Citywide Creek & Overland Flow Path Mapping

Final Report

Prepared by Brisbane City Council and GHD Pty Ltd

April 2017

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Brisbane City Council

Citywide Creek & Overland Flow Path Mapping

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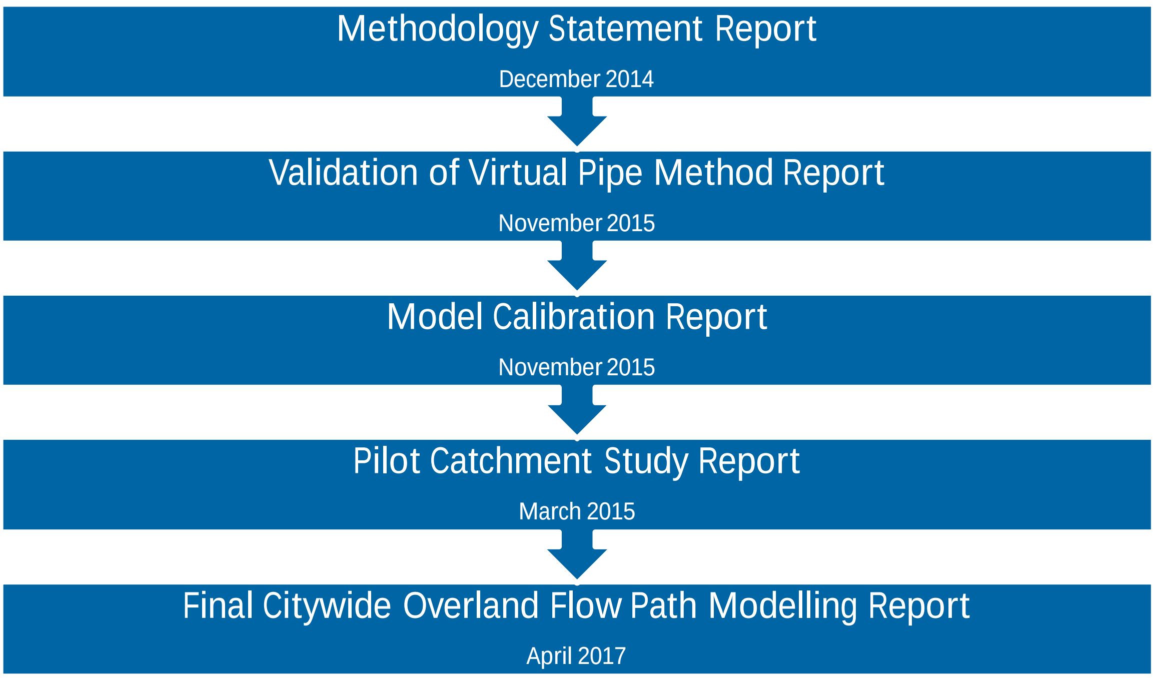
Executive summary

GHD Pty Ltd was engaged by Brisbane City Council (BCC) to build citywide hydrologic and hydraulic models of Brisbane's overland flow paths & un-modelled creeks to establish the extent, depth, velocity and hazard of flood waters associated with the 2, 5, 10, 20, 50,100, 500 and 2000 year ARI design flood events.

A three phased project approach to improving existing flood risk information that is flexible, updatable and expandable was preferred by BCC with the following key phases:

- In Phase 1 of the project, the stormwater pipe network was not required to be modelled in detail and assumptions were required to be made to account for the capacity of the underground drainage network;
- Phase 2 was proposed to be an incremental update to include stormwater trunk drainage; and
- Phase 3 was proposed to include full hydraulic representation and modelling of the entire stormwater pipe network.

GHD's current commission relates only to Phase 1 of the project. The project was undertaken as a series of separate stages, culminating in this final report. The diagram below provides an overview of the key stages and associated reports that have been provided to Council as part of Phase 1.



In order to meet the requirements of Phase 1 of the project, GHD developed a flood modelling methodology that was based on:

- A two-dimensional (2D) "rain on grid" hydraulic modelling approach;
- TUFLOW GPU software; and
- Representation and modelling of the citywide stormwater pipe network using a custom made "virtual pipe" TUFLOW GPU add on module (in lieu of full 1D/2D coupled modelling of all stormwater infrastructure).

The details of the flood modelling methodology are provided in the Methodology Statement Report (GHD, 2014). The agreed approach for this project was a rapid and cost-effective methodology that achieves the project aims within the scope of Phase 1.

GHD, in agreement with BCC, undertook a series of intermediate steps (as shown on the previous page) to develop the final citywide TUFLOW GPU models. The approach focused on the development, testing, calibration and validation of the models on small areas before applying the adopted methodology and model parameters to the GHD models that cover the entire BCC area. The individual development, testing, calibration and validation process demonstrated that the TUFLOW GPU models and model results can satisfy BCC's project requirements.

Key aspects of the TUFLOW GPU direct rainfall approach (including the use of a high-resolution DEM, fully dynamic 2D shallow water equations, spatially-distributed rainfall and plausible modelling of the stormwater drainage network) represent a significant improvement compared to other methods previously used to map overland flow paths in the Brisbane City Council area. Nonetheless, limitations primarily relating to the broad-scale nature of the current project apply. Brisbane City Council's decisions on the usage of the models and model results should be guided by the stated assumptions, limitations and potential sources of inaccuracy outlined in this high-level report and the four supporting detailed technical reports[1] prepared to meet the objectives and requirements of this project.

The key deliverables provided by GHD as part of this project included:

- Interim and final reports associated with all stages of the project (as outlined in Section 1.3);
- Raw & processed hydraulic model results (flood levels, depths, velocities and velocity-depth products) for the entire BCC area (as outlined in Section 3) for the 2, 5, 10, 20, 50, 100, 500 and 2000-year ARI storm events;
- Full TUFLOW GPU models of the entire study area; and
- GHD's direct rainfall filtering post-processing tool.

[1] *The Methodology Statement Report (GHD, 2014), the Pilot Study Report (GHD, 2015a), the Validation of the Virtual Pipes Method Report (GHD, 2015b), and the Model Calibration Report (GHD, 2015c).*

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Glossary & key terms

1D	One-Dimensional
2D	Two-Dimensional
AEP	Annual Exceedance Probability (refer to Table 1)
AHD	Australian Height Datum
ARI	Average Recurrence Interval[2] (refer to Table 1)
AR&R	Australian Rainfall & Runoff
BCC	Brisbane City Council
BoM	Bureau of Meteorology
CL	Continuing Loss (mm/hr)
DEM	Digital Elevation Model
FAM	Flood Awareness Maps (Brisbane City Council's flood mapping tool)
FPA	Flood Planning Areas (Brisbane City Council's City Plan Overlay)
GIS	Geospatial Information Services
GPU	Graphical Processing Unit
IL	Initial Loss (mm)
TUFLOW	Hydraulic model used in this study

Table 1 Flood magnitude descriptors

Average Recurrence Interval (ARI)	Annual Exceedance Probability (AEP)
10 year	10%
20 year	5%
50 year	2%
100 year	1%
500 year	0.2%
2000 year	0.05%

[2] It is noted that while AEP is considered the preferred term for describing flood magnitudes, the ARI naming convention has been adopted in this report for consistency with the terminology adopted in BCC's Project Brief and other internal BCC documents.

References

Department of Energy and Water Supply (2013), Queensland Urban Drainage Manual, Third edition (provisional)

IEAust (1999) Australian Rainfall and Runoff, A guide to flood estimation, Volumes 1 and 2, The Institution of Engineers, Australia, Barton, 1999 Edition

GHD (2014) Citywide Creek and Overland Flow Path Modelling, Methodology Statement

GHD (2015a) Citywide Creek and Overland Flow Path Modelling, Pilot Study

GHD (2015b) Citywide Creek and Overland Flow Path Modelling, Validation of Virtual Pipe Method

GHD (2015c) Citywide Creek and Overland Flow Path Modelling, Model Calibration Report

1. Introduction

This report provides an overview of the Citywide Creek and Overland Flow Path Modelling project undertaken by GHD Pty Ltd on behalf of Brisbane City Council (BCC).

1.1 Background

GHD Pty Ltd was engaged by BCC to build citywide hydrologic and hydraulic models of Brisbane's overland flow paths to establish the extent, depth, velocity and hazard of flood waters associated with the 2, 5, 10, 20, 50,100, 500 and 2000 year ARI design flood events. The extent of the study area and individual model locations are discussed in Section 2 of this report.

A three phased project approach to improving existing flood risk information that is flexible, updatable and expandable was preferred by BCC with the following key phases:

- In Phase 1 of the project, the stormwater pipe network was not required to be modelled in detail and assumptions were required to be made to account for the capacity of the underground drainage network;
- Phase 2 was proposed to be an incremental update to include stormwater trunk drainage; and
- Phase 3 was proposed to include full hydraulic representation and modelling of the entire stormwater pipe network.

GHD's current commission relates only to Phase 1 of the project.

1.2 Purpose of this report

This final report provides a general high-level overview of the project (including the methodology, limitations, assumptions, results, and potential applications for the model outputs). Specific technical detail is provided in the four intermediate technical reports prepared over the course of the project (refer Section 1.3), and reference to those documents is made throughout this report.

It is the purpose of this report that it be used as a record of the key steps undertaken as part of the project, as well as a reference document for BCC to help understand the project background and methodology when undertaking further work with the models or model results developed as part of this project.

1.3 Project stages

The project was undertaken as a series of separate stages, culminating in this final report. Figure 1-1 provides an overview of the key stages and associated reports that have been provided to Council as part of Phase 1 of the Citywide Creek and Overland Flow Path Modelling project.

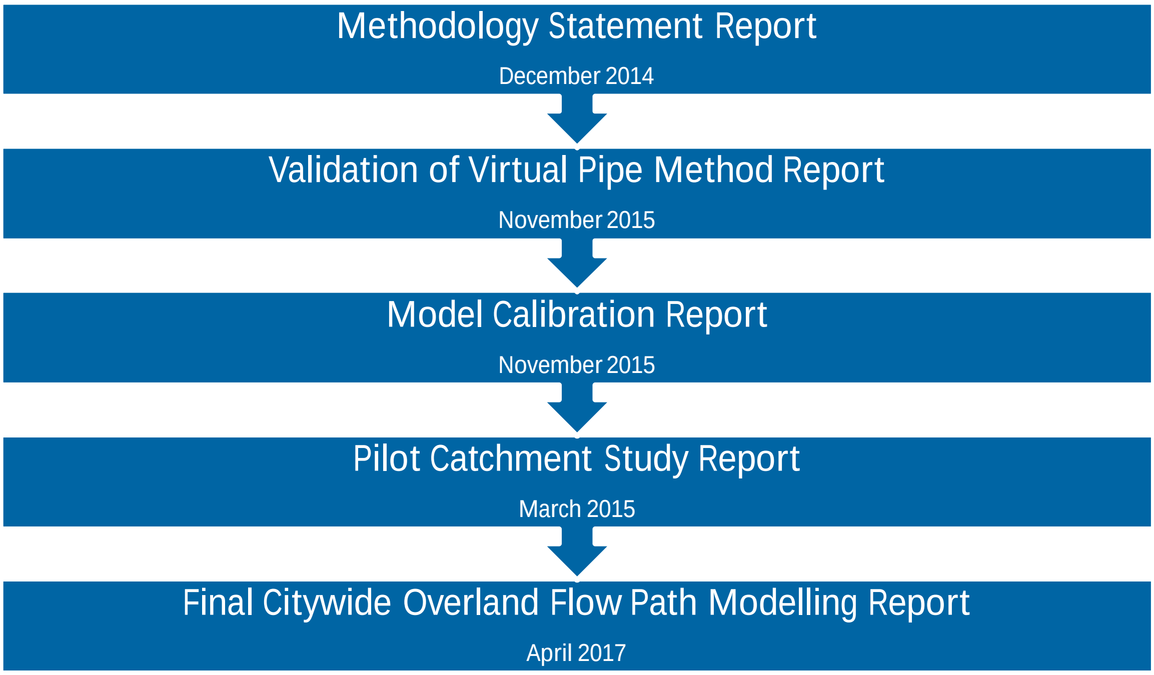


Figure 1-1 Citywide Creek and Overland Flow Path Modelling Reports

1.4 Technical overview & modelling approach

In order to meet the requirements of Phase 1 of the project, GHD developed a flood modelling methodology that was based on:

- A two-dimensional (2D) “rain on grid” hydraulic modelling approach;
- TUFLOW GPU software; and
- Representation and modelling of the citywide storm water network using a custom made “virtual pipe” TUFLOW GPU add on module (in lieu of full 1D/2D coupled modelling of all stormwater infrastructure).

The details of the flood modelling methodology are provided in the Citywide Creek and Overland Flow Path Modelling Methodology Statement Report (GHD, 2014). The agreed approach for this project was a rapid and cost-effective methodology that achieves the project aims within the scope of Phase 1.

1.5 Review process

A staged approach was adopted for the project, as outlined above. At each stage of the project, a review process was undertaken whereby BCC provided independent review and commentary on draft versions of the reports, and actions were agreed between BCC and GHD before moving to subsequent stages.

In addition to regular internal reviews of reports and models by GHD's project team, the Methodology Statement and Pilot Study reports were reviewed by an appointed external peer reviewer, Dr Bill Weeks.

A schedule of key dates relating to the review process is included below.

Table 1-1 Progress report endorsement

Report Name	Submitted to BCC	Date of BCC Endorsement
Methodology Statement Report	January 2015	20/01/2015
Validation of Virtual Pipe Method Report	March 2015	14/05/2015
Model Calibration Report	November 2015	20/01/2016
Pilot Catchment Study Report	November 2015	20/01/2016
Draft Citywide Overland Flow Path Modelling Report	April 2016	11/08/2016
Final Citywide Overland Flow Path Modelling Report (this report)	April 2017	20/04/2017

1.6 Key deliverables

GHD has provided a range of key deliverables over the course of the project. These include:

- Interim and final reports associated with all stages of the project (as outlined in Section 1.3);
- Raw & processed hydraulic model results (flood levels, depths, velocities and velocity-depth products) for the entire BCC area (as outlined in Section 3) for the 2, 5, 10, 20, 50, 100, 500 and 2000-year ARI storm events;
- Full TUFLOW GPU models of the entire study area; and
- GHD's direct rainfall filtering post-processing tool.

1.7 Scope and limitations

This report is subject to the same scope and limitations as the intermediate technical reports (refer Figure 1-1)[3] prepared as part of the Phase 1 of the Citywide Creek and Overland Flow Path Modelling project.

This report has been prepared by GHD for Brisbane City Council and may only be used and relied on by Brisbane City Council for the purpose agreed between GHD and the Brisbane City Council as set out in Section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Brisbane City Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the limitations set out in Section 5 and elsewhere throughout the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Brisbane City Council and others who provided information to GHD, which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

[3] *The Methodology Statement Report (GHD, 2014), the Pilot Study Report (GHD, 2015a), the Validation of the Virtual Pipes Method Report (GHD, 2015b), and the Model Calibration Report (GHD, 2015c).*

2. Hydraulic Modelling

2.1 Overview

In order to estimate flood characteristics for a range of flood events for all overland flow paths and un-modelled creeks in the BCC area, GHD developed a series of hydraulic models using the TUFLOW GPU software. The models use the direct rainfall or “rain-on-grid” approach to simulate catchment runoff processes.

2.2 Software

The citywide creek and overland flow path models use TUFLOW GPU. As per the BMT WBM’s documentation, TUFLOW GPU uses the same front end and model inputs as traditional TUFLOW, but makes use of the parallel computing capability of GPUs. The model is an explicit solver for the full 2D Shallow Water Equations, and conserves both momentum and volume. Presently, TUFLOW GPU is limited to 2D models only, and the inclusion of fully coupled 1D/2D elements is planned for a future release.

For further information on TUFLOW GPU, the reader is referred to the official online documentation available at http://tuflow.com/Tuflow%20Documentation.aspx.

2.2.1 Software version

The citywide TUFLOW GPU models were run using the development build of TUFLOW provided to GHD and BCC by BMT WBM that includes the virtual pipes feature. Prior to the recent 2016 TUFLOW version release, the virtual pipes feature was not available in the general public release of TUFLOW.

For subsequent iterations of the citywide modelling, it is recommended that the latest public release of TUFLOW be used. Testing should be undertaken to confirm that the latest TUFLOW version gives the same results as the previous development version.

2.3 Hardware

TUFLOW GPU requires a Windows PC with an NVIDIA CUDA enabled GPU. The models for this study will be developed and run using workstation PC’s with Intel Xeon E5-1620 CPUs, 32 GB of RAM, and NVIDIA TITAN BLACK GPUs (6 GB memory).

2.4 Model sub-areas

A series of twenty seven (27) individual sub-models was developed to cover the entire BCC area.

The extents and boundary locations for each of the 27 individual sub-models are shown on Figure 2-1. A list of individual sub-model names is provided below.

Table 2 Model sub-areas

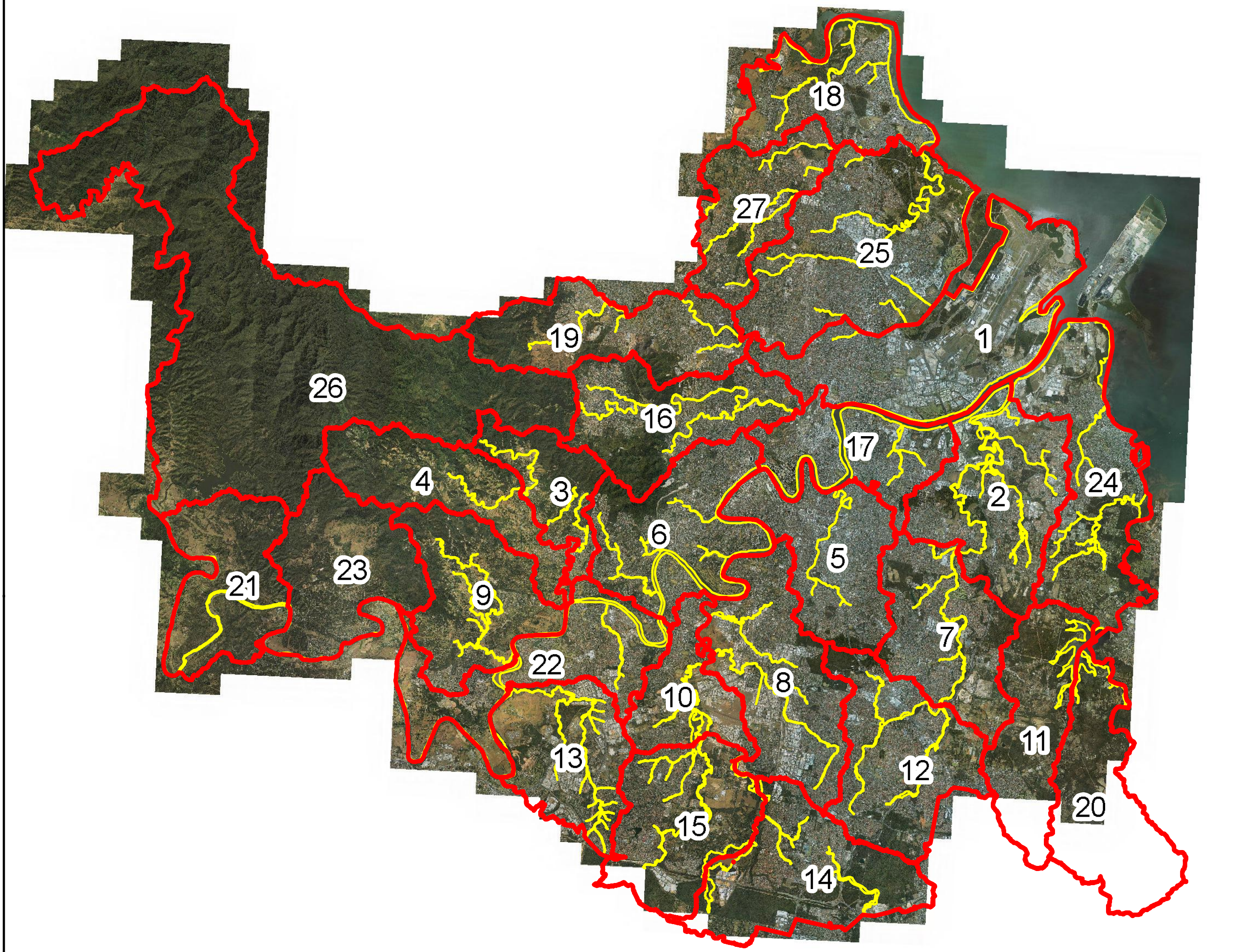
Airport	Enoggera	MiddleBulimba	TingalpaResEast
Bald Hills	InnerWest	MoggillEast	TingalpaRestWest
Blunder	Jindalee	MoggillWest	UpperBulimba
Brookfield	Kholo	Norman	UpperKedron
CabbageTree	LotaWynnum	Nundah	UpperOxley
Central	LowerBulimba	PullenPullen	WolstonSandy
Daguilar	LoxeyOxley	StableSwamp	-

Model boundaries were delineated based on local catchment boundaries, with consideration of cross-catchment flows in large events. The size and extents of the sub-models were selected in order to limit the run times of each simulation and to allow the models to be run on commonly available hardware. Each individual sub-model can be run in isolation to the other models.

For each sub-model, the following boundary conditions were used:

- Direct rainfall hyetographs applied to every active cell within the model extents;
- Downstream boundary conditions (assuming free outfall & no tailwater influence) are applied along the edge of coastal areas, the Brisbane River, and all creeks within the BCC area for which detailed hydraulic models currently exist. This approach, referred to as the “dry creek bed” approach, is explained in full in the Methodology Statement Report (GHD, 2014).

Using this approach, the TUFLOW GPU models developed as part of this study fill the gaps (in terms of overland flow paths and un-modelled creeks) in BCC’s existing suite of detailed hydraulic models without duplicating any currently modelled areas.



Catchment / Sub-Model Names

1 - Airport	7 - MiddleBulimba	14 - UpperOxley	21 - Kholo
2 - LowerBulimba	8 - StableSwamp	15 - Blunder	22 - Jindalee
3 - MoggillEast	9 - PullenPullen	16 - Enoggera	23 - Brookfield
4 - MoggillWest	10 - LowerOxley	17 - Central	24 - LotaWynnum
5 - Norman	11 - TingalpaResWest	18 - BaldHills	25 - Nundah
6 - InnerWest	12 - UpperBulimba	19 - UpperKedron	26 - Daguilar
	13 - WolstonSandy	20 - TingalpaResEast	27 - CabbageTree

LEGEND

Catchment / Sub-Model Extent

Downstream Boundary Location

1:300,000 @ A4

0 2,500 5,000 7,500 10,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Brisbane City Council
Citywide Creek and Overland Flow Path Modelling

Citywide Modelling
Catchment / Sub-Model Extents

Job Number 41-28167
Revision A
Date 05 April 2017

Figure 2.1

Hazelwood Drive (cnr Lignite Court) Morwell VIC 3840 Australia T 61 3 5136 5800 F 61 3 5136 5888 E mwlmail@ghd.com W www.ghd.com

G:\41\28167\GIS\Maps\Deliverables\01_Final_Report\Fig_01_Model_Sub_Areas.mxd

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:dcopelin

2.5 Model development, calibration & validation

GHD, in agreement with BCC, has undertaken a series of intermediate steps to develop the final citywide TUFLOW GPU models. The approach focused on the development, testing, calibration and validation of the models on small areas before applying the adopted methodology and model parameters to the GHD models that cover the entire BCC area. A general overview of key steps in the process is provided below:

1. Initial methodology development and testing was undertaken for the Norman Creek pilot catchment. The virtual pipes methodology was developed and tested in conjunction with the software vendor (BMT WBM) at this stage in the process.

2. After the initial methodology was developed and tested, the first revision of a pilot study was undertaken on the Norman Creek catchment. In this pilot study, the results of GHD's TUFLOW GPU virtual pipes models were compared to the results of BCC's existing XP-RAFTS hydrologic model and MIKE FLOOD hydraulic model developed as part of the BCC Norman Creek Flood Study. Significant sensitivity testing was also undertaken during this stage in order to understand how the pilot model behaves in response to changes in a range of key input parameters.

3. Following the completion of the initial revision of the Norman Creek pilot study, BCC and GHD agreed that the TUFLOW GPU virtual pipes method should be validated against the results of several detailed 1D/2D coupled TUFLOW models that had recently been developed by BCC. These models, developed as parts of the Castlemaine Caxton, Stratton Street and Pashen Creek Local Stormwater Management Plans, included full representation of the underground stormwater network as 1D elements coupled to the 2D surface grid. GHD was able to demonstrate that the TUFLOW GPU virtual pipes methodology together with the right set of parameters was able to achieve similar results to the detailed 1D/2D coupled TUFLOW models across a range of design storm events.

4. BCC and GHD agreed that the GHD TUFLOW GPU models should be calibrated against real world data for a range of different locations across the BCC area in order to satisfy the level of confidence in model results. GHD identified seven locations across the BCC area where sufficient historic stream gauge and rainfall data was available that could be used to inform the study. While no direct data relating to overland flow rates and levels was available, GHD selected small creek catchments (with available calibration data) that were as similar in size and scale to overland flow catchments as possible. The results of the calibration exercise across the seven locations provided confidence that the GHD TUFLOW GPU models and adopted model parameters would give satisfactory results when applied to the entire BCC area.

5. Following the completion of the pilot study, validation and calibration steps, GHD and BCC agreed on a methodology and a set of model parameters that could be applied to the entire BCC area (refer to Section 2.6). GHD then developed the 27 individual TUFLOW GPU models using the agreed approach, and ran those models for the agreed design storm events.

2.6 Technical parameters

Following completion of the Methodology Statement Report (GHD, 2014), Model Calibration Report (GHD, 2015c), Model Validation Report (GHD, 2015b) and Pilot Study Report (GHD, 2015a), a set of final TUFLOW GPU model parameters was agreed with BCC. Full details of these parameters are contained within the individual reports. However, a summary of the key model parameters is provided below.

2.6.1 DEM

The citywide TUFLOW GPU models currently use a digital elevation model (DEM) derived from BCC's 2014 LIDAR DEM. The LIDAR DEM is provided to TUFLOW GPU at the original resolution of 1 m x 1 m, and the model resamples the DEM at the specific computational grid cell size (2 m for all models except for the D'Aguilar sub-model which uses a 4 m grid cell size).

2.6.2 Building footprints

The obstruction to overland flow caused by buildings was represented in the TUFLOW GPU model through increased Manning's n values as outlined below. The approximate extent of buildings were derived from BCC's Impervious Surface Mapping layer which is based on the 2014 LIDAR and WorldView-2 satellite ima gery (at a 2 m grid resolution).

2.6.3 Manning's n hydraulic roughness coefficients

A set of Manning's 'n' hydraulic roughness parameters that vary with flood depth were adopted (refer Table 2-3). It is noted that higher roughness values have been introduced for shallow flood depths for most material categories. This is to represent greater resistance experienced by shallow sheet flows as they traverse vegetated areas and private properties. The spatial coverage and distribution of the different surface types was based on the same Impervious Surface Mapping layer as the approximate building extents.

Table 2-3 Manning's n roughness coefficients

Material Layer	Depth 1 (m)	Manning's 1	Depth 2 (m)	Manning's 2
Water	0.02 *(constant Manning's n value)*			
Bare Earth	0.02	0.1	0.09	0.035
Open Ground	0.02	0.2	0.09	0.029
Vegetation	0.02	0.2	0.09	0.1
Buildings	0.02	0.013	0.05	0.1
Road Pavement	0.017 *(constant Manning's n value)*			
Backyard	0.02	0.2	0.09	0.15

2.6.4 Stormwater network and virtual pipes model parameters

The "Virtual Pipe" module of the TUFLOW GPU software was used to represent the exiting stormwater network across the 27 catchments that comprise the BCC area. A number of model parameters were required to define the function of the stormwater drainage network in the Virtual Pipes module. These included:

- Stormwater gully inlet locations;
- Stormwater gully inlet depth vs discharge curves;
- Maximum stormwater network outlet capacities; and
- Culvert inlet curves.

The capped inlet curves (for stormwater gully inlets) as recommended in GHD's Validation of the Virtual Pipe Method report were adopted for the final TUFLOW GPU citywide model runs. These capped inlet curves resulted in the best match between the results of the TUFLOW GPU virtual pipes models and BCC's existing detailed coupled 1D/2D TUFLOW models. The capping of the inlet curves serves as a proxy for hydraulic losses and other capacity constraints within the stormwater network that are not explicitly included in the virtual pipes method. When using the capped inlet curves, with all other model parameters held constant, the difference between peak water levels from the TUFLOW GPU virtual pipes approach and the traditional coupled 1D/2D TUFLOW approach is generally less than +/- 0.1 m for most areas over a range of design storm event magnitudes. Full details of this testing is provided in the Validation of Virtual Pipe Method Report.

Culvert inlet curves (for each specific culvert configuration) as well as all other virtual pipes parameters have been set as outlined in the Methodology Statement. The curves were calculated based on a set of standardised BCC inlet pit types following the procedure outlined in the Queensland Urban Drainage Manual (QUDM, DEWS, 2013) Section 7.5.4 (using weir and orifice equations). A full comprehensive blockage assessment (as outlined in ARR 2015 Book 6, Chapter 6) was not undertaken within the scope of this project.

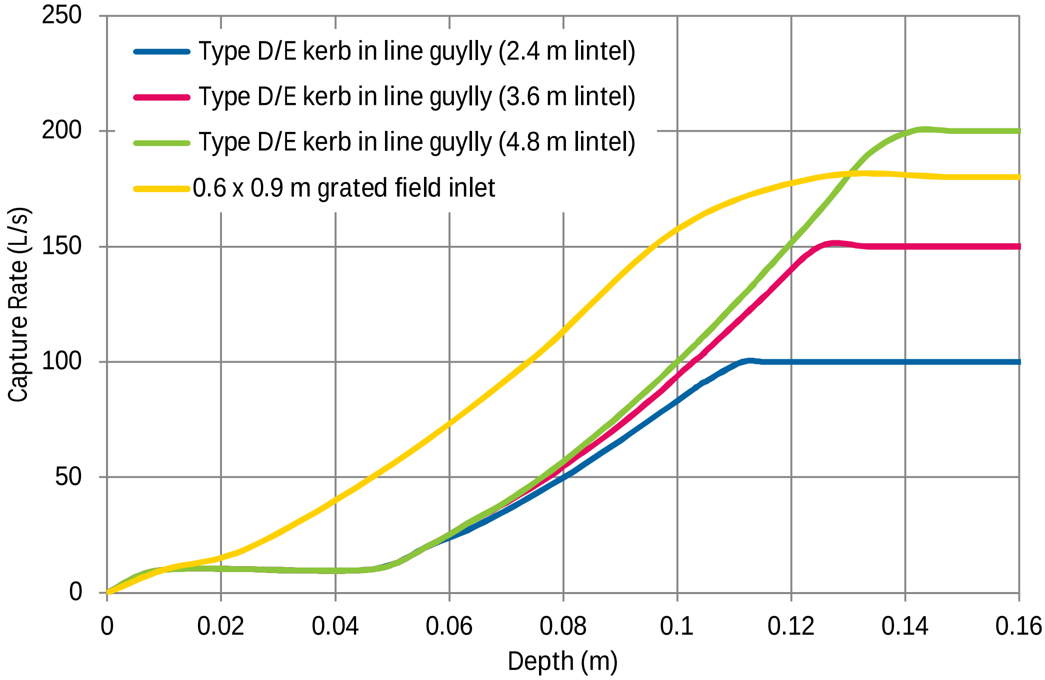


Figure 2-2 Adopted stormwater inlet capture curves

2.6.5 Design event rainfall

As outlined in the Methodology Statement, BCC-supplied design rainfall data has been adopted for this study. The data sources for the various storm events are provided below.

Source of rainfall IFD data

Storm event	Source
ARIs: 2-100yr Durations: 0.25-4 hr	BCC's Infrastructure Design Planning Scheme Policy – Chapter 7 Stormwater Drainage. The adopted IFD values were derived using the Australian Rainfall and Runoff 1987 methodology for a location in the Brisbane CBD (27.475S, 153.025E), and were obtained from the Bureau of Meteorology.
ARIs: 2-100yr Durations: 4-24 hr	The full set of rainfall IFD data (ARR 1987) for the adopted location (27.475S, 153.025E) were obtained from BoM.
ARIs: 500-2000yr Durations: 0.25-4 hr	BCC supplied rainfall IFD data derived using the CRC-FORGE methodology for this purpose.

2.6.6 Rainfall loss rates

As agreed with BCC, a uniform initial loss and continuous loss approach has been adopted for the final citywide models. The general findings from the model development, validation and calibration process was that the citywide models are relatively insensitive to modest changes (within generally accepted bounds) in applied loss rates. This is due in large part to the short duration of the storm events that result in peak flood levels for the majority of the overland flow flooding areas in BCC.

Accordingly, the final adopted loss rates applied to all pervious areas in the model are:

- Initial loss = 0 mm
- Continuous loss = 1.5 mm / hr

No losses were applied to impervious areas (buildings and pavement).

2.7 Model format & file structure

A simple and well-organised directory structure (file and folder format) has been adopted for the citywide models. The setup of the TUFLOW GPU model takes advantage of the software's in-built support for "scenarios" and "events" to simplify the model setup and to facilitate effective file management. The model itself uses a single set of control files, with "scenario" and "event" definition that allow the user to run any storm event over any of the 27 sub-models. The general structure of the model control files is outlined below.

2.7.1 TUFLOW GPU control files

The following single set of control files are used as part of the citywide TUFLOW GPU models:

- ***TUFLOW control file (bcc_01_citywide_~e~.tcf)*** – The primary model and simulation control file that contains references to the other control files, as well as key model parameters such as simulation times and results types and formats. This file also contains the names of the each of the individual sub-models (defined as TUFLOW "variables"), which allows the user to select the desired sub-model each time the model is run.
- ***TUFLOW events files (events.tef)*** – Contains definitions of each storm recurrence interval and storm duration, which allows the user to select the desired storm event each time the model is run.
- ***TUFLOW geometry control file (bcc_01_citywide.tgc)*** – Contains parameters that specify the model extents and grid cell size, as well as references to key sources of geometry and topography data (such as the DEM, spatial Manning's n distribution, etc.).
- ***TUFLOW boundary condition control file (bcc_01_citywide.tbc)*** – Contains references to the direct rainfall boundary condition, and the downstream boundary condition shape files.
- ***TUFLOW materials file (materials.tmf)*** – Specifies Manning's n roughness values for each surface roughness category.
- ***TUFLOW soils file (losses.tsoilf)*** – Specifies initial and continuous loss rates for each surface type.
- ***Boundary condition database (bc_dbase.csv)*** – Specifies time varying water levels and rainfall depths to be applied to the model.
- ***Pit inlet database (pit_inlet_database_<<_catchment_>>_25_blockage.csv)*** – A database that defines the suite of stormwater drainage inlet rating curves and the culvert rating curves (one file per catchment / sub-model to limit the size of each individual database).

2.7.2 Folder structure

The following folder structure is used for the citywide TUFLOW GPU models (indents represent sub-folders):

- ***A-check\bcc_01_citywide*:**
  - ***Catchment*** (a folder for each sub-model, i.e. Airport, BaldHills, etc.):
    - ***ARI_duration*** (a folder for each storm event, i.e. 0100yr_0060min):
      - ***1d*** – Contains 1D model check files
      - ***2d*** – Contains 2D model check files

- ***B-bc_dbase*** – contains boundary condition and pit inlet databases, as well as the source rainfall and pit inlet curve data in csv file format.
- ***C-model\:***
    - ***bcc_01_citywide*** – contains geometry and boundary condition control files, as well as the materials and losses definition files.
    - ***dem*** - Contains the individual LIDAR DEM's (1 m x 1 m resolution) for each sub-model.
    - ***mat*** - Contains the surface roughness category rasters (for spatial Manning's n variation) for each sub-model.
    - ***shp\:***
        - ***bc*** - contains main boundary condition GIS files (around the border of the sub-model extents).
            - ***bed*** - Contains the boundary condition GIS files for the internal boundaries within the sub-model (creeks, rivers and coastal locations).
        - ***code*** - Contains the main GIS file that determines the extent of the active area of the sub-model.
            - ***bed*** - Contains the GIS file that defines the inactive area of the model within creeks, rivers and coastal areas).
        - ***culverts* -** Contains the GIS files specifying the location and characteristics of all culverts.
        - ***mat*** - Contains a GIS file specifying some surface roughness categories outside the extents of the surface roughness raster file (generally applies to some small external catchments outside of the BCC area).
        - ***pits*** - Contains the GIS files specifying the location and characteristics of all stormwater inlets and outlets.
        - ***zsh* -** Contains GIS files that are used to modify small areas of the LIDAR DEM (i.e. to remove bridges, or to patch significant holes in the DEM).
    - ***soils*** - Contains the surface type rasters (for spatial loss variation) for each sub-model.
- ***D-results\bcc_01_citywide\:***
    - **2d**:
        - ***Catchment*** (a folder for each sub-model, i.e. Airport, BaldHills, etc.):
            - ***ARI_duration*** - Contains 1D model results (i.e. peak flow, water levels and velocity at each 1D pit element).
                - ***grids*** – Contains the raw 2D model results grids (maximum depth, water level, velocity and velocity-depth product).
                - ***plot***:
                    - ***csv* -** Contains csv files with time series results at each 1D pit element.
                    - ***gis* -** Contains GIS files that assist with plotting 1D model results.

    - ***log\:***
        - ***Catchment*** (a folder for each sub-model, i.e. Airport, BaldHills, etc.):
            - ***ARI_duration*** - Contains log files for each simulation.
- ***E-runs\bcc_01_citywide*** **-** Contains main TUFLOW control files (.tcf and .tef).

2.8 Design events & simulation management

As outlined above, the model uses an events definition file (events.tef) in order to define individual storm ARIs and durations that can be specified each time the model is run. This simplifies the model setup, and also helps to manage simulation outputs (as all check files, log files and results are automatically named according to the specified storm event and sorted into sub-folders).

2.8.1 Storm ARIs

The following storm ARIs are defined in the events file. A standard string length (with leading zeroes) means that post-processing scripts are easier to write and implement.

0002yr*	0010yr	0020yr	0050yr
0100yr	0500yr	2000yr	-

* The 2-year ARI event is defined and was used for QA purposes, but full citywide results were not generated for this event as it was outside the project scope.

2.8.2 Storm durations

The following storm durations are defined in the events file.

9999min*	00015min[+]	0030min	0045min
0060min	0090min	0120min	0180min
0360min	0540min[+]	0720min[+]	1080min[+]
1440min[+]	-	-	-

* Dummy event used for testing purposes.

[+] Not available for the 500-year and 2000-year ARI events.

2.8.3 Simulation management & running models

The best way to run a simulation with the citywide TUFLOW GPU model is to use a batch file. The catchment / sub-model name and the storm event (ARI and duration) is specified in the batch file itself. The format of the batch file command line is as follows:

<path to TUFLOW executable> -b –e1 <ARI> -e2 <DURATION> -s1 <CATCHMENT> <path to TUFLOW control file>

An example command to run the 100-year ARI 60-minute duration event on the Airport catchment is as follows:

"C:\Program Files\TUFLOW\Releases\2015\GPU_with_SW_network_w64\TUFLOW_iSP_w64.exe" -b –e1 0100yr -e2 0060min -s1 Airport "G:\41\28167\Technical\01_TUFLOW\02_Citywide\E-runs\bcc_01_citywide\bcc_01_citywide_~e~.tcf"

2.9 QA procedures

Due to the size and scale of the citywide models, it is not feasible (nor was it within the project scope) to undertake full manual QA checking of every model element. Instead, GHD undertook a range of high-level model checks in order to minimise the potential for significant errors in the model. Key QA checks are outlined below.

- The primary QA management strategy was to adopt a standardised model structure (including the above-mentioned catchment names and storm event definitions) to ensure correct procedure when running each simulation.
- A manual inspection of the results of preliminary citywide 2-year ARI and 100-year ARI results was undertaken. Where significant property flooding was evident in the 2-year ARI results, the local stormwater network (virtual pipes input layers) was manually inspected and adjusted where necessary. Common errors encountered at this step included:
  - Culvert inlets that were incorrectly tagged as stormwater gully inlets in the original BCC GIS database (or had other errors or omissions). In these scenarios, the attributes of the virtual pipes GIS file were adjusted to correctly represent the correct culvert inlet type.
  - Culvert inlets and other significant stormwater inlets that were incorrectly located (relative to the LIDAR DEM) in the original BCC GIS database (i.e. the culvert inlet was located in the roadway rather than in the invert of the channel). In these scenarios, the inlet was moved to the correct location.
  - Significant stormwater outlets that had no pipe diameter information in the original BCC GIS database, and therefore defaulted to a size of 375 mm as per the Methodology Statement. In these scenarios, a manual search was undertaken to identify the largest pipe within the upstream network (where such information existed in the original BCC GIS database), and that pipe size was adopted for the outlet.

3. Results & Mapping

3.1 Results types

The citywide TUFLOW GPU models generate results on a 2D grid at 1 m x 1 m resolution (half of the computational grid cell size). The grid results are created by the model in the .flt raster format. Each grid output contains the maximum value recorded by the model throughout the simulation. The following result types are saved:

- Peak water levels (mAHD);
- Maximum water depths (m);
- Maximum flow velocities (m/s); and
- Maximum velocity-depth products (m^2/s).

As the direct rainfall approach has been used, the direct (raw) model outputs contain values at every active model grid cell. Filtering (as described below) is required to generate flood extents.

3.2 Post-processing

Post-processing of the raw results is required in order to generate flood extents for each event.

3.2.1 Converting to ESRI File Geodatabase format

As the first step, the raw TUFLOW model results (in .flt format rasters) are converted to rasters in ESRI File Geodatabases. This allows for faster post-processing and smaller storage requirements.

A geodatabase is created for each catchment / sub-model which contains all raw (unfiltered) results for all storm events.

3.2.2 Combining storm durations to create envelope of maximums

For each catchment / sub-model and for each storm event ARI, an envelope of maximum values from all storm durations is created. The following process is used:

- At each cell, the storm duration that results in the highest water level is identified. This is then recorded as the critical storm duration for that cell.
- At each cell, based on the identified critical storm duration for that cell, the maximum water levels, depths, velocities and velocity-depth products are identified from the corresponding raw results files for each storm duration.
- A raster containing the maximum values from all storm durations is created. The following files are created for each catchment / sub-model and each ARI:
  - Peak water levels;
  - Maximum water depths;
  - Maximum flow velocities; and
  - Maximum velocity-depth products.
- A single raster containing the critical storm duration for each cell is also created.

3.2.3 Rain on grid filtering

Due to the nature of rain on grid flood modelling, flood model results must be filtered to produce overland flow path extents. The filtering technique is designed to remove insignificant "sheet flow" or catchment runoff and small isolated "ponds" or "islands". A full description of the rain on grid model result filtering methodology is provided in the Methodology Statement Report (GHD, 2014). The general process used for filtering the raw results for each catchment / sub-model and each ARI is outlined below:

1. Thresholds are applied based on the depth and velocity-depth product values at each cell. If the results for a given exceed either of the thresholds, then a value of 1 (flooded) is recorded in a mask or filter raster, otherwise a value of 0 (flood-free) is recorded.
2. As a secondary measure, cells with a velocity-depth product value smaller than a secondary low threshold are flagged as 0 (this helps to reduce the area of isolated ponds of water with no active conveyance). This defines the preliminary extents of flooding that will be included in the final output.
3. The preliminary filter created at Step 1 is analysed for the presence of isolated "ponds" (flooded areas) or islands (flood-free areas). If the total area of each "pond" or "island" is below a user-specified threshold, then it is removed. "Ponds" below the threshold area are tagged as 0 (flood-free) and "islands" below the threshold area are tagged as 1 (flooded).
4. Based on the filter or mask created in Steps 1 and 2 (containing values of 1 to represented flooded areas and values of 0 to represent flood-free areas), the raw results are clipped to the extents of the mask. The resulting output represents the defined footprint or extent of flooding.

As agreed with BCC, the following filtering parameters have been used to filter the final citywide raw model results strictly for the purposes of this study:

- Firstly, with a maximum depth less than 0.15 m and a maximum velocity-depth product less than 0.125 m^2/s are removed in Step 1.
- Then, cells with maximum velocity-depth products < 0.01 m^2/s are removed in Step 2.
- "Ponds" or "islands" with an area of less than 500 m^2 are removed in Step 3.

The final filtered results for each catchment / sub-model and each ARI are saved in ESRI File Geodatabases.

The filtering tool developed by GHD has been provided to Council, and it is intended that Council will develop its own filters in future, depending on the purpose for which the flood mapping results are implemented within Council.

4. Sensitivity Testing

4.1 Scenarios

In order to determine the sensitivity of estimated flood extents, depths, velocity and hazard to key model parameters, a wide range of sensitivity testing scenarios were undertaken as part of the Norman Creek Pilot Study (GHD, 2015a) (as summarised in Section 7 of that report). As agreed with BCC, a final set of sensitivity testing scenarios was run for all citywide models. The sensitivity cases that were assessed are as follows:

- Base case – No changes to the adopted design model parameters.
- Case 1 – A global 20% increase in Manning's n values, with the upper limit of depth-varying roughness in forested areas increased from 0.2 to 0.5.
- Case 2 – Zero initial and continuing losses.
- Case 3 – No stormwater or culvert infrastructure (100% blockage of stormwater drainage network).

To limit the number of required model simulations, the sensitivity analysis was limited to the 100-year ARI 60-minute duration storm event. This event was selected as it is the most prevalent 'critical' duration storm event across the BCC local government area.

4.2 Results

4.2.1 Case 1 - Manning's "n" increase

A global 20% increase in Manning's n generally results in increases in flood level in the order of 0 – 0.05 m. In ponding areas with low velocities and conveyance of stormwater, negligible changes in flood level are seen. In some isolated areas, very small reductions in flood level (in the order of 0 – 0.02 m) are seen due to the slight reduction in direct rainfall catchment discharges due to the increased roughness.

4.2.2 Case 2 – Zero initial and continuing losses

The use of initial and continuous loss values of zero for pervious areas results in minor increases in flood level generally ranging from 0 – 0.05 m.

4.2.3 Case 3 – No stormwater or culvert infrastructure (100% blockage of network)

100% blockage of the stormwater network can result in substantial increases in flood level. The increases generally range from 0.1 – 0.5 m, while in some isolated areas (such as trapped sags and local depressions) the increases are most significant (generally ranging from 0.5 – 1 m depending on the local conditions). In some areas immediately downstream of trapped sags (i.e. downstream of a raised rail embankment that causes ponding on the upstream side), 100% blockage of the stormwater and culvert network may result in slight decreases in flood level due to the retention of water in the storage area upstream.

For longer duration rainfall events which comprise greater volumes of runoff, it is expected that flood levels under a 100% blockage case will continue to increase above those in the sensitivity test. Comprehensive blockage simulation was outside the scope of this Phase 1 study, however may be undertaken by Council in future if conservative flood maps are required.

4.3 Recommendations

It is recommended that BCC utilise the results of the sensitivity testing scenarios as a tool to guide engineering judgement on a case-by-case basis. In general terms, depending on the intended use of the model results, areas showing relatively high sensitivity to key model parameters may warrant further localised review, refinement and validation of the model results. Conversely, in areas that do not show high sensitivity to changes in key parameters, the existing design flood event results may be used with a greater level of confidence.

The general observation from these sensitivity testing scenarios is that for most areas, the potential range of differences in peak water levels is often less than the normal freeboard requirements (0.3 m for non-habitable floor areas and 0.5 m for habitable floor areas).

So that BCC can visualise the spatial varying impact of the sensitivity analysis on estimated flood depths, the results of these sensitivity testing scenarios have been provided to BCC (in raw and filtered form) as an ESRI File Geodatabase.

5. Limitations & Usage

5.1 Overview

As outlined elsewhere in this report, the Citywide Creek & Overland Flow Path Mapping project was a broad-scale project focused on rapid and efficient modelling techniques using existing available data sources. By its nature, such broad-scale modelling may not be as accurate as detailed, localised modelling that is supported by field verification and detailed survey, despite the significant effort invested in model calibration, validation and sensitivity testing. This section of the report outlines the potential tolerances in the model results, and also provides guidance relating to BCC's potential end uses of the study outputs.

5.2 Key limitations on accuracy

A range of factors limit the level of accuracy that can be achieved for this project, given the constraints on scope, time, budget and other practicalities. In general, there is no way to quantify the level of tolerance in the final model results without exhaustive field verification and/or calibration, and additional detailed survey across the entire citywide modelling extents.

However, if users of the model results understand the factors impacting on potential accuracy, a case-by-case assessment of the potential accuracy relative to the desired usage can be made. If the risk is considered to be low, the citywide model results may be used directly. If the potential tolerance is perceived to be significant relative to the desired use of the model results, further refinement supported by field survey or independent local investigations will be required.

5.2.1 Data currency

The citywide TUFLOW GPU models rely on various data sources provided by BCC. Key among these are:

- Stormwater and culvert GIS datasets (compiled from many data sources from different dates, provided to GHD in November 2014);
- The surface type classification raster used to define impervious areas, open ground, dense vegetation, etc. (dated 2014); and
- The LIDAR DEM (dated 2014).

The currency of this data is a key limitation on the accuracy of the citywide models. Any changes since the date of data capture (such as new development or infrastructure, or re-survey of pre-existing infrastructure) will not be reflected in the model results.

In some areas, such as near major new road infrastructure projects that have occurred since the model input data was created, the imprecision in model results may be significant.

5.2.2 Data completeness & accuracy

The completeness and accuracy of the datasets provided to GHD by BCC also limit the ultimate accuracy of the models. In particular, missing data (i.e. existing inlet pits, stormwater pipes or culverts that aren't present in the GIS dataset) or incomplete data (i.e. stormwater pipes in the GIS dataset that have incomplete attributes – missing pipe sizes, for example) will affect the local accuracy of the final model results. It is not within the scope of this project to field verify or re-survey any existing infrastructure.

In areas where overland flow flooding is highly sensitive to the capacity of the underground drainage network, such as within trapped sags, missing, inaccurate or incomplete stormwater data may have a significant effect on model accuracy.

5.2.3 LIDAR accuracy

The processed LIDAR DEM is created by the original surveyor by post-processing a raw point cloud of laser returns to create a regular 1 m x 1 m grid of ground elevations. The accuracy of the resulting DEM depends on both the inherent accuracy of the laser surveying technique, and the accuracy of the post-processing techniques used to remove non-ground features such as buildings and vegetation. Providers of LIDAR data often quote a nominal vertical accuracy of +/- 0.3 m. In open areas with relatively smooth surfaces (such as roads or open ground with short grass), the actual accuracy achieved can be better than +/- 0.3 m, while in areas of dense vegetation, closely spaced buildings or standing water the accuracy may be poorer.

In some localised areas, the LIDAR results might also be biased (i.e. consistently higher than the true values). The accuracy of the TUFLOW GPU model results in these areas will be impacted by the accuracy of the LIDAR data, however this is an issue common to almost all large-scale hydraulic models.

5.2.4 Lot-scale features

The urban environment is complex, changeable and in some ways unregulated. Particularly within private residential allotments, lot-scale features such as sheds, retaining walls, fences, garden beds, roof gutters and downpipes and rainwater tanks can have significant localised effects on overland flow flooding. However, these effects cannot be simulated in this current broad-scale study.

If significant lot-scale features are identified on a particular site, further refinement or independent small-scale modelling may be deemed necessary.

5.2.5 Sub-grid-scale features

The TUFLOW GPU models use a 2 m x 2 m computational grid resolution. Features smaller than this scale may not be fully represented in the hydraulic models.

5.2.6 General model uncertainty

General model uncertainty relates to a range of fundamental assumptions in the modelling techniques and modelling inputs. These include, but are not limited to, the underlying hydraulic equations and numerical scheme, assumptions about the extent of vegetation cover that might vary over time, assumptions regarding the blockage of hydraulic structures (which can vary with the ARI of the storm event and the availability of debris in the catchment), and assumptions about the antecedent catchment conditions (i.e. the degree of saturation before the most intense burst of a storm event). Significant effort has been invested in model calibration, validation and sensitivity testing in order to minimise, as far as practical within the study scope, the potential for general model uncertainty. Nonetheless, as with any model, residual and unquantified uncertainty remains.

5.3 Potential applications

At the project outset, as detailed in the Methodology Statement Report (GHD, 2014) and the Norman Creek Pilot Study Report (GHD, 2015a), the primary objectives of the study were to provide:

- A dependable technical output that addresses the relevant recommendations of the Queensland Flood Commission of Inquiry; and
- A technical resource that support’s BCC’s needs in the areas of development assessment, land use planning, flood awareness, and stormwater drainage design.

In discussions with BCC, BCC have identified a range of potential additional applications for the study outputs. GHD’s general recommendation is that BCC consider developing usage policies and procedures for the outputs of this study that acknowledge the assumptions, limitations and potential sources of inaccuracy presented in this report.

6. Conclusion & Recommendations

This report provides a general overview of the Phase 1 - Citywide Creek and Overland Flow Path Modelling project undertaken by GHD on behalf of BCC. The outputs of this study include TUFLOW GPU rain on grid hydraulic models covering the entire BCC area and outputs from these models that provide levels, depths, velocities and velocity-depth products relating to overland flow and previously un-modelled creek flooding for a range of design storm events.

Key aspects of the TUFLOW GPU direct rainfall approach (including the use of a high-resolution DEM, fully dynamic 2D shallow water equations, spatially-distributed rainfall and plausible modelling of the stormwater drainage network) represent a significant improvement compared to other methods previously used to map overland flow paths in the Brisbane City Council area. Nonetheless, limitations primarily relating to the broad-scale nature of the current project apply.

BCC's decisions regarding usage of the models and model results should be guided by the stated assumptions, limitations and potential sources of imprecision outlined in this high-level report.

7. RPEQ Statement

In relation to this final study report *City Wide Creek and Overland Flow Path Mapping Final Report (GHD, April 2017)* our Registered Professional Engineer of Queensland, Paul Priebbenow makes the following statement:

The assumptions, qualifications and limitations documented in the report are suitable for the product purposes and limited uses as described in the report.

Paul Priebbenow

RPEQ No. 09313

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