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INVESTIGATION INTO SUB FIVE MINUTE TIME OF CONCENTRATION IN URBAN DRAINAGE DESIGN

A report submitted by

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Abstract

Professional civil engineers hold an important responsibility to consider the impact of surface runoff in the design of developments of any type. Surface runoff from rainfall can produce large amounts of discharge through overland flow corridors including creeks, rivers and can damage property, life and the natural environment. Effective management of surface runoff is necessary to reduce risk of potential damages.

This research aims to investigate the impact of sub five minute time of concentration (Tc) in high density urban developments to determine if the current minimum Tc (as used Australia wide as part of hydrological calculations) is promoting inaccurate design solutions. The findings will allow conclusions to be drawn on realistic minimum Tc s for small urban design cases and recommendations for reducing the minimum Tc in the current Queensland Urban Drainage Manual (QUDM).

This project looks to confirm that urban drainage guidelines in Australia are in touch with current urban site characteristics and that responsible design solutions are promoted in order to reduce risk to property and life.

A mixed method research approach was used to investigate the project topic. Primary data was collected in the form of physically test Tc in residential sub catchments which was then compared against comparative modelling results replicating the same design scenarios. Additionally, secondary data was collected in the form of a content analysis on the opinions and views of industry professionals and relevant authority representatives.

Early results indicate that Tc of between two and five minutes is a very realistic Tc for urban sub catchments. Preliminary modelling has confirmed that a reduced Tc can equate to a higher catchment discharge.

It is clear that because of the current findings catchment discharges have the potential to be underestimated because of assuming a minimum 5 minute Tc. This study should be considered during the consideration of urban water quality design principles and devices, which is an important aspect of development engineering responsibility. Additionally, as roofed catchments utilise use of downpipes for directing flow to the outlet point, it should
be investigated whether current Australia Standard plumbing guidelines (Standards Australia, 2003) recognise the feasibility of sub five minute catchment $T_c$.

Investigation has confirmed that sub five minute $T_c$s are realistic and produce a higher flow from catchments. For this reason it is suggested that drainage guidelines consider minimum $T_c$ of less than five minutes (down to the shortest duration of available IFD data that is available for that particular area).
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30/10/2014
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Glossary of Terms

AEP – Average Exceedance Probability

ARI – Average Recurrence Interval

ARR – Australian Rainfall and Runoff (Reference document for flood estimation published by Engineers Australia)

BOM – Bureau of Meteorology (Australian Government Executive Agency)

Detention – Detaining water in a tank or basin to allow discharge to be released at a reduced rate to help reduce flooding or erosion in rivers and streams

F_i – Fraction Impervious

GFA – Gross Floor Area

IFD – Intensity-Frequency-Duration

Impervious Surface – A surface which fluid will not pass though and will run off

T_c – Time of Concentration – Time needed for water to flow from the most remote point in a catchment to the catchment outlet

QUDM – Queensland Urban Drainage Manual
CHAPTER 1 - INTRODUCTION

1.1 Outline of the Study

Catchment time of concentration \((T_C)\) is defined as being the time needed for water to flow from the most remote point in a catchment to the catchment outlet. This research aims to investigate the impact of sub five minute \(T_C\) in urban development to determine if the current five minute minimum \(T_C\) (as used Australia wide as part of hydrological calculations) is promoting inaccurate design solutions. The findings will allow conclusions to be drawn on realistic \(T_C\) minima for urban design cases and recommendations for reducing the minimum \(T_C\) in the current Queensland Urban Drainage Manual (QUDM) third edition 2013 (IPWEA (Queensland), 2013) may be made. Both stormwater runoff quantity and quality design will be considered in the scope of this investigation, which is outlined in detail in section 1.4.

1.2 Introduction

Professional civil engineers hold an important responsibility to consider the impact of surface runoff in the design of developments of any type. Surface runoff and flooding from rainfall, in both rural and urban areas, can produce large amounts of discharge through creeks, rivers and overland flow areas (natural or artificial) and can damage property, life and natural resources.

For this reason civil engineers are tasked with the responsibility to minimise the damage during storm events by safely and effectively conveying surface flow through adequately sized open or closed conduits to an outlet location where it will not affect property or life.

South East Queensland is in a location that is subject to relatively intense storms, compared to other locations within Australia. An example of the extreme nature of South East Queensland’s rainfall extent was on display during January 2011 during which an extremely intense storm event occurred in the Toowoomba region which caused significant damage to property and life in the Toowoomba CBD from flash
flooding. This event drew international news coverage, especially the footage caught of flash flooding within Toowoomba.

Since January 2011 development policies have been updated to revise flooding levels in order to ensure future development has less risk of flood damage, with minimum developable floor levels rising in many locations throughout Brisbane and surrounding cities.

While storm events leading up to the Toowoomba flash floods of January 2011 were extreme with an estimated ARI in the order of 1 in 200 to 1 in 300 for a one hour duration storm event (Neil Collins, 2011), given the potential damage events like this can impose it highlights the responsibility engineers have in the community to ensure adequate design of drainage infrastructure.

In Australia (and around the world) urban density is steadily increasing. While cities are still expanding out from the city centre, they are also increasing in height with many inner city suburbs changing from houses or low rise apartments into medium/high rise apartments with increased areas of pavement.

In South East Queensland the regulations that curb what type of developments can be built change almost every year and in the past few years the new land use, state
and local planning policies (Brisbane City Council, 2014) have been updated accordingly. This has meant that many areas of low and medium density residential areas have been rezoned as medium and high density residential land use, with the development application process for these higher density sites becoming increasingly easy. Additionally, as house and apartment prices in Australia increase, the minimum allowed gross floor area (GFA) is starting to decrease to keep entry level size houses within reach of first home buyers. As an example of the impact these rule changes are having on the landscape; on a standard size residential lot in an inner city suburb of around 1000m$^2$ it means that developers are now demolishing any existing single unit dwelling houses and building up to 12 units (multi storey townhouses) within the same lot area, with associated visitor car parking and paved courtyard areas.

Refer Appendix B through E for an example of recent developments within Brisbane and Ipswich. These developments will be analysed later within this dissertation, and were chosen because of their very high fraction impervious and potentially short $T_c$ to the outlet point. When comparing the existing and developed scenarios within Appendix B through E it is easy to see the dramatic increase in impervious area. While a single house within a 1000m$^2$ lot may have a site fraction impervious of around 25% - 35%, up to 12 units with paved areas on the same site may increase the fraction impervious close to 95%. For commercial development sites it is not uncommon for a site to become fully impervious.

Most state and local council guidelines have clear guidelines on the hydrologic objectives of drainage design for a new development. Most importantly, these are;

- The proposed development shall ensure that all stormwater drainage is directed to a lawful point of discharge (QUDM, 2013)
- No increase in post development discharges, up to and including the 100 year ARI at the lawful point of discharge; and,
- No adverse impact on adjoining or downstream properties.
Additionally, water quality objectives are governed by state and local council guidelines and recommend that the following water quality objectives must be achieved to protect downstream receiving waters;

South East Queensland Objectives (Infrastructure and Planning Department of State Development, 2013);

- Total Suspended Solids (TSS) 85% reduction
- Total Phosphorus (TP) 60% reduction
- Total Nitrogen (TN) 45% reduction
- Gross Pollutant (>5mm) 90% reduction

While both the water quantity and quality objectives above a very clear to the developer and responsible engineer, the accuracy of the proposed solutions are dependent on accurate calculation of the site catchment flows.

Given that (QUDM, 2013) states minimum $T_c$ for a catchment is to be specified as five minutes this dissertation aims to investigate whether sub five minute $T_c$ for urban development may impact solutions for drainage quantity and quality design objectives. This will be discussed further in the next section.
1.3 The Problem

When considering urban drainage with developing cities a dramatic increase in fraction impervious is becoming commonplace for some development sites. Subsequently, the associated $T_C$ has the potential to decrease when draining to the sites lawful point of discharge.

The Queensland Urban Drainage Manual (QUDM) is considered “one of the primary reference documents for stormwater practitioners in Queensland. The document has also attracted wide use outside Queensland” (QUDM, 2013) (3rd edition) section 4.6.2 states “although travel time from individual elements of a system may be as short as two minutes, the total nominal flow travel time to be adopted from any catchment to its point of entry into the drainage network should not be less than 5 minutes.” Although this particular guideline clearly directs the absolute minimum $T_C$ to use in any catchment discharge calculations to be five minutes, it does not provide additional commentary or explanation as to why this should be the case. A sub goal of this dissertation is to provide more information on this rule within QUDM, or bring to light that this rule is possibility detrimental to drainage infrastructure design objectives in Queensland, increasing potential damage to property and life.

Although QUDM states clearly in section 1 that it is only to be used as a guide and that “Designers are nevertheless responsible for conferring with relevant local authorities to determine local design requirements are not to be taken as gospel for all circumstances where drainage design is concerned”, it’s ‘standard inlet times’ are generally adopted throughout civil engineering firms as part of development applications and operational works applications to council. Additionally, many local councils within Queensland point to QUDM as the primary reference document for drainage, with only a few of the larger councils specifying slightly different design guidelines as amendments to QUDM. Most of the smaller Councils do not propose to alter the recommendations of the QUDM document at all for drainage design. Given this wide adoption of the guidelines and rules within QUDM it is therefore it would seem prudent that the ‘standard inlet times’ within QUDM version 3 may need to be amended to allow for high density residential developments in order to
ensure that ‘stormwater practitioners’ do not wrongly use the minimum standard inlet time of five minutes, where in reality this may not be the case.

As discussed in the previous section, both drainage quantity (detention) and quality are dependent on accurate estimation of the catchment flows. It may be possible that these important drainage design components are potentially being impacted by high flows from sites with $T_c$ of sub five minutes, where the designer is assuming a minimum of five minutes in their drainage design calculations.

Additionally, as roofed catchments utilise use of downpipes for directing flow to the outlet point, it should be investigated whether current Australia Standard ‘plumbing’ guidelines (Standards Australia, 2003) recognise the feasibility of sub five minute catchment $T_c$ – although this is not the focus of this project.

### 1.4 Research Objectives

The objectives of this research are as follows:

- Research background information on $T_c$, Rational Method and other relevant urban drainage components relevant to the topic.
- Determine the reason why five minutes is the adopted minimum $T_c$ for catchments as per QUDM
- Develop a methodology and test catchments to to gather data on the realistic $T_c$ for small urban catchments
- Model small urban catchments with five minute $T_c$ compared to sub five minute $T_c$ to determine the difference in outflows and what impact this may have on urban drainage design
- Propose changes to the minimum $T_c$ as specified in QUDM as necessary
- Submit an academic dissertation on the research.
CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

This chapter will provide a comprehensive literature review on several topical areas relevant to the project. It is intended to provide a platform of understanding of the relevant areas so that it can be more easily understood where the project proposal fits in amongst existing literature and additionally to confirm its relevance as a problem.

The primary source of literature was online and in particular online science and engineering journal databases accessed through USQ Online Library Search webpage.

As discussed in Chapter 1, $T_C$ and also intensity-frequency-duration are two important topics relevant to the project. Literature surrounding both of these topics will be reviewed in depth with several other topics touched on in order to promote a good level of background knowledge.

Other topics reviewed will include use of the Rational Method with the scope of Urban Drainage Design. This method remains as a heavily used catchment discharge calculation method because of its simplicity and speed to produce usable results, though some would question its accuracy.

The concept of development density within urban areas will be reviewed in order to draw conclusions on how town planning influence can impact the drainage design parameters with the creation of high density and high fraction impervious development sites, with potential for sub five minute $T_C$.

Urban drainage will be looked at in a holistic sense to determine its goals and limitations and investigate if there are any gaps in relevant design guidelines.

Lastly, stormwater quantity (detention) and stormwater quality design aspects will be reviewed.
2.2 Time of Concentration

(T. J. Mulvany, 1851) first presented the concept of time of concentration ($T_c$) as ‘the time at which discharge is the highest for a uniform rate of rainfall as the runoff from every portion of the catchment arrives at the outlet’. In recent literature $T_c$ is a time parameter widely used to estimate peak discharges in hydrologic designs (X. Fang et al., 2008). Its significance is in the assumption that for a given design storm frequency, peak flow at the catchment outlet will result from a storm of duration equal to the $T_c$ (IPWEA (Queensland), 2013).

Time of Concentration is often explained in conjunction with the Time-Area graph as highlighted in figure 2.1 and 2.2 below.
Most empirical equations of estimating $T_c$ reference four types of input parameters: slope, catchment size, flow resistance, and water input. Some of the more common empirical equations utilised in Queensland include:

- Friends equation (1954), which uses Horton’s ‘n’ value for surface roughness, and is suitable for use in sheet flow time calculations
- The Kinematic Wave Equation (Ragen & Duru – 1972) which is also used in sheet flow time calculations but only for plans that are homogenous in slope and roughness
- Bransby-Williams Equation for rural catchments
- Izzard’s Equation (1946) for kerb and channel flow time calculations
- Mannings Equation (1890) for channelised (including piped) flow time calculations

(IPWEA (Queensland), 2013)

It is to be noted that during review into the available literature on $T_c$ the vast majority of studies of catchments and $T_c$ were for medium to large rural or urban ‘water sheds’ This is believed to be because that rural catchment studies have a ‘higher risk’ than small urbanised catchments in the context of flooding and drainage design, and that urbanised $T_c$ calculations can effectively be ‘broken down’ into the different elements and the times calculated using existing sheet flow and channelized flow equations as highlighted above.

Although the Mulvany described definition of $T_c$ is generally accepted in industry, it is noted that some researchers have preferred to consider impervious surfaces only. This is particularly relevant in urban areas where Watkins (L. H. Watkins, 1962) found that the contribution from the unpaved surfaces is unlikely to be a significant portion of the peak flood. The circumstance which Watkins describes above is similar to the ‘Partial Area Effect’ which occurs when the maximum flow from a catchment can occur when only a part of the upstream catchment is contributing. Usually this case occurs when considering a subcatchment of pervious surface and large $T_c$ within a greater catchment which is predominantly impervious with a low $T_c$. In this case the maximum flow would occur at a $T_c$ which ignores the pervious
sub catchment $T_C$ value. This effect is fully described within (IPWEA (Queensland), 2013). The simplified procedure for partial area effect is utilised later in this report. Understanding the $T_C$ parameter within catchment discharge design as described above is crucial for this project, which attempts to physically test and then model the $T_C$ for small subcatchments. Some of the empirical equations as described earlier will be used to calculate the theoretical $T_C$.

The Queensland Urban Drainage Manual clearly nominates the recommended ‘roof to main’ travel times as the following:

![Table 2.1 - QUDM 2013 ‘Roof to Main’ Inlet Times](image)

**2.3 Intensity-Frequency-Duration Data**

Design rainfall intensity estimates are an essential component of the design of infrastructure including gutters, roofs, culverts, storm water drains, flood mitigation levees and retarding basins (F Johnson J Green, 2011). Intensity-Frequency-Duration (IFD) information organises rainfall intensity data into useable data sets (and graphically – IFD ‘curves’). In some countries these curves are referred to as Intensity-Duration-Frequency (IDF) curves.

(Canterford et al, 1985) suggests that the procedures for users to determine IFD curves have been slowly improved with each version of Australian Rainfall and Runoff (ARR). Starting with ARR (1977) when there was limited pluviometer and daily rainfall data, interpolation was done for ‘data sparse’ areas using statistical methods. ARR (1986) utilised more pluviograph data with greater resolution, along with more advanced statistical methods of interpolation.
As the base of the IFD data is gauged data from pluviometers it should be noted that for the 1977 release there were only 100 representative pluviometer stations, while in the current data set (1986) there are 7500 daily read rainfall stations, and now for the upcoming 2014 ARR publication there are more than approximately 20,000 daily read rainfall stations that have contributed data.

![Location of Bureau daily read rain gauges](image)

In Australia, where it is recognised accurate IFD data is crucial to allow for adequate flood estimate and drainage design as a whole, significant time and money has been invested in the development of better and more widely placed infrastructure to record IFD data. Where previously the process to derive a sites IFD data was relatively manual (looking at six ‘key maps’ and using interpolation) to derive them (Canterford et al, 1985) now it’s current state it is as simple as inputting a sites latitude/longitude and the IFD data (in multiple formats) will be generated for use. Free online access the ARR 1987 published IFD data has been available from the Bureau of Meteorology website for several years. The 2013 publishing is expected to build on this to increase functionality and provide a larger data set covering more storm durations.
For previous AR&R IFD data sets, the focus of the end users included the design of structures on predominantly rural catchments, hence the AR&R data sets only included rainfall data for minimum storm duration of five minutes. However, with the increase in relevance of urban drainage and in particular for small urbanised catchments, the new IFD set includes data for short duration storms down to one minute in length (F Johnson J Green, 2011).

Kennedy and Minty (1992) proposed a procedure for estimating rainfall intensity data for durations shorter than the five-minute limit. In this study it was recognised there was a need for short duration IFD data not only for the design of drainage systems for very small area catchments, but also to solve a problem within the telecommunications industry where the scattering of radiation from a beam at ultra-high frequencies decreases with very heavy rainfall (short duration storms of very high intensity). The study is based on research performed in America and Australia.

Where real rainfall data for a particular site is not available, rainfall data is estimated for the site. Depending on the storm duration AR&R contributors have used different analysis and regression methods to come up with data that generally fits the pattern of IFD data for the surrounding areas.

Particularly for sub-hourly very short durations, the record length from gauges is short and the spatial coverage is sparse. The reason for this is that the technology for adequately recording rain events down to one minute has only been around for at most 20 years from the mid 1990’s, which was when Tipping Bucket Rain Gauges (TBRGs) were installed. Hence, because of the lack of quality in short duration data there is difficulties in developing sub-hourly design rainfall data directly from the records.

For very short duration rainfall estimates down to one minute, four methods were explored: ratios of rainfall annual maxima, ratios of quantiles, simple scaling and extending the BGLSR (Bayesian Generalised Least Squares Regression) down to one minute (Karin Xuereb, 2012)
It should be noted that although some site locations may be able to utilise 2013 IFD data that is real data from a storm, there may be sites that are lacking in real data, in which case IFD data is derived from varying array of estimation methods depending on the particular storm event as mentioned above.

2.4 Rational Method

Connecting both $T_c$ and IFD data is the widely used catchment discharge calculation method – the Rational Method. Although first described 150 years ago by Irish engineer Thomas Mulvany in 1851, the method remains a popular hydrologic analysis and design tool, although it’s use is usually restricted to small unregulated drainage areas (C. Young and B. McEnroe, 2014).

As described in (C. Young and B. McEnroe, 2014) the Rational formula is commonly written as

$$Q_T = k \cdot C \cdot I \cdot A$$

Where

$Q_T$ = design discharge (in $m^3/s$) for the recurrence interval, $T$;

$k$ = unit conversion factor (1/360 for SI units)

$C$ = Runoff Coefficient

$I$ = Rainfall intensity (mm/hr); and

$A$ = Catchment area ($km^2$) upstream of the point of interest.

The rainfall intensity $I$ is selected from Intensity-Frequency-Duration (IFD) relations for the recurrence interval of interest using a duration that is equal to a characteristic time (or averaging period) for the catchment ($T_c$).

The Rational Method ‘C’ runoff coefficient is linked, in a complex manner, to the infiltration characteristics of the catchment and impacts of other runoff ‘losses’ (IPWEA (Queensland), 2013)

Several studies have been undertaken in different parts of the world to investigate the C values of particular catchments. These include
• Schaake et al. (1967) – 20 small catchments in Baltimore, America
• French et al. (1974) – 37 catchments of different sizes in New South Wales, Australia ranging in size up to 250km²
• Hotckkiss and Provaznik (1995) – 24 rural catchments in South-Central Nebraska
• Yong et al. (2009) – 72 rural catchments in Kansas

As observed in the (C. Young et al.) Kansas study, C values seemed to correlate with two main factors being annual rainfall and also soil permeability. Importantly it was concluded that C values increase with recurrence interval.

(D. Froehlich, 2012) writes that ‘more than a century of practical experience with the Rational formula has led to accepted ranges of C that are tabulated in many references’ (as in (IPWEA (Queensland), 2013)), with values varying with development category (land use) and ARI.

In Australia, the recent ARR 2013 Project 13 provides a review discussion of the Urban Rational Method for catchment discharge estimation. It also acknowledges that catchment characteristics can influence the C value and therefore the authors of the project do not recommend the use of the Urban Rational Method.

Use of Rational Method is strongly favoured by engineers, because it requires few parameters which are physical and easily obtained from site surveys (S. Bennis and E. Crobeddu, 2007).

The Rational Method is understood to be a current industry standard catchment discharge estimation method, particularly for small catchments. The Rational Method will be used in this project to model chosen catchments utilising appropriate times of concentration.

2.5 Development Density
Development density is an important concept relevant to the project topic, primarily because the relevance of the topic has increased because of increase in development density.
As introduced in section 1.2, and highlighted in analytic figures 2.4 and 2.5 (Department of Economic and Social Affairs United Nations, 2011), as the population steadily rises within Australia, the proportion of people living in urban areas is increasing over the proportion of people living in rural areas. This is a primary driver behind the increased development density in cities in Australia and globally, where a similar pattern exists.

Figure 2.4 – Urban vs Rural Living Proportions in Australia (Department of Economic and Social Affairs United Nations, 2011)

Figure 2.5 – Urban and Rural Population – Australia (Department of Economic and Social Affairs United Nations, 2011)
Through review of the Rational Method it is clear that the fraction impervious ($F_i$) directly affects the discharge coefficient ($C$) which then affects the catchment discharge. A higher $F_i$ equates to a higher discharge.

As suggested in (Johanna Deak Sjöman and Susannah E. Gill, 2014), floods are also strongly related to the increased area of impermeable surfaces in the urbanised landscape, where settlements and urbanisation form a solid impervious barrier in the hydrological system. The effect of this development pattern is an increase in surface runoff, which often leads to unpredicted pluvial flooding in areas outside recognised river floodplain.

Additionally, According to (Hatt Et Al, 2004) urbanisation—operationalised as poor drainage and quantity of impervious surfaces—is the most likely factor in the degradation of stream water quality. Additionally, stormwater runoff from roads, rooftops, parking lots, and other impervious cover in urban and suburban environments is a well known cause of stream degradation. It is obvious from the these statements that the proper design of water quality treatment systems is particularly important in areas of high density development where impervious surfaces makes up the majority area. Water Quality treatment design may be impacted by the findings of this project, however, review of water quality is not proposed to be included within the scope.

Analysing trends in urbanisation worldwide it is evident that high density development will become more and more common as populations grow and cities with them. Subsequently, without stringent planning restrictions for pervious areas in development, it is inevitable that the fraction impervious of sites will increase dramatically, negatively impacting stormwater management outcomes regarding quantity and quality as studies have suggested.

This project recognises that changes urban density does impact drainage design and endeavours to highlight possible negative impacts it may have on new and existing development areas.
2.6 Conclusions

Time of Concentration

- Time of Concentration ($T_c$) is the time it takes for 100% of watershed in a catchment to contribute to flows at outlet point
- Peak flow at outlet will result from a storm duration equal to the time of concentration
- For most instances of $T_c$ input parameters are slope, catchment size, flow resistance and water input
- The Queensland Urban Drainage Manual clearly nominates the recommended ‘roof to main’ travel time as a minimum of five minutes

Intensity-Frequency-Duration

- Intensity-Frequency-Duration (IFD) information organises rainfall intensity estimates into useable data sets
- Design rainfall intensity estimates are a primary input into catchment discharge methods and therefore are an essential component of the design of drainage infrastructure
- Current IFD data (1987 published) is measured to a minimum of five (5) minute durations.
- 2013 published draft IFD data is measured to a minimum of one (1) minute durations.

Rational Method

- Method for estimating discharge from a catchment
- Links Time of Concentration with IFD data
- Although 150 years old it remains a popular hydrologic analysis and design tool
- $Q = k \cdot C \cdot I \cdot A$
- $I = \text{The rainfall intensity in } \text{mm/hr} \text{ is selected from Intensity- Frequency–Duration (IFD) for the ARI of interest using a storm duration that is equal to the Time of Concentration (T_c).}$
• The Rational Method is understood to be an industry accepted catchment discharge estimation method.

Urbanisation

• Urbanisation of cities is occurring globally
• Increasing urbanisation generally results in areas of higher fraction impervious, and subsequently more runoff
• Increasing urbanisation generally results in decrease in water quality
CHAPTER 3 – METHODOLOGY AND RESULTS

3.1 Introduction

This chapter will include details of the methodology and subsequent details of all the testing, data collection, modelling and analysis of data, and summary of results. Within each section will be necessary commentary on the components in order to give the reader a better understanding.

An important concept to consider while working through this chapter is the need for engineers to assume a ‘conservative’ (and responsible) approach to drainage design. Several site characteristics may combine to form a catchment which has a greater chance to have a sub five minute $T_C$, greater flows off site and therefore a potentially increased impact to property or life.

These characterises include:

- Fully impervious (i.e. roofed or paved) catchment
- Smooth surface properties (i.e. steel, paint or smooth concrete)
- Steep surface grades towards outlet
- Pre-soaked catchment
- Site in locality prone to ‘burst’ rainfalls

Although some of the testing sites do not necessarily have all the characteristics as listed above, they do reflect some characteristics of ‘worst case’ catchments and therefore are deemed suitable for analysis for this dissertation.

3.2 Methodology

The Methodology follows a research and testing scope of works in order to drawing conclusions on a hypothesis (that sub five minute TC is realistic and may impact drainage infrastructure). The research component includes the literature review. The testing component includes the physical testing of the site and then the follow up modelling and analysis.
3.3 Data Collection

Data Collection involved physically testing impervious sub catchments to gauge what realistic $T_c$ may be for impervious catchments.

Ideally, the aim of the testing is to prove that subcatchments (and potentially the entire catchment) for a development can have a time of concentration of less than five minutes.

It was deemed that residential house sites with varying and accessible roof types, that drain directly to an outlet point (drainage pit at back of lot or kerb and channel) and not through roof water tanks would be suitable for testing.

A minimum of three (3) sites will be tested to determine a suitable answer.

Of particular importance was to as accurately as possible replicate a real, high intensity rainfall event in order to determine realistic data. This was achieved using an adjustable sprinkler head.

The process of testing will be;

1. Gather testing equipment and safety gear
2. Travel to the testing site
3. Assess safety, survey site and take photos
4. Identify outlet point and catchment to test
5. Prepare sprinkler and hose arrangement
6. Measure flow rate with electronic gauge (3x)
7. Access roof
8. With a testing partner, apply sprinkler to catchment and test that flows reach outlet point
9. Stop application for 3 minutes to reset flows to nil
10. Start timer and application to catchment to simulate 'burst' rainfall
11. Stop timer when flows reach outlet
12. Repeat test 3 times for the catchment to ensure consistency between results
13. Record results
14. Document the test catchment and testing itself with sketches and photos
15. Assess safety again before climbing down from roof
16. Pack away equipment
17. Save photos and results to computer
18. Collate results and other observations for analysis
Testing Equipment

Figure 3.1 - Digital Gauge with Meter – Blyth, 2014

Figure 3.2 – Digital Gauge – Blyth, 2014

Figure 3.3 – Sprinkler Head – Blyth, 2014

Figure 3.4 - Sprinkler Rate Test Arrangement – Blyth, 2014
<table>
<thead>
<tr>
<th>Site Location</th>
<th>Application (Sprinkler) Gauge Depth per 2.5min (mm)</th>
<th>Equivalent Intensity (mm/hr)</th>
<th>Approx. Locality AEP (2 min Tc)</th>
<th>Approx. Locality AEP (5 min Tc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oakland Dr</td>
<td>9</td>
<td>216</td>
<td>5% AEP (Q5 ARI)</td>
<td>10% AEP (Q10 ARI)</td>
</tr>
<tr>
<td>Oakland Dr</td>
<td>10</td>
<td>240</td>
<td>5% AEP (Q5 ARI)</td>
<td>5% AEP (Q20 ARI)</td>
</tr>
<tr>
<td>Oakland Dr</td>
<td>9</td>
<td>216</td>
<td>5% AEP (Q5 ARI)</td>
<td>10% AEP (Q10 ARI)</td>
</tr>
<tr>
<td>Menangle Ave</td>
<td>13</td>
<td>312</td>
<td>2% AEP (Q50 ARI)</td>
<td>1% AEP (Q100 ARI)</td>
</tr>
<tr>
<td>Menangle Ave</td>
<td>13</td>
<td>312</td>
<td>2% AEP (Q50 ARI)</td>
<td>1% AEP (Q100 ARI)</td>
</tr>
<tr>
<td>Menangle Ave</td>
<td>14</td>
<td>336</td>
<td>1% AEP (Q100 ARI)</td>
<td>1% AEP (Q100 ARI)</td>
</tr>
<tr>
<td>Farrow St</td>
<td>11</td>
<td>264</td>
<td>5% AEP (Q5 ARI)</td>
<td>2% AEP (Q50 ARI)</td>
</tr>
<tr>
<td>Farrow St</td>
<td>12</td>
<td>288</td>
<td>5% AEP (Q5 ARI)</td>
<td>2% AEP (Q50 ARI)</td>
</tr>
<tr>
<td>Farrow St</td>
<td>12</td>
<td>288</td>
<td>5% AEP (Q5 ARI)</td>
<td>2% AEP (Q50 ARI)</td>
</tr>
</tbody>
</table>

**Oakland Drive, Tewantin**

The first testing site was Tewantin, where a roof catchment was tested with the time of concentration measured to the kerb outlet. Observations were that this roof catchment was particularly wide with gentle roof slopes and the downpipe had relatively gentle grades from the house to the kerb outlet.
Menangle Street, Arana Hills

Mangle Street, Arana Hills was proposed as the second test site where the roof catchment was a steeper and smaller than Oakland Drive, with the outlet point at a lower grade, making the downpipes a steeper grade.
Farrow Street, McDowall

The third site was in MacDowall, where the roof catchment was particularly small but with a longer drainage pipe to the outlet point. It was around 25m length but the grade of the pipe was relatively steep.
Figure 3.20 - Outlet Point at Kerb and Channel

Figure 3.21 - Gutter and Downpipe Arrangement

Figure 3.22 - Roof Catchment and Gutter Arrangement
Figure 3.25 - View from Roof Crest to Road

Figure 3.26 - Lowest Time Reading
### Physical Test Results

<table>
<thead>
<tr>
<th>Site Address</th>
<th>Catchment</th>
<th>Test Time 1 (mins)</th>
<th>Test Time 2 (mins)</th>
<th>Test Time 3 (mins)</th>
<th>Average Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 Oakland Drive, Tewantin</td>
<td>Roof (main, tiled)</td>
<td>1.50</td>
<td>1.40</td>
<td>1.38</td>
<td>1.43</td>
</tr>
<tr>
<td>29 Menage Ave, Arana Hills</td>
<td>Roof (main, tiled)</td>
<td>2.10</td>
<td>1.50</td>
<td>1.55</td>
<td>1.72</td>
</tr>
<tr>
<td>23 Farrow Street, Mcdowall</td>
<td>Roof (garage, tiled)</td>
<td>1.50</td>
<td>1.35</td>
<td>1.24</td>
<td>1.36</td>
</tr>
</tbody>
</table>

### Theoretical Test Results

The chosen layouts will be broken down into components (roof, gutter, pipe flow) and analytical solutions for the $T_C$ will be completed and compared against the results of the physical testing.

Conservative assumptions have been made for the flow in the gutters and the pipes. It is expected that in a real storm scenario, with the full roof catchment contributing to flows in the gutter and the pipe, that the water would be ‘entrained’ more effectively, increasing velocity and potentially decreasing $T_C$ further.

### ROOF FLOW TIMES (FRIENDS)

<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>APPROX. ROOF SLOPE %</th>
<th>APPROX ROOF WIDTH (m)</th>
<th>HORTONS ROUGHNESS *</th>
<th>FLOW TIME (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OAKLAND DR</td>
<td>15</td>
<td>4.5</td>
<td>0.012</td>
<td>1.23</td>
</tr>
<tr>
<td>MENANGLE AVE</td>
<td>20</td>
<td>4</td>
<td>0.012</td>
<td>1.12</td>
</tr>
<tr>
<td>FARROW ST</td>
<td>15</td>
<td>3.5</td>
<td>0.012</td>
<td>1.13</td>
</tr>
</tbody>
</table>

*Hortons roughness for painted tiles

### GUTTER FLOW TIME (MANNINGS CHANNELS)

<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>APPROX. GUTTER LENGTH TO DOWNPIPE (m)</th>
<th>VELOCITY (m/s)</th>
<th>HORTONS ROUGHNESS</th>
<th>FLOW TIME (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OAKLAND DR</td>
<td>5</td>
<td>0.2</td>
<td>0.019</td>
<td>0.42</td>
</tr>
<tr>
<td>MENANGLE AVE</td>
<td>3.5</td>
<td>0.2</td>
<td>0.019</td>
<td>0.29</td>
</tr>
<tr>
<td>FARROW ST</td>
<td>2.5</td>
<td>0.2</td>
<td>0.019</td>
<td>0.21</td>
</tr>
</tbody>
</table>

*Assume channel base width of 0.15m  
*Assume gutter slope of 1:500 (Standards Australia minimum)  
*Assume Hortons Roughness of 0.019 (steel)  
*Assume $5m^2$ of flow contributing to gutter flow (0.8L/s) at 0.02m depth
<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>APPROX. PIPE LENGTH TO OUTLET (m)</th>
<th>APPROX. AVERAGE IN GROUND PIPE GRADE %</th>
<th>VELOCITY (m/s)</th>
<th>HORTONS ROUGHNESS</th>
<th>FLOW TIME (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OAKLAND DR</td>
<td>17</td>
<td>6</td>
<td>1.01</td>
<td>0.012</td>
<td>0.28</td>
</tr>
<tr>
<td>MENANGLE AVE</td>
<td>15</td>
<td>12</td>
<td>1.45</td>
<td>0.012</td>
<td>0.17</td>
</tr>
<tr>
<td>FARROW ST</td>
<td>30</td>
<td>15</td>
<td>1.58</td>
<td>0.012</td>
<td>0.32</td>
</tr>
</tbody>
</table>

*Assumes 10% full pipe flow
* Mannings n = 0.011
* Pipe diameter = 150mm

<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>ROOF (min)</th>
<th>GUTTER (min)</th>
<th>PIPE (min)</th>
<th>TOTAL (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OAKLAND DR</td>
<td>1.23</td>
<td>0.42</td>
<td>0.28</td>
<td>1.93</td>
</tr>
<tr>
<td>MENANGLE AVE</td>
<td>1.12</td>
<td>0.29</td>
<td>0.17</td>
<td>1.58</td>
</tr>
<tr>
<td>FARROW ST</td>
<td>1.13</td>
<td>0.21</td>
<td>0.32</td>
<td>1.66</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>PHYSICAL TIME (min)</th>
<th>ANALYTICAL TIME (min)</th>
<th>DIFFERENCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OAKLAND DR</td>
<td>1.43</td>
<td>1.93</td>
<td>-25.90</td>
</tr>
<tr>
<td>MENANGLE AVE</td>
<td>1.72</td>
<td>1.58</td>
<td>8.65</td>
</tr>
<tr>
<td>FARROW ST</td>
<td>1.36</td>
<td>1.66</td>
<td>-18.00</td>
</tr>
</tbody>
</table>

The physical testing data and the analytical data have rough correlation. An outlier is the Menangle Avenue results which show the physical testing time as 9% more than the analytical time, where both the other sites have an approx. 20% reduction in time between the physical and analytical times. It was observed at the Menangle Site that the gutters were particularly flat (and somewhat ingrained with dirt – although free of leaves), with the roof flow taking seemingly longer to flow to the downpipe along the gutter.

### 3.4 Modelling Introduction

Modelling will involve utilising industry standard catchment discharge methods to model high density and high fraction impervious urban catchments using a range of low $T_C$ to test how flow rates change when subject to low $T_C$s.
Manipulation of new IFD Data

ARR published IFD data in 1987 that is current and available from the Bureau of Meteorology (BOM) website. The 1987 data set provides data to a minimum duration of five minutes (see figure 3.27 below), which as stated earlier is the reason why current guidelines stipulate (without apparent explanation) five minutes being the minimum $T_c$ to use with urban drainage design.

![Intensity-Frequency-Duration Table](image)

Figure 3.27 - 1987 IFD Chart Example – 5 minute minimum storm durations

In 2013 ARR published several chapters of the upcoming ARR 2014 update, which will provide a revision of the ARR document including the publishing of updated set of IFD data delivered again through the BOM website. A ‘draft’ set of 2013 BOM data was made available in late 2013 which included IFD data down to a storm duration of 1 minute. This was made possible because of development in technology and subsequent accuracy of rainfall testing equipment in the recent decades. The new set of IFD data will ‘officially’ supersede the 1987 published data in December 2015, and is said to be a better representation of rainfall intensities throughout Australia. The 2013 data, although not ‘current’ will be used for modelling purposes during this project.
The new 2013 IFD data set is presented in a different format than the previous data set. Most notably, the 1987 data was in ‘intensity’ (mm/hr) while the 2013 is presented in a rainfall ‘depth’ (mm). While the new ARR encourages use depth in order to more easily model ‘direct’ rainfall, for the purposes, it was necessary to convert the depths from 2013 data to intensities in order to use with existing drainage design spreadsheets and subsequently to compare the difference in flows for different catchment $T_C$.

Additionally the new terminology for design events used in the 2013 data sets is different than the 1987, with a comparison shown below.

Table 3.1 - ARR Design Storm Naming Conventions

<table>
<thead>
<tr>
<th>1987 Terminology</th>
<th>Q1 (1yr ARI)</th>
<th>Q2 (2yr ARI)</th>
<th>Q5 (5yr ARI)</th>
<th>Q10 (10yr ARI)</th>
<th>Q20 (20yr ARI)</th>
<th>Q50 (50yr ARI)</th>
<th>Q100 (100yr ARI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013 Terminology</td>
<td>1EY</td>
<td>50% AEP</td>
<td>20% AEP</td>
<td>10% AEP</td>
<td>5% AEP</td>
<td>2% AEP</td>
<td>1% AEP</td>
</tr>
</tbody>
</table>

While commentary provided with the publishing states that there will be changes in the new IFD values for areas, when comparing the 1987 values with 2013 values there was almost a negligible difference with 1-4 minute data fitting well with the previous 1987 data sets, particularly with the larger storm events. The smaller storm events (Q1 to Q5) showed convergence of rainfall intensities for 4 min (2013) and 5 minute (1987) durations in some localities.

With the modelling component of the project to focus on catchment discharge calculations using the Rational Method, it is worth noting that the ARR research project 13 has told us because of the apparent errors in the values of the coefficient of runoff then

“It is the view of the authors that continued use of the Rational Method for urban drainage analysis and design can no longer be justified” (Australian Rainfall and Runoff, 2013)

This statement for ARR authors seems to be made under a tone of professional responsibility because of the fact that the coefficient of runoff values which were determined by testing real catchments in Canberra, may not apply to all situations.
in all areas. This particular aspect of Rational has seemed to be overlooked and no further effort or funding has been allocated to revising the C10 values that are important to integrity of the Rational Method.

Now that there are easily accessible ‘software’ alternatives for determining a catchment discharge, which are understood to provide more accurate answers for flooding estimation purposes, then it seems responsible for the ARR authors to state as shown above, given that use of the relatively simple Rational Method may lead to inaccurate discharge results. However, the continued use of the Rational Method for quickly calculating an estimate for minor catchment discharges will not stop soon given it is relatively ‘ingrained’ into the drainage design processes of so many engineers within Australia (and internationally). Although, it is expected its use will begin to decrease as drainage software becomes more accessible, quick and efficient to use which will allow more complex and accurate catchment discharge methods to be utilised more readily.

The Rational Method was used to estimate the catchment discharge for the testing sites, with the $T_C$ input varied to gauge how a catchment discharge with a five minute $T_C$ might compare with the same catchment but a smaller $T_C$.

**Test Sites**

The chosen layouts will be modelled using the Rational Method and assuming a realistic sub 5 minute $T_C$. The resulting catchment discharge will be compared with the results of using a minimum 5 minute $T_C$.

**OAKLAND DRIVE, TEWANTIN (RESIDENTIAL)**

During physical testing the site at Oakland Drive, Tewantin was found to have an average roof catchment $T_C$ of 1 minutes 43 which equates to a Q100 rainfall intensity difference of more than 70mm/hr (326mm/hr compared to 405mm/hr) and is approximately a 24% increase in intensity from the 5 minute TOC intensity.

The majority of the 900m$^2$ site is a 500m$^2$ impervious roof and paved area catchment which when subject to ‘burst’ rainfall would have a $T_C$ of less than five
minutes, with the worst case expected to be feasibly three minutes. Fraction impervious for the property is 0.56 which is high for a residential site.

Table 3.2 shows the IFD data for the Tewantin site with duration down to one minute – of importance is to note that the rainfall intensities become heavier as duration (or $T_C$) decreases.

IFD data from the 2013 data set was used which is shown below:

<table>
<thead>
<tr>
<th>Duration (mins)</th>
<th>1EY (mm/hr)</th>
<th>50% AEP (mm/hour)</th>
<th>20% AEP (mm/hour)</th>
<th>10% AEP (mm/hour)</th>
<th>5% AEP (mm/hour)</th>
<th>2% AEP (mm/hour)</th>
<th>1% AEP (mm/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>168</td>
<td>192</td>
<td>258</td>
<td>306</td>
<td>348</td>
<td>402</td>
<td>438</td>
</tr>
<tr>
<td>2</td>
<td>144</td>
<td>162</td>
<td>225</td>
<td>267</td>
<td>306</td>
<td>363</td>
<td>405</td>
</tr>
<tr>
<td>3</td>
<td>134</td>
<td>152</td>
<td>210</td>
<td>248</td>
<td>286</td>
<td>336</td>
<td>374</td>
</tr>
<tr>
<td>4</td>
<td>127</td>
<td>145.5</td>
<td>199.5</td>
<td>234</td>
<td>268.5</td>
<td>315</td>
<td>348</td>
</tr>
<tr>
<td>5</td>
<td>122</td>
<td>139.2</td>
<td>189.6</td>
<td>223.2</td>
<td>254.4</td>
<td>296.4</td>
<td>326.4</td>
</tr>
</tbody>
</table>

Table 3.2 - IFD Data Oakland Drive

When catchment discharge is calculated utilising the Rational Method, the difference in flows is found to be as per below

DISCHARGE COMPARISON (L/s) – Oakland Drive, Tewantin, Impervious Catchment (500m³)

<table>
<thead>
<tr>
<th>EVENT</th>
<th>TOC 5 min</th>
<th>TOC 4 min</th>
<th>$QA$ (TOC 4 min % &gt; TOC 5 min)</th>
<th>TOC 3 min</th>
<th>$QA$ (TOC 3 min % &gt; TOC 5 min)</th>
<th>TOC 2 min</th>
<th>$QA$ (TOC 2 min % &gt; TOC 5 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q10</td>
<td>27.5</td>
<td>28.9</td>
<td>5%</td>
<td>30.6</td>
<td>11%</td>
<td>33.0</td>
<td>20%</td>
</tr>
<tr>
<td>Q20</td>
<td>33.0</td>
<td>34.8</td>
<td>6%</td>
<td>37.1</td>
<td>12%</td>
<td>39.7</td>
<td>20%</td>
</tr>
<tr>
<td>Q100</td>
<td>45.3</td>
<td>48.3</td>
<td>7%</td>
<td>51.9</td>
<td>15%</td>
<td>56.2</td>
<td>24%</td>
</tr>
</tbody>
</table>

Table 3.3 – OAKLAND DRIVE DISCHARGE COMPARISON

When comparing the discharges from the impervious catchment when using differing TOC (between 2 and 5 minutes) you can see how much the flow rate can potential increase with the lesser $T_C$. Comparing 2 minutes with 5 minutes for Q100 flows yields a 27% increase, which is dramatic. When comparing 3 minutes with 5 minutes for Q100 there is still a substantial increase of 17%, with difference between 4 minutes with 5 minutes being 7%. The more common rainfall events yield a significant increase although less than the Q100 event.
MENANGLE STREET, ARANA HILLS (RESIDENTIAL)

During physical testing the site at 29 Menangle Street, Arana Hills was found to have an average roof catchment $T_C$ of 2 minutes 15 which equates to a Q100 rainfall intensity difference of more than 50mm/hr (320mm/hr compared to 370mm/hr) and is a 15% increase in intensity from the 5 minute TOC intensity.

IFD data from the 2013 data set was used which is shown below:

<table>
<thead>
<tr>
<th>Duration (mins)</th>
<th>1EY (mm/hr)</th>
<th>50% AEP (mm/hour)</th>
<th>20% AEP (mm/hour)</th>
<th>10% AEP (mm/hour)</th>
<th>5% AEP (mm/hour)</th>
<th>2% AEP (mm/hour)</th>
<th>1% AEP (mm/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>156.0</td>
<td>174.0</td>
<td>240.0</td>
<td>282.0</td>
<td>324.0</td>
<td>378.0</td>
<td>414.0</td>
</tr>
<tr>
<td>2</td>
<td>129.0</td>
<td>147.0</td>
<td>198.0</td>
<td>234.0</td>
<td>270.0</td>
<td>318.0</td>
<td>354.0</td>
</tr>
<tr>
<td>3</td>
<td>122.0</td>
<td>136.0</td>
<td>186.0</td>
<td>220.0</td>
<td>252.0</td>
<td>296.0</td>
<td>330.0</td>
</tr>
<tr>
<td>4</td>
<td>115.5</td>
<td>130.5</td>
<td>177.0</td>
<td>210.0</td>
<td>240.0</td>
<td>282.0</td>
<td>313.5</td>
</tr>
<tr>
<td>5</td>
<td>111.6</td>
<td>128.0</td>
<td>170.4</td>
<td>200.4</td>
<td>230.4</td>
<td>268.8</td>
<td>297.6</td>
</tr>
</tbody>
</table>

Table 3.4 - IFD Data Menangle Street

DISCHARGE COMPARISON (L/s) – Menangle Street, Arana Hills, Impervious Catchment (227m²)

<table>
<thead>
<tr>
<th>EVENT</th>
<th>TOC 5 min</th>
<th>TOC 4 min</th>
<th>QA (TOC 4 min % &gt; TOC 5 min)</th>
<th>TOC 3 min</th>
<th>QA (TOC 3 min % &gt; TOC 5 min)</th>
<th>TOC 2 min</th>
<th>QA (TOC 2 min % &gt; TOC 5 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q10</td>
<td>11.2</td>
<td>11.7</td>
<td>5%</td>
<td>12.3</td>
<td>10%</td>
<td>13.1</td>
<td>17%</td>
</tr>
<tr>
<td>Q20</td>
<td>13.5</td>
<td>14.1</td>
<td>4%</td>
<td>14.8</td>
<td>9%</td>
<td>15.9</td>
<td>17%</td>
</tr>
<tr>
<td>Q100</td>
<td>18.7</td>
<td>19.7</td>
<td>5%</td>
<td>20.8</td>
<td>11%</td>
<td>22.3</td>
<td>19%</td>
</tr>
</tbody>
</table>

Table 3.5 – MENANGLE STREET DISCHARGE COMPARISON

Comparing 2 minutes with 5 minutes for Q100 flows yields a 19% increase, which is dramatic. When comparing 3 minutes with 5 minutes for Q100 there is still a substantial increase of 11%, with difference between 4 minutes with 5 minutes being 5%. The more common rainfall events yield a significant increase although generally less than the Q100 event.

Additional Modelled Sites

Two additional sites will be modelled, within Brisbane and Ipswich. Both have a maximum site area of 1500m² and a very high fraction impervious.
HEDLEY AVENUE, NUNDAH (MULTI UNIT RESIDENTIAL)

Appendix D shows catchment plans of the development.

<table>
<thead>
<tr>
<th>Duration (mins)</th>
<th>1EY (mm/hr)</th>
<th>50% AEP (mm/hour)</th>
<th>20% AEP (mm/hour)</th>
<th>10% AEP (mm/hour)</th>
<th>5% AEP (mm/hour)</th>
<th>2% AEP (mm/hour)</th>
<th>1% AEP (mm/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>162.0</td>
<td>180.0</td>
<td>246.0</td>
<td>288.0</td>
<td>330.0</td>
<td>384.0</td>
<td>426.0</td>
</tr>
<tr>
<td>2</td>
<td>132.0</td>
<td>150.0</td>
<td>207.0</td>
<td>243.0</td>
<td>282.0</td>
<td>333.0</td>
<td>372.0</td>
</tr>
<tr>
<td>3</td>
<td>124.0</td>
<td>142.0</td>
<td>192.0</td>
<td>228.0</td>
<td>262.0</td>
<td>310.0</td>
<td>346.0</td>
</tr>
<tr>
<td>4</td>
<td>118.5</td>
<td>135.0</td>
<td>183.0</td>
<td>216.0</td>
<td>249.0</td>
<td>292.5</td>
<td>325.5</td>
</tr>
<tr>
<td>5</td>
<td>114.0</td>
<td>128.4</td>
<td>175.2</td>
<td>206.4</td>
<td>237.6</td>
<td>277.2</td>
<td>308.4</td>
</tr>
</tbody>
</table>

Table 3.6 - IFD Hedley Avenue

<table>
<thead>
<tr>
<th>EVENT</th>
<th>TOC 5 min</th>
<th>TOC 4 min</th>
<th>QA (TOC 4 min % &gt; TOC 5 min)</th>
<th>TOC 3 min</th>
<th>QA (TOC 3 min % &gt; TOC 5 min)</th>
<th>TOC 2 min</th>
<th>QA (TOC 2 min % &gt; TOC 5 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q10</td>
<td>31.1</td>
<td>32.5</td>
<td>5%</td>
<td>34.3</td>
<td>10%</td>
<td>36.6</td>
<td>18%</td>
</tr>
<tr>
<td>Q20</td>
<td>37.6</td>
<td>39.4</td>
<td>5%</td>
<td>41.4</td>
<td>10%</td>
<td>44.6</td>
<td>19%</td>
</tr>
<tr>
<td>Q100</td>
<td>52.2</td>
<td>55.1</td>
<td>6%</td>
<td>58.6</td>
<td>12%</td>
<td>63.0</td>
<td>21%</td>
</tr>
</tbody>
</table>

Table 3.7 - HEDLEY AVE DISCHARGE COMPARISON

BRISBANE STREET, IPSWICH (COMMERCIAL DEVELOPMENT)

Appendix E shows catchment plans of the development.

<table>
<thead>
<tr>
<th>Duration (mins)</th>
<th>1EY (mm/hr)</th>
<th>50% AEP (mm/hour)</th>
<th>20% AEP (mm/hour)</th>
<th>10% AEP (mm/hour)</th>
<th>5% AEP (mm/hour)</th>
<th>2% AEP (mm/hour)</th>
<th>1% AEP (mm/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>138.0</td>
<td>156.0</td>
<td>216.0</td>
<td>258.0</td>
<td>300.0</td>
<td>348.0</td>
<td>390.0</td>
</tr>
<tr>
<td>2</td>
<td>114.0</td>
<td>129.0</td>
<td>180.0</td>
<td>213.0</td>
<td>249.0</td>
<td>297.0</td>
<td>336.0</td>
</tr>
<tr>
<td>3</td>
<td>108.0</td>
<td>122.0</td>
<td>168.0</td>
<td>200.0</td>
<td>232.0</td>
<td>276.0</td>
<td>310.0</td>
</tr>
<tr>
<td>4</td>
<td>103.5</td>
<td>117.0</td>
<td>160.5</td>
<td>192.0</td>
<td>222.0</td>
<td>262.5</td>
<td>292.5</td>
</tr>
<tr>
<td>5</td>
<td>98.4</td>
<td>111.6</td>
<td>154.8</td>
<td>183.6</td>
<td>211.2</td>
<td>249.6</td>
<td>278.4</td>
</tr>
</tbody>
</table>

Table 3.8 - IFD Brisbane Street

<table>
<thead>
<tr>
<th>EVENT</th>
<th>TOC 5 min</th>
<th>TOC 4 min</th>
<th>QA (TOC 4 min % &gt; TOC 5 min)</th>
<th>TOC 3 min</th>
<th>QA (TOC 3 min % &gt; TOC 5 min)</th>
<th>TOC 2 min</th>
<th>QA (TOC 2 min % &gt; TOC 5 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q10</td>
<td>53.6</td>
<td>56.0</td>
<td>5%</td>
<td>58.4</td>
<td>9%</td>
<td>62.2</td>
<td>16%</td>
</tr>
<tr>
<td>Q20</td>
<td>64.5</td>
<td>68.0</td>
<td>5%</td>
<td>71.1</td>
<td>10%</td>
<td>76.3</td>
<td>18%</td>
</tr>
<tr>
<td>Q100</td>
<td>91.8</td>
<td>96.5</td>
<td>5%</td>
<td>102.3</td>
<td>11%</td>
<td>110.8</td>
<td>21%</td>
</tr>
</tbody>
</table>

Table 3.9 – BRISBANE STREET DISCHARGE COMPARISON
3.5 Summary of Results

Physical Testing
After performing physical testing on the sites it is evident that high fraction impervious urban subcatchments may feasibly have a time of concentration of less than five minutes.

Sites tested resulted in $T_C$s of the following:

<table>
<thead>
<tr>
<th>Site Address</th>
<th>Catchment</th>
<th>Test Time 1 (mins)</th>
<th>Test Time 2 (mins)</th>
<th>Test Time 3 (mins)</th>
<th>Average Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 Oakland Drive, Tewantin</td>
<td>Roof (main, tailed)</td>
<td>1.50</td>
<td>1.40</td>
<td>1.38</td>
<td>1.43</td>
</tr>
<tr>
<td>29 Menagle Ave, Arana Hills</td>
<td>Roof (main, tailed)</td>
<td>2.10</td>
<td>1.50</td>
<td>1.55</td>
<td>1.72</td>
</tr>
<tr>
<td>23 Farrow Street, Mc dowall</td>
<td>Roof (garage, tailed)</td>
<td>1.50</td>
<td>1.35</td>
<td>1.36</td>
<td>1.40</td>
</tr>
</tbody>
</table>

Although all roofs were tilled they had varying slopes and varying widths to the gutter, with varying downpipe lengths to the outlet point. Results confirm that for roof catchments on residential sites the $T_C$ to the kerb and channel is feasible to be marginally less than two minutes, with the third testing site showing times as low as 1.35 minutes.

Analytical Testing
The physical testing data and the analytical data have rough correlation.

<table>
<thead>
<tr>
<th>TOTAL THEORETICAL TRAVEL TIME</th>
<th>ADDRESS</th>
<th>ROOF (min)</th>
<th>GUTTER (min)</th>
<th>PIPE (min)</th>
<th>TOTAL (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OAKLAND DR</td>
<td>1.23</td>
<td>0.42</td>
<td>0.28</td>
<td>1.93</td>
<td></td>
</tr>
<tr>
<td>MENANGLE AVE</td>
<td>1.12</td>
<td>0.29</td>
<td>0.17</td>
<td>1.58</td>
<td></td>
</tr>
<tr>
<td>FARROW ST</td>
<td>1.13</td>
<td>0.21</td>
<td>0.32</td>
<td>1.66</td>
<td></td>
</tr>
</tbody>
</table>

Rational Method
After manipulating draft IFD (2013) data and modelling the test sites, as well as multiple other sites with Rational method it is evident that:

- Heavier (more intense) rainfall occurs for storms of shorter durations
• Flows increase up to 20% for minor events when comparing 2 minute $T_c$ with the 5 minute minimum
• Flows increase up to 24% for major event (Q100) when comparing 2 minute $T_c$ with the 5 minute minimum
CHAPTER 4 - CONCLUSIONS

Understanding that the Rational Method (as described in QUDM) is used as the standard catchment discharge calculation method throughout Queensland and other states, where the $T_C$ is one of the main inputs, other inputs of the Rational Method were considered which may influence the prescribed minimum five minute $T_C$. Refer to Literature review section 2.4 for an outline of the Rational Method equation and its components.

The rainfall intensity is governed by ‘$T$’ which is the nominal design storm duration as defined by the $T_C$. Subsequently this means that for any $T_C$ the intensity (in mm/hr) must be obtained for that duration of storm.

In Australia the Bureau of Meteorology (BOM) being an Executive Agency of the Australian government is responsible for providing weather services to Australia (The Free Encyclopedia Wikipedia, 2014, February 12) and are the publisher of Intensity-Frequency-Duration (IFD) data sets that are used with design flow estimation techniques Australia wide. The IFD data is referenced heavily by Engineers Australia’s ‘Australian Rainfall and Runoff’ (ARR) document which is a national guidelines for the estimation of design flood characteristics in Australia (Australian Rainfall and Runoff, 2013)

The current IFD data set which was first published by the BOM in 1987 and then revised in 1999 is used extensively within the engineering profession for estimation of runoff rates and subsequently the responsible design of infrastructure. It is apparent when looking at the IFD 1987/1999 data that the storm durations have a minimum storm duration of five minutes, with a maximum of 72 hours. When considering a $T_C$ of less than five minutes with the Rational Method, it becomes difficult to source the associated rainfall intensity for that storm duration as it is not a part of the IFD 1987 data set.

In July 2013, as a part of a large revision of the ARR document, BOM published a new expanded data that considered a more extensive dataset, with nearly 30 years' additional rainfall data and data from 2300 extra rainfall stations and more accurate
estimates, combining contemporary statistical analyses and techniques with an expanded rainfall database (Australian Rainfall and Runoff, 2013).

Within this data set it is important to note that ‘higher resolution’ rainfall data has been supplied down to a storm duration of one minute. This has been possible because of improved gauge technology which enables the accurate recording of this level of resolution.

Data collection which involved testing impervious urban subcatchments suggests sub five minute \( T_C \) is realistic for urban sub catchments with data showing subcatchments with \( T_C \) down to 1.5 minutes.. Modelling using Rational Method has confirmed that a reduced \( T_C \) can equate to a higher catchment discharge (up to 20% larger comparing 2 to 5 minute \( T_C \)).

It is clear that because of the current findings catchment discharges have the potential to be underestimated because of assuming a minimum five (5) minute \( T_C \).

4.1 Impact of Findings

The analysed results of the physical testing data collection and software modelling suggests that low time of concentration is feasible for smaller impervious catchments and the implications are that flows at the outlet point could be larger than expected.

In ‘worst case’ circumstances the chances of considerably larger flows at the outlet point are high. These ‘worst case’ sites may have characteristics (or a combination of) such as:

- High density urban or CBD areas not larger than 1000m\(^2\)
- Sites with very high fraction impervious and negligible landscaped areas
- Well drained impervious ground surface
- Steep sites (groud surfaces and/or roof slopes)
- Sites in localities subject to potentially intense storm events
- Sites that have been already wetted by rains
If a high intensity ‘burst’ rainfall event was to occur at a site with a combination of characteristics described above then the probability of the $T_c$ for the site being less than five is high.

In hindsight, it may mean that high density urban development sites have been designed with inadequately sized drainage infrastructure at the outlet point.

### 4.2 Recommendations

The outcome of the data collection, modelling and investigation is outlined in the sections above and these conclusions suggest that current drainage guidelines which highlight a minimum time of concentration for urban catchments may not be realistic.

In this case it is suggested that Australian drainage guidelines should update their minimum time of concentration to be used in urban drainage to be one (1) minute as soon as new IDF data that includes durations down to one minute are released by the Bureau of Meteorology.

Internationally, it is recommended that developed countries should consider investing in the necessary infrastructure and studies to record high resolution rainfall data (down to 1 minute) if they have not already done so.

### 4.3 Further Work to be done

Recommended further work includes:

- Drainage design authorities to work with industry to break the stigma of minimum $T_c$ of 5 minutes which currently exists, with commentary in revised guidelines to highlight design cases that are potentially sub five minute $T_c$.
- Consideration by local councils to perform studies on piped infrastructure sizes of street drainage infrastructure especially in CBD areas or in high density areas to ensure infrastructure can handle site flows as intended (understanding contributing site flows may have a $T_c$ less than 5 minutes as originally designed for). In ‘burst’ events these pipes may be under designed.
- Consider of how on-site detention volume calculations in high density areas may have been impacted if assuming $T_c$ of 5 minutes while actual $T_c$ may have been less.
• Consider how on-site water quality devices designed for particular site flow rates (assuming a 5 minute $T_c$) may not function as intended if flows are larger than expected.
CHAPTER 5 - APPENDICES

5.1 APPENDIX A - Project Specification V4 (final)

USQ Student: Mitchell Blyth
USQ Student No: 0050056630

Project Title:
Investigation into Sub Five Minute Time of Concentration in Urban Drainage Design

Supervisor: Ian Brodie
Enrolment: ENG4111 - S1 2014
ENG4112 - S2 2014

Project Aim: Many drainage design manuals in Australia including the Queensland Urban Drainage Manual (QUDEM) specifies a minimum time of concentration as five (5) minutes. As developments within urban areas becoming increasingly compact with developed site impervious area fractions increasing, sub five minute time of concentration may need to be considered to be reality for many developments. It is my aim to investigate sub five minute Tc’s in urban areas and the comment on the impact it may have on drainage infrastructure.

Programme:
1. Research scientific papers, engineering journal articles and existing design guidelines from around the world which discuss principles of urban drainage design. Critically evaluate current published design methodology for stormwater management in Australian regions.
2. Conduct Tc test on urban subcatchments that allow adequate access and whose plumbing does not run through tanks to the legal point of discharge (kerb and channel or gully within road). Aim of this task is to prove sub five minute Tc’s are feasible and/or realistic.
3. Perform analytical modelling using Friends and Mannings equations to support the physical testing data
4. Perform runoff calculations for impervious subcatchments using industry accepted methods and software. Compare runoff values using realistic sub five minute Tc’s compared to minimum five minute Tc’s.
5. Consolidate all relevant findings into a set of suggestions for amending minimum Tc’s in currently accepted Australian drainage guidelines, and draw conclusions on how sub five minute Tc’s could impact existing drainage infrastructure and property if not acknowledged in industry.
7. Submit a finalised academic dissertation on the research.

AGREED:  

(Student)  Date: 30 / 10 / 2014

(Supervisor/s)  Date: ______________
5.2 APPENDIX A –NearMap Screenshot- Oakland Drive, Tewantin
5.3 APPENDIX B – NearMap Screenshot– Menangle Avenue, Arana Hills
5.4 APPENDIX C – NearMap Screenshot- Farrow Street, McDowall
5.5 APPENDIX D – Development – Hedley Avenue, Nundah

EXISTING SITE
DEVELOPED SITE
5.6 APPENDIX E - Development - Brisbane Street, Ipswich

EXISTING SITE
DEVELOPED SITE
CHAPTER 6 - REFERENCES


Runoff, A. R. a. 2013. *Australian Rainfall & Runoff*


