University of Southern Queensland

Faculty of Health, Engineering and Sciences

Impacts of climate change on peak design discharge of unmitigated urban catchments – a comparative analysis

A dissertation submitted by

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Abstract

For engineers and designers of critical stormwater infrastructure, peak design discharge must be appropriately modelled in order to ensure safety to person and property is upheld respectively. As it is now widely accepted that climate change is attributable to the actions of humans, the prevalence and intensity of rainfall impacts from these actions needs to be quantified in efforts to mitigate the associated risks and implications to existing and the future planning of stormwater infrastructure.

Traditional urban stormwater methodology broadly does not currently account for the unprecedented impacts of climate change. This research will seek to fill this gap providing a comparative analysis of peak design discharge (Q) using the rational method with and without climate change factors for a range of plausible scenarios. Completion of the research aims to understand the difference in peak design discharge Q for respective Annual Exceedance Probability (AEP) events and climate change scenarios to promote resilience in the future proofing of urban drainage systems. In doing so, this project will seek to understand and guide how climate change considerations will influence stormwater infrastructure requirements and the spill over effects onto Council budgets.

A series of model iterations were run for the nominated project site on an unmitigated urban catchment within the Logan City Local Government Area (LGA). Varying AEP rainfall events centred on specific planning design horizons using scaling factors derived from applicable emissions trajectories of Representative Concentration Pathway (RCP) 4.5 and 8.5 were applied. This work is guided by Book 1 of the Australian Rainfall and Runoff 2019 (ARR) and its approach to address the risks of climate change. Q values derived from modelled scenarios allow for drainage infrastructure requirements to be realised with cost comparisons for each outcome presented.

The outcomes from the modelling conducted indicated relatively minor changes in the short term and a large impact over the longer term. Specifically, when considering differences between the RCP 4.5 and RCP 8.5 scenarios, the effect on peak design discharge was observed as a function of increased rainfall intensity. These observed differences are attributable to the increased rainfall intensity as projected by RCPs as influenced by temperature variations as a result of climate change. The impact on infrastructure was realised and appeared negligible under most design scenarios however noting the outlier of the 2090 1% AEP event under RCP 8.5, which indicated a significant increase in costs associated with the additional infrastructure requirements. Nevertheless, on balance, RCP 4.5 was proved to be the optimal choice for Local Councils.

It is hoped that this research and its findings could be extended to apply to LGAs beyond Logan City to assist and guide stormwater infrastructure programs to ensure sufficient budgetary adjustments are accounted for in the forward planning for respective design horizons and inform policy decision making.

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Limitations of Use

Candidate Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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List of Abbreviations, Acronyms, Initials and Symbols

Abbreviations

I	Rainfall Intensity (mm/hr)
ICM	Interim Climate Change
Q	Peak discharge (m^3/s)
Qe	Peak discharge estimated (m^3/s)

Acronyms

AEP	Annual Exceedance Probability
AR5	Intergovernmental Panel on Climate Change Fifth Assessment Report
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff (2019)
BoM	Bureau of Meteorology
CSIRO	Commonwealth of Scientific and Industrial Research Organisation
DTMR	Department of Transport and Main Roads (QLD)
GCM	Global Climate Models
IFD	Intensity-Frequency-Duration
IPCC	Intergovernmental Panel on Climate Change
LGA	Local Government Area
NRM	Natural Resource Management
RCP	Representative Concentrated Pathway
QUDM	Queensland Urban Drainage Manual (2017)

Chapter 1 – Introduction

The role of urban stormwater management historically is best understood as a design process employed to transport stormwater (Coombes & Roso 2019). Objectives of the urban drainage system are to remove nuisance water in lower order or minor rainfall events, and to protect dwellings and properties from flood water and potential damage in major rainfall events (Coombes & Roso 2019). Management of this stormwater runoff has conventionally been completed through the use of a networked pipe and channel system with the intention of shifting flows from a respective site to a receiving environment as quickly and safely as possible (Coombes & Roso 2019). Compounding on this is the consideration for additional environmental factors specifically climate change for which Bates et al. (2015) discusses having heavy impacts on rainfall intensity.

1.1 Background and problem

1.1.1 Temperature trends

It is now well established that climate change is attributable to the actions of humans. However, while it is broadly accepted that climate change is unavoidable, uncertainty remains around how fast and on what scale the impacts of climate change will be experienced. Since the pre-industrial period, global temperatures have been increasing at an alarming rate. This point is highlighted in figure 1 below.

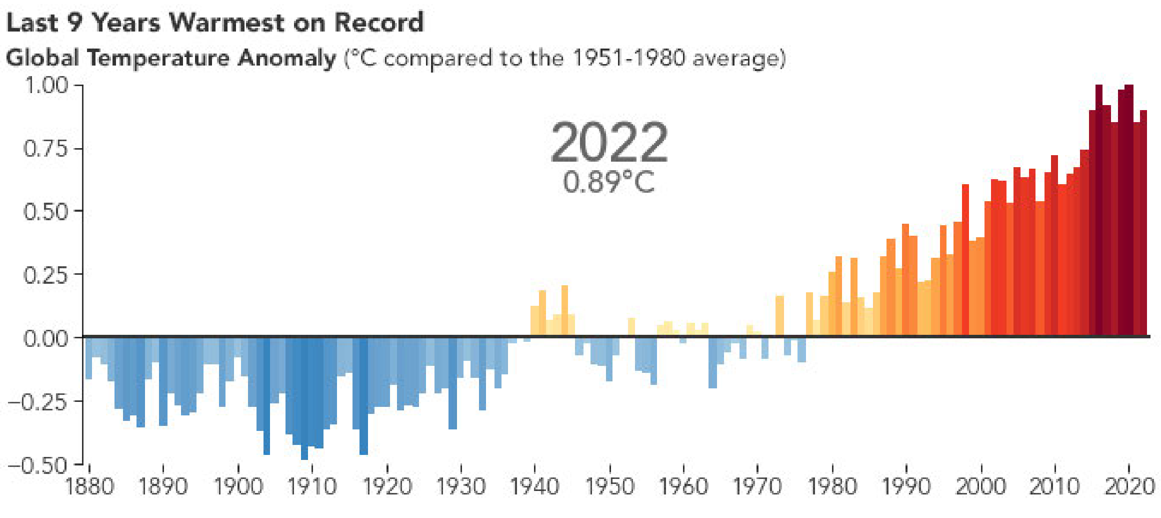

Figure 1 Global temperature anomaly increase since pre-industrial period (NASA Earth Observatory 2023)

Burton and Dredge (2007) note that there is growing support for the position that to prevent runaway positive feedback mechanisms, by 2050 global warming must be contained between 2°C – 2.4°C above pre-industrial levels. As global mean surface temperatures increase, over wet tropical regions and most mid-latitude land masses, heavy rainfall events, being those over the 95th or 99th percentile of daily rainfall, will be very likely to become more frequent and more intense at the turn of the century (Bates et al. 2015). At the top of the list, the relationship between rainfall Intensity-Frequency-Duration (IFD) is the most likely to be impacted by climate change when considering the five flood design characteristics (Ball et. al. 2019). As a result, the risk of flooding at many locations would be increased by the adverse impact of climate change on rainfall (Bates et al. 2015). Bates et al. (2015) goes on to describe a growing body of evidence indicating the increased likelihood of intense rainfall events as a result of atmospheric warming, as water vapour also increased. These extreme weather events expose infrastructure and built environments to considerable strain (Burton & Dredge 2007) and modifies their vulnerability during these events (Ennesser & Ray 2011).

1.1.2 Future pathways

Walker (2022) suggests that the emission reduction pathway chosen will impact both the rate and extent of further climate change. In response to the changing climate and uncertainty this brings, Representative Concentration Pathways (RCP) were developed by the Intergovernmental Panel on Climate Change (IPCC) in its 2013 Fifth Assessment Report (AR5) to estimate emissions projections across four possible pathways (Bates et al. 2015). Each of the four pathways predict varying levels of increased rainfall intensity depending on the amount of effort that is undertaken curb emissions.

RCPs span a range of radiative forcing scenarios that are considered plausible (Jubb, Canadell & Dix 2016) and help the climate research community in a number of ways. These scenarios are prescribed pathways for greenhouse gas and aerosol concentrations that are used to drive global climate models (GCMs). Bates et al. (2015) note that relative to pre-industrial levels, the four RCPs (RCP 8.5, RCP 6, RCP 4.5 and RCP 2.6) are characterised by the radiative forcing, the extra heat measured as watts per square metre (W/m^2) retained in the lower atmosphere due to additional greenhouse gasses (Jubb, Canadell & Dix 2016) produced by the year 2100.

Table 1 The four RCPs (Jubb et al. 2016)

Radiative forcing (W/m^2)	Atmospheric CO2 equivalent (parts per million)	When
8.5	>1370	By 2100, but rising
6	850	Stabilisation after 2100
4.5	650	Stabilisation after 2100
2.6	490	Peak before 2100 then decline

The RCP pathways presented in Table 1 above by Jubb, Canadell and Dix (2016) include a low-level forcing scenario, ambitious in its prediction of a dynamic decline of carbon dioxide from the atmosphere, two plausible stabilisation scenarios and a worst-case scenario being RCP 8.5 where little to no effort to reduce emissions is actioned representative of a failure to curb global warming by the year 2100. Figure 2 below represents how the concentrated pathways are tracking across the four scenarios.

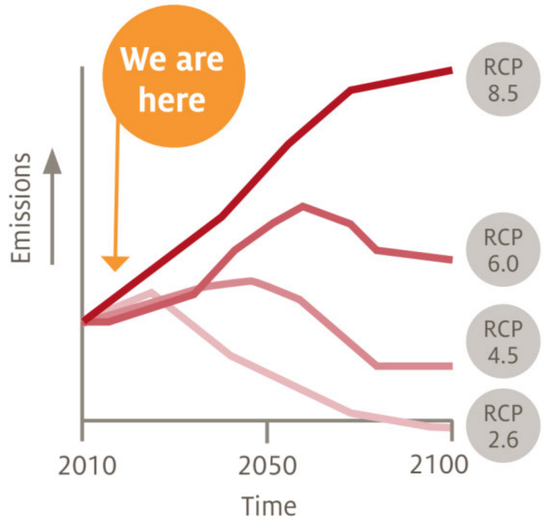

Figure 2 Emissions projections (Coast Adapt 2016)

RCPs provide more detailed and better standardised and consistent greenhouse gas concentration inputs for running climate models than those provided by any previous scenario sets. This is because the RCP scenarios explicitly explore the impact of different climate policies to assist in meeting long-term climate goals.

However, in the context of drainage requirements, while application of a specific RCP can be justified by generally supporting documentation and guidelines for an impact assessment, interpreting what should be used in practice is not so easy to accomplish. For example, in the context of planning scheme development in particular, where a developer will be called upon to design to a specific criterion for development approval, the decision-making process on which RCP to adopt cannot be left open to interpretation. RCP adoption needs to be reflective of a broader Council strategy to combat climate change.

Given the possible variance in increased rainfall intensity, it is imperative to understand how this impacts stormwater infrastructure. Ennesser and Ray (2011) argue that all road infrastructures are directly impacted by extreme climate events. The authors suggest that while economic consequences are most often observed, safety is also a primary concern. They contend that with a changing climate comes an increased vulnerability when exposed to these events. While design events are known and documented in specifying what return occurrence should be applied in the design of minor and major stormwater systems, there is little to prescriptively guide LGAs on how RCPs should be applied. As RCPs directly impact on projected increased rainfall intensity there is a need for this to be factored in the design phase to understand the impact this has on stormwater infrastructure requirements and their associated costs.

To understand the volume of water these urban drainage systems are expected disperse, and the infrastructure required to do so, it is first necessary to apply an appropriate methodology to understand relationships between the characteristics of a given catchment and a nominated rainfall input to convert run-off into an estimated peak flow (Hicks, Gray & Ball 2009). Although having its limitations, the most popular and commonly adopted method used to determine peak flow is the rational method (Goyen, Phillips & Pathiraja 2014). The method is used extensively and considered standard practice in Australia (French 2002) with its use extended throughout State and LGAs.

This project seeks to address this problem of RCP uncertainty by providing guidance on the application of RCP pathways through use of the rational mehtod to understand peak design discharge. There is clearly appetite for the application of this research as according to the ALGA (2022), local authorities are acutely aware of the significant threat posed by climate change to their community's natural environment, economy and wellbeing. Further, LGAs have been faced with declining federal funding since the 1980's (ALGA 2022). It is anticipated that this research will identify budget adjustments that may be required in responding to the challenges of climate change that these communities are facing.

1.2 Project Outline

1.2.1 Project Aim

The project aim is to undertake a comparative analysis of peak design discharge in unmitigated urban catchments with and without the inclusion of climate change factors for LGAs to consider and adopt in practice to guide planning scheme policy. The results of this assessment can be used to better understand potential implications for infrastructure expenditure and the impacts to capital works program budgets.

1.2.2 Project Objectives

The proposed project objectives will look to achieve the following:

- Understanding of the impacts climate change has on peak design discharge
- Identify which rainfall scaling approach leads to greater rainfall
- Determine infrastructure requirements and address cost implications

1.2.3 Project Justification

Understanding peak discharge is a critical component in the stormwater design process. Discharge volumes are paramount and are used to govern and quantify appropriate sizing of drainage infrastructure to adequately convey stormwater runoff. As a consequence, inaccurate discharge estimates may result in stormwater networks potentially being either under or over designed and lead to excessive expenditure on infrastructure impacting on frugal Council budgets. Engineers and designers are tasked with the design of urban stormwater systems to ensure safety to person and property is upheld (IPWEAQa 2017).

Bates et al. (2015) discuss the impact of rainfall intensity for varying AEP events, a critical component for estimating peak design discharge. This compounds the responsibility engineers and designers of stormwater infrastructure given the additional environmental factors that need to be considered. The prevalence and projected intensity of rainfall impacts need to be quantified to mitigate the associated risks and assess implications to stormwater infrastructure costs. While it is important to plan and accommodate for climate change, at the same time it is important not to be too conservative so as to not place infrastructure that caters for unlikely scenarios. With increases in rainfall contributing to significant impacts to future project capital costs and longer-term maintenance programs, the potential risks and costs cannot be disregarded. Where climate change exposure is projected to be medium to high, failure to account for hazards as a result can in turn lead to poor decision making (Ball et al 2019).

Burton and Dredge (2017) hold a position that local governments play a key role and are paramount in shifting rhetoric climate change support and acceptance into action by way of implementing scientific research into their planning schemes that guide development for which up until this point is vague and nonprescriptive. Discussed further in Chapter 2 and identified as a gap in the knowledge is the lack of direction available specifically to LGAs to prescriptively guide a climate strategy with respect to projections in increased rainfall heavily influenced by emission projections categorised as RCPs.

It is anticipated that when modelling has been completed for this research, differences between respective RCPs and design events will be conclusive in which to formulate a narrative on the direction on which Councils should follow with respect to climate change considerations. This will guide how climate change considerations influence stormwater infrastructure requirements, promote resilience in the future proofing of urban drainage systems and assist Councils to understand the spill over effects on their budgets.

1.3 Challenges for Local Government Areas

The science of climate change in constantly changing with advice updated frequently (Babister et al. 2016). As an example, one of the challenges for Councils is selecting a particular temperature window with the frequency in which data is being updated. For example, Bates et al. (2015) reports on a 2010 study completed by the Queensland Government that predicts scaled temperature increases for application that include 2°C by 2050 and 3°C by 2070. Comparatively, interim climate change factors retrieved from the ARR Datahub in 2023 indicate temperature increases of 1.3°C and 1.7°C under an RCP 4.5 scenario and 1.7°C and 2.7°C under the RCP 8.5 scenario respectively. While the above provides some context that climate change is tangible and that its associated factors need to be constantly considered, sourcing prescriptive information on RCPs, and how to apply them can prove difficult.

In addition to the application of climate change factors, the challenge for Councils is exacerbated by constrained budgets in which to allocate their resources to implement climate adaption and mitigation strategies. Over the past three decades, assistance provided to local governments in the form of Financial Assistance Grants declined to around 0.55 percent from one percent of Commonwealth taxation revenue (ALGA 2022). Councils have no direct mechanism to raise funds for infrastructure such as road and drainage construction, and collect just 3.5 percent of Australia's taxable revenue (ALGA 2022). Nevertheless, Councils are responsible for providing and maintaining this infrastructure for their communities.

It is the expected physical effects of climate change that will significantly impact on Council owned assets and investments, known as infrastructure risk (Burton & Dredge 2007), which in the long-term could be costly under already strained budgets. Council have the ability plan and mange such risks with a greater understanding of what these look like and the magnitude of the impact on their assets (HCC 2020). However considerable uncertainty exists due to a lack of research on the consequences of climate change for local areas and how to identify such risks and implement appropriate mitigation strategies (Burton & Dredge 2007).

1.4 Research benefits to Local Government Areas

There are a range of benefits to local Councils from the work of this research project. In particular, this work will provide an understanding of best practice use of RCPs for the forward planning of infrastructure requirements and relevant design horizons. It is hoped that this will in turn inform planning scheme policy with respect to the design of stormwater infrastructure to incorporate climate change factors. In addition, it will assist Councils to understand climate influenced budget impacts for contingency forecasting of master drainage programs.

Chapter 2 – Literature review

As the project's title suggests, this section will discuss what the current literature articulates on the importance of understanding peak design discharge in urban catchments with consideration given to the influence of climate change. To support this project proposal, this review will also be used to identify the need for new knowledge areas while at the same time expose any knowledge gaps that exist within the current literature.

2.1 Related studies

Studies completed early in 2023 by Michalek et al. (2023) recognise a bias towards regional modelling in the pursuit of understanding hydrologic projections with respect to the impacts of climate change. Recognising a gap in quantity of studies completed on a local scale, the authors go on the compare peak discharge projections at a local level influenced by two respective emissions scenarios of RCP 4.5 and 8.5, across 1000 communities in the US state of Iowa. The authors describe the need to complete this research in efforts to improve resiliency in both the planning and design of stormwater management systems at a local level. Similar to the approaches used in this dissertation, Michalek et al. (2023) selects a suite of global climate models to characterize potential future mid and high range emission scenarios. On application and with an emphasis on assessing annual discharge characteristics, varying discharge magnitudes are examined across three, nominal thirty-year periods from 2006 up until 2095. Predicatively, outcomes of the study found maximum discharge on average to follow emission projection trends under both RCP8.5 and RCP 4.5 scenarios complimentary to the graphic shown in Figure 2. Under RCP4.5 discharges increased initially by +6.7 declining mid-century to +3.9 before significantly reducing to +0.6% prior to the turn of the century. Under the RCP8.5 scenario, agreement was found alongside climate projections initially up until mid-century with increases of +8.1% and +10.4%, however interestingly, Michalek et al. (2023) return a reduction of -1.1% in the third term 2026-2095 period. This result does not follow congruent emission consensus where Jubb, Canadel and Dix (2016) describe the RCP 8.5 trajectory to increase all the way through to 2100 and beyond stemming from minimal effort to reduce emissions and in turn failure to curb warming. Further discrepancy in the research observed under this pathway found in the author's conclusion whereby closing statements are made nominating an increase in intensity and projected annual maximum discharge between the 2066 to 2095 period. Solace however is found within the conclusion that under RCP 4.5 the study finds discharge to stabilise in the 2036-2065 mid-century period in alignment with the respective emissions trajectory.

In a similar study, Halsnaes and Kaspersen (2018) use emissions trends influencing climate change as the factor driving increased rainfall intensity to complete a risk-based damage assessment attributed to the impact extreme precipitation events have on the urban landscape and its infrastructure, with the city of Odense in Denmark used as the case study. An emphasis is made on the increasing occurrence and losses incurred from extreme weather events calling for decision-makers to focus on climate change adaption with the need for further investment into mitigation strategies in response to limiting the vulnerability of assets. Complimentary in part to this dissertation is the authors' use of respective current,climatic conditions, 2018 in this case for

RCP 4.5 and RCP 8.5 scenarios to simulate rainfall events in a 100 year return event across three, 19 year time horizons from 2016 through to 2100 to complete their assessment. Land use characteristics for the study are described as having a low level of infiltration in the city centre resulting in higher runoff due to the impervious densely developed street scape when compared to the less developed pervious surfaces radiating out towards the city's boundaries. The software-based modelling results of rainfall under the RCP 8.5 scenario were congruent with the projections of increasing emissions of Coast Adapt's (2016) Figure 2 beyond 2100, although expectations of a reduction in rainfall under the RCP 4.5 scenario towards turn of the century (2081-2100) were not evident, with the research still tracking an increase in rainfall. Although emissions stabilisation under RCP 4.5 is expected in the lead up to the year 2100 (Jubb, Canadell & Dix 2016), the global climate models used in this literature project an increase in rainfall still during this period reflected as elevated discharge volumes. This phenomenon was also experienced in the modelling of this dissertation described further in Chapter 4.

2.2 Infrastructure inadequacies in urban environments

Correlating the discharge trends found by Michalek et al. (2023) and Halsnaes and Kaspersen (2018), Bibi and Kara (2023) confirm studies in the urban development space identifying variations in rainfall intensity impacting greatly on urban catchments appearing as flooding issues. Their works also discuss an analysis by Hassan et al. (2017) that concludes rainfall intensity variations attributable to the actions of climate change are rising as challenges to be overcome that are exposing urban catchments to increased flood risk. Following this, further reporting considered the efficiency and adequacy of stormwater drainage systems when subjected to the impacts of climate change. Bibi and Kara (2023) note studies completed in this space identifying failures and capacity insufficiencies within existing urban stormwater drainage systems to cope with increased runoff volumes stemming from climate change. In 2021, Padulano et al. (2021) through employment of GCMs in their work evaluate what impacts projected rainfall has on hydrological process when applied to the urban environment. Their results were also in agreement that stormwater management infrastructure in its current state would be unable to accommodate anticipated peak design discharge ending in increased flooding.

Bibi and Kara (2023) also discuss increased runoff as a contributing factor being experienced as a result of existing natural, previously permeable surfaces of open fields changing to impervious areas as roads and paved surfaces are constructed. Without hydrological process that includes factorization of both projected climate change conditions and urbanization combined, Akter et al. (2018) returned results in their research that this will also lead to infrastructure failure and frequent inundation. As Bibi and Kara (2023) report, urbanization and climate change are acknowledged as the two factors leading to increased runoff and in turn peak discharge that must be considered in detail during the design of stormwater management systems. The urbanization component with respect to pervious and impervious surfaces areas is factored into hydrological processes generally in the form of a defined coefficient of discharge applicable to the particular landuse characteristics of a study site or catchment. For example, in the use of the rational method, this coefficient if defined as C_y that combines a frequency factor and ten-year discharge coefficient for the required design storm which is then applied directly to the rational method equation. However, factoring of climate change is less common in practice particularly in the availability of its application with respect to prescription of an RCP scenario. Granted guidance is available and can be readily sourced, it is this absence of prescriptive advice that leaves local governments exposed and vulnerable to climate risks that may prove expensive in the long-term (The Health, Environment & Waste Branch Logan City Council (HEW) 2023).

Impacted by the relentless pressure of land development, population increase and climate change, the control of urban flooding and management of its conveyance infrastructure networks is recognised as one of the largest issues being faced by local authorities (Hassan et al 2017).

2.3 Planning guidelines and governance

Australian Rainfall and Runoff 2019 (ARR) is one such publication that does deliver guidance in the assessment of climate change with respect to flood estimation. A national guideline document of heavy influence used extensively throughout Australia in its 2019 edition, introduces recommended approaches for use by decision-makers and designers to address the risks of climate change at a project level (Bates et al. 2015). This information is relatively new as ARR's earlier version (ARR 1987) while acknowledging climate change, did not provide guidance or address how climate change should be considered (Ball et al. 2019). Described as an interim recommendation, the approaches within were delivered for inclusion in ARR 2019 following an ARR revision research project. Climate change specific research was completed as a measure to allow the factorisation of design rainfall based on temperature scaling derived from temperature projections developed by the Commonwealth of Scientific and Industrial Research Organisation (CSIRO) future climates tool (Ball et al. 2019). The two approaches (Midpoint and Datahub) offered to project climate change scaling factors are discussed in detail within Chapter 3 of this paper. These approaches are recommended under radiative concentration pathways of 4.5 as a minimum base for any design coupled with RCP 8.5 for impact assessment. The low RCP of 2.6 is dismissed in practice as associated targets and efforts required to achieve this representative emissions reduction are considered ambitious. A novel approach also captured in ARR recommends applying directly a 5% increase in rainfall (intensity or depth) for each °C of local warming. Sound in its advice in a high-level nominal approach, however it cannot be applied in isolation without consideration for a projected temperature increase for a predetermined planning horizon. It is the selection of an applicable RCP and its projected emissions trajectory that is required to accompany this approach. This guideline acts as historical interim advice as Bates et al. (2015) notes this guide was in place in the short term until further detailed information was readily available, appearing now and superseded by the recommendations of ARR 2019.

Of notable influence also particularly in the best practice design of urban drainage infrastructure in Queensland is the Queensland Urban Drainage Manual (QUDM). Sound in its description of practices to relate rainfall and runoff and its management through urban environments, there is little offered in its 2017 version with respect to guidance on how climate change should be factored prescriptively other than "Designers should consider the impact of climate change" (IPWEAQa 2017 pp. 8-2). Granted, both QUDM and its 2017 background notes do discuss the importance of factoring in climate change particularly on its effects to IFD data, other than deflecting guidance to be sourced from ARR, its literature still leaves how climate change considerations are applied to stormwater infrastructure in the hands of local authorities. The absence of guidance however may be by design providing flexibility in the selection of an approach or methodology that is best suited and applicable to their respective environments, land use conditions and in alignment with a broader climate change strategy. In fairness, the background notes do also highlight that even at a State level, Queensland's Site Planning Policy as of 2016 does not offer a detailed guide on the application of considerations to climate change (IPWEAQb 2017). Contrary to this, a 2015 Climate Change Adaption Guideline produced by the Government of South Australia (DIT 2015) although with reference to the recommendations of ARR, the guideline does set out specific RCP scenarios to be employed for respective asset design life periods. In addition, a series of climate variables are tabled including temperature increase and rainfall intensity percentage for the various South Australian regions however only under RCP 8.5.

At the local government level and at the focus of this dissertation, literature surrounding prescriptive advice was absent. A simple journal search of "*what RCP values should be used by local Councils*" did not return any articles that specifically address RCP pathways in which to pursue. A search undertaken by Burton and Dredge (2007) at both State and local Government levels across South East Queensland (SEQ) into their respective local planning policy and regulation, discovered climate risks are not adequately captured. The authors found this alarming considering the IPCC's assessment of SEQ as a region facing intensified risk to climate change sighting its aggressive urban development and geographic locations as contributing factors. This discovery is still evident in 2023 within Logan City Council's Planning Scheme, Version 8.1 for 2015 (LCC PSP), (City of Logan 2015), a planning document designed to manage growth and guide sustainable land development throughout the city returning no discussion of climate change. Upon review simple statements regarding definitions of climate change adoption and mitigation are included, however there is no guidance or discussion of key terms such as climate change or representative concentration pathways, all critical criteria for the careful consideration in the design and development assessment of stormwater infrastructure for its town planners or developers alike. In this case, this has been perceived as a gap in the knowledge for the LGA of Logan however could be extended broadly to other SEQ Local Government Areas when combined with the results of literature reviews completed by Burton and Dredge (2007) discussed earlier. Granted the LCC PSP is towards the back end of its lifecycle with LCC's PSP 2025 being prepared for release in the second half of 2024 (Logan City Council 2023), there has been opportunity to include guidance advice on how to employ and cater for climate change factors during revisions of LCC PSP 5 that have been rolled out progressively over the years. This aligns with statements made by Burton and Dredge (2007) describing LGAs as the drivers, key to transitioning scientific discourse on matters of climate change into action, although commenting that implementation at the local level is often lacking appearing fragmented in spite of growing support for adaption and mitigation strategy.

All is not lost following discovery of LCC's 2020 Climate Change Resilience policy (HCC 2020). Content of the policy described its purpose in establishing a commitment by Council to manage the associated risks of varying climate conditions. In summary, the document holds steadfast in its statements with Council's recognition of climate variability, being cognisant of the adverse impacts to community and its commitments to embedding adaption strategies throughout the organisation. However, respectful of its merit, information on how this relates to driving policy change with respect to the design of infrastructure of any kind is absent. This policy in its content aligns with discussions by Hurlimann, Bush and Cobbinah (2023) that knowledge regarding climate change is prevalent, however, further work is required to incorporate and better communicate this in practice, when it comes to policy structure.

Further research discovered early 2023 correspondence prepared by the Local Government Association of Queensland (LGAQ) to the Queensland Treasury on behalf of local Governments in response to the Treasury's calls for feedback on proposed disclosure surrounding climate-related financial risk and opportunities within Australia. In summary of the LGAQ's response, the correspondence highlights two main areas local Councils throughout Queensland are seeking. These include appropriate legislative framework and policy led by Federal and State Government for Councils to issue essential decision making and responses to climate change without excessive risk. This was followed by requests for access to consistent national data applicable locally alongside methodologies and standards developed by both Federal and State Governments ensuring climate change responses are safe, balanced and equitable (LGAQ 2023).

These two points are reflected in Logan City Council's contributions to LGAQ requesting Government to develop a set of standards for use that ensures consistency between organisations broadly, and an agreed RCP model or respective set of scenarios for employment when it comes to the analysis of climate-related risk (HEW 2023). This further supports the need for this research paper in the impacts of climate change addressing a gap in the knowledge at the local level on this topic.

In summary, this literature review returned agreements between multiple sources that climate change does influence the intensification of rainfall impacting the hydrological process presenting as increased peak design discharge in urban catchments, placing strain on its infrastructure networks. Advice in mitigating these risks was found in its offerings as guidance only throughout the Federal, State and local levels. Of this guidance and literature available, as presumed being a national guideline document, ARR returned the most comprehensive approach with regards to providing an understanding of climate change, its related RCPs, and the application of them in a methodical approach. However, as a reoccurring trend throughout, prescriptive advice on RCP adoption was absent for which this project will look to resolve. To follow is the methodology used in the practice of this research project incorporating the findings from the above literature review.

Chapter 3 – Methodology

This research seeks to determine peak discharge using rainfall IFDs influenced by climate factors for design horizons to determine infrastructure requirements. To correlate the identified climate change impacts and their effects to peak design charge in unmitigated urban catchments, a study site, base rainfall, input parameters and a suitable modelling approach needs to be selected. The two approaches provided by ARR, Midpoint and Datahub will be compared in the first instance to identify the appropriate rainfall scaling method to be carried forward for use throughout the modelling. Figure 3 below illustrates a broad outline of the methodology used for this research project.

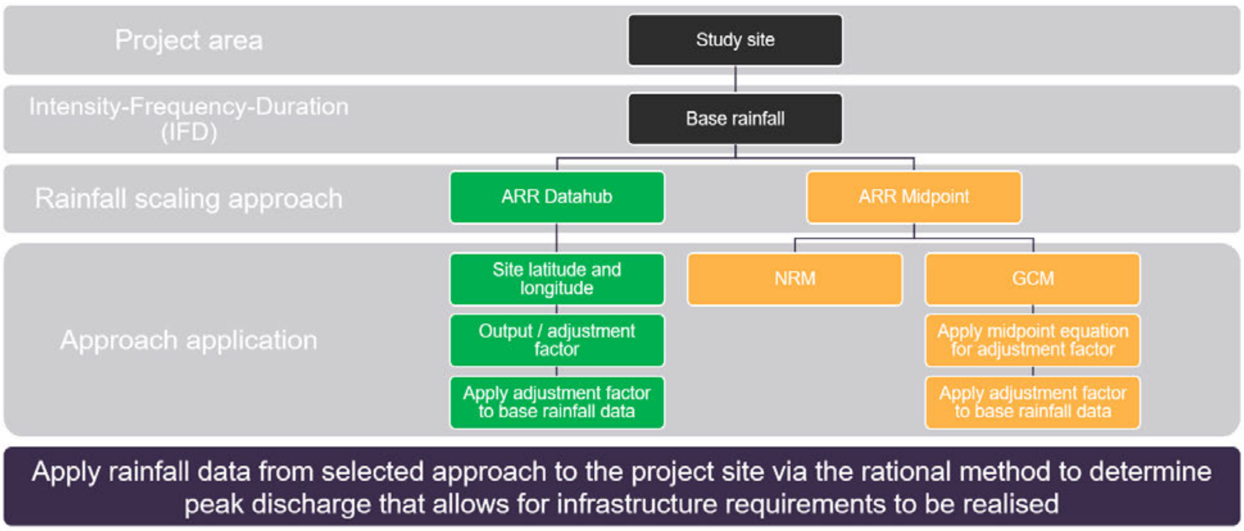

Figure 3 Research methodology

3.1 Project area

The LGA of Logan City will be used as the Project area. Logan City is described as one of the fastest growing cities in Australia of mixed land use with its Council responsible for managing approximately $6.5 billion in assets (LCC 2023). Figure 4 below indicates the city's unique positioning within the bounds of adjoining LGAs.

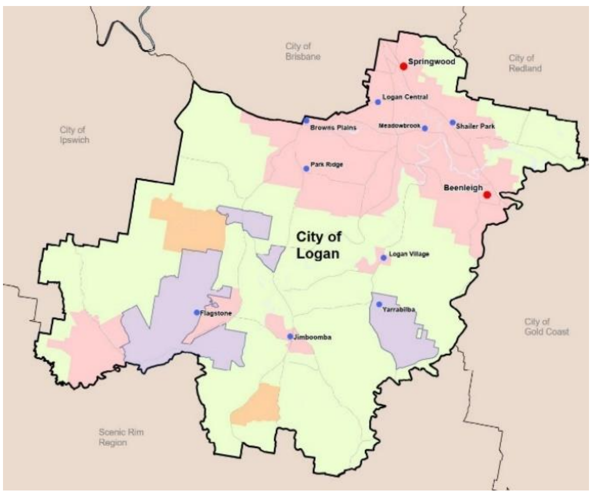

Figure 4 City of Logan (City of Logan 2015)

The study site within Logan City is located in the suburb of Shailer Park. Shailer Park is mapped as a low-density residential land use area and the analysis will take place within one of the fully developed suburban catchments. The area is best described as a suburban catchment measuring 3.44ha (34,400m^2) in area. The site selected would be an example of a typical project site that would be included for upgrade in a Councils capital works master drainage program. This design site will be subjected to the modelling scenarios discussed within this chapter. Figure 5 below shows the site location and catchment area.

Figure 5 Site Location - Shailer Park

3.2 Base rainfall and Intensity-Frequency-Duration

Essential to the design of stormwater infrastructure and the key input into a hydrologic model is the procurement of an estimated rainfall depth for a project site. In cases where rainfall data is known from empirical record, rainfall depth is identifiable and applied based on its probability of occurrence. For instances where empirical rainfall data is not available, common particularly for urban environments, a design rainfall approach needs to be employed. Design rainfall can be described as a probabilistic approach to estimate the likelihood for a specific rainfall depth to be recorded at a certain location for a defined duration classified by its annual exceedance probability (Bates et al. 2015) This designed rainfall cannot be considered real as this information has not been observed and by design is probabilistic by nature (Bates et al. 2015).

Current base rainfall data is made available on the Bureau of Meteorology’s website known as the 2016 Design Rainfalls and is based off historical rainfall data and contemporary statistical analysis superseding earlier ARR 1987 and interim 2013 datasets (BOM 2023). Outputs of this data are returned in the form of IFD tables that correlate rainfall intensity, frequency and duration characteristics for a geographical region based on its spatial coordinates. The IFD table as shown in Table 2 accompanied by its corresponding IFD curve in Appendix B indicate rainfall IFD relationships for the study site adopted in the modelling. Sound in its application for design under current climatic conditions, it is the imminent variations in climate that suggests statistical data from the past cannot be relied in the future (Ennesser & Ray 2011). To understand future variations in rainfall projections under respective greenhouse gas emissions scenarios, Babister et al. (2016) also known as RCPs an appropriate scaling method discussed in respective sections 3.5 and 3.6 must be applied for prescribed design events and horizons.

Table 2 Study site Intensity-Frequency-Duration (IFD) | Shailer Park (BOM 2023)

Copyright Commonwealth of Australia 2016 Bureau of Meteorology (ABN 92 637 533 532)								
IFD Design Rainfall Intensity (mm/h)								
Issued:	18-Aug-23							
Location Label:								
Requested coordinate:	Latitude	-27.644	Longitude	153.109				
Nearest grid cell:	Latitude	27.6375 (S)	Longitude	153.1125 (E)				
		Annual Exceedance Probability (AEP)						
Duration	Duration in min	**63.20%**	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
1 min	1	154	175	238	281	323	377	419
2 min	2	126	143	199	239	280	336	381
3 min	3	119	135	187	223	260	311	350
4 min	4	114	129	178	211	245	290	326
5 min	5	109	124	170	201	232	274	305
6 min	6	105	119	163	192	221	259	288
7 min	7	101	115	156	184	211	247	274
8 min	8	97.3	110	150	177	202	236	261
9 min	9	93.8	106	144	170	194	226	250
10 min	10	90.4	102	139	164	187	217	240
11 min	11	87.3	98.8	134	158	180	209	231
12 min	12	84.4	95.5	130	152	174	202	223
13 min	13	81.6	92.4	126	147	168	195	216
14 min	14	79.1	89.5	122	143	163	189	209
15 min	15	76.7	86.8	118	138	158	184	203
20 min	20	66.6	75.4	103	121	138	161	178
25 min	25	59	66.9	91.2	107	123	144	159
30 min	30	53.1	60.2	82.2	97.1	112	131	145
45 min	45	41.3	46.8	64.4	76.5	88.4	104	117
60 min	60	34.1	38.8	53.6	63.9	74.3	88.3	99.3
90 min	90	25.9	29.5	41.1	49.3	57.7	69.2	78.4
120 min	120	21.3	24.2	34	40.9	48.1	58	66

3.3 Design event

In most cases, infrastructure design is undertaken based on set regulation or an authority's planning policy (Ennesser & Ray 2011). Used interchangeably in practice during infrastructure design, a design event and AEP event can be described as the correlation of design rainfall for a design scenario. Logan City's planning scheme in the context of stormwater network design, calls for networks to be adequately designed for the conveyance of major and minor events in accordance with QUDM as its desired level of service (City of Logan 2015).

IPWEAQ (2017) recommends that a 10% AEP is utilised for the design of a minor system in urban residential high-density areas which is defined as greater than 20 dwellings per hectare. Similarly, major systems are to be designed using a 1% AEP. Minor events are described in QUDM as having flows conveyed through the stormwater drainage system restricting flow widths along kerb and channel to prescribed distances to ensure pedestrian and vehicle access is maintained without nuisance during said event. Major events utilise also the stormwater drainage system with the additional allowance of using the full road reserve to convey flows. This is under the provision that a prescribed minimum freeboard is maintained and that all flows are retained within the road reserve or a defined overland flow path not exceeding a governing flow velocity so as to ensure protection to person and property is upheld. On this basis and meeting LCC's policy requirements the recommendations of QUDM, the research that follows will apply a 10% AEP for the minor event and 1% AEP for the major event.

3.4 Design horizon and infrastructure lifespan requirements

On the selection of a design event, consideration needs to go into the design horizon for which the design event is taking place. In addition, considerable thought is required on the designed asset's lifespan. For this research in addition to current year, two additional design horizons have been selected for years 2040 and 2090 in which to determine peak discharge with and without the impacts of climate change.

Bates et al. (2019) recommend climate change impacts are assessed at a minimum of 20 years from the current year as a period shorter than will have limited influence to IFD tables, which in this paper will be reflected as the interim 2040 year. With consideration given to the planning horizon for major urban infrastructure shown in Figure 6, and a service lifespan of these assets recommended by Bates et al. (2015) in Figure 7, 2090 has been selected 50 years on from the 2040 interim year as the second and long-term design horizon adopted for this study.

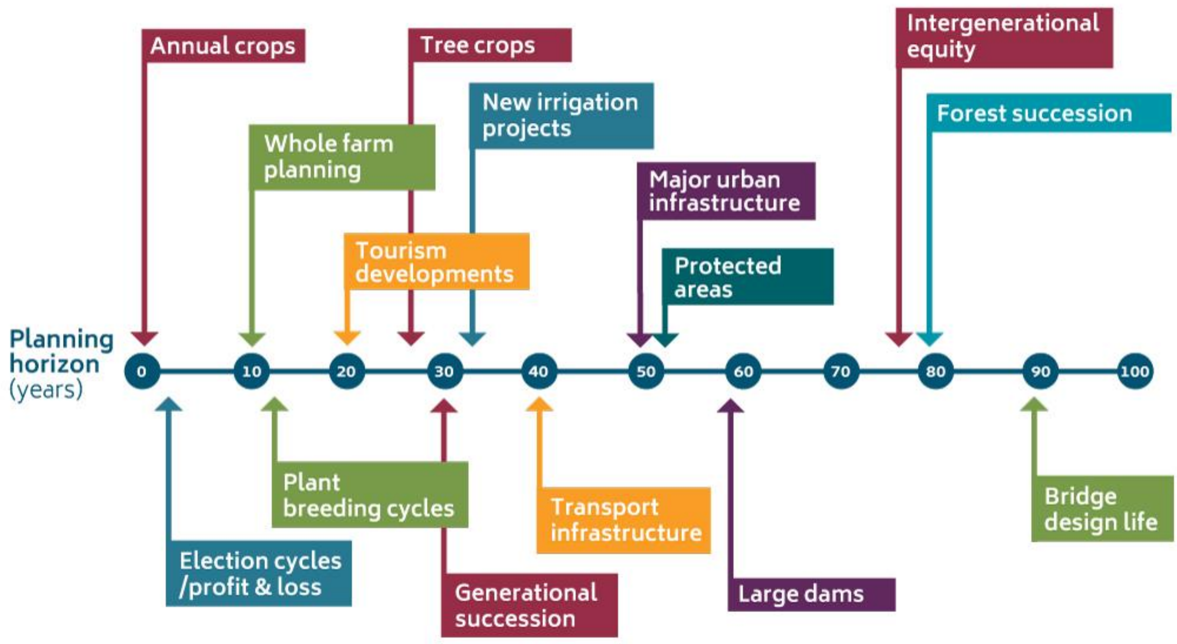

Figure 6 Typical planning horizon (years) for different sectors (Coast adapt 2017)

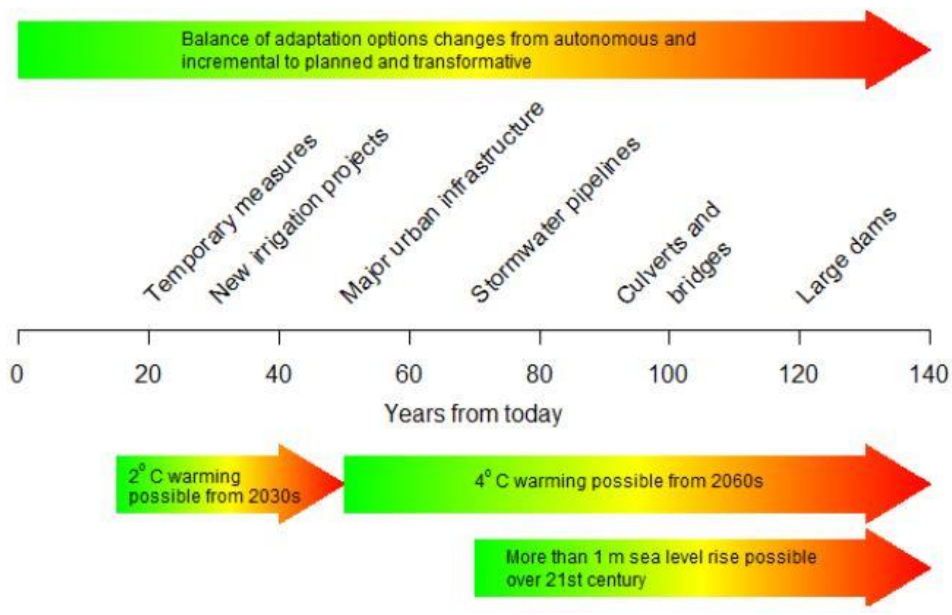

Figure 7 Indicative design service life of assets (Bates et al. 2015)

3.5 RCP selection

Introduced earlier in this paper were the representative concertation pathways announced by the IPCC to guide developing climate change scenarios. ARR recommends the use of RCP 4.5 and where of grounds of environmental and socioeconomic benefit RCP 8.5 for impact assessment (Ball et. al. 2019). On this advice and to broaden the datasets for comparative assessments both will be employed with RCP 8.5 representative of a worst-case scenario in the event global greenhouse gas emission continue on their current trajectory (Halsnaes & Kaspersen 2018). In support of ARR's RCP 4.5 recommendation, Hassan et al. (2017) are in agreement of adoption describing this pathway as the likely future representation particularly in the space of planning for local administrators. This based on the agreements made at 2015 and 2016 United Nation Climate Change Conference proceedings (COP21 and 2022) formally captured in a legally binding international treaty on climate change known as the Paris Agreement, to limit global temperature increase between 1.5-2°C closet to the scenario laid out by RCP 4.5.

Further support on the likelihood of RCP 4.5 being achieved is to be considered with respect to the actions proposed by the Australian Government under its net zero initiative. In a global effort, this initiative under a series of decarbonisation plans and strategies targets Australia's greenhouse gas emission to achieve net zero by 2050 honouring international commitments and party to the Paris Agreement (Department of Climate Change, Energy the Environment and Water (DCCEEW) 2023). This achievement would complement emissions trajectories suggested by Coast Adapt (2016) under RCP 4.5 illustrating a global emissions peak prior to 2050 and then falling before a year 2100 stabilisation as show in Figure 2. With the above as reference, RCP 8.5 is considered sound for impact assessment however could be considered excessive and a conservative pathway in which to mandate at a local level for design purposes.

3.6 Rainfall scaling approach

It is here that variation in climate change scaling factors need to be understood in which to apply to sourced IFD values. For the purposes of this project, both the ARR Midpoint and ARR Datahub approaches will be employed as a comparison in the first instance in this section to deliver a projected rainfall intensity (I_P) via scaling factors that incorporate the effects of climate change. Realising these scaling factors for the Midpoint approach will be achieved with the use of Equation 1 and the GCM consensus of the Natural Resource Management Cluster (NRM) - East Coast Cluster shown in Table 3. The Datahub approach will rely on Equation 2 and the data retrieved directly from the ARR Datahub website. These processes along with their outputs are described further below.

3.6.1 ARR Midpoint approach

For the Midpoint approach, first a temperature midpoint (T_m) for respective consensus temperature class intervals is to be calculated. This is completed first by considering the applicable NRM for where the site is located. NRMs are regions across Australia selected for their geographical location and biophysical attributes

(Dowdy et al 2015) with this project's study site being located within the East Coast Cluster as shown in Figure 8 below.

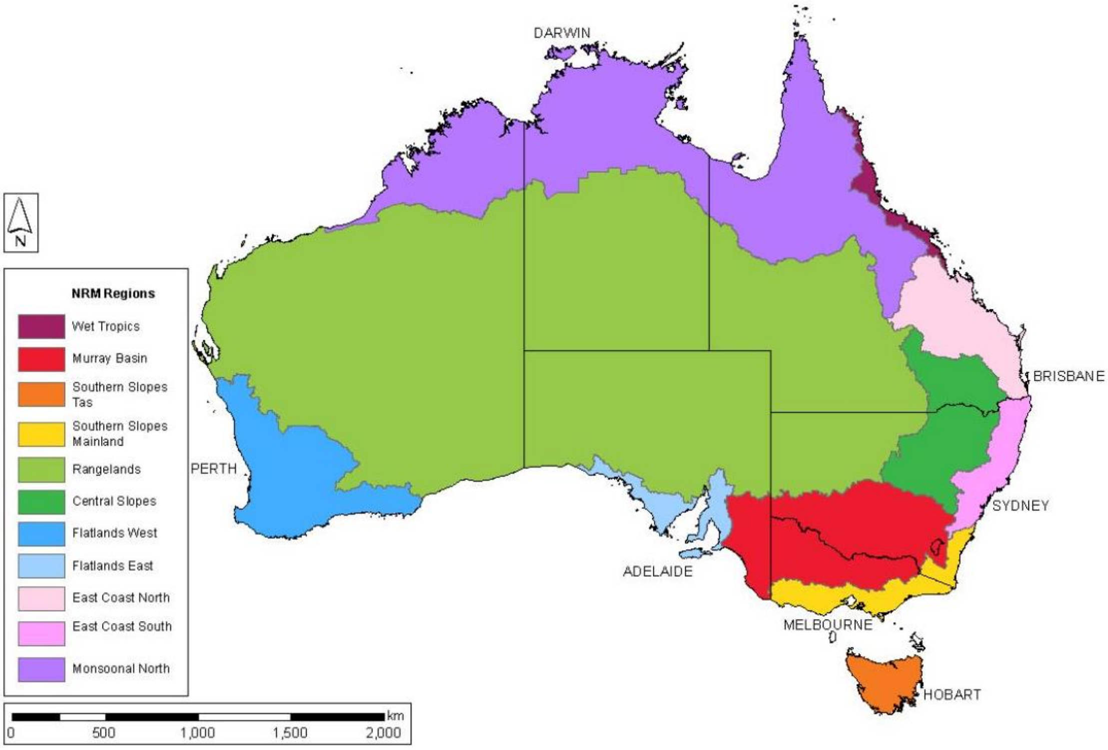

Figure 8 Natural Resource Management Location Clusters (Ball et al. 2019)

Following selection of an applicable NRM the corresponding GCM consensus shown in Table 3 is consulted to determine consensus or agreement in the likelihood of one of four temperature class intervals being experienced for the respective year and corresponding RCP.

Table 3 GCM Consensus for Natural Resource Management - East Coast Cluster (Ball et al. 2019)

Temperature Class Interval (°C)				
	Slightly warmer	**Warmer**	**Hotter**	**Much hotter**
Year	< 0.5	0.5 to 1.5	1.5 to 3.0	> 3.0, (median)
RCP 4.5 and 40 GCMs				
2040		36	4	
2050		30	10	
2060		18	22	
2070		17	23	
2080		14	26	
2090		12	28	
RCP 8.5 and 42 GCMs				
2040		28	14	
2050		12	30	
2060		1	39	2 (3.1)
2070			26	16 (3.3)
2080			16	26 (3.6)
2090			10	32 (4.1)

Following this a temperature midpoint (T_m) for the respective consensus temperature class interval is calculated with the outcomes of this below in Table 4.

Table 4 Temperature midpoints

	RCP 4.5		RCP 8.5	
Planning Horizon	Temperature class interval (°C)			
	Warmer 0.5 to 1.5	Hotter 1.5 to 3.0	Warmer 0.5 to 1.5	Much hotter >3.0, (median)
2040	$T_m = 1$		$T_m = 1$	
2090		$T_m = 2.25$		$T_m = 4.1$

Substitution of the above calculated midpoints into Equation 1 returns the rainfall intensity scaling factor shown below in Table 5 that will generate projected rainfall intensity using this approach.

Midpoint equation

$$I_p = I_{ARR} \times 1.05^{T_m}$$

[Equation 1]

Described as:

I_p	=	projected rainfall intensity (mm/h)
I_{ARR}	=	design rainfall intensity (mm/hr) for current climate conditions
T_m	=	temperature midpoint of a selected class interval
1.05	=	assumed temperature scaling based on the approximately exponential relationship between temperature and humidity

(Ball et al. 2019)

Table 5 Scaling factors for projected rainfall intensity – ARR Midpoint approach

Design Horizon	RCP 4.5	RCP 8.5
2040	$I_p = I_{ARR} 1.05$	$I_p = I_{ARR} 1.05$
2090	$I_p = I_{ARR} 1.12$	$I_p = I_{ARR} 1.22$

3.6.2 ARR Datahub approach

The online Datahub provides 10 commonly used design inputs which can be extracted for a series of outputs. Relevant to this research is the data generated on interim climate change factors. Simple in its use, the Datahub requires only selection of a desired output following the nomination of spatial coordinates over a specific project site. This approach was considered progressive in its design allowing designers and engineers alike to access data from a single location containing the most up to date information, which is particularly important when considering the frequency on which the data is updated (Babister et al. 2016).

Extracted from the ARR Datahub, Table 6 below demonstrates projected temperature increases and percentage increase in rainfall respectively for a suite of forecast years and respective RCP scenarios for the study site over Shailer Park.

Table 6 Interim Climate Change factors – Shailer Park (ARR 2023)

Interim Climate Change Factors			
Horizon	**RCP 4.5**	**RCP 6**	**RCP 8.5**
2030	0.869 (4.3%)	0.783 (3.9%)	0.983 (4.9%)
2040	1.057 (5.3%)	1.014 (5.1%)	1.349 (6.8%)
2050	1.272 (6.4%)	1.236 (6.2%)	1.773 (9.0%)
2060	1.488 (7.5%)	1.458 (7.4%)	2.237 (11.5%)
2070	1.676 (8.5%)	1.691 (8.6%)	2.722 (14.2%)
2080	1.810 (9.2%)	1.944 (9.9%)	3.209 (16.9%)
2090	1.862 (9.5%)	2.227 (11.5%)	3.679 (19.7%)

Although comparable in its approach, using the ARR Datahub, there is no need to calculate a midpoint with the above factors being applied directly into Equation 2 below to give a projected rainfall intensity. Table 7 demonstrates this application with respect to the interim climate change factors for the study site.

Datahub equation

$$I_p = I_{ARR} \times ICCF$$

[Equation 2]

I_p	=	projected rainfall intensity (mm/h)
I_{ARR}	=	design rainfall intensity (mm/hr) for current climate conditions
$ICCF$	=	interim climate change factor

Table 7 Scaling factors for projected rainfall intensity – ARR Datahub approach

Design Horizon	RCP 4.5	RCP 8.5
2040	$I_p = I_{ARR}1.053$	$I_p = I_{ARR}1.068$
2090	$I_p = I_{ARR}1.095$	$I_p = I_{ARR}1.197$

The projected rainfall intensity I_p as determined in Tables 5 or 7 depending on the ultimate approach selected is then substituted into the rational method formula shown as Equation 3 in Section 3.7 allowing peak design discharge to be realised.

3.7 Hydrologic method

Understanding climate change, its projected temperature increases, RCPs and impacts to rainfall is sound from a theoretical perspective however it is the relationships between this data and the available hydrological methods that correlates this phenomenon allowing peak discharge throughout a catchment or study site to be realised. For this project, the rational method will be adopted to translate rainfall to a peak design discharge volume Q with consideration of respective climate change factors, design scenarios and catchment characteristics.

Originating in the 19th century, the rational method is a popular approach to estimate peak stormwater discharge as generated by constant rainfall rate onto a catchment over a period of time (Coombes, Babister & McAllister 2015). According to the literature, while there are a number of methods that can be applied in estimating rainfall run-off, the rational method is likely to be used most often in estimating peak flood flows with its popularity stemming from the ability to apply simple hand calculations (Goyen, Phillips & Pathiraja 2014). The rational method relies on a relationship between a time of concentration for stormwater flow and a run-off coefficient. This determines the events averaged rainfall intensity which are expected to jointly account for rainfall run-off variations and characteristics of the subject catchment (Coombes, Babister & McAllister 2015).

The standard form of the rational method used throughout the civil industry is as follows as presented within the Queensland Urban Drainage Manual.

$$Q_y = \frac{C_y . {}^t I_y . A}{360}$$

[Equation 3]

Described as:

Q_y	=	peak flow rate (m3/s) for annual exceedance probability (AEP) in 'y' years
C_y	=	coefficient of discharge (dimensionless) for AEP of 1 in 'y' years
A	=	area of catchment (ha)
tI_y	=	average rainfall intensity (mm/h) for a design duration of 't' hours and an AEP of 1 in 'y' years
t	=	the nominal design storm duration as defined by the time of concentration t_c
360	=	unit conversion factor applicable to the units used

(IPWEAQ 2017)

With urban development and climate change, the size and frequency of urban flooding is increasing calling for the requirement of local measures to assist in mitigating the extent of these impacts. A more realistic representation of actual surface flow can be identified via the use of coupled 1D/2D models. Together, this has significantly contributed to their common use in understanding urban flow and expanded their application to the urban flood modelling space (Davidsen et al. 2017). This position is supported by Fan et al. (2017) where it is acknowledged 2D should ideally be utilised for flow modelling in urban environments. With strengths in predicting volumes through a drainage system stemming from the 1D model and 2D modelling providing the capability to simulate flow across a ground surface, the coupling of these is a considered a necessity to accurately understand interactions between pipe and surface through urban catchments (Fan et al. 2017). Although the above supports the use of computer-based modelling, these methods are complex and require the employment of sophisticated computer software.

In support of non-computer-based models, Coombes and Roso (2019) suggests common modelling approaches that can be used to model urban runoff outlining to users methods that may be considered for use dependent on, and to compliment a design tasks' performance objectives and intent. Support for the rational method in its intent for this study is further described in IPWEAQ (2017) where the method is considered appropriate for the design of LGA drainage systems where resources required to create complex, comprehensive computer models are absent. Table 8 below is an extract from book 9 of the ARR 2019 that captures urban model types, their design intent focus, hydrology in this instance and the model type's respective capability.

Table 8 Common types of Urban Models (Ball et al. 2019)

Focus	Urban Model Type	Estimation Capabilities (also refer Table 9.6.2)				Example Model Platforms (where relevant)
		Runoff Generation and Surface Routing	Channel and Storage Routing	Structure Hydraulics	Other specific capabilities or limitations	
Hydrology	Rational Method	Limited	None	None	Peak flow only – scalar quantity, single lumped catchment, requires 'Time of Concentration' assumption, only suitable for small catchments. It has best capabilities where there is no storage present.	RATHGL, PCdrain
Hydrology	Time Area Method, Extended Rational Method	Moderate	None	None	Suitable for small catchments only. Can be extended as a collection of linked sub-catchments.	ILSAX, DRAINS
Hydrology	Runoff Routing	Strong	Moderate	Limited	Full event hydrograph, empirically derived lag parameters, non-linear routing capabilities. Structure hydraulics can be moderately capable for discrete structures but not for continuous conveyance networks.	RORB, RAFTS, WBNM, URBS, HEC-HMS
Hydrology	Continuous Simulation	Strong	Moderate	Limited	Continuous multi-year runoff sequence, comprehensive infiltration loss models. Limited capability for rare to very rare floods unless utilised with replicates of conditioned synthetic continuous rainfall (such as DRIP)	XP-RAFTS, MUSIC, PURRS, Systems Framework

As per the table above, ARR is in agreement that the rational method is a suitable method capable of predicting peak flow Q in unmitigated urban environments and as such will be used in this research.

3.8 Model parameters

For the purpose of this research, governing parameters for the rational method will be adopted from the 2017 version of QUDM to undertake respective modelling scenarios. Details of these parameters that address frequency factors, fraction impervious coefficients for respective development categories and standard inlet times of concentration are captured in Appendix D of this report. These parameters were applied across the site for use in the project's hydrologic method.

3.9 Application of hydrologic method

To understand the hydrological impacts climate change has on the study site, design models were created for respective design events as documented in Section 4.2. To begin modelling, first sub-catchments for the project site were defined to understand the rainfall flow paths through the site and likely placement of gully pits. Figure 9 below indicates two sub-catchment layouts that were used during the design modelling. Due to the significant peak discharge experienced in the RCP 8.5 2090 1% AEP discussed in Chapter 4, a separate sub-catchment layout was created to cater for its respective flows that otherwise could not be catered for in the sub-catchment developed for all other events. A full suite of sub-catchments layouts are provided in Appendix C.

Figure 9 Project catchments

Taking advantage of the rational method's ability to be implemented through simple calculation methods, a spreadsheeting tool was developed to correlate site runoff coefficients, rainfall intensity, surface and pipe flow. Input details and resultant outputs are shown in Appendix E. In a similar approach, gully capture charts were applied to the surface flows of each sub-catchment for inlet type, capture and bypass rates to be realised. Alongside this process, spreadsheeting was used to determine pipe flow capacity and size guided by QUDM's governing pipe flow requirements. Examples of both gully capture and pipe flow calculations are shown in

Appendices F and G. Through application of the above hydrologic method, peak discharge *Q* was realised for all of the modelled design scenarios along with their respective drainage infrastructure requirements to inform cost estimates.

3.10 Estimates

On conclusion of hydrologic modelling, infrastructure requirements for each design scenario needed to be reconciled in which to identify projected costs. To do this, itemised estimates were undertaken documenting infrastructure requirements tabled under a bill of quantities with the costs for each item assigned accordingly. This was completed for the current year, and design horizons 2040 and 2090 under respective RCP scenarios. Appearing in Appendix H, each of the estimates were condensed to include only the supply and placement of required infrastructure on site. Consideration was given to including other such factors of kerb and channel replacement, ancillary road and pavement works however variation is these items for design scenarios were minimal and considered the same for all design scenarios, and as such were omitted from design estimates.

Chapter 4 – Results and discussion

In this chapter the results of scaling factor approaches and comparisons of the respective outcomes are considered. Following this, justification of the selected approach is discussed and peak design discharge results with and without the inclusion of climate change factors are presented. With this information, infrastructure requirements and applicable costs are determined. Observations of the implications for local Councils are identified and the chapter concludes by acknowledging limitations of this research project.

4.1 Scaling factor application to IFDs

Results of the scaling factors when applied to current base rainfall are reflected in Tables 9 and 10 below.
The initial hypothesis prior to application of RCP scenarios was for the projected rainfall to increase significantly across all events under each scenario. However, this was not reflected broadly in the results. Under the 10% AEP design event where there were only minor increases to rainfall intensity observed under both midpoint and Datahub scaling approaches across both RCPs and the 2040 design horizon. Although, rainfall intensity did increase moreso under each RCP for the 2090 design horizon. With respect to the 1% AEP design event, similarly the 2040 design horizon did not present significant increases in rainfall intensity under either RCP. However, under the 2090 design horizon, in particular under RCP 8.5 significant increases were observed attributable to the scaling factors calculated for those prescribed.

Table 9 Projected rainfall intensities – ARR Midpoint approach

	ARR Midpoint approach									
	AEP 10% - Minor Event					AEP 1% - Major Event				
mm/hr		RCP 4.5		RCP 8.5			RCP 4.5		RCP 8.5	
		Design Horizon					Design Horizon			
Duration (mins)	2023	2040	2090	2040	2090	2023	2040	2090	2040	2090
1	281	295	314	295	343	419	440	468	440	512
2	239	251	267	251	292	381	400	425	400	465
3	223	234	249	234	272	350	368	391	368	428
4	211	222	235	222	258	326	342	364	342	398
5	201	211	224	211	246	305	320	340	320	373
6	192	202	214	202	235	288	302	321	302	352
7	184	193	205	193	225	274	288	306	288	335
8	177	186	198	186	216	261	274	291	274	319
9	170	179	190	179	208	250	263	279	263	305
10	164	172	183	172	200	240	252	268	252	293
11	158	166	176	166	193	231	243	258	243	282
12	152	160	170	160	186	223	234	249	234	272
13	147	154	164	154	180	216	227	241	227	264
14	143	150	160	150	175	209	219	233	219	255
15	138	145	154	145	169	203	213	227	213	248
20	121	127	135	127	148	178	187	199	187	217
25	107	112	119	112	131	159	167	177	167	194
30	97.1	102	108	102	119	145	152	162	152	177
45	76.5	80	85	80	93	117	123	131	123	143
60	63.9	67	71	67	78	99.3	104	111	104	121
90	49.3	52	55	52	60	78.4	82	87	82	96
120	40.9	43	46	43	50	66	69	74	69	81

Table 10 Projected rainfall intensities – ARR Datahub approach

	ARR Datahub approach									
	AEP 10% - Minor Event					AEP 1% - Major Event				
mm/hr		RCP 4.5		RCP 8.5			RCP 4.5		RCP 8.5	
		Design Horizon					Design Horizon			
Duration (mins)	2023	2040	2090	2040	2090	2023	2040	2090	2040	2090
1	281	296	308	300	336	419	441	459	447	502
2	239	252	262	255	286	381	401	417	407	456
3	223	235	244	238	267	350	369	383	374	419
4	211	222	231	225	253	326	343	357	348	390
5	201	212	220	215	241	305	321	334	326	365
6	192	202	210	205	230	288	303	315	308	345
7	184	194	201	197	220	274	289	300	293	328
8	177	186	194	189	212	261	275	286	279	312
9	170	179	186	182	203	250	263	274	267	299
10	164	173	180	175	196	240	253	263	256	287
11	158	166	173	169	189	231	243	253	247	277
12	152	160	166	162	182	223	235	244	238	267
13	147	155	161	157	176	216	227	237	231	259
14	143	151	157	153	171	209	220	229	223	250
15	138	145	151	147	165	203	214	222	217	243
20	121	127	132	129	145	178	187	195	190	213
25	107	113	117	114	128	159	167	174	170	190
30	97.1	102	106	104	116	145	153	159	155	174
45	76.5	81	84	82	92	117	123	128	125	140
60	63.9	67	70	68	76	99.3	105	109	106	119
90	49.3	52	54	53	59	78.4	83	86	84	94
120	40.9	43	45	44	49	66	69	72	70	79

As a reference tool and for comparison check purposes, Tables 11 and 12 have been prepared reflecting 60-minute duration rainfall IFD values from the base current year IFD table, subject ARR midpoint and Datahub approaches and reference QLD Future climate dashboard outputs under the RCP 4.5 scenario for 1% AEP and 10% AEP design events respectively. Predictively, the IFD values against the base IFD rainfall increased, however it was pleasing to see congruent results in IFD values for each ARR approach alongside an alternative reference method of rainfall intensity projection. This alternative approach uses temperature projections from the Queensland Futures climate dashboard website and ARR's now superseded interim rainfall scaling factor which was discussed earlier in Chapter 2.

Table 11 Rainfall intensity comparisons between various approaches under a 1% AEP RCP 4.5 scenario

RCP 4.5 | 60-minute duration	Design Horizon		
	Current	2040	2090
BOM IFD Base	97	-	-
ARR Midpoint	-	104	111
ARR Datahub	-	105	109
Reference approach			
QLD Future climate dashboard	-	105[1.15]	109[2]
[ ] denotes respective increase in temperature (°) value applied based on ARR recommendation of a 5% increase in rainfall (mm/hr) for each 1° change in temperature			

Table 12 Rainfall intensity comparisons between various approaches under a 10% AEP RCP 4.5 scenario

RCP 4.5 | 60-minute duration	Design Horizon		
	Current	2040	2090
BOM IFD Base	63	-	-
ARR Midpoint	-	67	71
ARR Datahub	-	67	70
Reference approach			
QLD Future climate dashboard	-	68[1.15]	70[2]
[ ] denotes respective increase in temperature (°) value applied based on ARR recommendation of a 5% increase in rainfall (mm/hr) for each 1° change in temperature			

4.1.1 Adopted approach justification

Analysis of the IFD values derived from respective ARR approaches detailed above offer agreement under the selected scenarios and design horizons. From this, the ARR Datahub IFD data was selected to be taken through into modelling activities as this was considered to be the optimal method as it uses the most relevant up to date information available. Consideration was given to the ARR midpoint approach where although having merit, the criteria used in its calculation and GCM consensus tables on which it is based are derived from ARR guides published in 2019. As described earlier in this research, the advice on temperature increases is constantly evolving and therefore the midpoint approach in its calculation is not reflective of the most up to date data when compared to the Datahub which is updated frequently.

To further support the selection of the Datahub approach for this research and the validity of the data being used, Babister et al. (2016) offers comment on the intent of the Datahub being a single point source as a tool that is updated frequently with the latest information available at the time of access. The authors go on to discuss use of the Datahub as a mitigating factor for design error when practitioners are sourcing design inputs which in the past may have been procured from outdated publications.

4.2 Peak design discharge

To understand the hydrological impacts climate change factors have on the study site in which to draw comparison, design models were created for each of the modelled scenarios. Table 13 and Figure 10 present the results of peak design discharge estimates for respective AEP events, RCPs and design horizons. These outputs are detailed further in Appendix E where full calculation tables are provided.

Table 13 Peak design discharge Q (m3/s) increase comparisons (%) for modelled scenarios

	Current year	2040	2040	2090	2090
	Q (m^3/s)	*Q (m^3/s)*	*% increase*	*Q (m^3/s)*	*% increase*
			RCP 4.5		
10% AEP	1.527	1.625	***6.4***	1.692	***10.8***
1% AEP	2.610	2.748	***5.3***	2.860	***9.6***
			RCP 8.5		
10% AEP	1.527	1.650	***8.1***	1.849	***21.1***
1% AEP	2.610	2.790	***7.0***	3.144	***20.5***

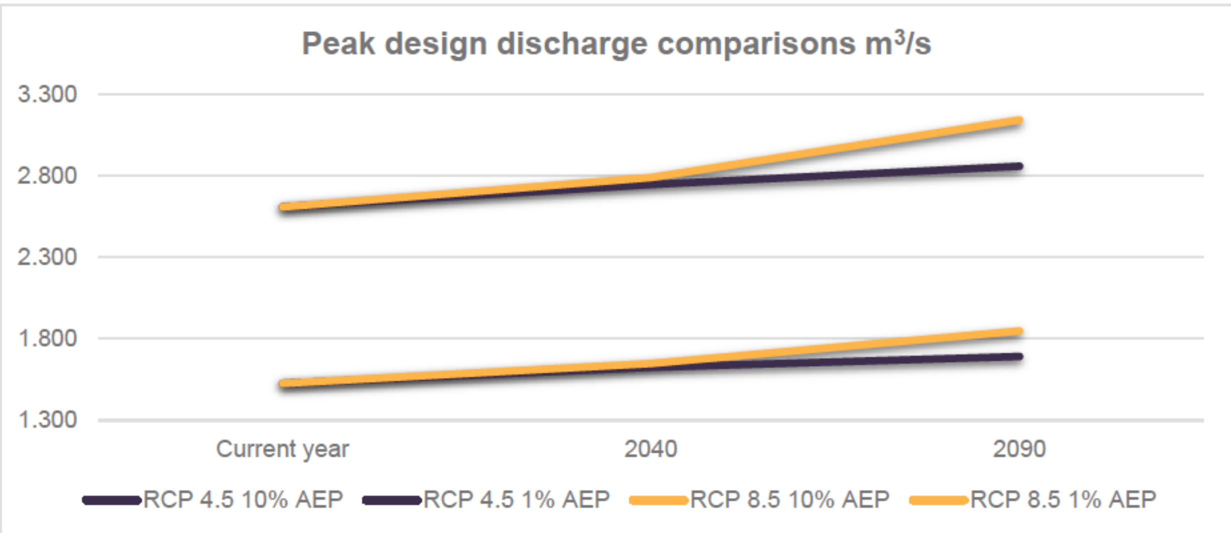

Figure 10 Peak design discharge Q (m3/s) comparisons for modelled scenarios

Under RCP 4.5 in both 10% and 1% AEP events, relatively minor discharge increases were observed over the current year discharge in the 2040 design horizon. However, more significant increases were observed under the 2090 design horizon under RCP 8.5. Marginally higher increases were observed under the 2040 design horizon for this RCP. However, as a percentage almost double the increase was observed in the 2090 design horizon under RCP 8.5 when compared to the RCP 4.5 scenario.

The outcome of this modelling shows relatively little change in the short term but predictably a large impact over the longer term particularly when considering differences between the RCP 4.5 and RCP 8.5 scenarios. The effect on peak design discharge is a function of the increased rainfall intensity projected by adoption of one RCP over another. Differences are explained by the increased rainfall intensity as projected by RCP influenced by temperature increase as a result of climate change

4.3 Infrastructure requirements and costs

To inform infrastructure requirements and costs, design estimates were completed for each of the modelled scenarios found in Appendix G, Table 14 and Figure 11 providing a summary of the respective design estimates resulting from the exercise.

When considering the 1% AEP for the current year, RCP 4.5 and RCP 8.5, although additional peak discharge was generated for each scenario, there was additional capacity in the infrastructure that could adequately capture and convey runoff and therefore this redundancy in the system indicates that no additional infrastructure would be required. As a result, the total cost of $201,005.00 estimated for the current year is also applicable under the RCP 4.5 and 8.5 scenarios to the 2040 design horizon when considering 1% AEP. The reason for this under the 2040 design horizon the scaling factors were relatively small resulting in minimal change to rainfall intensity from the current year.

Similarly, when considering the 10% AEP for the current year and its RCP 4.5, additional capacity in the system was observed and for RCP 8.5 a marginal increase in cost was projected. Under all scenarios as we approach the 2090 design horizon, costs start to increase as expected. In particular, under RCP 8.5 1% AEP, additional infrastructure would be required including both the number and size of gullies, and lengths of pipes attributable to the significant increase in rainfall and peak discharge. It should however be noted that in other instances, although infrastructure requirements in terms of the number of gully pits and pipe length appear the same, changes in the physical size of both the gully pits and networked pipes to collect and convey runoff would be required. This is reflected in the varying estimated costs presented in Table 14 below and further detailed within Appendix G. For budget forecasting purposes, based on the results, factoring in a 10% contingency to drainage infrastructure costs would be sufficient to inform program budgets during planning stages.

Table 14 Infrastructure requirement and cost

	Infrastructure requirements		Cost
Model scenario	**Number of gullies**	**Length of pipes**	**Total Cost**
Current year			
10% AEP	8	188m	$187,155.00
1% AEP	8	188m	$201,005.00
RCP 4.5 2040 10% AEP	8	188m	$187,155.00
RCP 4.5 2040 1% AEP	8	188m	$201,005.00
RCP 4.5 2090 10% AEP	8	188m	$187,959.00
RCP 4.5 2090 1% AEP	8	188m	$206,790.00
RCP 8.5 2040 10% AEP	8	188m	$187,436.00
RCP 8.5 2040 1% AEP	8	188m	$201,005.00
RCP 8.5 2090 10% AEP	8	188m	$188,922.00
RCP 8.5 2090 1% AEP	10	252m	$263,502.00

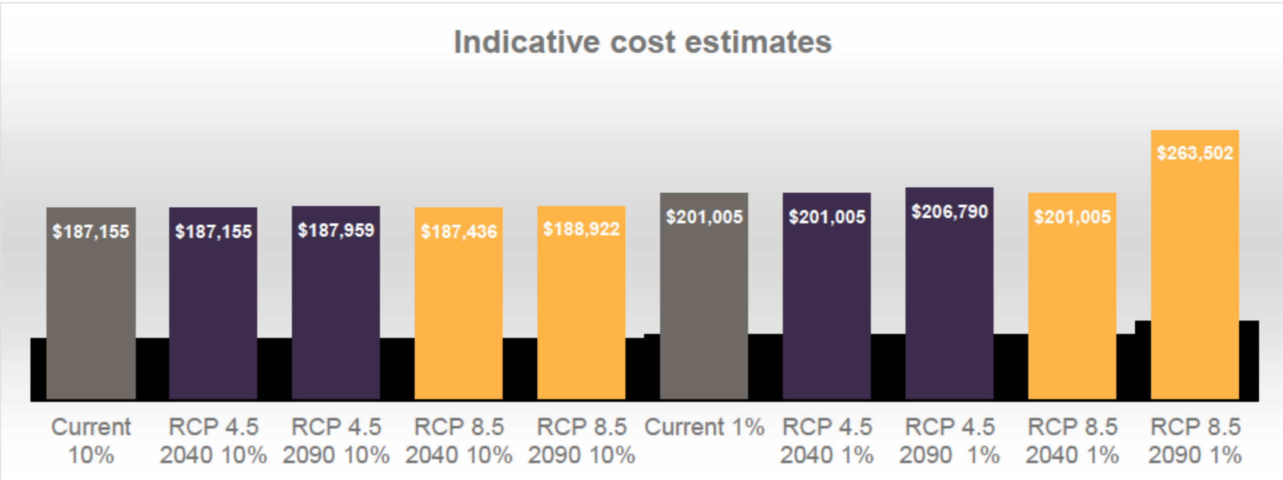

Figure 11 Indicative cost estimates

Table 15 that follows shows these costs as a percentage increase over estimates completed for the current year 10% and 1% AEP events. As observed and reflective of total cost estimates in Table 14, the 2040 10% and 1% AEP events under RCP 4.5 and the 1% AEP under RCP 8.5 did not show any percentage increases in costs compared against their respective current year estimates. While minimal increases were observed elsewhere, it was the significant 31.1% increase over the current year 1% AEP event under RCP 8.5 that was a clear standout against all others. The implication for local Councils under this scenario would prove a significant impact on Councill project budgets. In particular when considering a larger project and or a number of similar projects which need to be rolled out simultaneously under a capital works program, in absolute dollar terms would prove a significant impact on Council budgets. Furthermore, catering for RCP 8.5 scenario, which would be unlikely as detailed in Chapter 3 could be considered overly conservative resulting in excessive expenditure by Council and not the best use of ratepayer funds.

Table 15 Cost percentage increases

	Current year	2040	2040	2090	2090
	$	*$*	*% increase*	*$*	*% increase*
			RCP 4.5		
10% AEP	$187,155.00	$187,155.00	***0.0***	$187,959.00	***0.4***
1% AEP	$201,005.00	$201,005.00	***0.0***	$206,790.00	***2.9***
			RCP 8.5		
10% AEP	$187,155.00	$187,436.00	***0.2***	$188,922.00	***0.9***
1% AEP	$201,005.00	$201,005.00	***0.0***	$263,502.00	***31.1***

4.4 Limitations of research

This paper seeks to provide a comparative analysis of peak discharge in unmitigated urban catchments to factor in the impacts of climate change. However, it was necessary to limit the scope of the climate modelling component as a single urban catchment pilot study. To reinforce and test the robustness of the results presented here, a larger sample size of urban catchments with varying characteristic would need to be modelled. It is also acknowledged that this analysis did not consider hydraulic analysis due to time constraints. However, it is the position of this paper that the hydraulic analysis was not required to determine cost implications at this level of modelling. The main objective of this paper relied on the hydrologic process to determine peak design discharge Q, therefore the hydrologic assessment using the rational method was determined to be fit for purpose in providing peak discharge estimates to inform potential costs for budgeting purposes.

Chapter 5 – Recommendations and conclusion

Throughout this paper, the research has been focused on understanding the impacts of climate change and its factors on peak discharges in urban catchments. Further, this work has identified the appropriate rainfall scaling approach as Datahub to be adopted in conjunction with the plausible RCP scenario of RCP 4.5. In turn this paper has demonstrated what adopting these scenarios may look like for typical urban catchments with respect to infrastructure requirements and associated costs. This chapter provides, a series of recommendations to inform decisionmakers ending with concluding remarks.

5.1 Recommendations

In chapter 4 of this research infrastructure requirements were identified for a suite of design scenarios. This was following the application of increased rainfall reflective of projected future climate conditions. The results found that the RCP 4.5 scenario across all events could be accommodated broadly into drainage systems that otherwise would be designed to cater for the current year under present climatic conditions. To achieve this, only minor variations to gully pit and physical pipe sizes would be required for new major projects at minimal additional cost inclusive of a 10% contingency applied to planned drainage infrastructure requirements. This would also be suitable for interim works to solve minor flooding issues of existing systems in advance of potential future major drainage upgrades, funding permitted. This will prove valuable return in investment for Councils by providing improved immunity against 10% AEP events that are likely to be experienced more frequently than that of the infrequent 1% AEP events.

Similarly, in an assessment scenario, RCP 8.5 could also be extended for most events at minimal cost to Council budgets. However, this scenario would not be recommended to the 2090 1% AEP design event as the projected discharge would impact heavily on the network at significant cost. Furthermore, as discussed earlier in the paper, the likelihood of the RCP 8.5 scenario eventuating with consideration given to global efforts to curb emissions is improbable. It is therefore recommended that RCP 4.5 is adopted for use in the design of all new urban stormwater networks to ensure climate change factors have been captured. This will future proof and ensure long-term resiliency at a minimal cost to Council budgets.

A further recommendation of this paper would be to see stronger relationships created between Federal, State and local Governments. These respective authorities need to work in unison to provide prescriptive advice on RCP adoption and climate change mitigation strategies. This sentiment is echoed by Burton and Dredge (2017) who calls for a considered and coordinated approach. The authors contend that this is necessary to raise the response capacity of local Councils.

5.2 Further research

Broad in its topic this research provides opportunity for further research to be undertaken across a larger number, and a varying spectrum of urban catchments. This work could be further extended by the collection of rainfall data to compare actual rainfall against RCP projections longer term to calibrate against modelled events into the future. This data in the urban environment is something generally missing from data sets with regional areas usually taking preference. In addition, with research based on one-dimensional flow using the rational method, modelling completed using 2d computer analysis could further refine results as it is able to consider a greater number of physical factors such as storage and evolving Water Sensitive Urban Design (WSUD) systems (Willems et al. 2012).

5.3 Conclusion

This research has articulated the challenge faced by LGAs of being left vulnerable due to climate risks. It is clear however that there is a lack of direction and no prescriptive guidelines for LGAs. This has created RCP adoption uncertainty and unnecessary complexity for decision makers. This gap in the research has been addressed by this paper providing evidence to support a likely RCP scenario to be adopted by local Councils.

To this end, a comparative analysis of RCP 4.5 and RCP 8.5 was conducted across minor and major events for several design horizons in determining impacts on peak discharge. Infrastructure requirements were identified and estimated costs tabled. Differences between respective RCPs and design events were conclusive in which to formulate a narrative on the direction on which Councils should follow with respect to climate change considerations. The modelling and analysis led to the conclusion that local Councils would be best suited to adopt RCP 4.5 in future planning and design of urban stormwater networks. This research has provided an understanding of best practice use of RCPs for planning and infrastructure design horizons while informing impacts to budgets to assist with forecasting future infrastructure costs. In doing so, this research project has achieved its aim and objectives and hopefully provides a meaningful contribution to industry.

While the focus of this research was within Council area of Logan City, it is hoped that this research and its findings could be extended and applied to other LGAs. This would inform policy decision makers in updating or revising planning scheme policies that impact local Councils and development through their cities. Its adoption will also future proof urban drainage systems for an uncertain climatic future. In addition, it will build robust Council budgetary contingencies to meet the demands of a growing community. At a minimum this paper has provided the comparisons as a tool for city planners to consider and take the appropriate steps to implement in the design of urban stormwater infrastructure.

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Appendices

Appendix A: Project specification

For: Jeremy Wiegand

Title: Impacts of climate change on peak design discharge of unmitigated urban catchments – a comparative analysis

Major: Civil Engineering

Supervisor: Sreeni Chadalavada

Enrolment: ENG4111 – EXT S1, 2023
ENG4112 – EXT S2, 2023

Project Aim: The research aims to understand the difference in peak design discharge Q for respective AEP events under respective climate change scenarios and the impact this has to infrastructure requirements or selected design horizons.

Programme: Version 2, 18th August 2023

1. Undertake a desktop literature review regarding what impacts climate change has on the determination of peak design stormwater discharge.

2. Identify respective urban catchments within the Logan City LGA and apply manual calculation methods.

3. Setting up of the catchment models using the rational method and its associated parameters.

4. Complete model simulations of base case (current year), 2040 and 2090 design horizons.

5. Interrogate and review modeling results.

6. Complete comparison assessments between simulated scenarios and determine infrastructure requirements for each scenario at respective site.

7. Prepare cost estimates, document outcomes, and prepare recommendations.

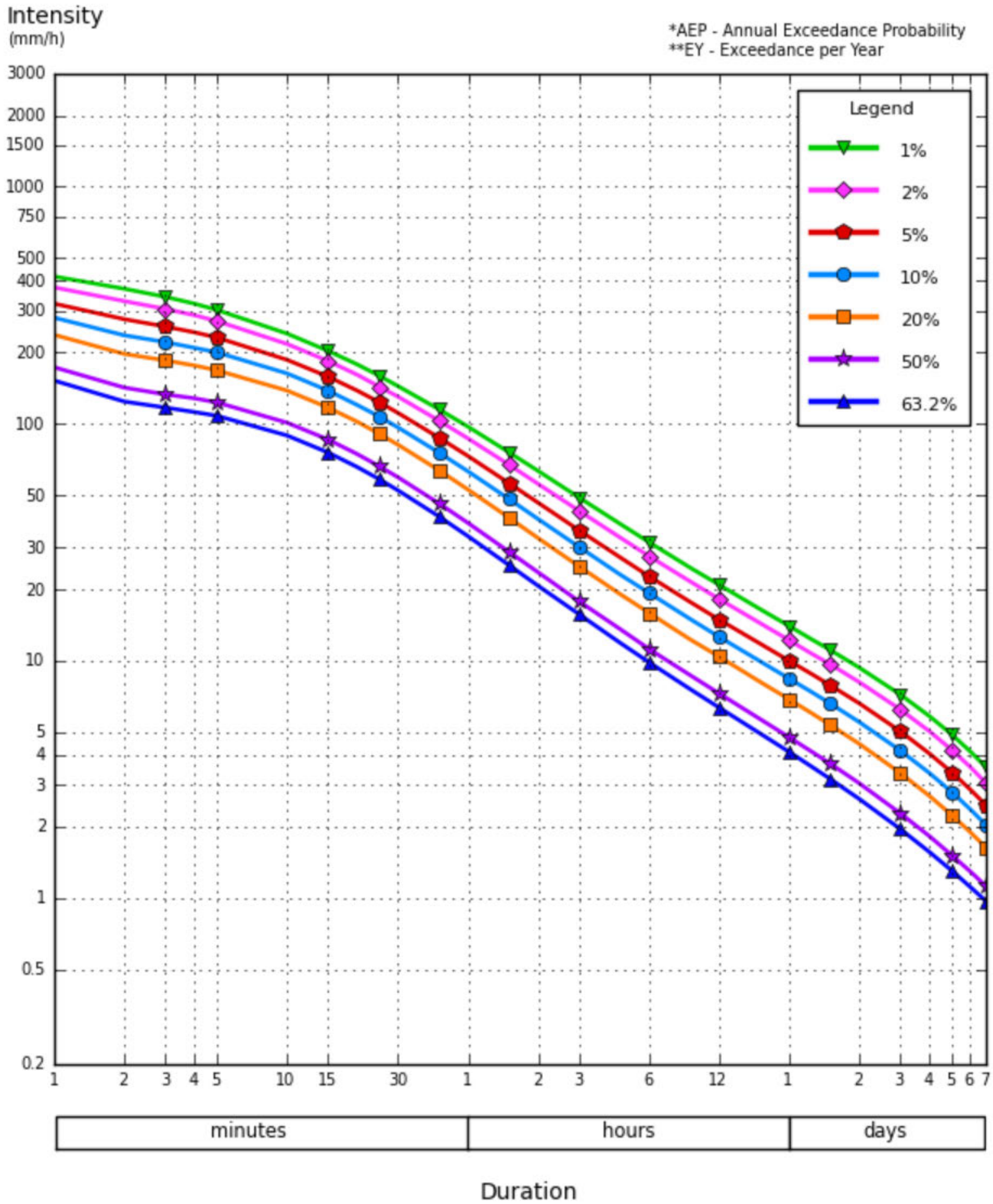
If time and resource permit:

8. Undertake modelling of additional urban catchments to increase the data set.

Appendix B: IFD Design Rainfall Intensity (mm/h) table – Current 2023

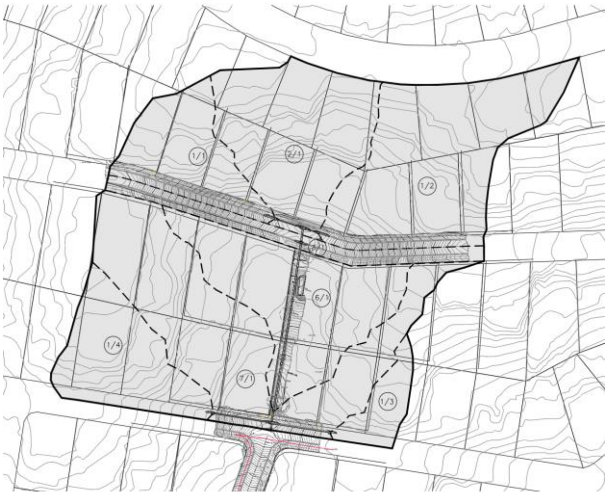
IFD Design Rainfall Intensity (mm/h)
Issued: 18-Aug-23
Location Label:
Requested coordinate: Latitude -27.653 Longitude 153.179
Nearest grid cell: Latitude 27.6625 (S) Longitude 153.1875 (E)

		Annual Exceedance Probability (AEP)						
Duration	**Duration in min**	**63.20%**	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
1 min	1	154	175	238	281	323	377	419
2 min	2	126	143	199	239	280	336	381
3 min	3	119	135	187	223	260	311	350
4 min	4	114	129	178	211	245	290	326
5 min	5	109	124	170	201	232	274	305
6 min	6	105	119	163	192	221	259	288
7 min	7	101	115	156	184	211	247	274
8 min	8	97.3	110	150	177	202	236	261
9 min	9	93.8	106	144	170	194	226	250
10 min	10	90.4	102	139	164	187	217	240
11 min	11	87.3	98.8	134	158	180	209	231
12 min	12	84.4	95.5	130	152	174	202	223
13 min	13	81.6	92.4	126	147	168	195	216
14 min	14	79.1	89.5	122	143	163	189	209
15 min	15	76.7	86.8	118	138	158	184	203
20 min	20	66.6	75.4	103	121	138	161	178
25 min	25	59	66.9	91.2	107	123	144	159
30 min	30	53.1	60.2	82.2	97.1	112	131	145
45 min	45	41.3	46.8	64.4	76.5	88.4	104	117
1 hour	60	34.1	38.8	53.6	63.9	74.3	88.3	99.3
1.5 hour	90	25.9	29.5	41.1	49.3	57.7	69.2	78.4
2 hour	120	21.3	24.2	34	40.9	48.1	58	66

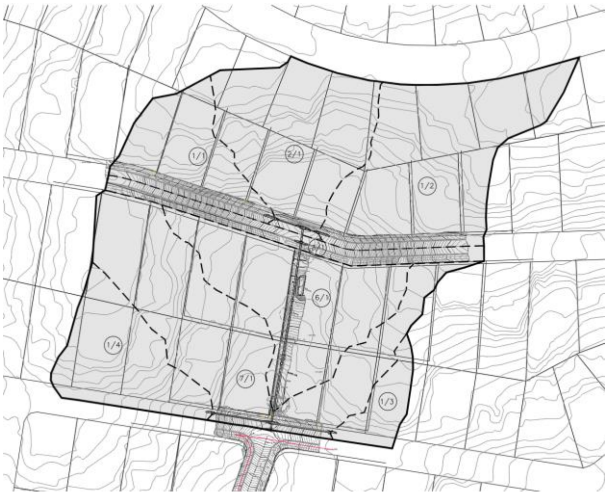

Intensity
(mm/h)
*AEP - Annual Exceedance Probability
**EY - Exceedance per Year
3000
2000
1500
1000
750
500
400
300
200
100
50
30
20
10
5
4
3
2
1
0.5
0.2
Legend
1%
2%
5%
10%
20%
50%
63.2%
1 2 3 4 5 10 15 30 1 2 3 6 12 1 2 3 4 5 6 7
minutes
hours
days
Duration

Appendix C: Project site design catchment layouts

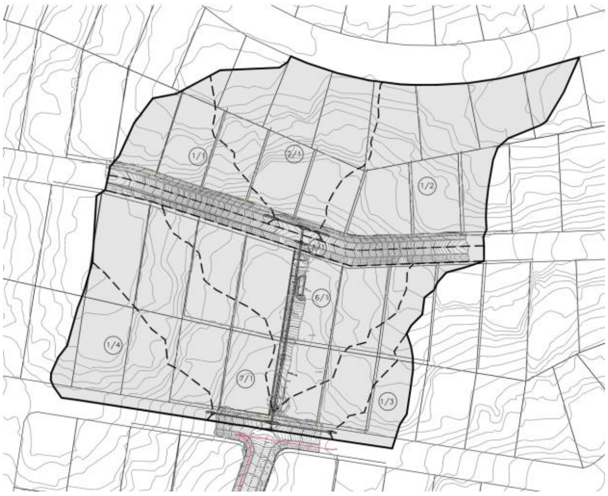
Current 2023 10% AEP



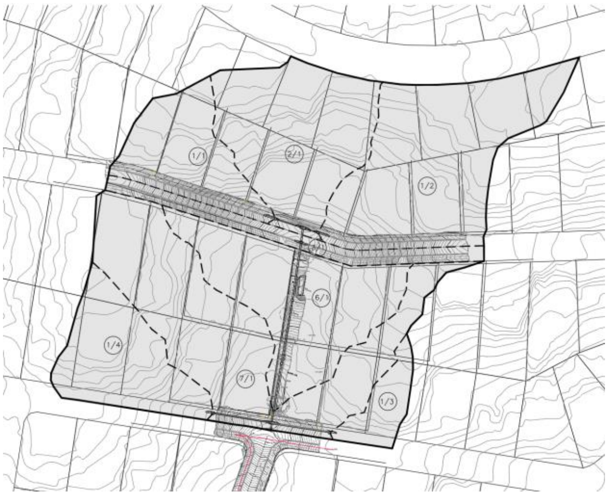
Current 2023 1% AEP



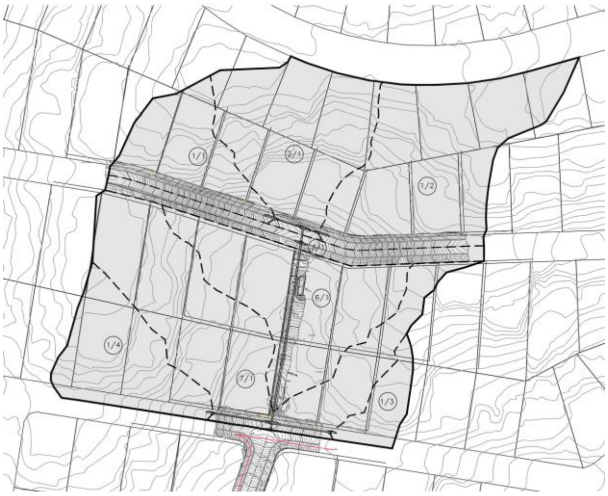
RCP 4.5 2040 10% AEP



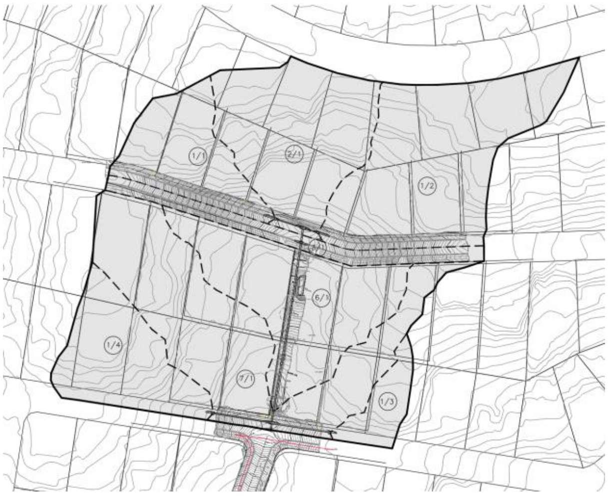
RCP 4.5 2040 1% AEP



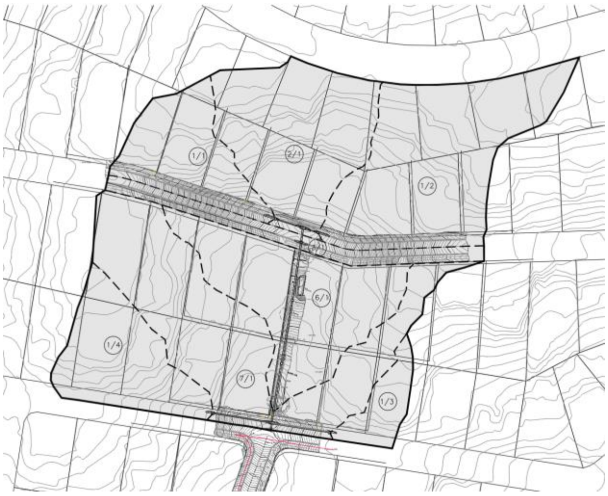
RCP 4.5 2090 10% AEP



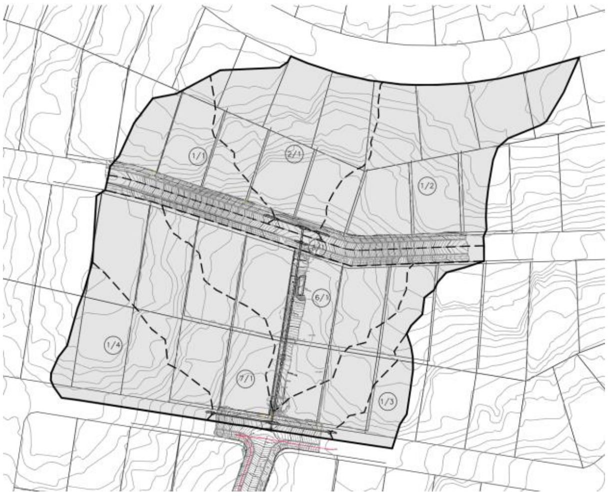
RCP 4.5 2090 1% AEP



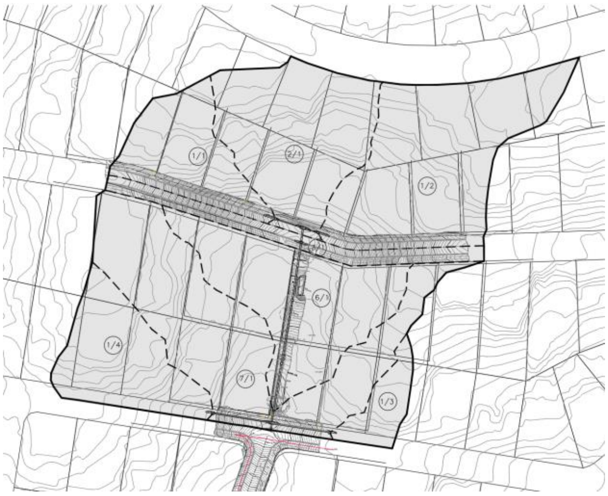
RCP 8.5 2040 10% AEP



RCP 8.5 2040 1% AEP



RCP 8.5 2090 10% AEP



RCP 8.5 2090 1% AEP

Appendix D: Queensland Urban Drainage Manual 2017 modelling parameters

Table 4.5.1 – Fraction impervious vs. development category

Development category	Fraction impervious (f_i)
Central business district	1.00
Commercial, local business, neighbouring facilities, service industry, general industry, home industry	0.90
Significant paved areas e.g. roads and car parks	0.90
Urban residential – high density	0.70 to 0.90
Urban residential – low density (including roads)	0.45 to 0.85
Urban residential – low density (excluding roads)	0.40 to 0.75
Rural residential	0.10 to 0.20
Open space and parks etc.	0.00

Table 4.6.2 – Recommended standard inlet times

Location	Inlet time (minutes)
Road surfaces and paved areas	5
Urban residential areas where average slope [1] of land at top of catchment is greater than 15%	5
Urban residential areas where average slope [1] of land at top of catchment is greater than 10% and up to 15%	8
Urban residential areas where average slope [1] of land at top of catchment is greater than 6% and up to 10%	10
Urban residential areas where average slope [1] of land at top of catchment is greater than 3% and up to 6%	13
Urban residential areas where average slope [1] at top of catchment is up to 3%	15

Discharge co-efficients					
			C_y10	C_y100	
Fi = 0.90		Fi	$Fy_{10} \times C_{10} = C_{10}$	$Fy_{100} \times C_{10} = C_{100}$	
	Current	0.9	1.0 x 0.87 = 0.87	1.2 x 0.87 = 1.04	> 1.0
RCP 4.5	2040	0.9	1.0 x 0.88 = 0.88	1.2 x 0.88 = 1.06	> 1.0
RCP 4.5	2090	0.9	1.0 x 0.88 = 0.88	1.2 x 0.88 = 1.06	> 1.0
RCP 8.5	2040	0.9	1.0 x 0.88 = 0.88	1.2 x 0.88 = 1.06	> 1.0
RCP 8.5	2090	0.9	1.0 x 0.88 = 0.88	1.2 x 0.88 = 1.06	> 1.0

Note: QUDM advises that the Cy should be limited to unity (1.0) within urban areas and as such was adopted for this research.

Table 4.5.2 – Table of frequency factors

AEP (%)	ARI (years)	Frequency factor (F_y)
63%	1	0.80
39%	2	0.85
18%	5	0.95
10%	10	1.00
5%	20	1.05
2%	50	1.15
1%	100	1.20

Table 4.5.3 – Table of C_{10} values

Intensity (mm/hr) $^1I_{10}$	Fraction impervious f_i						
	0.00	**0.20**	**0.40**	**0.60**	**0.80**	**0.90**	**1.00**
39-44	Refer to Table 4.5.4	0.44	0.55	0.67	0.78	0.84	0.90
45-49		0.49	0.60	0.70	0.80	0.85	0.90
50-54		0.55	0.64	0.72	0.81	0.86	0.90
55-59		0.60	0.68	0.75	0.83	0.86	0.90
60-64		0.65	0.72	0.78	0.84	0.87	0.90
65-69		0.71	0.76	0.80	0.85	0.88	0.90
70-90		0.74	0.78	0.82	0.86	0.88	0.90

Refer to notes on previous page.

Table 4.5.4 – C_{10} values for zero fraction impervious [1]

Land description	Dense bushland			Medium density bush, or Good grass cover, or High density pasture, or Zero tillage cropping			Light cover bushland, or Poor grass cover, or Low density pasture, or Low cover bare fallows		
Intensity (mm/hr) $^1I_{10}$	**Soil permeability**			**Soil permeability**			**Soil permeability**		
	High	**Med**	**Low**	**High**	**Med**	**Low**	**High**	**Med**	**Low**
39–44	0.08	0.24	0.32	0.16	0.32	0.40	0.24	0.40	0.48
45–49	0.10	0.29	0.39	0.20	0.39	0.49	0.29	0.49	0.59
50–54	0.12	0.35	0.46	0.23	0.46	0.58	0.35	0.58	0.69
55–59	0.13	0.40	0.53	0.27	0.53	0.66	0.40	0.66	0.70
60–64	0.15	0.44	0.59	0.30	0.59	0.70	0.44	0.70	0.70
65–69	0.17	0.50	0.66	0.33	0.66	0.70	0.50	0.70	0.70
70–90	0.18	0.53	0.70	0.35	0.70	0.70	0.53	0.70	0.70

Appendix E: Manual calculation (Rational Method) spreadsheets for design scenarios

Scenario	Structure No.	Drain Section	Sub-catchments Contributing	Sub-catchments Time of Concentration	Sub-catchment Area	Coefficient of Runoff	Equivalent Impervious Area	Rainfall Intensity	Calculated Sub-area Discharge	Flow in K&C (Including Bypass) (Qa)	Road Grade at Inlet	Inlet Type	Inlet (Qg)	Bypass	Pipe Diameter	Pipe Grade	Pipe Flow (Qu)	Pipe Velocity (Full)	Depth to Invert	Pipe length	MH diameter	MH depth
Location				Runoff coefficients and Rainfall intensity						Surface flow					Pipe flow				Infrastructure depth			
				tc	A	C	CxA	I	Q	Qa			Qg			S	Qu	V				
Current 10% AEP	No.			min	ha		ha	mm/h	l/sec	l/sec	%	Type	l/sec	l/sec	mm	%	l/sec	m^2/sec	m	m	mm	m
	1/1	1/1 to 2/1	1/1	5	0.296	0.87	0.258	201	144	144	5.40	1C1T	111	33	375	1.50	111	1.94	0-2	15	1050	0-2
	2/1	2/1 to 3/1	1/1,1/2	5	0.532	0.87	0.463	201	258	422	0.00	2CS2T0.2	422	0	600	1.50	705	2.88	0-2	8	1350E	0-2
	1/2	1/2 to 2/1	1/2	8	0.708	0.87	0.616	177	303	303	5.80	1C1T	172	131	375	3.00	172	2.75	0-2	8	1050	0-2
	3/1	3/1 to 4/1	1/1,1/2, 2/1,3/1	5	0.154	0.87	0.134	201	75	75	0.00	1C0T0.1	75	0	600	3.00	780	3.76	2-4	30	1050	2-4
	4/1	4/1 to 5/1	1/1,1/2, 2/1,3/1									MH			525	5.50	780	4.66	0-2	33	1050	0-2
	5/1	5/1 to 6/1	1/1,1/2, 2/1,3/1									MH			525	5.50	780	4.66	2-4	25	1050	2-4
	6/1	6/1 to 7/1	1/1,1/2, 2/1,3/1, 6/1	8	0.533	0.87	0.464	177	228	228	0.00	ICS0T0.2	220	8	600	3.00	1000	3.76	2-4	6	1.2x1.2	2-4
	1/3	1/3 to 7/1	1/3	8	0.105	0.87	0.091	177	45	45	5.40	1C1T	45	0	375	1.50	45	1.94	0-2	30	1050	0-2
	1/4	1/4 to 7/1	1/4	8	0.338	0.87	0.294	177	145	145	5.40	1C1T	112	33	375	1.50	112	1.94	0-2	30	1050	0.2
	7/1	7/1 to 8/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1	8	0.769	0.87	0.669	177	329	370	0.00	2CS2T0.2	370	0	675	4.00	1527	4.70	2-4	3	1350E	2-4
	8/1	8/1 to 9/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1									EXIST MH									break in	
								Total Q	**1527**	**m^3/s**												
RCP 4.5 2040 10% AEP	No.			min	ha		ha	mm/h	l/sec	l/sec	%	Type	l/sec	l/sec	mm	%	l/sec	m^2/sec	m	m	mm	m
	1/1	1/1 to 2/1	1/1	5	0.296	0.88	0.260	212	153	153	5.40	1C1T	115	38	375	1.50	115	1.94	0-2	15	1050	0-2
	2/1	2/1 to 3/1	1/1,1/2	5	0.532	0.88	0.468	212	276	457	0.00	2CS2T0.2	457	0	600	1.50	751	2.66	0-2	8	1350E	0-2
	1/2	1/2 to 2/1	1/2	8	0.708	0.88	0.623	186	322	322	5.80	1C1T	179	143	375	3.00	179	2.75	0-2	8	1050	0-2
	3/1	3/1 to 4/1	1/1,1/2, 2/1,3/1	5	0.154	0.88	0.136	212	80	80	0.00	1C0T0.1	80	0	600	3.00	831	3.76	2-4	30	1050	2-4
	4/1	4/1 to 5/1	1/1,1/2, 2/1,3/1			0.88	0.000					MH			525	5.50	831	4.66	0-2	33	1050	0-2
	5/1	5/1 to 6/1	1/1,1/2, 2/1,3/1			0.88	0.000					MH			525	5.50	831	4.66	2-4	25	1050	2-4
	6/1	6/1 to 7/1	1/1,1/2, 2/1,3/1, 6/1	8	0.533	0.88	0.469	186	242	242	0.00	ICS0T0.2	220	22	600	3.00	1051	3.76	2-4	6	1.2x1.2	2-4
	1/3	1/3 to 7/1	1/3	8	0.105	0.88	0.092	186	48	48	5.40	1C1T	48	0	375	1.50	48	1.94	0-2	30	1050	0-2
	1/4	1/4 to 7/1	1/4	8	0.338	0.88	0.297	186	154	154	5.40	1C1T	116	38	375	1.50	116	1.94	0-2	30	1050	0.2
	7/1	7/1 to 8/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1	8	0.769	0.88	0.677	186	350	410	0.00	2CS2T0.2	410	0	675	4.00	1625	4.70	2-4	3	1350E	2-4
	8/1	8/1 to 9/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1									EXIST MH			675	4.00	1625	4.70			break in	
								Total Q	**1625**	**m^3/s**												

Location			Runoff coefficients and Rainfall intensity						Surface flow					Pipe flow				Infrastructure depth			
Structure No.	Drain Section	Sub-catchments Contributing	Sub-catchments Time of Concentration	Sub-catchment Area	Coefficient of Runoff	Equivalent Impervious Area	Rainfall Intensity	Calculated Sub-area Discharge	Flow in K&C (Including Bypass) (Qa)	Road Grade at Inlet	Inlet Type	Inlet (Qg)	Bypass	Pipe Diameter	Pipe Grade	Pipe Flow (Qu)	Pipe Velocity (Full)	Depth to Invert	Pipe length	MH diameter	MH depth
			tc	A	C	CxA	I	Q	Qa			Qg			S	Qu	V				
RCP 4.5 2090 10% AEP																					
No.			min	ha		ha	mm/h	l/sec	l/sec	%	Type	l/sec	l/sec	mm	%	l/sec	m^2/sec	m	m	mm	m
1/1	1/1 to 2/1	1/1	5	0.296	0.88	0.260	220	159	159	5.40	1C1T	118	41	375	1.50	118	1.94	0-2	15	1050	0-2
2/1	2/1 to 3/1	1/1,1/2	5	0.532	0.88	0.468	220	286	480	0.00	2CS2T0.2	480	0	675	1.50	781	2.88	0-2	8	1350E	0-2
1/2	1/2 to 2/1	1/2	8	0.708	0.88	0.623	194	336	336	5.80	1C1T	183	153	375	3.00	183	2.75	0-2	8	1050	0-2
3/1	3/1 to 4/1	1/1,1/2, 2/1,3/1	5	0.154	0.88	0.136	220	83	83	0.00	1C0T0.1	83	0	600	3.00	864	3.76	2-4	30	1050	2-4
4/1	4/1 to 5/1	1/1,1/2, 2/1,3/1									MH			525	5.50	864	4.66	0-2	33	1050	0-2
5/1	5/1 to 6/1	1/1,1/2, 2/1,3/1									MH			525	5.50	864	4.66	2-4	25	1050	2-4
6/1	6/1 to 7/1	1/1,1/2, 2/1,3/1, 6/1	8	0.533	0.88	0.469	194	253	253	0.00	ICS0T0.2	220	33	675	3.00	1084	4.07	2-4	6	1.2x1.2	2-4
1/3	1/3 to 7/1	1/3	8	0.105	0.88	0.092	194	50	50	5.40	1C1T	50	0	375	1.50	50	1.94	0-2	30	1050	0-2
1/4	1/4 to 7/1	1/4	8	0.338	0.88	0.297	194	160	160	5.40	1C1T	118	42	375	1.50	118	1.94	0-2	30	1050	0.2
7/1	7/1 to 8/1	1/1,1/2, 2/1,3/1, 6/1,1/4, 7/1	8	0.769	0.88	0.677	194	365	440	0.00	2CS2T0.2	440	0	750	4.00	1692	5.00	2-4	3	1350E	2-4
8/1	8/1 to 9/1	1/1,1/2, 2/1,3/1, 6/1,7/1									EXIST MH			750	4.00	1692	5.00			break in	
							Total Q	**1692**	**m^3/s**												
RCP 8.5 2040 10% AEP																					
No.			min	ha		ha	mm/h	l/sec	l/sec	%	Type	l/sec	l/sec	mm	%	l/sec	m^2/sec	m	m	mm	m
1/1	1/1 to 2/1	1/1	5	0.296	0.88	0.260	215	156	156	5.40	1C1T	117	39	375	1.50	117	1.94	0-2	15	1050	0-2
2/1	2/1 to 3/1	1/1,1/2	5	0.532	0.88	0.468	215	280	466	0.00	2CS2T0.2	466	0	675	1.50	763	2.88	0-2	8	1350E	0-2
1/2	1/2 to 2/1	1/2	8	0.708	0.88	0.623	189	327	327	5.80	1C1T	180	147	375	3.00	180	2.75	0-2	8	1050	0-2
3/1	3/1 to 4/1	1/1,1/2, 2/1,3/1	5	0.154	0.88	0.136	215	81	81	0.00	1C0T0.1	81	0	600	3.00	844	3.76	2-4	30	1050	2-4
4/1	4/1 to 5/1	1/1,1/2, 2/1,3/1									MH			525	5.50	844	4.66	0-2	33	1050	0-2
5/1	5/1 to 6/1	1/1,1/2, 2/1,3/1									MH			525	5.50	844	4.66	2-4	25	1050	2-4
6/1	6/1 to 7/1	1/1,1/2, 2/1,3/1, 6/1	8	0.533	0.88	0.469	189	246	246	0.00	ICS0T0.2	220	26	600	3.00	1064	3.76	2-4	6	1.2x1.2	2-4
1/3	1/3 to 7/1	1/3	8	0.105	0.88	0.092	189	49	49	5.40	1C1T	49	0	375	1.50	49	1.94	0-2	30	1050	0-2
1/4	1/4 to 7/1	1/4	8	0.338	0.88	0.297	189	156	156	5.40	1C1T	117	39	375	1.50	117	1.94	0-2	30	1050	0.2
7/1	7/1 to 8/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1	8	0.769	0.88	0.677	189	355	420	0.00	2CS2T0.2	420	0	675	4.00	1650	4.70	2-4	3	1350E	2-4
8/1	8/1 to 9/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1									EXIST MH			675	4.00	1650	4.70			break in	
							Total Q	**1650**	**m^3/s**												

	Location			Runoff coefficients and Rainfall intensity						Surface flow					Pipe flow				Infrastructure depth			
	Structure No.	Drain Section	Sub-catchments Contributing	Sub-catchments Time of Concentration	Sub-catchment Area	Coefficient of Runoff	Equivalent Impervious Area	Rainfall Intensity	Calculated Sub-area Discharge	Flow in K&C (Including Bypass) (Qa)	Road Grade at Inlet	Inlet Type	Inlet (Qg)	Bypass	Pipe Diameter	Pipe Grade	Pipe Flow (Qu)	Pipe Velocity (Full)	Depth to Invert	Pipe length	MH diameter	MH depth
				tc	A	C	CxA	I	Q	Qa			Qg			S	Qu	V				
RCP 8.5 2090 10% AEP	No.			min	ha		ha	mm/h	l/sec	l/sec	%	Type	l/sec	l/sec	mm	%	l/sec	m^2/sec	m	m	mm	m
	1/1	1/1 to 2/1	1/1	5	0.296	0.88	0.260	241	174	174	5.40	1C2T	137	37	375	1.50	137	1.94	0-2	15	1050	0-2
	2/1	2/1 to 3/1	1/1,1/2	5	0.532	0.88	0.468	241	313	501	0.00	2CS2T0.2	501	0	675	1.50	854	2.88	0-2	8	1350E	0-2
	1/2	1/2 to 2/1	1/2	8	0.708	0.88	0.623	212	367	367	5.80	1C2T	216	151	375	3.00	216	2.75	0-2	8	1050	0-2
	3/1	3/1 to 4/1	1/1,1/2, 2/1,3/1	5	0.154	0.88	0.136	241	91	91	0.00	1C0T0.1	91	0	600	3.00	945	3.76	2-4	30	1050	2-4
	4/1	4/1 to 5/1	1/1,1/2, 2/1,3/1									MH			525	5.50	945	4.66	0-2	33	1050	0-2
	5/1	5/1 to 6/1	1/1,1/2, 2/1,3/1									MH			525	5.50	945	4.66	2-4	25	1050	2-4
	6/1	6/1 to 7/1	1/1,1/2, 2/1,3/1, 6/1	8	0.533	0.88	0.469	212	276	276	0.00	ICS0T0.2	220	56	600	3.00	1165	3.76	2-4	6	1.2x1.2	2-4
	1/3	1/3 to 7/1	1/3	8	0.105	0.88	0.092	212	54	54	5.40	1C1T	54	0	375	1.50	54	1.94	0-2	30	1050	0-2
	1/4	1/4 to 7/1	1/4	8	0.338	0.88	0.297	212	175	175	5.40	1C1T	125	50	375	1.50	125	1.94	0-2	30	1050	0.2
	7/1	7/1 to 8/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1	8	0.769	0.88	0.677	212	399	505	0.00	2CS2T0.2	505	0	750	4.00	1849	5.04	2-4	3	1350E	2-4
	8/1	8/1 to 9/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1									EXIST MH			750	4.00	1849	5.04			break in	
								Total Q	**1849**	**m^3/s**												
Current 1% AEP	No.			min	ha		ha	mm/h	l/sec	l/sec	%	Type	l/sec	l/sec	mm	%	l/sec	m^2/sec	m	m	mm	m
	1/1	1/1 to 2/1	1/1	5	0.296	1.0	0.296	305	251	251	5.40	1C3T	190	61	375	1.50	190	1.94	0-2	15	1050	0-2
	2/1	2/1 to 3/1	1/1,1/2	5	0.532	1.0	0.532	305	451	734	0.00	2CS2T0.2	506	228	675	1.50	987	2.88	0-2	8	1350E	0-2
	1/2	1/2 to 2/1	1/2	8	0.708	1.0	0.708	261	513	513	5.80	1C3T	291	222	375	3.00	291	2.75	0-2	8	1050	0-2
	3/1	3/1 to 4/1	1/1,1/2, 2/1,3/1	5	0.154	1.0	0.154	305	130	358	0.00	2CS2T0.2	358	0	675	3.00	1345	4.07	2-4	30	1350E	2-4
	4/1	4/1 to 5/1	1/1,1/2, 2/1,3/1									MH			600	5.50	1345	5.09	0-2	33	1050	0-2
	5/1	5/1 to 6/1	1/1,1/2, 2/1,3/1									MH			600	5.50	1345	5.09	2-4	25	1050	2-4
	6/1	6/1 to 7/1	1/1,1/2, 2/1,3/1, 6/1	8	0.533	1.0	0.533	261	386	386	0.00	ICS0T0.2	220	166	750	3.00	1565	4.37	2-4	6	1.2x1.2	2-4
	1/3	1/3 to 7/1	1/3	8	0.105	1.0	0.105	261	76	76	5.40	1C1T	76	0	375	1.50	76	1.94	0-2	30	1050	0-2
	1/4	1/4 to 7/1	1/4	8	0.338	1.0	0.338	261	245	245	5.40	1C3T	187	58	375	1.50	187	1.94	0-2	30	1050	0.2
	7/1	7/1 to 8/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1	8	0.769	1.0	0.769	261	558	782	0.00	2CS2T0.2	506	276	825	4.00	2334	5.40	2-4	3	1350E	2-4
	8/1	8/1 to 9/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1									EXIST MH			825	4.00	2334	5.40			break in	
								Total Q	**2610**	**m^3/s**												

	Location			Runoff coefficients and Rainfall intensity						Surface flow						Pipe flow				Infrastructure depth			
	Structure No.	Drain Section	Sub-catchments Contributing	Sub-catchments Time of Concentration	Sub-catchment Area	Coefficient of Runoff	Equivalent Impervious Area	Rainfall Intensity	Calculated Sub-area Discharge	Flow in K&C (Including Bypass) (Qa)	Road Grade at Inlet	Inlet Type	Inlet (Qg)	Bypass	Pipe Diameter	Pipe Grade	Pipe Flow (Qu)	Pipe Velocity (Full)	Depth to Invert	Pipe length	MH diameter	MH depth
				tc	A	C	CxA	I	Q	Qa			Qg			S	Qu	V				
RCP 4.5 2040 1% AEP	No.			min	ha		ha	mm/h	l/sec	l/sec	%	Type	l/sec	l/sec	mm	%	l/sec	m^2/sec	m	m	mm	m
	1/1	1/1 to 2/1	1/1	5	0.296	1.0	0.296	321	264	264	5.40	1C3T	196	68	375	1.50	196	1.94	0-2	15	1050	0-2
	2/1	2/1 to 3/1	1/1,1/2	5	0.532	1.0	0.532	321	474	783	0.00	2CS2T0.2	506	277	675	1.50	1002	2.88	0-2	8	1350E	0-2
	1/2	1/2 to 2/1	1/2	8	0.708	1.0	0.708	275	541	541	5.80	1C3T	300	241	375	3.00	300	2.75	0-2	8	1050	0-2
	3/1	3/1 to 4/1	1/1,1/2, 2/1,3/1	5	0.154	1.0	0.154	321	137	414	0.00	2CS2T0.2	414	0	675	3.00	1416	4.07	2-4	30	1350E	2-4
	4/1	4/1 to 5/1	1/1,1/2, 2/1,3/1			1.0	0.000					MH			600	5.50	1416	5.09	0-2	33	1050	0-2
	5/1	5/1 to 6/1	1/1,1/2, 2/1,3/1			1.0	0.000					MH			600	5.50	1416	5.09	2-4	25	1050	2-4
	6/1	6/1 to 7/1	1/1,1/2, 2/1,3/1, 6/1	8	0.533	1.0	0.533	275	407	407	0.00	ICS0T0.2	220	187	750	3.00	1636	4.37	2-4	6	1.2x1.2	2-4
	1/3	1/3 to 7/1	1/3	8	0.105	1.0	0.105	275	80	80	5.40	1C1T	80	0	375	1.50	80	1.94	0-2	30	1050	0-2
	1/4	1/4 to 7/1	1/4	8	0.338	1.0	0.338	275	258	258	5.40	1C3T	193	65	375	1.50	193	1.94	0-2	30	1050	0.2
	7/1	7/1 to 8/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1	8	0.769	1.0	0.769	275	587	839	0.00	2CS2T0.2	506	333	825	4.00	2415	5.400	2-4	3	1350E	2-4
	8/1	8/1 to 9/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1									EXIST MH			825	4.00	2415	5.400			break in	
								Total Q	**2748**	**m^3/s**												
RCP 4.5 2090 1% AEP	No.			min	ha		ha	mm/h	l/sec	l/sec	%	Type	l/sec	l/sec	mm	%	l/sec	m^2/sec	m	m	mm	m
	1/1	1/1 to 2/1	1/1	5	0.296	1.0	0.296	334	275	275	5.40	1C3T	201	74	375	1.50	201	1.94	0-2	15	1050	0-2
	2/1	2/1 to 3/1	1/1,1/2	5	0.532	1.0	0.532	334	494	824	0.00	2CS2T0.2	506	318	675	1.50	1013	2.88	0-2	8	1350E	0-2
	1/2	1/2 to 2/1	1/2	8	0.708	1.0	0.708	286	562	562	5.80	1C3T	306	256	450	3.00	306	2.2	0-2	8	1050	0-2
	3/1	3/1 to 4/1	1/1,1/2, 2/1,3/1	5	0.154	1.0	0.154	334	143	461	0.00	2CS2T0.2	461	0	750	3.00	1474	4.37	2-4	30	1350E	2-4
	4/1	4/1 to 5/1	1/1,1/2, 2/1,3/1									MH			675	5.50	1474	5.51	0-2	33	1050	0-2
	5/1	5/1 to 6/1	1/1,1/2, 2/1,3/1									MH			675	5.50	1474	5.51	2-4	25	1050	2-4
	6/1	6/1 to 7/1	1/1,1/2, 2/1,3/1, 6/1	8	0.533	1.0	0.533	286	423	423	0.00	ICS0T0.2	220	203	750	3.00	1694	4.37	2-4	6	1.2x1.2	2-4
	1/3	1/3 to 7/1	1/3	8	0.105	1.0	0.105	286	83	83	5.40	1C1T	83	0	375	1.50	83	1.94	0-2	30	1050	0-2
	1/4	1/4 to 7/1	1/4	8	0.338	1.0	0.338	286	269	269	5.40	1C3T	198	71	375	1.50	198	1.94	0-2	30	1050	0.2
	7/1	7/1 to 8/1	1/1,1/2, 2/1,3/1, 6/1,7/1	8	0.769	1.0	0.769	286	611	885	0.00	2CS2T0.2	506	379	825	4.00	2481	5.40	2-4	3	1350E	2-4
	8/1	8/1 to 9/1	1/1,1/2, 2/1,3/1, 6/1,7/1									EXIST MH			825	4.00	2481	5.40			break in	
								Total Q	**2860**	**m^3/s**												

	Location			Runoff coefficients and Rainfall intensity						Surface flow					Pipe flow				Infrastructure depth			
	Structure No.	Drain Section	Sub-catchments Contributing	Sub-catchments Time of Concentration	Sub-catchment Area	Coefficient of Runoff	Equivalent Impervious Area	Rainfall Intensity	Calculated Sub-area Discharge	Flow in K&C (Including Bypass) (Qa)	Road Grade at Inlet	Inlet Type	Inlet (Qg)	Bypass	Pipe Diameter	Pipe Grade	Pipe Flow (Qu)	Pipe Velocity (Full)	Depth to Invert	Pipe length	MH diameter	MH depth
				tc	A	C	CxA	I	Q	Qa			Qg			S	Qu	V				
RCP 8.5 2040 1% AEP	No.			min	ha		ha	mm/h	l/sec	l/sec	%	Type	l/sec	l/sec	mm	%	l/sec	m^2/sec	m	m	mm	m
	1/1	1/1 to 2/1	1/1	5	0.296	1.0	0.296	326	268	268	5.40	1C3T	198	70	375	1.50	198	1.94	0-2	15	1050	0-2
	2/1	2/1 to 3/1	1/1,1/2	5	0.532	1.0	0.532	326	482	799	0.00	2CS2T0.2	506	293	675	1.50	1006	2.88	0-2	8	1350E	0-2
	1/2	1/2 to 2/1	1/2	8	0.708	1.0	0.708	279	549	549	5.80	1C3T	302	247	375	3.00	302	2.75	0-2	8	1050	0-2
	3/1	3/1 to 4/1	1/1,1/2, 2/1,3/1	5	0.154	1.0	0.154	326	139	432	0.00	2CS2T0.2	432	0	675	3.00	1438	4.07	2-4	30	1350E	2-4
	4/1	4/1 to 5/1	1/1,1/2, 2/1,3/1									MH			600	5.50	1438	5.09	0-2	33	1050	0-2
	5/1	5/1 to 6/1	1/1,1/2, 2/1,3/1									MH			600	5.50	1438	5.09	2-4	25	1050	2-4
	6/1	6/1 to 7/1	1/1,1/2, 2/1,3/1, 6/1	8	0.533	1.0	0.533	279	413	413	0.00	ICS0T0.2	220	193	750	3.00	1658	4.37	2-4	6	1.2x1.2	2-4
	1/3	1/3 to 7/1	1/3	8	0.105	1.0	0.105	279	81	81	5.40	1C1T	81	0	375	1.50	81	1.94	0-2	30	1050	0-2
	1/4	1/4 to 7/1	1/4	8	0.338	1.0	0.338	279	262	262	5.40	1C3T	195	67	375	1.50	195	1.94	0-2	30	1050	0.2
	7/1	7/1 to 8/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1	8	0.769	1.0	0.769	279	596	856	0.00	2CS2T0.2	506	350	825	4.00	2440	5.40	2-4	3	1350E	2-4
	8/1	8/1 to 9/1	1/1,1/2, 2/1,3/1, 6/1,1/3, 1/4,7/1									EXIST MH			825	4.00	2440	5.40			break in	
								Total Q	**2790**	**m^3/s**												
RCP 8.5 2090 1% AEP	No.			min	ha		ha	mm/h	l/sec	l/sec	%	Type	l/sec	l/sec	mm	%	l/sec	m^2/sec	m	m	mm	m
	1/1	1/1 to 2/1	1/1	5	0.296	1.0	0.296	365	300	300	5.40	1C3T	212	88	375	1.50	212	1.94	0-2	15	1050	0-2
	2/1	2/1 to 3/1	1/1,1/2	5	0.532	1.0	0.532	365	539	835	0.00	2CS2T0.2	506	329	750	1.50	1124	3.09	0-2	8	1350E	0-2
	1/2	1/2 to 2/2	1/2	8	0.140	1.0	0.140	312	121	121	5.80	1C3T	121	0	375	3.00	121	2.75	2-4	26	1050	2-4
	2/2	2/2 to 2/1	1/2,2/2	8	0.568	1.0	0.568	312	492	492	4.00	1C3T	285	207	375	3.00	285	2.75	0-2	8	1050	0-2
	3/1	3/1 to 4/1	1/1,1/2, 2/2,2/1, 3/1	5	0.154	1.0	0.154	365	156	485	0.00	2CS2T0.2	485	0	750	3.00	1609	4.37	2-4	30	1350E	2-4
	4/1	4/1 to 5/1	1/1,1/2, 2/2,2/1, 3/1									MH			675	5.50	1609	5.5	0-2	33	1050	0-2
	5/1	5/1 to 6/1	1/1,1/2, 2/1,3/1									MH			675	5.50	1609	5.5	2-4	25	1050	2-4
	6/1	6/1 to 7/1	1/1,1/2, 2/2,2/1, 3/1,6/1	8	0.533	1.0	0.533	312	462	462	0.00	ICS0T0.2	220	242	750	3.00	1829	4.37	2-4	6	1.2x1.2	2-4
	1/3	1/3 to 7/1	1/3	8	0.105	1.0	0.105	312	91	91	5.40	1C2T	91	0	375	1.50	91	1.94	0-2	30	1050	0-2
	1/4	1/4 to 2/4	1/4	5	0.152	1.0	0.152	365	154	154	5.40	1C3T	139	15	375	1.50	126	1.94	2-4	55	1050	2-4
	2/4	2/4 to 7/1	1/4,2/4	8	0.326	1.0	0.326	312	283	298	4.00	1C3T	207	91	450	1.50	346	2.20	2-4	13	1050	2-4
	7/1	7/1 to 8/1	1/1,1/2, 2/2,2/1, 3/1,6/1, 1/3,1/4, 2/4,7/1	8	0.629	1.0	0.629	312	545	878	0.00	2CS2T0.2	506	372	825	4.00	2772	5.40	2-4	3	1350E	2-4
	8/1	8/1 to 9/1	1/1,1/2, 2/2,2/1, 3/1,6/1, 1/3,1/4, 2/4,7/1									EXIST MH			825	4.00	2772	5.40			break in	
								Total Q	**3144**	**m^3/s**												

Appendix F: Stormwater gully capture charts

Max Q	DRAINWAY PLUS INLET CAPTURE	
Common	Grate / Cover	Maxflow
	Inlet Code - Opening - Overall	3TP/X - 5400 - 8100
	Kerb Type	Mountable M1 & Rolltop M3
	Pavement Crossfall	3%
On Grade	Blockage Factor - On Grade	0.9 - (Qudm Kerb Inlet & Grate)
	Insert Road Grade % >	5.40
	Insert Approach Flow on Grade >	245
	CAPTURE ON GRADE >	187
In Sag	Blockage Factor - In Sag	0.8 - (Qudm Kerb Inlet & Cover)
	Insert Required Sag Capture >	196
	INVERT DEPTH mm >	70
	PONDING FROM INVERT m >	1.6

Max Q	DRAINWAY PLUS INLET CAPTURE	
Common	Grate / Cover	Maxflow
	Inlet Code - Opening - Overall	1TP/X - 2700 - 4900
	Kerb Type	Mountable M1 & Rolltop M3
	Pavement Crossfall	3%
On Grade	Blockage Factor - On Grade	0.9 - (Qudm Kerb Inlet & Grate)
	Insert Road Grade % >	5.80
	Insert Approach Flow on Grade >	336
	CAPTURE ON GRADE >	183
In Sag	Blockage Factor - In Sag	0.8 - (Qudm Kerb Inlet & Cover)
	Insert Required Sag Capture >	196
	INVERT DEPTH mm >	116
	PONDING FROM INVERT m >	3.2

Max Q	DRAINWAY PLUS INLET CAPTURE	
Common	Grate / Cover	Maxflow
	Inlet Code - Opening - Overall	1TP/X - 2700 - 4900
	Kerb Type	Mountable M1 & Rolltop M3
	Pavement Crossfall	3%
On Grade	Blockage Factor - On Grade	0.9 - (Qudm Kerb Inlet & Grate)
	Insert Road Grade % >	5.40
	Insert Approach Flow on Grade >	76
	CAPTURE ON GRADE >	76
In Sag	Blockage Factor - In Sag	0.8 - (Qudm Kerb Inlet & Cover)
	Insert Required Sag Capture >	196
	INVERT DEPTH mm >	116
	PONDING FROM INVERT m >	3.2

Max Q	DRAINWAY PLUS INLET CAPTURE	
Common	Grate / Cover	Maxflow
	Inlet Code - Opening - Overall	2TP/X - 4050 - 6500
	Kerb Type	Mountable M1 & Rolltop M3
	Pavement Crossfall	3%
On Grade	Blockage Factor - On Grade	0.9 - (Qudm Kerb Inlet & Grate)
	Insert Road Grade % >	5.40
	Insert Approach Flow on Grade >	91
	CAPTURE ON GRADE >	91
In Sag	Blockage Factor - In Sag	0.8 - (Qudm Kerb Inlet & Cover)
	Insert Required Sag Capture >	196
	INVERT DEPTH mm >	94
	PONDING FROM INVERT m >	2.4

Max Q	DRAINWAY PLUS INLET CAPTURE	
Common	Grate / Cover	Maxflow
	Inlet Code - Opening - Overall	3TP/X - 5400 - 8100
	Kerb Type	Mountable M1 & Rolltop M3
	Pavement Crossfall	3%
On Grade	Blockage Factor - On Grade	0.9 - (Qudm Kerb Inlet & Grate)
	Insert Road Grade % >	5.40
	Insert Approach Flow on Grade >	154
	CAPTURE ON GRADE >	139
In Sag	Blockage Factor - In Sag	0.8 - (Qudm Kerb Inlet & Cover)
	Insert Required Sag Capture >	196
	INVERT DEPTH mm >	70
	PONDING FROM INVERT m >	1.6

Max Q	DRAINWAY PLUS INLET CAPTURE	
Common	Grate / Cover	Maxflow
	Inlet Code - Opening - Overall	3TP/X - 5400 - 8100
	Kerb Type	Mountable M1 & Rolltop M3
	Pavement Crossfall	3%
On Grade	Blockage Factor - On Grade	0.9 - (Qudm Kerb Inlet & Grate)
	Insert Road Grade % >	5.40
	Insert Approach Flow on Grade >	300
	CAPTURE ON GRADE >	212
In Sag	Blockage Factor - In Sag	0.8 - (Qudm Kerb Inlet & Cover)
	Insert Required Sag Capture >	196
	INVERT DEPTH mm >	70
	PONDING FROM INVERT m >	1.6

Max Q	DRAINWAY PLUS INLET CAPTURE	
Common	Grate / Cover	Maxflow
	Inlet Code - Opening - Overall	1TP/X - 2700 - 4900
	Kerb Type	Mountable M1 & Rolltop M3
	Pavement Crossfall	3%
On Grade	Blockage Factor - On Grade	0.9 - (Qudm Kerb Inlet & Grate)
	Insert Road Grade % >	5.40
	Insert Approach Flow on Grade >	144
	CAPTURE ON GRADE >	111
In Sag	Blockage Factor - In Sag	0.8 - (Qudm Kerb Inlet & Cover)
	Insert Required Sag Capture >	120
	INVERT DEPTH mm >	87
	PONDING FROM INVERT m >	2.2

Max Q	DRAINWAY PLUS INLET CAPTURE	
Common	Grate / Cover	Maxflow
	Inlet Code - Opening - Overall	1TP/X - 2700 - 4900
	Kerb Type	Mountable M1 & Rolltop M3
	Pavement Crossfall	3%
On Grade	Blockage Factor - On Grade	0.9 - (Qudm Kerb Inlet & Grate)
	Insert Road Grade % >	5.80
	Insert Approach Flow on Grade >	336
	CAPTURE ON GRADE >	183
In Sag	Blockage Factor - In Sag	0.8 - (Qudm Kerb Inlet & Cover)
	Insert Required Sag Capture >	120
	INVERT DEPTH mm >	87
	PONDING FROM INVERT m >	2.2

Appendix G: Pipe flow

Data Input

DIAMETER (mm)	825 mm	DIAMETER (mm)	675 mm	DIAMETER (mm)	750 mm	FLOW (l/s)	1189 l/s	FLOW (l/s)	1189 l/s
SLOPE (%)	4 %	FLOW (l/s)	1189 l/s	VELOCITY (m^2/s)	3.3 m^2/s	SLOPE (%)	2 %	VELOCITY (m^2/s)	3.3 m^2/s

Results

FLOW (l/s)	2872.027 l/s	SLOPE (%)	1.999 %	FLOW (l/s)	1458.482 l/s	DIAMETER (mm)	674.947 mm	DIAMETER (mm)	677.176 mm
VELOCITY (m^2/s)	5.371 m^2/s	VELOCITY (m^2/s)	3.321 m^2/s	SLOPE (%)	1.715 %	VELOCITY (m^2/s)	3.322 m^2/s	SLOPE (%)	1.965 %

Areas of Pipes

Pipe Size	Pi	Area	2x	3x
300	3.141593	0.0707	0.1414	0.2121
375	3.141593	0.1104	0.2209	0.3313
450	3.141593	0.1590	0.3181	0.4771
525	3.141593	0.2165	0.4330	0.6494
600	3.141593	0.2827	0.5655	0.8482
675	3.141593	0.3578	0.7157	1.0735
725	3.141593	0.4128	0.8256	1.2385
825	3.141593	0.5346	1.0691	1.6037
900	3.141593	0.6362	1.2723	1.9085
975	3.141593	0.7466	1.4932	2.2399
1050	3.141593	0.8659	1.7318	2.5977
1125	3.141593	0.9940	1.9880	2.9821

Constants Used

N= 23.98546

PIE = 3.14286

Appendix H: Bill of quantities and estimates

SHAILER PARK - CURRENT 10% AEP ESTIMATE

No.	Description	Comment	Unit	Unit Cost	Quantity	Amount
	DRAINAGE					
3076	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**0-2m depth**	m	$ 401.47	83	$ 33,323.00
3176	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**2-4m depth**	m	$ 491.47		$ -
3077	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**0-2m depth**	m	$ 580.57		$ -
3177	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**2-4m depth**	m	$ 690.57		$ -
3078	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**0-2m depth**	m	$ 643.94	33	$ 21,251.00
3178	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**2-4m depth**	m	$ 763.94	25	$ 19,099.00
3079	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**0-2m depth**	m	$ 655.02	8	$ 5,241.00
3179	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**2-4m depth**	m	$ 792.32	36	$ 28,524.00
3080	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**0-2m depth**	m	$ 690.18		$ -
3180	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**2-4m depth**	m	$ 850.18	3	$ 2,551.00
3081	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**0-2m depth**	m	$ 743.36		$ -
3181	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**2-4m depth**	m	$ 908.36		$ -
3082	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**0-2m depth**	m	$ 865.37		$ -
3182	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**2-4m depth**	m	$ 1,045.37		$ -
3083	Supply/excavate/lay/backfill 900mm RC pipe Class 3	**0-2m depth**	m	$ 887.08		$ -
0139	Break into & alter existing manholes	***Structure 8/1***	ITEM	$ 3,600.00	1	$ 3,600.00
0140	Supply/install Side entry pit Type 1C0T	***Structure 3/1***	No.	$ 2,889.38	1	$ 2,890.00
0141	Supply/install Side entry pit Type 1C1T	***Structure 1/1, 1/2, 1/3, 1/4***	No.	$ 3,495.44	4	$ 13,982.00
0142	Supply/install Side entry pit Type 1C2T		No.	$ 4,150.92		$ -
0143	Supply/install Side entry pit Type 1C3T		No.	$ 4,406.40		$ -
0144	Supply/install Side entry pit Type 2C2T	***Structure 2/1, 7/1***	No.	$ 4,910.20	2	$ 9,821.00
0146	Supply/construct Manholes 1050mm 0-2m	***Structure 1/1, 1/2, 4/1, 1/3, 1/4***	No.	$ 2,823.22	5	$ 14,117.00
0151	Supply/construct Manholes 1050mm 2-4m	***Structure 3/1, 5/1***	No.	$ 4,777.74	2	$ 9,556.00
0155	Manholes Special in place (Elongated 1350)	***Structure 2/1, 7/1***	ITEM	$ 9,500.00	2	$ 19,000.00
0156	Supply/construct Field inlet 1200x1200	***Structure 6/1***	ITEM	$ 4,200.00	1	$ 4,200.00
	TOTAL					$ 187,155.00

SHAILER PARK - RCP 4.5 2040 10% AEP ESTIMATE

No.	Description	Comment	Unit	Unit Cost	Quantity	Amount
	DRAINAGE					
3076	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**0-2m depth**	m	$ 401.47	83	$ 33,323.00
3176	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**2-4m depth**	m	$ 491.47		$ -
3077	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**0-2m depth**	m	$ 580.57		$ -
3177	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**2-4m depth**	m	$ 690.57		$ -
3078	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**0-2m depth**	m	$ 643.94	33	$ 21,251.00
3178	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**2-4m depth**	m	$ 763.94	25	$ 19,099.00
3079	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**0-2m depth**	m	$ 655.02	8	$ 5,241.00
3179	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**2-4m depth**	m	$ 792.32	36	$ 28,524.00
3080	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**0-2m depth**	m	$ 690.18		$ -
3180	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**2-4m depth**	m	$ 850.18	3	$ 2,551.00
3081	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**0-2m depth**	m	$ 743.36		$ -
3181	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**2-4m depth**	m	$ 908.36		$ -
3082	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**0-2m depth**	m	$ 865.37		$ -
3182	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**2-4m depth**	m	$ 1,045.37		$ -
3083	Supply/excavate/lay/backfill 900mm RC pipe Class 3	**0-2m depth**	m	$ 887.08		$ -
0139	Break into & alter existing manholes	***Structure 8/1***	ITEM	$ 3,600.00	1	$ 3,600.00
0140	Supply/install Side entry pit Type 1C0T	***Structure 3/1***	No.	$ 2,889.38	1	$ 2,890.00
0141	Supply/install Side entry pit Type 1C1T	***Structure 1/1, 1/2, 1/3, 1/4***	No.	$ 3,495.44	4	$ 13,982.00
0142	Supply/install Side entry pit Type 1C2T		No.	$ 4,150.92		$ -
0143	Supply/install Side entry pit Type 1C3T		No.	$ 4,406.40		$ -
0144	Supply/install Side entry pit Type 2C2T	***Structure 2/1, 7/1***	No.	$ 4,910.20	2	$ 9,821.00
0146	Supply/construct Manholes 1050mm 0-2m	***Structure 1/1, 1/2, 4/1, 1/3, 1/4***	No.	$ 2,823.22	5	$ 14,117.00
0151	Supply/construct Manholes 1050mm 2-4m	***Structure 3/1, 5/1***	No.	$ 4,777.74	2	$ 9,556.00
0155	Manholes Special in place (Elongated 1350)	***Structure 2/1, 7/1***	ITEM	$ 9,500.00	2	$ 19,000.00
0156	Supply/construct Field inlet 1200x1200	***Structure 6/1***	ITEM	$ 4,200.00	1	$ 4,200.00
	TOTAL					$ 187,155.00

Shailer Park - RCP 4.5 2090 10% AEP Estimate

No.	Description	Comment	Unit	Unit Cost	Quantity	Amount
	Drainage					
3076	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**0-2m depth**	m	$ 401.47	83	$ 33,323.00
3176	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**2-4m depth**	m	$ 491.47		$ -
3077	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**0-2m depth**	m	$ 580.57		$ -
3177	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**2-4m depth**	m	$ 690.57		$ -
3078	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**0-2m depth**	m	$ 643.94	33	$ 21,251.00
3178	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**2-4m depth**	m	$ 763.94	25	$ 19,099.00
3079	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**0-2m depth**	m	$ 655.02		$ -
3179	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**2-4m depth**	m	$ 792.32	30	$ 23,770.00
3080	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**0-2m depth**	m	$ 690.18	8	$ 5,522.00
3180	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**2-4m depth**	m	$ 850.18	6	$ 5,102.00
3081	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**0-2m depth**	m	$ 743.36		$ -
3181	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**2-4m depth**	m	$ 908.36	3	$ 2,726.00
3082	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**0-2m depth**	m	$ 865.37		$ -
3182	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**2-4m depth**	m	$ 1,045.37		$ -
3083	Supply/excavate/lay/backfill 900mm RC pipe Class 3	**0-2m depth**	m	$ 887.08		$ -
0139	Break into & alter existing manholes	***Structure 8/1***	ITEM	$ 3,600.00	1	$ 3,600.00
0140	Supply/install Side entry pit Type 1C0T	***Structure 3/1***	No.	$ 2,889.38	1	$ 2,890.00
0141	Supply/install Side entry pit Type 1C1T	***Structure 1/1, 1/2, 1/3, 1/4***	No.	$ 3,495.44	4	$ 13,982.00
0142	Supply/install Side entry pit Type 1C2T	***Structure 1/2***	No.	$ 4,150.92		$ -
0143	Supply/install Side entry pit Type 1C3T	***Structure 1/1, 1/2, 1/4***	No.	$ 4,406.40		$ -
0144	Supply/install Side entry pit Type 2C2T	***Structure 2/1, 7/1***	No.	$ 4,910.20	2	$ 9,821.00
0146	Supply/construct Manholes 1050mm 0-2m	***Structure 1/1, 1/2, 4/1, 1/3, 1/4***	No.	$ 2,823.22	5	$ 14,117.00
0151	Supply/construct Manholes 1050mm 2-4m	***Structure 3/1, 5/1***	No.	$ 4,777.74	2	$ 9,556.00
0155	Manholes Special in place (Elongated 1350)	***Structure 2/1, 7/1***	ITEM	$ 9,500.00	2	$ 19,000.00
0156	Supply/construct Field inlet 1200x1200	***Structure 6/1***	ITEM	$ 4,200.00	1	$ 4,200.00
	TOTAL					$ 187,959.00

Shailer Park - RCP 8.5 2040 10% AEP Estimate

No.	Description	Comment	Unit	Unit Cost	Quantity	Amount
	Drainage					
3076	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**0-2m depth**	m	$ 401.47	83	$ 33,323.00
3176	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**2-4m depth**	m	$ 491.47		$ -
3077	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**0-2m depth**	m	$ 580.57		$ -
3177	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**2-4m depth**	m	$ 690.57		$ -
3078	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**0-2m depth**	m	$ 643.94	33	$ 21,251.00
3178	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**2-4m depth**	m	$ 763.94	25	$ 19,099.00
3079	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**0-2m depth**	m	$ 655.02		$ -
3179	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**2-4m depth**	m	$ 792.32	36	$ 28,524.00
3080	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**0-2m depth**	m	$ 690.18	8	$ 5,522.00
3180	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**2-4m depth**	m	$ 850.18	3	$ 2,551.00
3081	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**0-2m depth**	m	$ 743.36		$ -
3181	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**2-4m depth**	m	$ 908.36		$ -
3082	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**0-2m depth**	m	$ 865.37		$ -
3182	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**2-4m depth**	m	$ 1,045.37		$ -
3083	Supply/excavate/lay/backfill 900mm RC pipe Class 3	**0-2m depth**	m	$ 887.08		$ -
0139	Break into & alter existing manholes	***Structure 8/1***	ITEM	$ 3,600.00	1	$ 3,600.00
0140	Supply/install Side entry pit Type 1C0T	***Structure 3/1***	No.	$ 2,889.38	1	$ 2,890.00
0141	Supply/install Side entry pit Type 1C1T	***Structure 1/1, 1/2, 1/3, 1/4***	No.	$ 3,495.44	4	$ 13,982.00
0142	Supply/install Side entry pit Type 1C2T		No.	$ 4,150.92		$ -
0143	Supply/install Side entry pit Type 1C3T		No.	$ 4,406.40		$ -
0144	Supply/install Side entry pit Type 2C2T	***Structure 2/1, 7/1***	No.	$ 4,910.20	2	$ 9,821.00
0146	Supply/construct Manholes 1050mm 0-2m	***Structure 1/1, 1/2, 4/1, 1/3, 1/4***	No.	$ 2,823.22	5	$ 14,117.00
0151	Supply/construct Manholes 1050mm 2-4m	***Structure 3/1, 5/1***	No.	$ 4,777.74	2	$ 9,556.00
0155	Manholes Special in place (Elongated 1350)	***Structure 2/1, 7/1***	ITEM	$ 9,500.00	2	$ 19,000.00
0156	Supply/construct Field inlet 1200x1200	***Structure 6/1***	ITEM	$ 4,200.00	1	$ 4,200.00
	TOTAL					$ 187,436.00

SHAILER PARK - RCP 8.5 2090 10% AEP ESTIMATE

No.	Description	Comment	Unit	Unit Cost	Quantity	Amount
	DRAINAGE					
3076	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**0-2m depth**	m	$ 401.47	83	$ 33,323.00
3176	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**2-4m depth**	m	$ 491.47		$ -
3077	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**0-2m depth**	m	$ 580.57		$ -
3177	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**2-4m depth**	m	$ 690.57		$ -
3078	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**0-2m depth**	m	$ 643.94	33	$ 21,251.00
3178	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**2-4m depth**	m	$ 763.94	25	$ 19,099.00
3079	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**0-2m depth**	m	$ 655.02		$ -
3179	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**2-4m depth**	m	$ 792.32	36	$ 28,524.00
3080	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**0-2m depth**	m	$ 690.18	8	$ 5,522.00
3180	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**2-4m depth**	m	$ 850.18		$ -
3081	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**0-2m depth**	m	$ 743.36		$ -
3181	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**2-4m depth**	m	$ 908.36	3	$ 2,726.00
3082	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**0-2m depth**	m	$ 865.37		$ -
3182	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**2-4m depth**	m	$ 1,045.37		$ -
3083	Supply/excavate/lay/backfill 900mm RC pipe Class 3	**0-2m depth**	m	$ 887.08		$ -
0139	Break into & alter existing manholes	***Structure 8/1***	ITEM	$ 3,600.00	1	$ 3,600.00
0140	Supply/install Side entry pit Type 1C0T	***Structure 3/1***	No.	$ 2,889.38	1	$ 2,890.00
0141	Supply/install Side entry pit Type 1C1T	***Structure 1/3, 1/4***	No.	$ 3,495.44	2	$ 6,991.00
0142	Supply/install Side entry pit Type 1C2T	***Structure 1/1, 1/2***	No.	$ 4,150.92	2	$ 8,302.00
0143	Supply/install Side entry pit Type 1C3T		No.	$ 4,406.40		$ -
0144	Supply/install Side entry pit Type 2C2T	***Structure 2/1, 7/1***	No.	$ 4,910.20	2	$ 9,821.00
0146	Supply/construct Manholes 1050mm 0-2m	***Structure 1/1, 1/2, 4/1, 1/3, 1/4***	No.	$ 2,823.22	5	$ 14,117.00
0151	Supply/construct Manholes 1050mm 2-4m	***Structure 3/1, 5/1***	No.	$ 4,777.74	2	$ 9,556.00
0155	Manholes Special in place (Elongated 1350)	***Structure 2/1, 7/1***	ITEM	$ 9,500.00	2	$ 19,000.00
0156	Supply/construct Field inlet 1200x1200	***Structure 6/1***	ITEM	$ 4,200.00	1	$ 4,200.00
	TOTAL					$ 188,922.00

SHAILER PARK - CURRENT 1% AEP ESTIMATE

No.	Description	Comment	Unit	Unit Cost	Quantity	Amount
	DRAINAGE					
3076	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**0-2m depth**	m	$ 401.47	83	$ 33,323.00
3176	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**2-4m depth**	m	$ 491.47		$ -
3077	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**0-2m depth**	m	$ 580.57		$ -
3177	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**2-4m depth**	m	$ 690.57		$ -
3078	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**0-2m depth**	m	$ 643.94		$ -
3178	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**2-4m depth**	m	$ 763.94		$ -
3079	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**0-2m depth**	m	$ 655.02	33	$ 21,616.00
3179	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**2-4m depth**	m	$ 792.32	25	$ 19,808.00
3080	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**0-2m depth**	m	$ 690.18	8	$ 5,522.00
3180	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**2-4m depth**	m	$ 850.18	30	$ 25,506.00
3081	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**0-2m depth**	m	$ 743.36		$ -
3181	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**2-4m depth**	m	$ 908.36	6	$ 5,451.00
3082	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**0-2m depth**	m	$ 865.37		$ -
3182	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**2-4m depth**	m	$ 1,045.37	3	$ 3,137.00
3083	Supply/excavate/lay/backfill 900mm RC pipe Class 3	**0-2m depth**	m	$ 887.08		$ -
0139	Break into & alter existing manholes	***Structure 8/1***	ITEM	$ 3,600.00	1	$ 3,600.00
0140	Supply/install Side entry pit Type 1C0T		No.	$ 2,889.38		$ -
0141	Supply/install Side entry pit Type 1C1T	***Structure 1/3***	No.	$ 3,495.44	1	$ 3,496.00
0142	Supply/install Side entry pit Type 1C2T		No.	$ 4,150.92		$ -
0143	Supply/install Side entry pit Type 1C3T	***Structure 1/1, 1/2, 1/4***	No.	$ 4,406.40	3	$ 13,220.00
0144	Supply/install Side entry pit Type 2C2T	***Structure 2/1, 3/1, 7/1***	No.	$ 4,910.20	3	$ 14,731.00
0146	Supply/construct Manholes 1050mm 0-2m	***Structure 1/1, 1/2, 4/1, 1/3, 1/4***	No.	$ 2,823.22	5	$ 14,117.00
0151	Supply/construct Manholes 1050mm 2-4m	***Structure 5/1***	No.	$ 4,777.74	1	$ 4,778.00
0155	Manholes Special in place (Elongated 1350)	***Structure 2/1, 3/1, 7/1***	ITEM	$ 9,500.00	3	$ 28,500.00
0156	Supply/construct Field inlet 1200x1200	***Structure 6/1***	ITEM	$ 4,200.00	1	$ 4,200.00
	TOTAL					$ 201,005.00

SHAILER PARK - RCP 4.5 2040 1% AEP ESTIMATE

No.	Description	Comment	Unit	Unit Cost	Quantity	Amount
	DRAINAGE					
3076	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**0-2m depth**	m	$ 401.47	83	$ 33,323.00
3176	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**2-4m depth**	m	$ 491.47		$ -
3077	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**0-2m depth**	m	$ 580.57		$ -
3177	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**2-4m depth**	m	$ 690.57		$ -
3078	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**0-2m depth**	m	$ 643.94		$ -
3178	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**2-4m depth**	m	$ 763.94		$ -
3079	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**0-2m depth**	m	$ 655.02	33	$ 21,616.00
3179	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**2-4m depth**	m	$ 792.32	25	$ 19,808.00
3080	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**0-2m depth**	m	$ 690.18	8	$ 5,522.00
3180	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**2-4m depth**	m	$ 850.18	30	$ 25,506.00
3081	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**0-2m depth**	m	$ 743.36		$ -
3181	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**2-4m depth**	m	$ 908.36	6	$ 5,451.00
3082	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**0-2m depth**	m	$ 865.37		$ -
3182	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**2-4m depth**	m	$ 1,045.37	3	$ 3,137.00
3083	Supply/excavate/lay/backfill 900mm RC pipe Class 3	**0-2m depth**	m	$ 887.08		$ -
0139	Break into & alter existing manholes	***Structure 8/1***	ITEM	$ 3,600.00	1	$ 3,600.00
0140	Supply/install Side entry pit Type 1C0T		No.	$ 2,889.38		$ -
0141	Supply/install Side entry pit Type 1C1T	***Structure 1/3***	No.	$ 3,495.44	1	$ 3,496.00
0142	Supply/install Side entry pit Type 1C2T		No.	$ 4,150.92		$ -
0143	Supply/install Side entry pit Type 1C3T	***Structure 1/1, 1/2, 1/4***	No.	$ 4,406.40	3	$ 13,220.00
0144	Supply/install Side entry pit Type 2C2T	***Structure 2/1, 3/1, 7/1***	No.	$ 4,910.20	3	$ 14,731.00
0146	Supply/construct Manholes 1050mm 0-2m	***Structure 1/1, 1/2, 4/1, 1/3, 1/4***	No.	$ 2,823.22	5	$ 14,117.00
0151	Supply/construct Manholes 1050mm 2-4m	***Structure 5/1***	No.	$ 4,777.74	1	$ 4,778.00
0155	Manholes Special in place (Elongated 1350)	***Structure 2/1, 3/1, 7/1***	ITEM	$ 9,500.00	3	$ 28,500.00
0156	Supply/construct Field inlet 1200x1200	***Structure 6/1***	ITEM	$ 4,200.00	1	$ 4,200.00
	TOTAL					$ 201,005.00

SHAILER PARK - RCP 4.5 2090 1% AEP ESTIMATE

No.	Description	Comment	Unit	Unit Cost	Quantity	Amount
	DRAINAGE					
3076	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**0-2m depth**	m	$ 401.47	75	$ 30,111.00
3176	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**2-4m depth**	m	$ 491.47		$ -
3077	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**0-2m depth**	m	$ 580.57	8	$ 4,645.00
3177	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**2-4m depth**	m	$ 690.57		$ -
3078	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**0-2m depth**	m	$ 643.94		$ -
3178	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**2-4m depth**	m	$ 763.94		$ -
3079	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**0-2m depth**	m	$ 655.02		$ -
3179	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**2-4m depth**	m	$ 792.32		$ -
3080	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**0-2m depth**	m	$ 690.18	41	$ 28,298.00
3180	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**2-4m depth**	m	$ 850.18	25	$ 21,255.00
3081	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**0-2m depth**	m	$ 743.36		$ -
3181	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**2-4m depth**	m	$ 908.36	36	$ 32,702.00
3082	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**0-2m depth**	m	$ 865.37		$ -
3182	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**2-4m depth**	m	$ 1,045.37	3	$ 3,137.00
3083	Supply/excavate/lay/backfill 900mm RC pipe Class 3	**0-2m depth**	m	$ 887.08		$ -
0139	Break into & alter existing manholes	***Structure 8/1***	ITEM	$ 3,600.00	1	$ 3,600.00
0140	Supply/install Side entry pit Type 1C0T		No.	$ 2,889.38		$ -
0141	Supply/install Side entry pit Type 1C1T	***Structure 1/3***	No.	$ 3,495.44	1	$ 3,496.00
0142	Supply/install Side entry pit Type 1C2T		No.	$ 4,150.92		$ -
0143	Supply/install Side entry pit Type 1C3T	***Structure 1/1, 1/2, 1/4***	No.	$ 4,406.40	3	$ 13,220.00
0144	Supply/install Side entry pit Type 2C2T	***Structure 2/1, 3/1, 7/1***	No.	$ 4,910.20	3	$ 14,731.00
0146	Supply/construct Manholes 1050mm 0-2m	***Structure 1/1, 1/2, 4/1, 1/3, 1/4***	No.	$ 2,823.22	5	$ 14,117.00
0151	Supply/construct Manholes 1050mm 2-4m	***Structure 5/1***	No.	$ 4,777.74	1	$ 4,778.00
0155	Manholes Special in place (Elongated 1350)	***Structure 2/1, 3/1, 7/1***	ITEM	$ 9,500.00	3	$ 28,500.00
0156	Supply/construct Field inlet 1200x1200	***Structure 6/1***	ITEM	$ 4,200.00	1	$ 4,200.00
	TOTAL					$ 206,790.00

Shailer Park - RCP 8.5 2040 1% AEP Estimate

No.	Description	Comment	Unit	Unit Cost	Quantity	Amount
	Drainage					
3076	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**0-2m depth**	m	$ 401.47	83	$ 33,323.00
3176	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**2-4m depth**	m	$ 491.47		$ -
3077	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**0-2m depth**	m	$ 580.57		$ -
3177	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**2-4m depth**	m	$ 690.57		$ -
3078	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**0-2m depth**	m	$ 643.94		$ -
3178	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**2-4m depth**	m	$ 763.94		$ -
3079	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**0-2m depth**	m	$ 655.02	33	$ 21,616.00
3179	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**2-4m depth**	m	$ 792.32	25	$ 19,808.00
3080	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**0-2m depth**	m	$ 690.18	8	$ 5,522.00
3180	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**2-4m depth**	m	$ 850.18	30	$ 25,506.00
3081	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**0-2m depth**	m	$ 743.36		$ -
3181	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**2-4m depth**	m	$ 908.36	6	$ 5,451.00
3082	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**0-2m depth**	m	$ 865.37		$ -
3182	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**2-4m depth**	m	$ 1,045.37	3	$ 3,137.00
3083	Supply/excavate/lay/backfill 900mm RC pipe Class 3	**0-2m depth**	m	$ 887.08		$ -
0139	Break into & alter existing manholes	***Structure 8/1***	ITEM	$ 3,600.00	1	$ 3,600.00
0140	Supply/install Side entry pit Type 1C0T		No.	$ 2,889.38		$ -
0141	Supply/install Side entry pit Type 1C1T	***Structure 1/3***	No.	$ 3,495.44	1	$ 3,496.00
0142	Supply/install Side entry pit Type 1C2T		No.	$ 4,150.92		$ -
0143	Supply/install Side entry pit Type 1C3T	***Structure 1/1, 1/2, 1/4***	No.	$ 4,406.40	3	$ 13,220.00
0144	Supply/install Side entry pit Type 2C2T	***Structure 2/1, 3/1, 7/1***	No.	$ 4,910.20	3	$ 14,731.00
0146	Supply/construct Manholes 1050mm 0-2m	***Structure 1/1, 1/2, 4/1, 1/3, 1/4***	No.	$ 2,823.22	5	$ 14,117.00
0151	Supply/construct Manholes 1050mm 2-4m	***Structure 5/1***	No.	$ 4,777.74	1	$ 4,778.00
0155	Manholes Special in place (Elongated 1350)	***Structure 2/1, 3/1, 7/1***	ITEM	$ 9,500.00	3	$ 28,500.00
0156	Supply/construct Field inlet 1200x1200	***Structure 6/1***	ITEM	$ 4,200.00	1	$ 4,200.00
	TOTAL					$ 201,005.00

Shailer Park - RCP 8.5 2090 1% AEP Estimate

No.	Description	Comment	Unit	Unit Cost	Quantity	Amount
	Drainage					
3076	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**0-2m depth**	m	$ 401.47	53	$ 21,279.00
3176	Supply/excavate/lay/backfill 375mm RC pipe Class 3	**2-4m depth**	m	$ 491.47	81	$ 39,810.00
3077	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**0-2m depth**	m	$ 580.57		$ -
3177	Supply/excavate/lay/backfill 450mm RC pipe Class 3	**2-4m depth**	m	$ 690.57	13	$ 8,978.00
3078	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**0-2m depth**	m	$ 643.94		$ -
3178	Supply/excavate/lay/backfill 525mm RC pipe Class 3	**2-4m depth**	m	$ 763.94		$ -
3079	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**0-2m depth**	m	$ 655.02		$ -
3179	Supply/excavate/lay/backfill 600mm RC pipe Class 3	**2-4m depth**	m	$ 792.32		$ -
3080	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**0-2m depth**	m	$ 690.18	33	$ 22,776.00
3180	Supply/excavate/lay/backfill 675mm RC pipe Class 3	**2-4m depth**	m	$ 850.18	25	$ 21,255.00
3081	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**0-2m depth**	m	$ 743.36	8	$ 5,947.00
3181	Supply/excavate/lay/backfill 750mm RC pipe Class 3	**2-4m depth**	m	$ 908.36	36	$ 32,702.00
3082	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**0-2m depth**	m	$ 865.37		$ -
3182	Supply/excavate/lay/backfill 825mm RC pipe Class 3	**2-4m depth**	m	$ 1,045.37	3	$ 3,137.00
3083	Supply/excavate/lay/backfill 900mm RC pipe Class 3	**0-2m depth**	m	$ 887.08		$ -
0139	Break into & alter existing manholes	***Structure 8/1***	ITEM	$ 3,600.00	1	$ 3,600.00
0140	Supply/install Side entry pit Type 1C0T		No.	$ 2,889.38		$ -
0141	Supply/install Side entry pit Type 1C1T		No.	$ 3,495.44		$ -
0142	Supply/install Side entry pit Type 1C2T	***Structure 1/3***	No.	$ 4,150.92	1	$ 4,151.00
0143	Supply/install Side entry pit Type 1C3T	***Structure 1/1, 1/2, 2/2, 1/4, 2/4***	No.	$ 4,406.40	5	$ 22,032.00
0144	Supply/install Side entry pit Type 2C2T	***Structure 2/1, 3/1, 7/1***	No.	$ 4,910.20	3	$ 14,731.00
0146	Supply/construct Manholes 1050mm 0-2m	***Structure 1/1, 2/2, 4/1, 1/3***	No.	$ 2,823.22	4	$ 11,293.00
0151	Supply/construct Manholes 1050mm 2-4m	***Structure 1/2, 5/1, 1/4, 2/4***	No.	$ 4,777.74	4	$ 19,111.00
0155	Manholes Special in place (Elongated 1350)	***Structure 2/1, 3/1, 7/1***	ITEM	$ 9,500.00	3	$ 28,500.00
0156	Supply/construct Field inlet 1200x1200	***Structure 6/1***	ITEM	$ 4,200.00	1	$ 4,200.00
	TOTAL					$ 263,502.00