Applying ARR 2016 to Stormwater Drainage Design

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The methods and advice presented in Australian Rainfall and Runoff 2016 are not yet complete, and there has been a slow uptake of these by the stormwater industry. The paper notes the parts of ARR 2016 relevant to urban drainage system design, and assesses the most important of these – the handling of ARR 2016 rainfall ensembles and the application of a new urban hydrological model using effective impervious areas (EIAs) and initial and continuing losses (IL-CL). Using software, analysis and design of drainage systems with ensembles of rainfall patterns is more complicated than with previous rainfall inputs, but is not particularly difficult to apply or interpret.

The estimation of EIAs is illustrated by an analysis of storm data from Jamison Park, Penrith. DRAINS models of sub-catchments at various locations show that that the IL-CL model performs similarly to established models such as ILSAX and the extended rational model, but that there are uncertainties in its application.

Other matters discussed include (a) the effects of changed design rainfall intensities and climate change adjustments (b) the analysis of stormwater detention storages, and (c) the relevance of the rational method. The parts of ARR 2016 that can be readily adopted by designers are noted, and the need for further data collection and development of methods is emphasised.

1. INTRODUCTION

The editions of *Australian Rainfall and Runoff* published in 1958, 1977 and 1987 featured sections on urban stormwater drainage design, with design examples for street drainage systems. Other publications, such as the drainage manuals of councils and road authorities, have drawn on this information and advice.

The 1977 edition of ARR introduced an improved hydraulic grade line design method, and the 1987 edition expanded the coverage of urban drainage systems to include detention basins and trunk drains. The latest edition, ARR 2016 (Ball et al., 2016), includes many innovations. There is an emphasis on volumetric aspects of stormwater runoff as well as peak flowrates, and on extensive modelling involving sets of design rainfall patterns.

The authors of this paper have been involved in the incorporation of ARR 2016 methods in the DRAINS program, and in providing information on the new methods to program users. Here, they identify the parts of ARR 2016 affecting the analysis and design of urban drainage systems, and provide information and comments on these.

2. ARR 2016 GUIDANCE

ARR 2016 is a larger document than its predecessors, available in electronic form at arr.ga.gov.au. Its development began around 2005 and is ongoing. Most sections are still in draft form, and it will be necessary to complete these, and then to update the document regularly. Geoscience Australia has taken over the administration of ARR from Engineers Australia.

Book 9, dealing with urban stormwater, appeared as a rough draft in 2015, which was replaced when ARR 2016 was released in late 2016. Chapter 6 of Book 9 was released for comment in January 2018. The book provides a significant amount of guidance, emphasizing an approach oriented to the control of volumes of stormwater, as well as peak flowrates. It also encourages integrated water management, where three main objectives – flood protection, stormwater pollution control and water harvesting, are considered, and stormwater drainage systems are integrated with water supply, sewerage and waterway management systems. The information and guidance supplied is rational, and should, in the main, be accepted by drainage authorities and professionals.

A problem is that most of the advice is at high- and medium-levels, and there is insufficient material about the practical application of principles and procedures. The only example in Book 9 is a case study of urban flood modelling. It appears that designers must refer to other publications for detailed guidance. The ARR Team has not specified software products or models until the release of Chapter 6 in Book 9, which recommends appropriate models for different scales and types of development.

The material in the following sections shows that sets of input data and methods from ARR 2016 can be applied in stormwater system design, but there are incomplete parts that make it impracticable to apply some recommended methods fully.

3. HYDROLOGY

3.1. Rainfall Inputs

The Bureau of Meteorology (BOM) has almost completed the significant task of revising and extending intensity-frequency-duration (I-F-D) data that provides design rainfall estimates for a range of frequencies and durations, at all locations in Australia. I-F-D data are easily obtained from the Bureau's website (www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016). The team responsible for producing *Australian Rainfall and Runoff* has developed sets of temporal rainfall patterns to be used in conjunction with I-F-D data to provide rainfall hyetographs as design inputs. The patterns are supplied in ensembles of ten different hyetographs for each storm duration, in rare, intermediate and frequent frequency groups. This information can be obtained easily from the ARR Data Hub (data.arr-software.org/).

The background to these data is set out in Chapters 3 and 6 of Book 2 of ARR 2016. The I-F-D data have been developed from a much larger set of recorded rainfalls than the previous 1987 relationships, using superior statistical analysis techniques. They cover a wider range of frequencies and storm durations than the previous relationships. The temporal patterns have also been derived from a large database of storm data. They are bursts of rainfall, often extracted from longer storms, rather than complete storms.

The ARR 2016 I-F-D relationships can be used in relatively simple rational method calculations, estimating peak flowrates. In models that produce flow hydrographs, the I-F-D and ensemble data must be combined. Use of the ensembles considerably increases the numbers of cases to be considered, and makes the use of software compulsory, since the volume of calculations is too great for hand or spreadsheet calculations.

In DRAINS, ensembles are inputted from the .csv files provided on the BOM website and the ARR Data Hub, and the required frequencies and storm durations are selected for design. The program performs design calculations that define pit and pipe sizes and analyses that simulate the behaviour of drainage systems in major or minor events. After an analysis run, all components (pits, pipes, detention basins, etc.) can be interrogated to display the results for each storm in charts like those in Figure 1.

These display ten results for all storm durations modelled, except 5 minutes. For each duration a median storm is selected, shown pink, and from these the highest is selected as the design value, shown red. The design storms can differ for the various components in a model, depending on the type of component and its location in a catchment. Generally, the critical duration will increase as flows move downstream through a system. The chart outputs give a good overview of how the various parts of a drainage system operate. Extremes are shown, but designs work on the basis of the median storms. Individual storms can be modelled in detail if required.

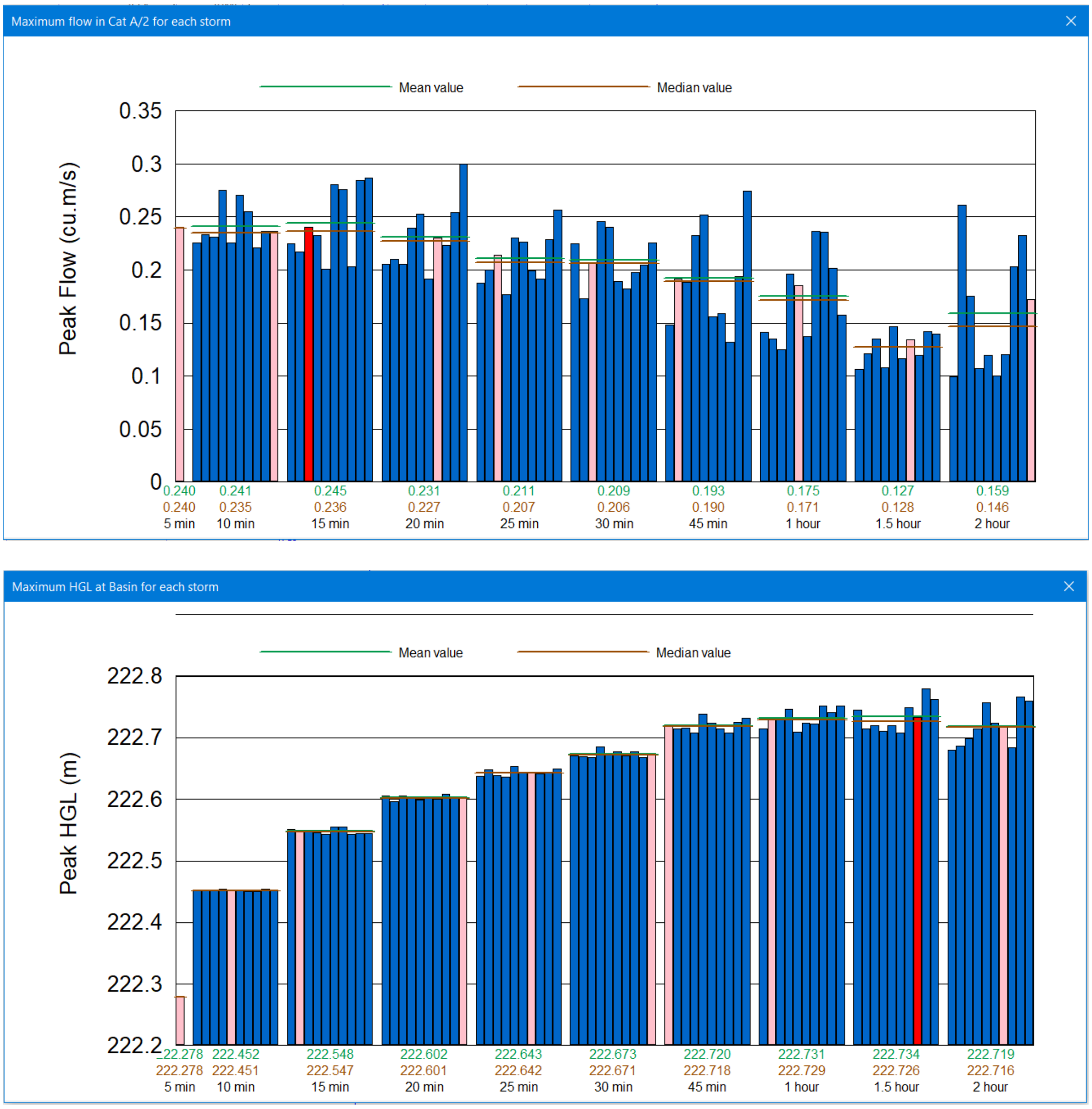

Figure 1 DRAINS Chart Outputs for Sub-Catchment (Top) and a Detention Basin (Bottom)

This process has been found to be easy to apply, and calculations in DRAINS have been streamlined to operate quickly, facilitating trial and error calculations. A designer has additional work to do, compared to running storms from ARR 1987, but the design process works smoothly.

The BOM has compared 1987 and 2016 rainfall intensities in the FAQ information on its website. At the majority of locations, intensities will be smaller, but at some locations, such as Newcastle, designers must cope with higher rainfall intensities.

Drainage authorities and designers must also consider the climate change adjustments to design rainfalls covered in Book 1 of ARR 2016. The adjustment is specified in the equation:

$$I_p = I_{ARR} \times 1.05^{T_m} \quad (1)$$

where I_p is the projected rainfall intensity or equivalent depth (mm/h or mm), I_{ARR} is the rainfall intensity or depth for current conditions (mm/h or mm), and T_m is the expected temperature increase at a selected time in the future (°C).

For each 1° C rise in temperature, rainfalls are increased by approximately 5%. Designers must decide on an appropriate climate change scenario, based on a judgement of the extent to which climate change can be arrested, and then to assess whether adjustments should be applied. An assessment procedure is presented in Section 6.3 of Book 1.

3.2. Recommended Urban Hydrological Models

ARR 2016 provides considerable material on hydrological modelling, largely geared to rural and urban flood studies and large catchments. The most important section for urban drainage systems is Chapter 3 in Book 5, dealing with hydrological losses. For urban areas, Chapter 3 applies the concept of effective impervious area (EIA), representative of the area within a catchment that generates a rapid runoff response in rainfall events. The EIA includes part of the impervious area directly connected to the drainage system (DCIA). The remaining part of the catchment area lumps together the rest of the DCIA, the indirectly-connected impervious area (ICIA) which discharges onto pervious surfaces, and pervious areas.

This division of urban catchments into two parts – EIA and 'other' or 'remaining', is applied in Section 3.5 of Book 5, together with the application of a loss model. The preferred model is an initial loss–constant continuing loss (IL-CL) model. Other models were considered, and can still be used, including the proportional continuing loss and Horton infiltration models, but the IL-CL model was adopted as being equally or more effective and simpler. Some specifications for applying this model are presented in Table 1.

Table 1 Details of the EIA IL-CL Model

Part of Sub-Catchment	Loss Parameters
Effective impervious Area (EIA) made up of part of the DCIA and perhaps some of the ICIA. EIA is 50% to 70% of the TIA (ARR 2016, Section 3.4.2.2.2), or 60 to 80% of the DCIA.	1 - 2 mm initial loss (IL), zero constant continuing loss (CL) (Section 3.5.3.2.1 of ARR 2016)
Indirectly Connected Areas (also known as other or remaining areas), made up of some DCIA, the ICIA and pervious areas that interact with impervious areas.	IL is 60% to 80% of the rural IL for the location (Section 3.5.3.2.1) with some qualifications; CL is 1 - 4 mm/h, with a typical value of 2.5 mm/h for South Eastern Australia. For some state or territory capitals, losses could be determined from Figures 5.3.21 and 5.3.22. (The ARR Data Hub cautions against using rural loss estimates in urban areas, conflicting with Section 3.5.3.2.1.).
Urban Pervious Areas (large, self-contained areas such as parks or bushland).	IL and CL are to be the same as for a rural area at the same location (Section 3.5.3.2.3).

The application of the EIA is new, and it has not been featured in any of the hydrological models previously applied to urban drainage systems. Earlier models use total impervious area (TIA) in the rational method and RORB, for example, and DCIA, in MUSIC. The ILSAX hydrological model in DRAINS considers DCIA (termed paved) and ICIA (supplementary) impervious areas. EIA cuts across the previously-used categories, and is hard to define. The recommended EIA percentage for a catchment is about 60% of the TIA, or 70% of the DCIA determined from aerial imagery, based on an analysis of rainfalls and runoff from eight urban gauged catchments that produced the ratios shown in the first eight rows of Table 2.

This analysis was explained in the ARR revision project report by Phillips et al (2014). It entailed the estimation of the volumes of storms and runoff hydrographs at the selected stations, and the plotting of these to obtain an assumed ratio between the EIA and the TIA. Events that only produced runoff from the EIA were assumed to be the storms for which:

$$Q < TIA/TA \times (P - IL) \quad (2)$$

where Q is the runoff depth (mm), P is the rainfall depth (mm), TIA and TA are defined from a GIS or map analysis and IL is the initial loss on impervious surfaces (typically 1 mm).

The criterion does not necessarily separate large and small storms; and large storms appear in both EIA Runoff Only and EIA + Other Runoff categories.

Table 2 Results of Urban Gauged Catchment Analyses

Catchment	Total Area, TA (ha)	Total Impervious Area, TIA (ha)	TIA/TA	DCIA/TIA (from GIS or maps)	Assumed EIA/TA Ratio from Plots	EIA/TIA = EIA/TA / TIA/TA	EIA/DCIA = EIA/TIA / DCIA/TIA
Albany Drain , WA	8.2	2.9	0.35	0.83	0.21	0.59	71
McArthur Park, NT	144	53.7	0.37	0.93	0.24	0.66	70
Giralang, ACT	91	28.4	0.31	0.95	0.25	0.79	82
Parra Hills Drain, SA	55.1	26.9	0.49	0.87	0.27	0.56	64
Kinkora Road, Vic	202	122	0.60	0.87	0.35	0.59	68
Powells Creek, NSW	232	152	0.66	0.81	0.38	0.59	75
Ithica Creek, Qld	926	128	0.14	0.95	0.075	0.55	58
Argyle Street, Tas	1900	292	0.15	0.93	0.091	0.63	68
Jamison Park, NSW	23.4	8.34	0.36	0.93	0.235	0.65	0.70

To understand the process, the analysis has been performed using storm data collected from 1984 to 1988 at a gauged catchment at Penrith, NSW operated by the University of Technology, Sydney and Penrith City Council. The results are shown in the last row of Table 2. The EIA/TA ratio was obtained from the slope of the line fitted to the blue points (diamonds) in Figure 2, assumed to be for storms where runoff comes from the EIA only. The slope of this line (0.235) can be divided by the TIA/TA ratio (0.36) to give the EIA/TA ratio of 0.65, which can also be transformed into an EIA/DCIA ratio of 0.70 by dividing by DCIA/TIA (0.93). The answers are sensitive to the slope of the line fitted to the EIA Only Runoff values.

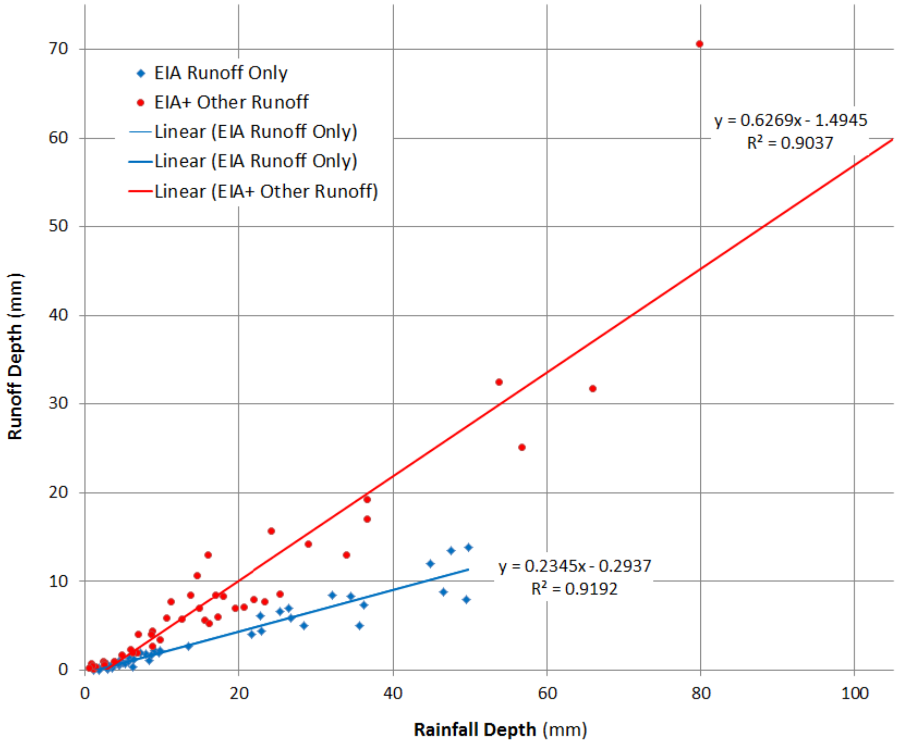

Figure 2 Rainfall & Runoff Volumes of 1984-88 Storms at Jamison Park Gauge, Penrith

In the storms considered, the volumes of runoff are less than those of the corrresponding rainfalls, showing that losses are occurring. The EIA concept is based on the observation that the losses from the DCIA are greater than we would expect from an impervious area connected to the drainage system. The reasons for this deficit are unclear and few explanations are supplied in ARR 2016. Possible causes of this missing runoff are infiltration into soils, stormwater flows into sanitary sewers (perhaps 5% to 15% of the volume), retention in depression storages and temporary ponds against walls and fences on properties.

The analysis is entirely based on volumes of rainfalls and runoff (depths × catchment area), and peak flowrates have not been considered. To estimate runoff, the loss model must be combined with a routing model, and ARR 2016 offers two choices for this – time-area routing or runoff routing using conceptual storages, applied in models such as RORB, XPRAFTS, WBNM and URBS. There is little new material in ARR 2016 on hydrological routing, or on the important topic of urbanisation, related to the comparison of pre- and post-developed runoff peaks and volumes in land, property and infrastructure development applications.

3.3. Difficulties with the IL-CL Model

Two problems have been identified while attempting to apply the recommended urban EIA IL-CL model in DRAINS:

(a) The recommended EIA/TIA and EIA/DCIA ratios are typically 60% and 70%. These may be plausible for larger sub-catchments involving buildings, paved open areas and gardens, with some footpaths and streets. However, they seem to be too low to apply to small sub-catchments and to catchments on roads where runoff processes are direct, particularly in new drainage systems, and it is difficult to see where runoff could be lost. In the authors' own modelling practice with DRAINS, an EIA/TIA ratio of 90% to 100% has been applied in smaller sub-catchments. Book 9 of ARR 2016 gives some guidance in Section 6.2.1 (Coombes et al., 2018), suggesting that ratios should be higher in more densely-developed sub-catchments. Designers will need to make their own decisions. Swan et al (2018) describe a system for determining EIA/TIA ratios for different land uses, developed for Melbourne Water flood mapping, and Gribble (2017) has estimated DCIA values for Western Sydney.

(b) As shown in Figure 3, rainfall hyetographs can be separated into various components. The rainfall patterns supplied by the ARR Data Hub are bursts. Usually, it will be necessary to subtract a pre-burst rainfall estimate from an initial loss to determine the burst initial loss IL_B to be applied to ensemble patterns. The ARR team have emphasised the importance of using pre-burst depths. However, pre-burst estimates are only available from the ARR Data Hub for storms with durations of 1 hour or greater. This makes it difficult to apply the ARR 2016 preferred model on urban catchments, where storms with durations below 1 hour usually produce the most critical results. Users must guess pre-burst values. There are other complexities with pre-burst adjustments, and these throw into doubt the applicability of the recommended procedure.

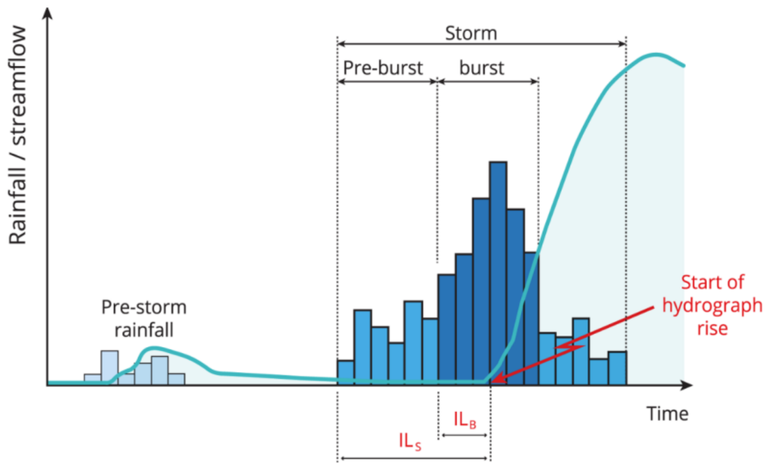

Figure 3 Distinction between Storm and Burst Initial Loss (Figure 5.3.5, ARR 2016)

Another problem is that peak flowrates from the IL-CL model can show little change as EIA increases if the remaining area times of concentration are not decreased. The combined EIA and remaining area hydrographs provide only small increases in peak flowrates, making it difficult to compare pre- and post-developed catchment results.

Like other hydrological models, the IL-CL model has faults that need to be managed when it is applied. It cannot be improved without further testing using available urban catchment data, which is limited, and is not easily accessible to designers.

4. COMPARISON OF RESULTS FROM ALTERNATIVE MODELS

To test the EIA IL-CL model against commonly-used models for urban drainage design (ILSAX, rational method and extended rational method (ERM)), a series of simple 0.25 ha catchment models have been created in DRAINS for impervious area percentages between 5% and 95%, as shown in Figure 4. These have been run for 1% annual exceedance probability (AEP) and 0.2 EY (5 year average recurrence interval) frequency storm ensembles for durations of 5 minutes to 4.5 hours. The times of concentration applied in all models is 5 minutes for impervious areas and a diminishing time of 15 minutes down to 5 minutes for pervious areas as the percentage of impervious area increases. Volumes have been calculated using ensembles of 1 hour duration storms. ILSAX has been configured with a Soil Type of 3, an Antecedent Moisture Condition (AMC) of 3, and depression storages of 1 mm, 1 mm and 5 mm for paved, supplementary and grassed areas respectively. Refer to the DRAINS User Manual (2018) for further information on DRAINS parameters.

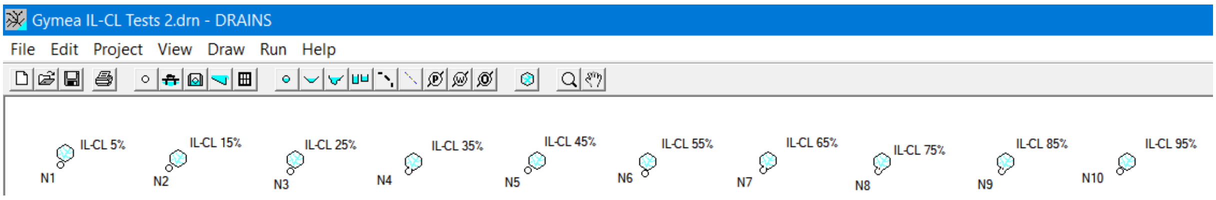

Figure 4 DRAINS Test Model with Sub-Catchments

Three sets of results are provided for catchments at Gymea, NSW to compare the models and demonstrate the sensitivity of varying IL-CL parameters. An initial loss of 22 mm and continuing loss of 2 mm/h are used for the 'remaining' areas, and 1 mm initial loss and zero continuing loss for the EIA runoff. The first set of results shown in Figure 5 compares commonly-used models against an IL-CL model that considers EIA areas that are 60% of the TIA, in accordance with ARR 2016.

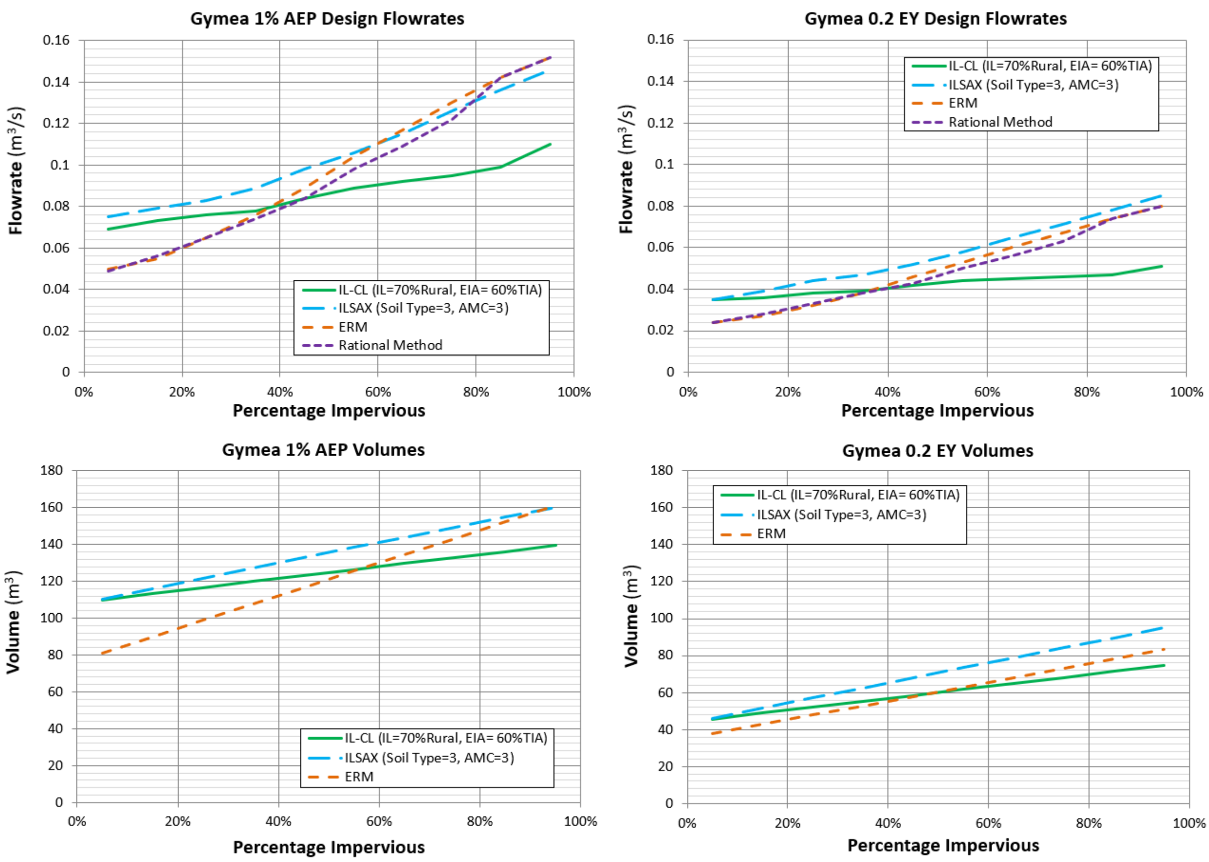

Figure 5 Design Peak Flowrates and 1 Hour Hydrograph Volumes from Models applied to a 0.25 ha Catchment at Gymea, NSW

When the EIA IL-CL model is run a 60% EIA/TIA ratio, flowrates change only slightly with the increase of impervious area, due to the effect of the combination of hydrographs noted in Section 3.3.

For Gymea, the IL-CL results shown in Figure 5 are in the same region as the results from ILSAX for low impervious percentages, although when applying EIAs that are 60% of the TIA, they are significantly lower for highly impervious areas. This may potentially lead to smaller designed pipe diameters and reduced on-site detention basin requirements for pre- vs post-development runoff in smaller urban projects. The other models show a good agreement in both peak flowrates and volumes, particularly when the impervious area is higher. The volumes plot as straight lines against the impervious area.

To compare the impacts of varying the percentages of TIA, Set 2 shown in Figure 6 compares the IL-CL model with EIA areas ranging from 60% to 100% of TIA, with the previous results from ILSAX included for reference. Both the Set 1 and Set 2 models are run assuming zero pre-burst rainfalls, which will underestimate peak flowrates, probably slightly. Figure 6 demonstrates that increasing the percentage of EIA/TIA ratio towards 100% provides a closer agreement between the IL-CL model results and those of other models for both flowrates and volumes for highly impervious catchments.

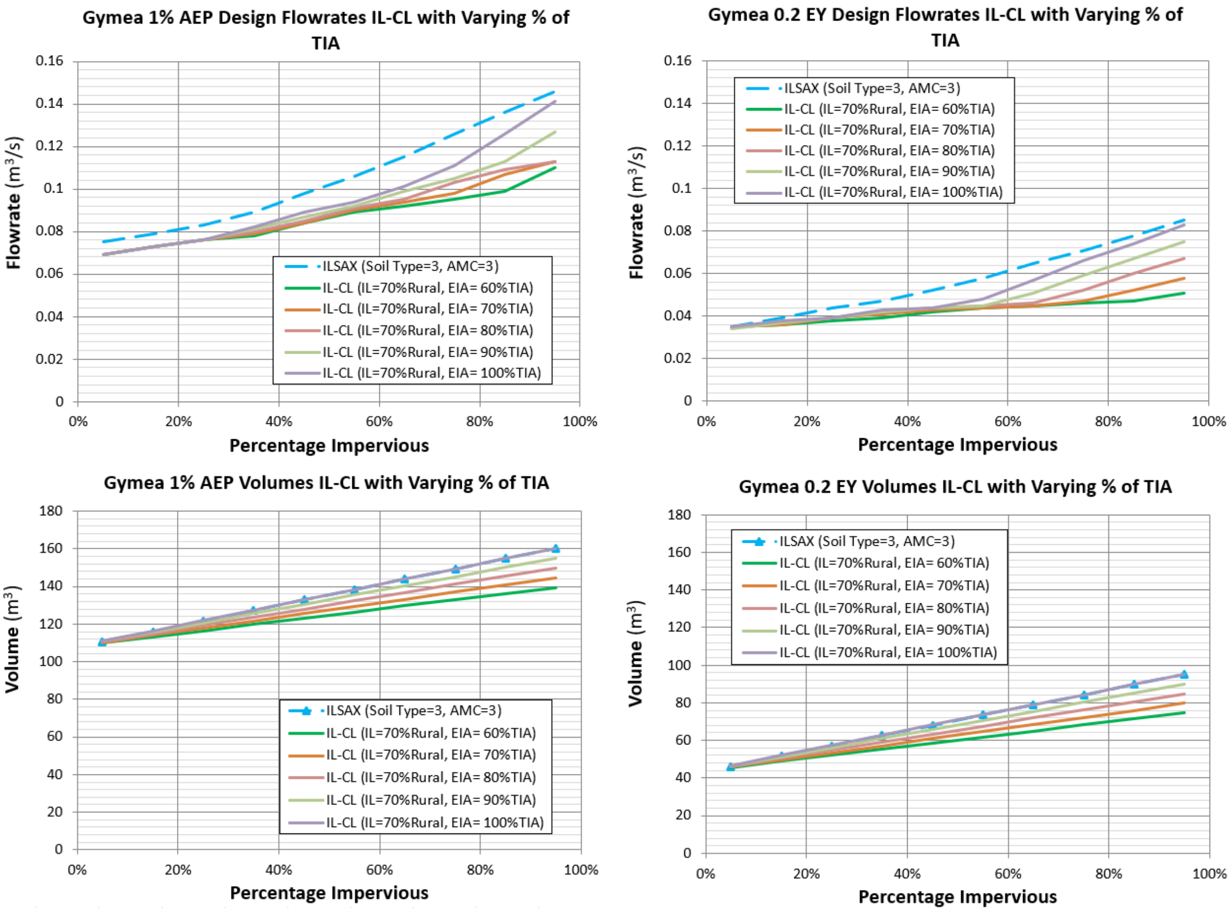

Figure 6 Peak Flowrates and 1 Hour Volumes from the IL-CL Model with Varying EIA/TIA Ratios applied to a 0.25 ha Catchment at Gymea, NSW

A third set of results for Gymea is provided to examine the inclusion of assumed pre-burst rainfall. Table 3 shows the median pre-burst depths provided by the ARR Data Hub for Gymea (2018_v1). Some AEPs show depths increasing as durations increase, while others show depths decreasing. This variability occurs at different geographic locations. Without pre-burst data for durations less than 60 minutes, and with no clear guidance on how to extrapolate results, the authors have adopted the 60-minute pre-burst depths for smaller duration storms. The critical storm duration for all catchments in this example is always less than 60 minutes.

Table 3 ARR Data Hub Median Pre-Burst Depths (mm) for Gymea

AEP (%)	Storm Duration (hours)					
	1	1.5	2	3	6	12
20	4.8	7.4	8.2	6.8	12.4	9.7
1	2.8	1.5	1.9	4.2	10.5	22.0

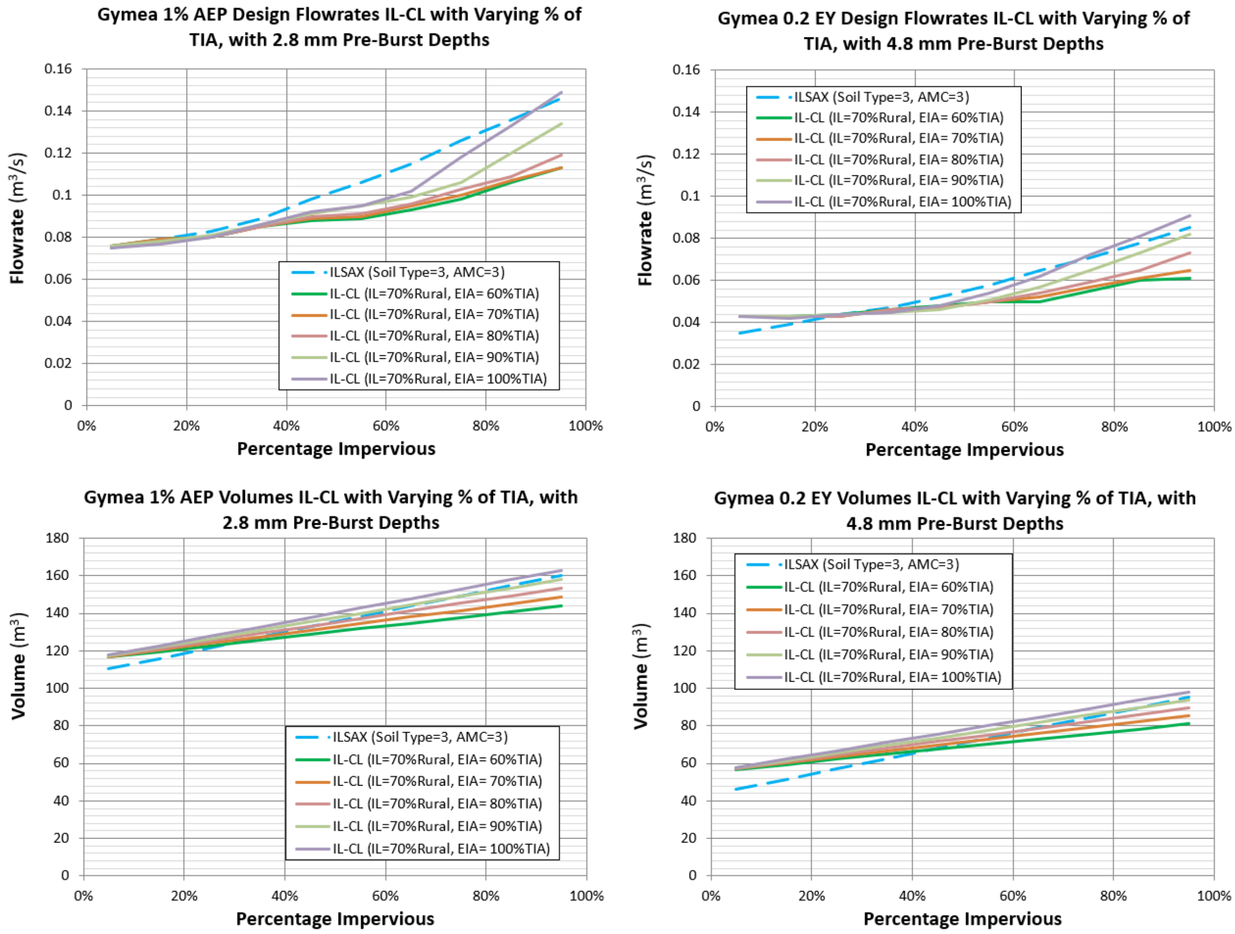

Figure 7 Peak Flowrates and 1 Hour Volumes from the IL-CL Model with assumed Pre-Burst Rainfall Depths applied to 0.25 ha Sub-Catchments at Gymea, New South Wales

The results in Figure 7 were obtained by analysing the full ensembles in DRAINS and selecting the highest median storm. Applying the pre-burst rainfall depths lifts the results of the IL-CL model, and for EIA = 100% TIA, 1% AEP peak flowrates are shifted closer to the ILSAX results. Although reasonably similar, adding pre-burst rainfall depths brings the peak volume results above those from ILSAX for low impervious catchments, and similarly for EIA = 100% TIA volumes. Although not explored further in this paper, varying the pre-burst depths up or down will have significant impacts on runoff from smaller urban catchments, especially as shorter duration storms have lower total depths of rainfall compared to the fixed initial loss for remaining areas. As mentioned in Section 3.3(b), the ARR team have emphasised the importance of using pre-burst rainfall depths.

Similar analyses have been conducted at Manly, a beachside suburb of Brisbane, and at Port Adelaide, with the results shown in Figure 8 and Figure 9. The 1% AEP, 1 hour rainfall intensities for Gymea, Manly and Port Adelaide are 66.2, 82.7 and 46.5 mm/h respectively. All locations show similar relationships between models and in most cases, the models provide similar flowrates and volumes.

5. HYDRAULICS

Book 6 of ARR 2016 deals with hydraulics extensively, covering open channel flows and 1- and 2-dimensional modelling, but there is very little material on piped drainage systems, and no changes to design calculation procedures, in contrast to previous versions of ARR. There have been advances since 1987, such as the determination of water and hydraulic grade line levels using unsteady flow hydraulics, and the development of a pit energy loss modelling procedure in the HEC-22 manual (US FHWA, 2009).

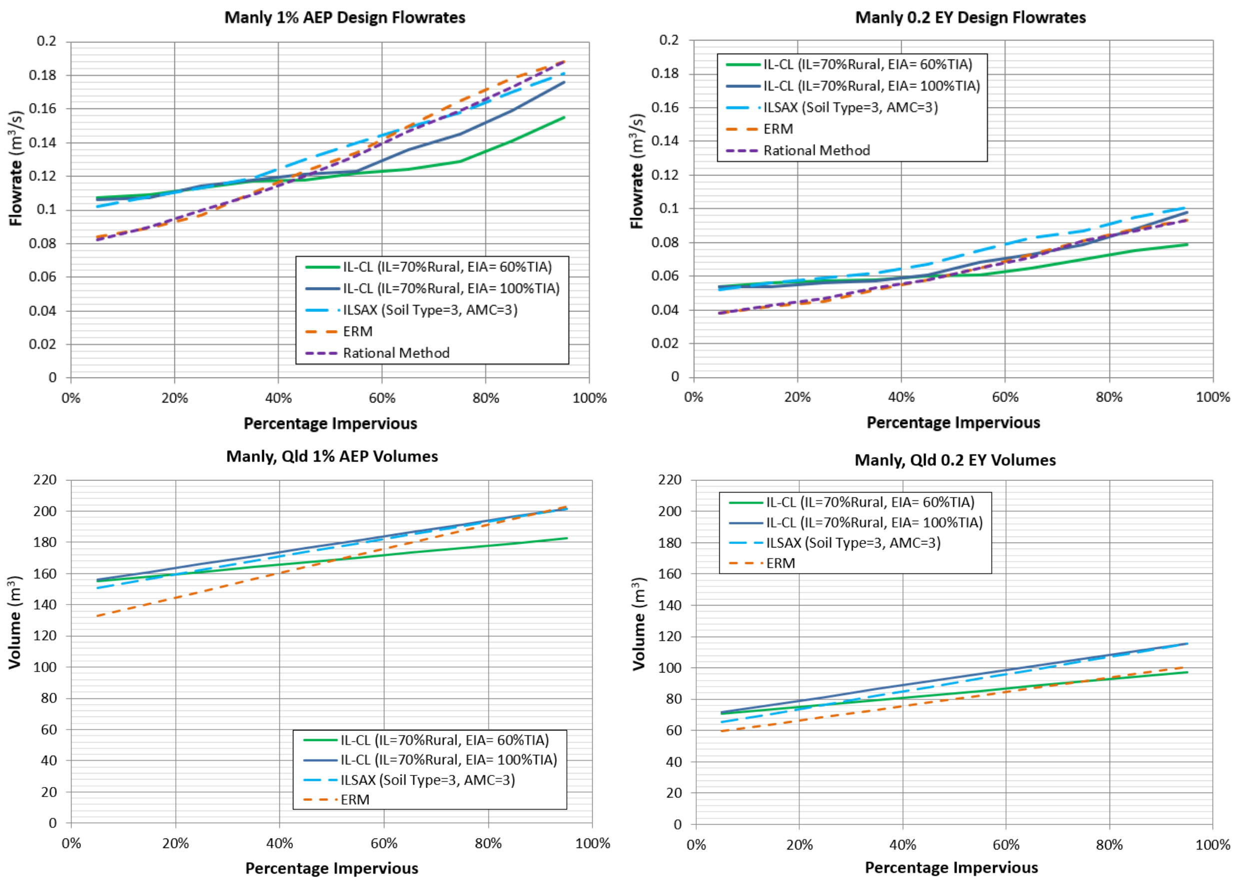

Figure 8 Results from Models applied to 0.25 ha Sub-Catchments at Manly, Queensland

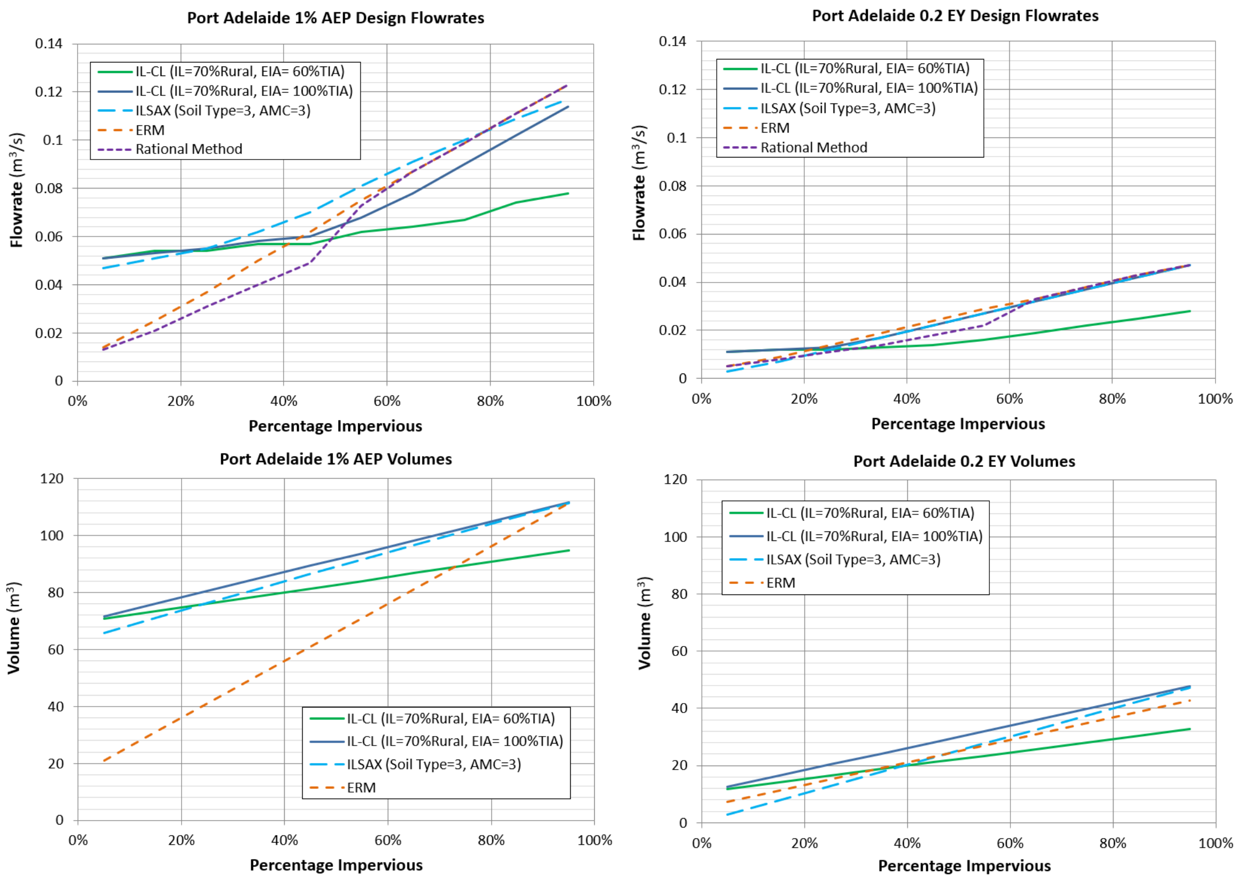

Figure 9 Results from Models applied to 0.25 ha Sub-Catchment at Port Adelaide, SA

6. DESIGN PROCEDURES

ARR 2016 provides design advice for stormwater drainage systems in Chapters 4 to 6 of Book 9, including some design aids, but with no examples. The fundamental hydrological process depends on calculations with ensembles of storms, and the sorting of results. The example provided for this is a flood estimation procedure for a 72 km^2 rural catchment in Section 5.10 of Book 2. Results are presented as box and whisker plots, providing similar information to the DRAINS charts in Figure 1. There is material on stormwater treatment and harvesting, and references to *Australian Runoff Quality* (Wong, 2005) but no detailed procedures are provided.

7. DETENTION BASINS

The DRAINS chart outputs shown in Figure 1 allow results from detention basin analyses (top water levels, storage volumes and peak discharges) to be viewed and assessed easily. Designers usually try to define a discharge from the developed catchment that is less than or equal to a pre-developed discharge, for all the representative median storms. One approach is to determine the median storms for pre-developed conditions, and then compare pre and post-development peak flows for those storms; another is to compare peak flows for the median post-development storms to the pre-development flows from these same storms. Opinions may differ on these. The design process must be carried out by trial and error, adjusting discharges (say by varying an orifice diameter) and volumes (by changing the horizontal area of a vertical-sided chamber, or varying more complex elevation-area relationships using a multiplier). The allowable top water level cannot be exceeded in the major storm event. Multiple frequency levels will probably need to be considered, which increases the calculations required. A set of discharge and volume parameters that works for 1% AEP and, say 50% AEP, will usually work for frequencies between these values.

This procedure could be adapted to focus on the volume of the hydrographs discharged from a detention storage in pre- and post-developed conditions, allowing for retained water storages and infiltration into the surrounding soil using appropriate software. Volumetric procedures have been applied in Western Australia (WA Department of Water and Environmental Regulation, 2017) and Queensland, but have not been generally applied elsewhere. Ronalds et al. (2017) applied DRAINS in assessing the adequacy of detention storages designed using generally lower ARR 1987 design rainfalls. They found that the lower intensities and runoff rates cause failures in frequent storms that could be avoided by reducing the size of outlet pipes.

A concern about the use of bursts is that the post-burst rainfall shown in Figure 3 may affect detention basin routing results if a burst is 'back loaded' with higher rainfalls occurring in its latter part. At present, ARR 2016 provides no way of defining post-burst rainfalls, so designers will ignore these.

8. USE OF THE RATIONAL METHOD

The rational method defined in ARR 1987 was compared with gauged catchments in Canberra by Willing & Partners (Phillips, 1995) and was found to compare poorly with frequency distributions fitted to gauged runoff data. Willing & Partners recommended that the rational method continue to be used, but with runoff coefficients and times of concentration derived from ARR 1977. In an ARR Project Report, Goyen et al (2014) used the results from this study to criticize the rational method, and recommended that it no longer be used. Major shortcomings of the rational method are that (a) it cannot calculate flow hydrographs, and therefore cannot be used in detention basin calculations, (b) it is difficult to reasonably estimate runoff coefficients or times of concentration, (c) it cannot be calibrated to measured storms since it relies on probabilistic I-F-D rainfall inputs, and (d) it does not account for the variability of rainfall events, as noted by Coombes at al. (2015). Several procedures have been developed to produce hydrographs from rational method calculations, including the ERM method available in DRAINS. These can be applied with rainfall ensembles, and as indicated by Section 4, they can give comparable results to more favoured procedures. Accurate times of concentration are notoriously difficult to derive, but they are not used solely by the rational method, and affect other methods such as ILSAX.

Other models may be preferred to the rational method because they have a history of being calibrated to gauged data, but they nevertheless have uncertain procedures for parameter estimation, and none can be regarded as being accurate. In the recent study by Wood (2018) the rational method provided better fits to flood frequency data from a 202 ha urban Melbourne catchment than other models. In the light of this, the rational method is not so bad that it should be limited to use on very small urban catchments. However, it should not be used as a basis for calibration.

9. ADOPTION OF ARR 2016 PROCEDURES

ARR2016 meets the needs of flood modelers, with procedures applicable to medium to large catchments and an extensive treatment of hydraulic modelling. This paper describes some of the difficulties facing the larger community of urban drainage designers in applying the ARR 2016 procedures. Anecdotally, it appears that many designers are still applying the older procedures from ARR 1987. The influential Queensland Urban Drainage Manual (IPWEA, Queensland, 2016) released in 2017, retains the rational method for use in rural and urban areas, and makes only a few references to ARR 2016. It was largely completed before ARR 2016 was released. Some papers reviewing ARR 2016 procedures have been published (Phillips and Yu (2015), Ronalds et al. (2017), Swan et al. (2018), Wood (2018)).

10. CONCLUSIONS

The Bureau of Meteorology and the ARR Team have provided valuable new information and methods, but for urban drainage designers, the information and guidance from ARR 2016 is incomplete. Designers must take what they can from ARR 2016 and apply this with only high-level guidance and limited examples. Software developers have provided the tools to do this, dealing with complex inputs such as the ensembles of rainfall patterns available from the ARR Data Hub. Overall, the stormwater industry has been slow to adopt the new procedures in ARR 2016.

An examination of the recommended IL-CL urban hydrological model presented in ARR 2016 has revealed shortcomings in its present form when applied to smaller 'pit & pipe' style urban catchments. Without clearer guidance, modellers adhering to Section 3.4.2.2.2 of Book 5, applying a default EIA equal to 60% of the TIA for smaller highly impervious catchments are likely to obtain smaller design flowrates and volumes, indicating that urbanisation has less impact than calculated in the past. The lack of pre-burst rainfall depths for durations less than 60 minutes exaggerates this problem further.

Although Section 6.2.1 in Book 9 of ARR 2016 provides some guidance in suggesting that EIA/TIA ratios should be higher in more densely-developed sub-catchments, it is still difficult for a modeller to accept ratios between 60% and 100%, especially with the limited information available. The results from Section 4 indicate that the alternative models in DRAINS still give broadly similar estimates of peak flowrates and hydrograph volumes when using the 2016 I-F-Ds and ensembles of storms, and that the IL-CL model will also provide similar results when considering pre-burst rainfall depths, with EIA/TIA percentages of 90% to 100% for smaller, highly impervious catchments. An EIA/TIA ratio of 60% may not always be appropriate for such catchments.

The uncertain results show that further guidance for designers is needed, and initiatives to collect hydrological data urban areas are needed for future model calibration and development of better design methods for urban drainage systems.

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