# CASE STUDY: A COMPARISON OF traditional and modern STORMWATER DESIGN methods

# introduction

## Preamble

Accurate stormwater design is necessary to protect Australian populations from the consequences of flooding. In Australia, floods are the most expensive natural disasters, causing large tangible and intangible loss (Queensland Government, 2011). There is hence strong justification to evaluate the benefits of 1D and 2D computer modeling, and its comparison to dated methods of achieving stormwater design. The reliance on modeling software to allow for accurate stormwater design is increasing as cities develop, as storm events bring increased risk, and as technology becomes more accessible.

This case study will rely upon flow volumes obtained through manual calculation as well as 1D modeling of a small catchment (less than 1 km2). The Rational Method was used for major storm design, with Manning’s equation used for minor storm design. For 1D and 2D modeling, XPRAFTS was used to conduct stormwater designs. A series of design storms were used to evaluate the impact of these storms on a typical suburban catchment. The flow volume results will be compared to determine agreement of the methods.

A report published by Australian Rainfall & Runoff (Goyen et. al, 2014) states that “…continued use of the Rational Method for urban drainage analysis and design can no longer be justified”.

## Traditional methods of stormwater design

The most widely used method for manual calculation of major storm design is the Rational Method. The Rational Method was first referenced in Australia by Australian Rainfall & Runoff in 1958; however, its use can be traced back to the mid-eighteenth century (Goyen et. al, 2014). The formula, although simple in appearance, can be used as an approximation for overland flow volumes in urban catchments up to 500 ha.

A number of councils and water authorities have published their own recommendations on how to use the formula, which makes use of a runoff coefficient and time of concentration. These values are estimated based upon the nature of the catchment, and can easily be contested between designers, causing disagreement with the obtained results.

### Rational Method formula

The Rational Method provides a simplistic model for overland flow through a catchment during specified storm durations. The Rational Method formula is typically stated as

$Q\_{y}=\frac{C\_{y}.^{ }^{t}I\_{y}.A}{360}$ (QUDM, 2013)

where $C\_{y}$ = coefficient of discharge for 1-in-$ y$ year storm

 $A^{ }^{t}I\_{y}$ = rainfall intensity for 1-in-$ y$ year storm, for storm duration $t$ (mm/hr)
 $A$ = catchment area (ha)

$C\_{y}$ is a coefficient that is based upon the density of the catchment, or impervious fraction of the catchment. The actual impervious fraction is ideally calculated, but recommendations are provided based upon typical values for certain developments. The chosen storm duration is often the major point of contention when using the Rational Method. A shorter storm will provide higher rainfall intensity, but will not necessarily result in more overall rainfall, which is an important consideration for stormwater systems with detention basins. The time of concentration (time taken for rainfall to flow from farthest point to outlet) can be estimated using:

1. Friend’s equation: $t\_{c}=\frac{107nL^{0.333}}{S^{0.2}}$ (QUDM, 2013)

where n = Horton’s roughness coefficient

L = length of channel (m)

S = slope of channel (%)

Or

1. Kinematic wave equation: $t\_{c}=\frac{6.94(Ln)^{0.6}}{I^{0.4}S^{0.3}}$ (QUDM, 2013)

where all parameters are previously described, and

 S = slope of channel (m/m).

These methods can provide different values of $t\_{c}$, which is used to determine the storm duration leading to peak discharge. The equations provide the most accurate results when used for a homogenous catchment with a uniform surface, such as a carpark (QUDM, 2013). It should be determined if a $t\_{c}$ above 5 minutes provides a higher peak discharge compared to storm durations shorter than $t\_{c}$; the difference being that not all of the catchment area will contribute to the discharge flow rate if the storm duration is less than $t\_{c}$.

If a detention basin is used in the stormwater design, an entire set of design storms should be used with varying durations and annual exceedance probabilities, increasing the time and effort required to perform the design tenfold.

### Manning’s equation

The Rational Method can be used in conjunction with Manning’s equation. Manning’s equation is used for overland channels such as swales or road profiles, as well as stormwater piping below ground, and therefore can be used for minor storm design. Manning’s equation is presented as:

$Q=\frac{1}{n}AR^{\frac{2}{3}}S^{\frac{1}{2}}$ (QUDM, 2013)

where n = Manning’s roughness coefficient

A = cross-sectional area of channel (m2)

R = hydraulic radius of channel (m)

S = slope of channel (m/m)

The use of Manning’s equation can lead to contention regarding the selected Manning’s n value, especially when used for large overland channels with varying surface conditions throughout the channel. However, the Manning’s roughness value is also used in many modelling suites.

## Modern methods of stormwater design

Often, 1D or 2D models are used to perform stormwater designs, with 3D modeling less commonly employed. 1D modeling performs calculations assuming an averaged flow along a cross-section. 2D modeling programs use 2D grids with depth-averaged velocity to find flow depths at each grid. 2D models benefit massively from using desktop GIS and contour maps which show all slope details, removing the need to calculate average catchment slopes. The following table summarises the benefits and drawbacks of flood modelling.

|  |  |  |
| --- | --- | --- |
| **Model type** | **Advantages** | **Disadvantages** |
| **1D** | * Low computation time
* Few inputs and no GIS required
 | * No visualisation of flows
* Limited results available
 |
| **Combined 1D/2D** | * Benefits of both 1D and 2D with less computation time compared to pure 2D
* 1D elements can compensate for grid size issues, e.g. a 1D element may be used to simulate a gully or culvert that the grid is too coarse to accurately represent
* 1D elements allow for pseudo-3D modelling, e.g. a 1D culvert can be passed under a 2D roadway, with the 1D model simulating losses through the culvert, allowing hydraulic holdup or backwaters to be examined
* Commonly used
 | * Basic visualisation only
 |
| **2D** | * Evaluates depths at certain grid elements of catchment with moderate computation time
 | * Basic visualisation only
 |
| **3D** | * Visually interesting representations of a 2D output
* Can handle depth-variable flow velocities and complicated structures
 | * Greatest computational time required and CFD options can be complicated to calibrate correctly
* Not commonly employed at this point – little need
 |

# Results

**Table 1:** **Overland flow through suburban properties – pre-development**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Annual Exceedance Probability (AEP)** | **Design storm duration (mins)** | **Rational method peak discharge (m3/s)** | **XPRAFTS model peak discharge (m3/s)** | **Agreement (%)** |
| 1% | 10  | 0.468 | 0.370 | 79 |
| 15  | 0.411 | 0.408 | 99 |
| 20  | 0.354 | 0.476 | 74 |
| 30  | 0.291 | 0.456 | 64 |
| 60  | 0.200 | 0.447 | 45 |
| 120  | 0.129 | 0.296 | 44 |

**Table 1:** **Overland flow through suburban properties – post-development**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Annual Exceedance Probability (AEP)** | **Design storm duration (mins)** | **Rational method peak discharge (m3/s)** | **XPRAFTS model peak discharge (m3/s)** | **Agreement (%)** |
| 1% | 10  | 0.483 | 0.612 | 79 |
| 15  | 0.424 | 0.615 | 69 |
| 20  | 0.365 | 0.640 | 57 |
| 30  | 0.301 | 0.564 | 53 |
| 60  | 0.206 | 0.596 | 35 |
| 120  | 0.133 | 0.433 | 31 |

The agreement between methods declined when modelling longer-duration storms, with the exception of the pre-development 15-minute storm, which resulted in almost complete agreement of peak discharge. Agreement between methods slightly declined further for post-development storms compared to pre-development storms. Pre-development Rational Method underestimated peak discharge flows for storm durations between 20 and 120 minutes, and overestimated peak discharge for the 10-minute storm; the method underestimated peak flows for all storm durations in the post-development scenario.

The Rational Method coefficient of runoff was calculated to be 0.97 pre-development for the 1% AEP storm. The coefficient is limited to 1.0 as a maximum value. Therefore, the difference in calculated peak flows between pre- and post-development scenarios is only 3%. XPRAFTS modelling provided increases in peak flows of up to 66% between pre- and post-development, indicating that infiltration and permeability is determined differently in XPRAFTS.

# Conclusion

Calculated peak discharges can vary greatly between 1D modelling results and Rational Method results. Significantly, the Rational Method was shown to underestimate peak flows for 10 out of 12 design storms. This could have significant impacts in a real storm design, with the possibility of under-designing drainage and flow control devices. Furthermore, the Rational Method was shown to be much more time-costly for a full set of design storms.

# References

1. Goyen, A. et. al. 2014. *Project 13 Stage 3: Urban Rational Method Review.* Australian Rainfall & Runoff, ACT.
2. Office of the Queensland Chief Scientist. 2011. *Understanding Floods.* Queensland Government, Qld.
3. Queensland Government. 2013. *Queensland Urban Drainage Manual – Third edition 2013 – provisional.* Department of Energy and Water Supply, Qld.