *2.22* | *1.59* | *13.24* | *5.59* | *2.29* | *5.96* | *3.02* |
| 19.5 | *5.49* | *4.86* | *2.47* | *2.22* | *1.59* | *13.24* | *5.59* | *2.29* | *5.96* | *3.02* |
| 19.75 | *5.49* | *4.86* | *2.47* | *2.22* | *1.59* | *13.24* | *5.59* | *2.29* | *5.96* | *3.02* |
| 20 | 5.49 | 4.86 | 2.47 | 2.22 | 1.59 | 13.24 | 5.59 | 2.29 | 5.96 | 3.02 |
| 20.25 | *9.99* | *5.57* | *14.64* | *3.71* | *0.43* | *3.94* | *4.01* | *6.09* | *4.94* | *1.78* |
| 20.5 | *9.99* | *5.57* | *14.64* | *3.71* | *0.43* | *3.94* | *4.01* | *6.09* | *4.94* | *1.78* |
| 20.75 | *9.99* | *5.57* | *14.64* | *3.71* | *0.43* | *3.94* | *4.01* | *6.09* | *4.94* | *1.78* |
| 21 | 9.99 | 5.57 | 14.64 | 3.71 | 0.43 | 3.94 | 4.01 | 6.09 | 4.94 | 1.78 |
| 21.25 | *10.16* | *2.55* | *8.67* | *6.81* | *0.11* | *5.78* | *6.14* | *6.26* | *8.78* | *11.31* |
| 21.5 | *10.16* | *2.55* | *8.67* | *6.81* | *0.11* | *5.78* | *6.14* | *6.26* | *8.78* | *11.31* |
| 21.75 | *10.16* | *2.55* | *8.67* | *6.81* | *0.11* | *5.78* | *6.14* | *6.26* | *8.78* | *11.31* |
| 22 | 10.16 | 2.55 | 8.67 | 6.81 | 0.11 | 5.78 | 6.14 | 6.26 | 8.78 | 11.31 |
| 22.25 | *10.21* | *4.12* | *3.38* | *5.15* | *3.51* | *10.91* | *3.68* | *3.51* | *12.64* | *6.63* |
| 22.5 | *10.21* | *4.12* | *3.38* | *5.15* | *3.51* | *10.91* | *3.68* | *3.51* | *12.64* | *6.63* |
| 22.75 | *10.21* | *4.12* | *3.38* | *5.15* | *3.51* | *10.91* | *3.68* | *3.51* | *12.64* | *6.63* |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 23 | 10.21 | 4.12 | 3.38 | 5.15 | 3.51 | 10.91 | 3.68 | 3.51 | 12.64 | 6.63 |
| 23.25 | *5.57* | *3.21* | *3.53* | *6.44* | *9.70* | *8.18* | *5.26* | *1.22* | *4.68* | *11.56* |
| 23.5 | *5.57* | *3.21* | *3.53* | *6.44* | *9.70* | *8.18* | *5.26* | *1.22* | *4.68* | *11.56* |
| 23.75 | *5.57* | *3.21* | *3.53* | *6.44* | *9.70* | *8.18* | *5.26* | *1.22* | *4.68* | *11.56* |
| 24 | 5.57 | 3.21 | 3.53 | 6.44 | 9.70 | 8.18 | 5.26 | 1.22 | 4.68 | 11.56 |
| Check Total | 549 | 549 | 549 | 549 | 549 | 549 | 549 | 549 | 549 | 549 |

2. Calculate the sub-duration intensities for each ensemble temporal pattern.
3. Calculate the median intensity for each sub-duration.

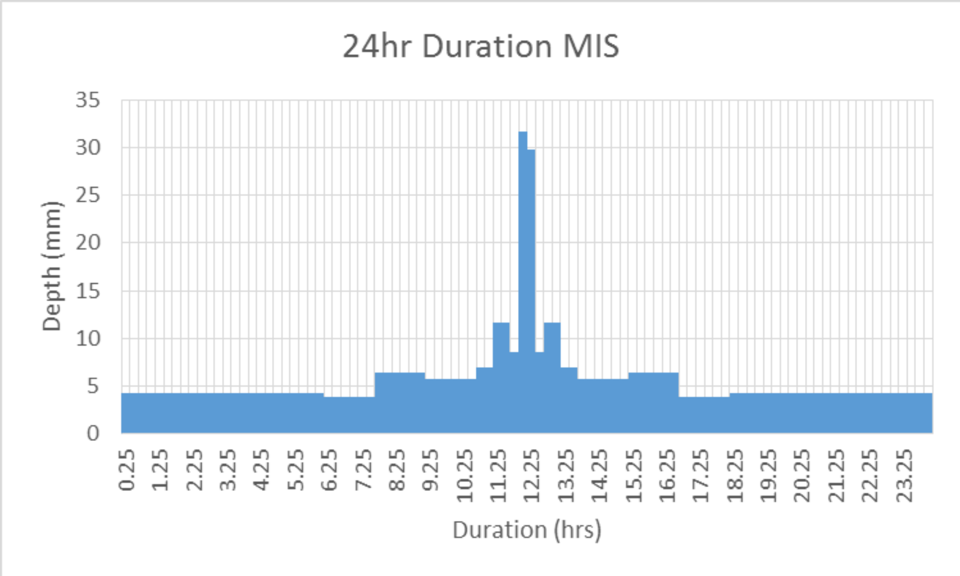
Intensity Analysis of Ensemble Patterns

| | Sub-duration Max Rainfall Depth (mm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sub-duration (hrs) | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | E9 | E10 | **Median** |
| 0.25 | 17.8 | 13.0 | 14.6 | 20.6 | 13.0 | 13.2 | 12.8 | 14.5 | 12.6 | 19.9 | **13.9** |
| 0.5 | 35.7 | 26.0 | 29.3 | 41.1 | 25.9 | 26.5 | 25.6 | 29.0 | 25.3 | 39.8 | **27.7** |
| 1 | 71.4 | 51.9 | 58.6 | 82.3 | 51.8 | 53.0 | 51.3 | 58.0 | 50.6 | 79.7 | **55.5** |
| 2 | 119.6 | 92.7 | 108.7 | 142.4 | 102.7 | 90.8 | 92.8 | 115.3 | 85.7 | 126.1 | **105.7** |
| 3 | 137.1 | 115.2 | 152.3 | 200.2 | 138.6 | 116.2 | 132.7 | 172.0 | 105.5 | 148.0 | **137.9** |
| 6 | 202.3 | 191.0 | 236.8 | 234.1 | 238.4 | 206.0 | 199.8 | 288.6 | 186.4 | 191.5 | **204.2** |
| 9 | 269.9 | 269.3 | 306.5 | 286.5 | 324.6 | 256.2 | 253.1 | 374.6 | 279.3 | 286.2 | **282.8** |
| 12 | 308.9 | 343.2 | 368.4 | 364.8 | 399.6 | 321.9 | 293.9 | 433.2 | 339.3 | 296.5 | **341.3** |
| 24 | 549 | 549 | 549 | 549 | 549 | 549 | 549 | 549 | 549 | 549 | **549** |

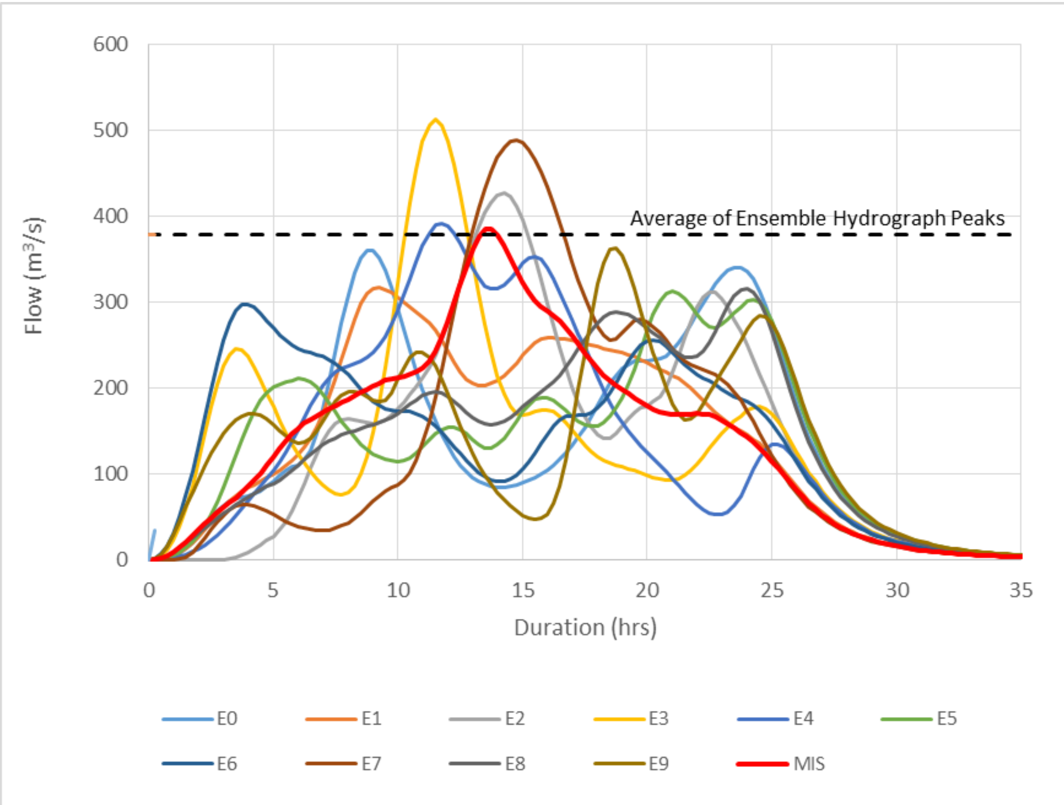


4. Calculate the MIS temporal pattern using the methodology of a Duration Independent Storm (DIS) as documented in Appendix A. Use the calculated median intensities instead of design intensities.

Temporal Pattern dervived from Median Intensities (MIS)




Hydrographs generated using the 10 ensemble 24hr temporal patterns and the 24hr MIS temporal pattern at the location of the Mooloolah River Gauge are presented below. All hydrogrpahs have the same volume. It can be seen that the MIS hydrograph has a peak that closely approximates the average of the ensemble hydrographs.



# Appendix D  Median Intensity Storm Duration Independent Storm (MIDIS)

The MIDIS temporal pattern is a temporal pattern derived from MIS temporal for a number of durations, except that the ensemble patterns used to generate the MIS pattern are based on an excess rainfall with the excess loss extracted from the individual rainfall temporal patterns.

The MIDIS is duration independent as it extracts the maximum sub-duration intensities from all of the individual MIS durations. A MIDIS temporal pattern is then constructed using the DIS methodology described in Appendix A.

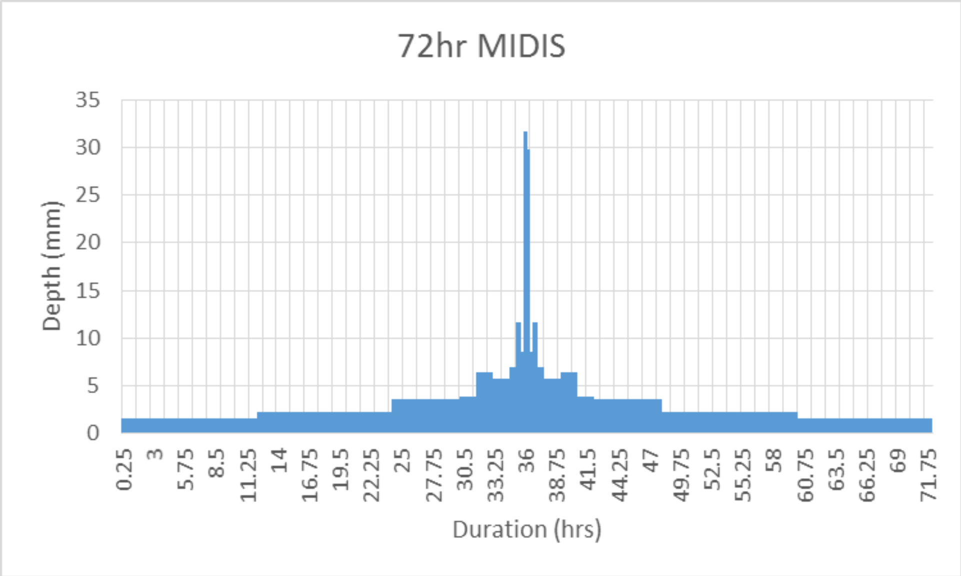
Compiled MIS sub-duration peak depths for all durations

| Sub drn (hrs) | MIS Temporal Pattern Durations | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1hr | 2hr | 3hr | 6hr | 9hr | 12hr | 18hr | 24hr | 36hr | 48hr | 72hr |
| 0.25 | 36.2 | 39.6 | 31.9 | 26.8 | 22.8 | 15.0 | 14.9 | 12.9 | 10.7 | 12.0 | 9.3 |
| 0.5 | 60.3 | 64.5 | 45.6 | 46.2 | 45.6 | 29.9 | 29.9 | 25.8 | 21.3 | 23.9 | 18.6 |
| 1 | | 81.3 | 76.6 | 76.5 | 75.2 | 57.2 | 59.8 | 51.6 | 42.6 | 47.8 | 37.2 |
| 2 | | | 129.1 | 121.6 | 126.3 | 99.9 | 106.6 | 96.8 | 85.3 | 95.6 | 74.4 |
| 3 | | | | 157.3 | 154.2 | 132.5 | 152.6 | 129.6 | 117.4 | 136.9 | 111.6 |
| 6 | | | | | 224.5 | 236.1 | 264.2 | 229.9 | 195.7 | 217.5 | 207.8 |
| 9 | | | | | | 311.0 | 341.9 | 319.7 | 270.0 | 273.7 | 254.0 |
| 12 | | | | | | | 395.0 | 388.9 | 335.2 | 322.4 | 300.0 |
| 24 | | | | | | | | | 497.5 | 542.1 | 483.3 |
| 36 | | | | | | | | | | 641.9 | 630.0 |
| 48 | | | | | | | | | | | 720.5 |
| 72 | | | | | | | | | | | |

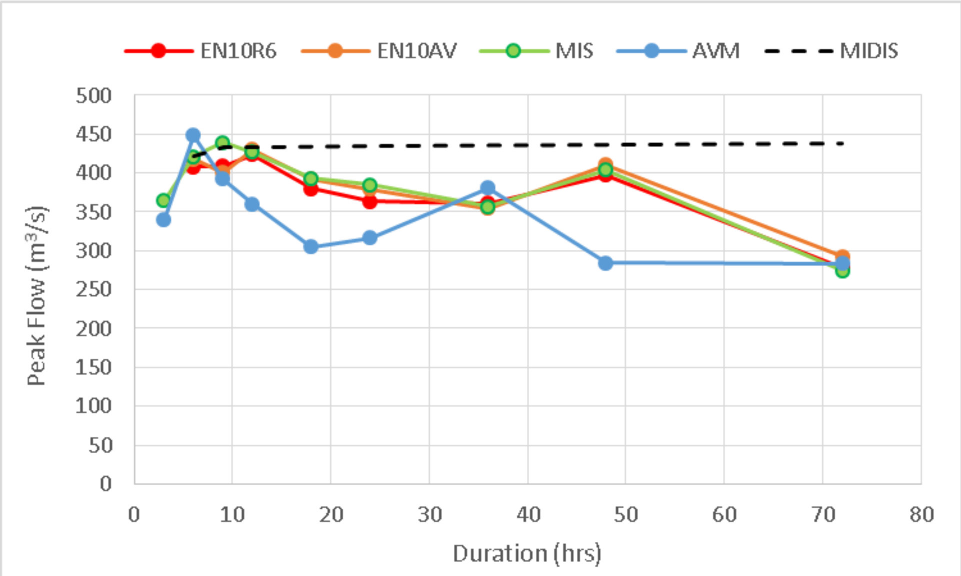
Max of the MIS sub-duration intensities (checking the Design IFD is not exceeded)

| Duration (hrs) | Max | Des IFD | **MDIS IFD** |
|---|---|---|---|
| 0.25 | 39.6 | 52.8 | **39.6** |
| 0.5 | 64.5 | 75.85 | **64.5** |
| 1 | 81.3 | 105.1 | **81.3** |
| 2 | 129.1 | 145.8 | **129.1** |
| 3 | 157.3 | 177.1 | **157.3** |
| 6 | 264.2 | 255.2 | **255.2** |
| 9 | 341.9 | 319.3 | **319.3** |
| 12 | 395.0 | 374.3 | **374.3** |
| 24 | 542.1 | 545.5 | **542.1** |
| 36 | 641.9 | 661.2 | **641.9** |
| 48 | 720.5 | 757.9 | **720.5** |
| 72 | | 884.9 | **886.0** |

MIDIS Temporal Pattern

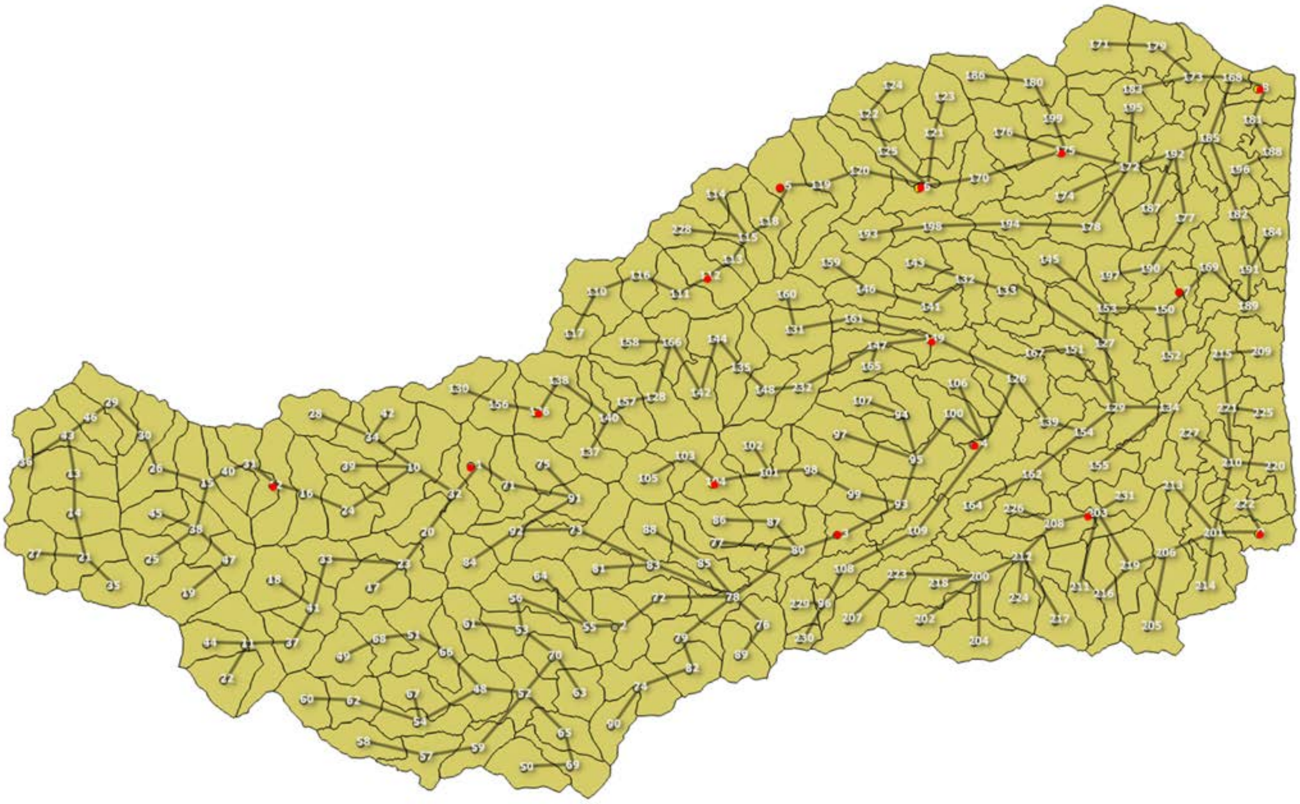



The peak from a hydrograph generated using a MIDIS temporal pattern was observed to show good agreement with critical duration analysis using ensemble and MIS methodologies.



# Appendix E  Multifocal Point Analysis

A number of focal points were established within the Mooloolah River URBS model. These are shown below.



| | Loc'n | Area | PK EN10 AV | Crit Drn | PK R6 | Crit Drn | PK MIS | Crit Drn | Pk AVM | Crit Drn | 72hr MIDIS | SCC RFFE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **T12** | 19.6 | 243 | 12 | 224 | 12 | 242 | 9 | 249 | 6 | 245 | 248 |
| **Mooloolah River Gauge** | **T1** | 39.3 | 430 | 12 | 424 | 12 | 439 | 9 | 448 | 6 | 441 | 433 |
| **Jordan St Gauge** | **T3** | 80.7 | 691 | 24 | 727 | 24 | 701 | 24 | 723 | 24 | 655 | 769 |
| | **T104** | 2.5 | 37 | 12 | 34 | 6 | 36 | 6 | 36 | 6 | 37 | |
| | **T4** | 98.0 | 829 | 24 | 875 | 24 | 847 | 24 | 861 | 24 | 780 | 899 |
| | **T136** | 3.0 | 42 | 12 | 39 | 6 | 41 | 9 | 42 | 6 | 42 | |
| | **T149** | 117.4 | 1018 | 24 | 1068 | 24 | 1039 | 24 | 1058 | 24 | 942 | 1039 |
| **Parrearra Gauge** | **T7** | 138.6 | 1175 | 24 | 1248 | 24 | 1203 | 24 | 1219 | 24 | 1105 | 1187 |
| | **T112** | 4.9 | 69 | 6 | 62 | 6 | 67 | 9 | 69 | 6 | 69 | |
| **Crosby Hill Rd, Tanawha** | **T5** | 10.3 | 134 | 6 | 122 | 9 | 133 | 9 | 140 | 6 | 139 | |
| **Dixon Rd, Mountain Creek** | **T6** | 18.6 | 226 | 6 | 212 | 6 | 227 | 9 | 240 | 6 | 235 | 238 |
| | **T175** | 25.3 | 285 | 6 | 277 | 6 | 288 | 9 | 306 | 6 | 295 | 304 |
| **Outlet** | **T8** | 187.6 | 1383 | 12 | 1361 | 6 | 1457 | 12 | 1463 | 24 | 1498 | 1511 |
| **Currimundi** | **T9** | 27.8 | 331 | 6 | 312 | 6 | 329 | 9 | 332 | 6 | 347 | 328 |

Mooloolah River

| | Loc'n | Area | PK EN10 AV | Crit Drn | PK R6 | Crit Drn | PK MIS | Crit Drn | Pk AVM | Crit Drn | 72hr MIDIS | SCC RFFE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **T12** | 19.6 | 243 | 12 | 224 | 12 | 242 | 9 | 249 | 6 | 245 | 248 |
| **Mooloolah River Gauge** | **T1** | 39.3 | 430 | 12 | 424 | 12 | 439 | 9 | 448 | 6 | 441 | 433 |
| **Jordan St Gauge** | **T3** | 80.7 | 691 | 24 | 727 | 24 | 701 | 24 | 723 | 24 | 655 | 769 |
| | **T4** | 98.0 | 829 | 24 | 875 | 24 | 847 | 24 | 861 | 24 | 780 | 899 |
| **Parrearra Gauge** | **T7** | 138.6 | 1175 | 24 | 1248 | 24 | 1203 | 24 | 1219 | 24 | 1105 | 1187 |
| **Outlet** | **T8** | 187.6 | 1383 | 12 | 1361 | 6 | 1457 | 12 | 1463 | 24 | 1498 | 1511 |

Sippy Creek

| | Loc'n | Area | PK EN10 AV | Crit Drn | PK R6 | Crit Drn | PK MIS | Crit Drn | Pk AVM | Crit Drn | 72hr MIDIS | SCC RFFE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **T136** | 3.0 | 42 | 12 | 39 | 6 | 41 | 9 | 42 | 6 | 42 | |
| | **T149** | 117.4 | 1018 | 24 | 1068 | 24 | 1039 | 24 | 1058 | 24 | 942 | 1039 |

Mountain Creek

| | Loc'n | Area | PK EN10 AV | Crit Drn | PK R6 | Crit Drn | PK MIS | Crit Drn | Pk AVM | Crit Drn | 72hr MIDIS | SCC RFFE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **T112** | 4.9 | 69 | 6 | 62 | 6 | 67 | 9 | 69 | 6 | 69 | |
| **Crosby Hill Rd, Tanawha** | **T5** | 10.3 | 134 | 6 | 122 | 9 | 133 | 9 | 140 | 6 | 139 | |
| **Dixon Rd, Mountain Creek** | **T6** | 18.6 | 226 | 6 | 212 | 6 | 227 | 9 | 240 | 6 | 235 | 238 |

Error relative to the Ensemble Average

| MIS | | | R6 | | | AVM | | | MIDIS 72hr | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Location** | **% Error** | | **Location** | **% Error** | | **Location** | **% Error** | | **Location** | **% Error** |
| **T12** | -0.2% | | T12 | -7.7% | | T12 | 2.7% | | T12 | 1.00% |
| **MOO** | 2.1% | | MOO | -1.5% | | MOO | 4.2% | | MOO | 2.54% |
| **T3** | 1.4% | | T3 | 5.3% | | T3 | 4.7% | | T3 | -5.17% |
| **T104** | -3.8% | | T104 | -7.7% | | T104 | -2.8% | | T104 | -0.14% |
| **T4** | -3.8% | | T4 | 5.5% | | T4 | -2.8% | | T4 | -5.95% |
| **T136** | -2.9% | | T136 | -7.1% | | T136 | 0.0% | | T136 | -0.33% |
| **T149** | 2.0% | | T149 | 4.9% | | T149 | 3.8% | | T149 | -7.50% |
| **T7** | 2.4% | | T7 | 6.2% | | T7 | 3.8% | | T7 | -5.96% |
| **T112** | -2.5% | | T112 | -9.9% | | T112 | 0.7% | | T112 | -0.65% |
| **T5** | -0.3% | | T5 | -9.1% | | T5 | 4.4% | | T5 | 3.36% |
| **T6** | 0.4% | | T6 | -6.1% | | T6 | 6.0% | | T6 | 3.97% |
| **T175** | 1.3% | | T175 | -2.5% | | T175 | 7.4% | | T175 | 3.35% |
| **T8** | 5.3% | | T8 | -1.6% | | T8 | 5.8% | | T8 | 8.31% |
| **T9** | -0.6% | | T9 | -5.9% | | T9 | 0.3% | | T9 | 4.87% |
| | | | | | | | | | | |
| **Average** | 0.1% | | Average | -2.7% | | Average | 2.7% | | Average | 0.12% |
| **Median** | 0.1% | | Median | -4.2% | | Median | 3.8% | | Median | 0.43% |
| **Worst** | 5.3% | | Worst | -9.9% | | Worst | 7.4% | | Worst | 8.31% |

The analyses presented in these tables utilised an ARF calculated at each of the multifocal locations for all temporal pattern methods except the MIDIS. The MIDIS utilises the ARF methodology discussed in the following appendix.

# Appendix F Adjustments for larger catchment Multifocal Analysis

The Mooloolah River URBS model covers a total catchment area of 215.4 $km^2$, including the Currimumdi Creek catchment. This is a large catchment. For the analysis of the ensemble temporal, AVM and MIS temporal patterns, an areal reduction factor (ARF) had to be applied for each focal locaton considered. In addition, depending on the whether the area of the focal location exceeds 100$km^2$ or 200$km^2$, the temporal patterns to adopt may also change.

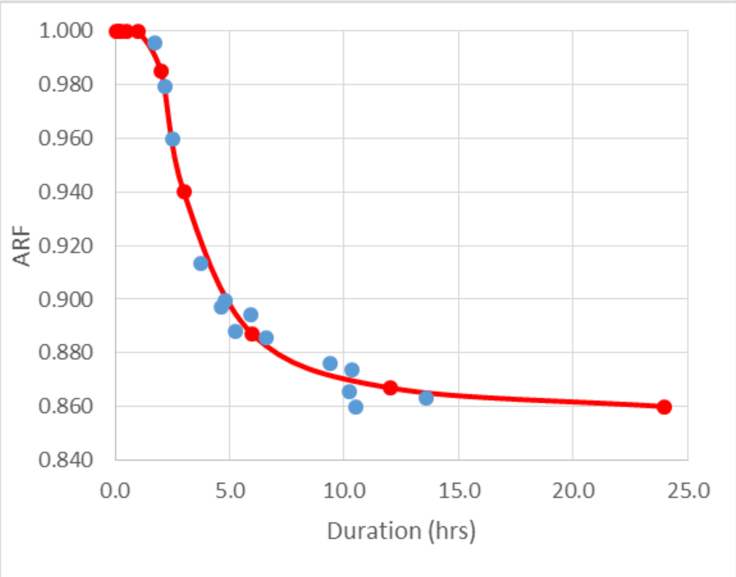
For large catchments a modification to the MIDIS temporal pattern can be implemented that:

1. Applies 100km2 temporal patterns for temporal durations above 720 minutes (12hrs).
2. Applies 200km2 temporal patterns for temporal durations above 1440 minutes (24hrs).
3. Applies an ARF correction that varies with duration.

### *ARF correction*

Analysis was undertaken using thePeak Flow Estimation methods of SCC (2018). This involved using each of the focal location in the URBS model, entering the area (ha) and the Dav as the centroid to outlet distance. A uniform catchment slope of 3% was assumed. For each focal location the Time of Concentration (hrs) was determined and an ARF was determined for that area, duration combination. Results were plotted for all focal locations and a curve was fitted to the data using practitioner judgement

| Focal Location | Area | Dav | ARF | ToC (hrs) |
|---|---|---|---|---|
| T12 | 19.6 | 4.69 | 0.897 | 4.7 |
| MOO | 39.27 | 8.19 | 0.886 | 6.6 |
| T3 | 80.65 | 13.79 | 0.876 | 9.4 |
| T104 | 2.47 | 1.4 | 0.996 | 1.8 |
| T4 | 98.04 | 15.93 | 0.874 | 10.3 |
| T136 | 2.98 | 1.66 | 0.980 | 2.2 |
| T149 | 117.38 | 14.33 | 0.866 | 10.2 |
| T7 | 138.63 | 19.74 | 0.860 | 10.5 |
| T112 | 4.89 | 1.93 | 0.960 | 2.5 |
| T5 | 10.32 | 3.72 | 0.914 | 3.8 |
| T6 | 18.63 | 5.28 | 0.900 | 4.8 |
| T175 | 25.31 | 7.72 | 0.894 | 5.9 |
| T8 | 187.6 | 22.82 | 0.863 | 13.6 |
| T9 | 27.8 | 5.42 | 0.888 | 5.3 |




.

| Duration | ARF |
|---|---|
| 0.083 | 1 |
| 0.167 | 1 |
| 0.25 | 1 |
| 0.5 | 1 |
| 1 | 1 |
| 2 | 0.985 |
| 3 | 0.94 |
| 6 | 0.887 |
| 12 | 0.867 |
| 24 | 0.86 |
| 48 | 0.86 |
| 72 | 0.86 |

| Focal Location | ToC | Ensemble Average Peak Flow | MIDIS Peak Flow TP Set 1 | Error | MIDIS Peak Flow TP Set 2 | Error | Diff between Peak Flows of TP Methods |
|---|---|---|---|---|---|---|---|
| T_12 | 4.7 | 243 | 246 | 1.16% | 254 | 4.39% | 1.03 |
| MOO | 6.6 | 430 | 438 | 1.81% | 456 | 5.95% | 1.04 |
| T_3 | 9.4 | 691 | 628 | -9.17% | 669 | -3.11% | 1.07 |
| T_104 | 1.8 | 37 | 37 | -0.35% | 38 | 2.68% | 1.03 |
| T_4 | 10.3 | 829 | 735 | -11.32% | 793 | -4.37% | 1.08 |
| T_136 | 2.2 | 42 | 42 | -0.71% | 43 | 2.69% | 1.03 |
| T_149 | 10.2 | 1018 | 901 | -11.50% | 955 | -6.15% | 1.06 |
| T_7 | 10.5 | 1175 | 1061 | -9.71% | 1123 | -4.42% | 1.06 |
| T_112 | 2.5 | 69 | 68 | -0.87% | 70 | 2.09% | 1.03 |
| T_5 | 3.8 | 134 | 138 | 2.94% | 142 | 6.14% | 1.03 |
| T_6 | 4.8 | 226 | 233 | 3.28% | 241 | 6.68% | 1.03 |
| T_175 | 5.9 | 285 | 292 | 2.49% | 302 | 5.99% | 1.03 |
| T_8 | 13.6 | 1383 | 1426 | 3.10% | 1516 | 9.58% | 1.06 |
| T_9 | 5.3 | 331 | 347 | 4.79% | 356 | 7.63% | 1.03 |
| Average | | | | -1.72% | | 2.55% | |
| Median | | | | 0.41% | | 3.54% | |
| Abs Max | | | | 11.50% | | 9.58% | |

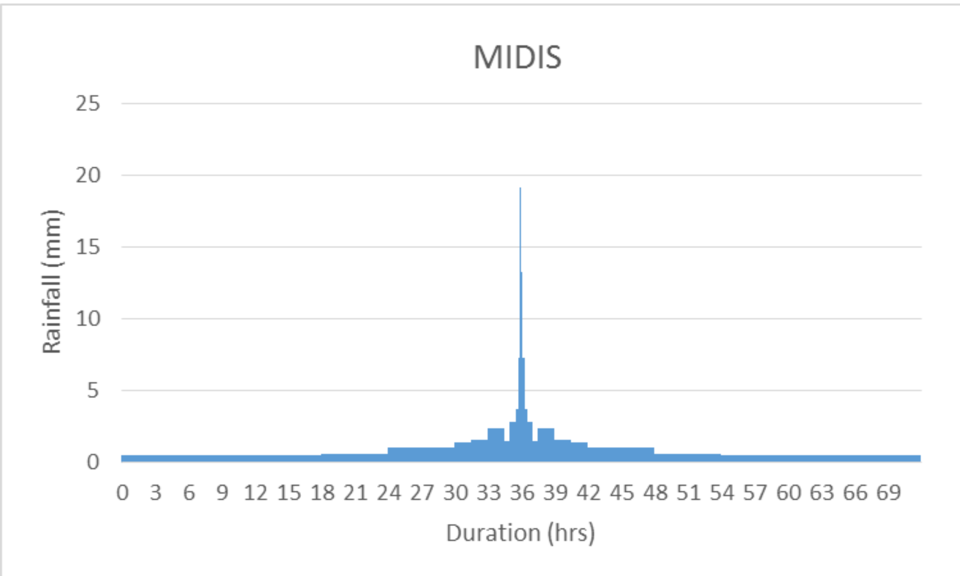
TP Set 1: ARR Temporal Patterns for catchment areas < 100 $km^2$.

TP Set 2: ARR Temporal Patterns for catchment areas <100km2 Duration <12hr
ARR Temporal Patterns for catchment areas > 100$km^2$, Duration 12-24hr
ARR Temporal Patterns for catchment areas > 200$km^2$, Duration >24hr

It was observed that TP Set 1 provided excellent agreement with ensemble average peak flows for Time of Concentration durations below 9hrs, but for longer durations and larger area focal locations TP Set 1 under estimates peak flows. When TP Set 2 is applied it is observed that the error improves for longer durations/larger area focal locations but a 3% overestimation also occurs for the shorter duration/smaller area focal locations. A factor of 0.97 is then applied to the ARFs for durations less than 12hrs.

| Duration | ARF | TP adj ARF | Final ARF |
|---|---|---|---|
| 0.083 | 1 | 0.97 | 0.97 |
| 0.167 | 1 | 0.97 | 0.97 |
| 0.25 | 1 | 0.97 | 0.97 |
| 0.5 | 1 | 0.97 | 0.97 |
| 1 | 1 | 0.97 | 0.97 |
| 2 | 0.985 | 0.97 | 0.955 |
| 3 | 0.94 | 0.97 | 0.912 |
| 6 | 0.887 | 0.97 | 0.860 |
| 12 | 0.867 | 1 | 0.867 |
| 24 | 0.86 | 1 | 0.86 |
| 48 | 0.86 | 1 | 0.86 |
| 72 | 0.86 | 1 | 0.86 |

The following figure shows the 72hr MIDIS with the ARF and temporal pattern adjustments.



The MIDIS peak flows at the various focal locations with the final ARF adjustment are shown in the table below. These have been compared to the ensemble average peak flow estimates.

| Focal Location | ToC | Ensemble Average Peak Flow | MIDIS Peak Flow Final ARF | Error |
|---|---|---|---|---|
| T_12 | 4.7 | 243 | 245 | 1.00% |
| MOO | 6.6 | 430 | 441 | 2.54% |
| T_3 | 9.4 | 691 | 655 | -5.17% |
| T_104 | 1.8 | 37 | 37 | -0.14% |
| T_4 | 10.3 | 829 | 780 | -5.95% |
| T_136 | 2.2 | 42 | 42 | -0.33% |
| T_149 | 10.2 | 1018 | 942 | -7.50% |
| T_7 | 10.5 | 1175 | 1105 | -5.96% |
| T_112 | 2.5 | 69 | 69 | -0.65% |
| T_5 | 3.8 | 134 | 139 | 3.36% |
| T_6 | 4.8 | 226 | 235 | 3.97% |
| T_175 | 5.9 | 285 | 295 | 3.35% |
| T_8 | 13.6 | 1383 | 1498 | 8.31% |
| T_9 | 5.3 | 331 | 347 | 4.87% |
| Average | | | | 0.12% |
| Median | | | | 0.43% |
| Abs Max | | | | 8.31% |

The MIDIS 72hr peak flow values shown in Appendix E have been derived using adjustments for larger catchment multi focal point analysis. The average, median and absolute maximum error (0.12%, 0.43 and 8.31%) are all better than the equivalent error statistics in estimating the peaks using the recommended method of ARR rank 6 pattern (-2.7 % , -4.2% and -.9.9%).

Applying this methodology allows for a single hydraulic design run to be undertaken for a give AEP and for the surface generated to provide an appropriate estimate of AEP neutral peak levels at any focal point within the surface.

# Appendix G  Example MIDIS Hydrograph Filtering Algorithm

```
Sub Hg_filter()
' Algorithm for filtering a MIDIS Hydrograph
Dim t45_1 As Single
Dim t45_2 As Single
Dim t90_1 As Single
Dim t90_2 As Single
Dim i As Integer
Dim peak As Single
Dim slope_rising As Single
Dim slope_falling As Single
Dim step As Single

Set datasheet = Sheet8
Set outsheet = Sheet8
timecol = 1
valcol = 2
outputcol = 3
startrow = 10
i = 1
peak = datasheet.Cells(7, valcol).Value
step = datasheet.Cells(11, timecol).Value

Do Until datasheet.Cells(startrow + i, timecol).Value = Empty
    If (datasheet.Cells(startrow + i, valcol).Value <= peak * 0.45 And datasheet.Cells(startrow + i + 1,
    valcol).Value > peak * 0.45) Then
      t45_1 = Cells(startrow + i + 1, timecol).Value
    End If
    If (datasheet.Cells(startrow + i, valcol).Value <= peak * 0.9 And datasheet.Cells(startrow + i + 1,
    valcol).Value > peak * 0.9) Then
      t90_1 = Cells(startrow + i + 1, timecol).Value
    End If
    If (datasheet.Cells(startrow + i, valcol).Value >= peak * 0.45 And datasheet.Cells(startrow + i + 1,
    valcol).Value < peak * 0.45 And t45_1 > 0) Then
      t45_2 = Cells(startrow + i, timecol).Value
    End If
    If (datasheet.Cells(startrow + i, valcol).Value >= peak * 0.9 And datasheet.Cells(startrow + i + 1,
    valcol).Value < peak * 0.9 And t90_1 > 0) Then
      t90_2 = Cells(startrow + i, timecol).Value
    End If

    i = i + 1
Loop
endrow = i - 1
slope_rising = (peak * 0.9 - peak * 0.45) / (t90_1 - t45_1)
slope_falling = (peak * 0.9 - peak * 0.45) / (t90_2 - t45_2)

'hydrograph between 45%peak rising and 45%peak falling
For i = 0 To endrow
If (datasheet.Cells(startrow + i, timecol).Value >= t45_1 And datasheet.Cells(startrow + i,
timecol).Value <= t45_2) Then
 outsheet.Cells(startrow + i, outputcol).Value = datasheet.Cells(startrow + i, valcol).Value
End If
```

```
Next i

i = 0

'hydrograph below 45%peak rising
Do Until datasheet.Cells(startrow + i, timecol).Value = t45_1
        i = i + 1
Loop
j = -1
Do Until i = 0
        i = i - 1
        j = j + 1
        outsheet.Cells(startrow + i, outputcol).Value = outsheet.Cells(startrow + i + 1, outputcol).Value
     - slope_rising / ((1 / step) * 2.5)
        If outsheet.Cells(startrow + i, outputcol).Value < 0 Then
           outsheet.Cells(startrow + i, outputcol).Value = 0
        End If
        If datasheet.Cells(startrow + i, outputcol).Value < outsheet.Cells(startrow + i, outputcol).Value
     Then
           outsheet.Cells(startrow + i, outputcol).Value = datasheet.Cells(startrow + i, outputcol).Value
        End If
Loop

i = 0

'hydrograph below 45%peak falling
Do Until datasheet.Cells(startrow + i, timecol).Value = t45_2
        i = i + 1
Loop
j = -1
Do Until i = endrow
        i = i + 1
        j = j + 1
        outsheet.Cells(startrow + i, outputcol).Value = outsheet.Cells(startrow + i - 1, outputcol).Value
     + slope_falling / ((1 / step) * 2.5)
        If outsheet.Cells(startrow + i, outputcol).Value < 0 Then
           outsheet.Cells(startrow + i, outputcol).Value = 0
        End If
Loop

End Sub
```

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