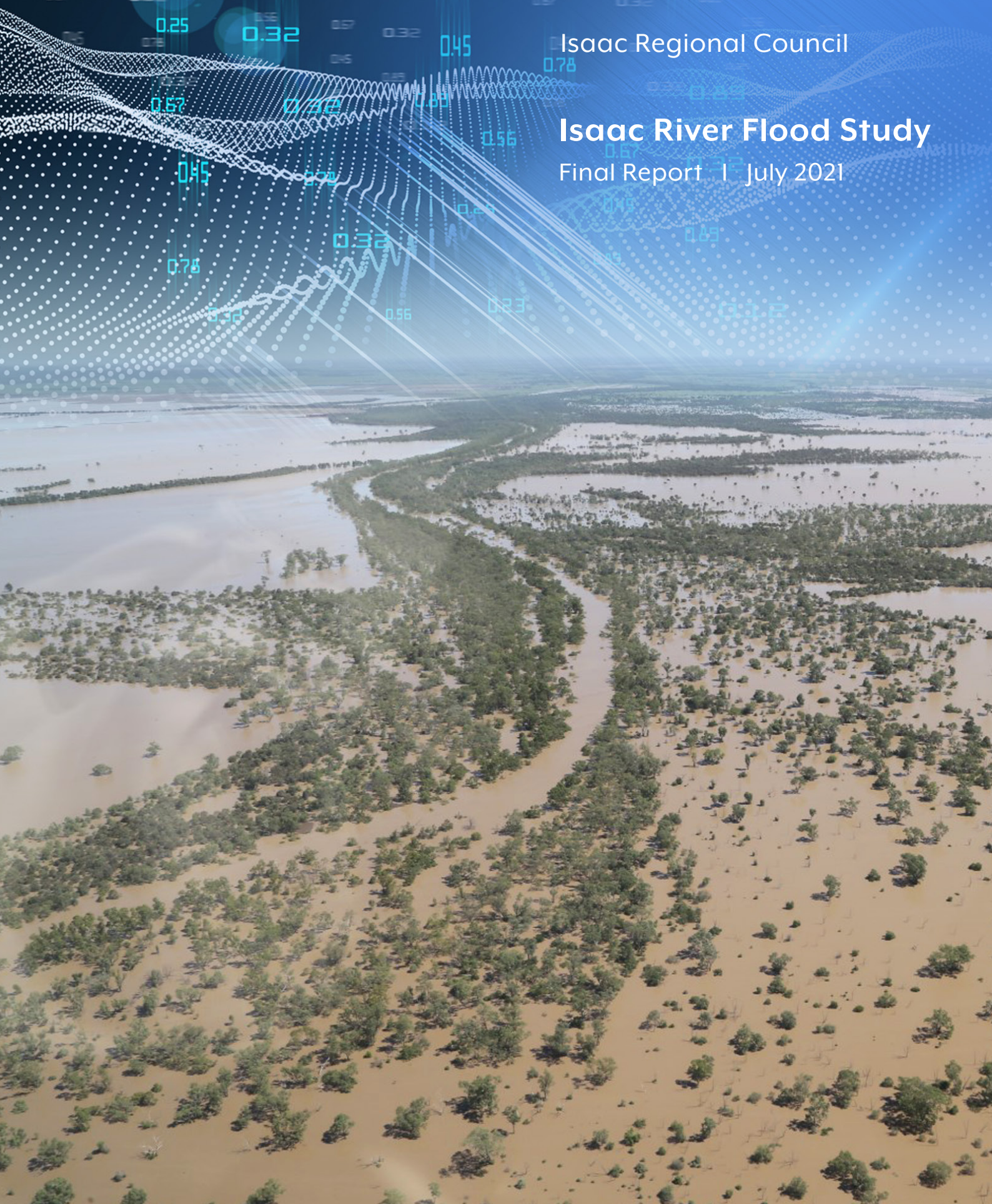
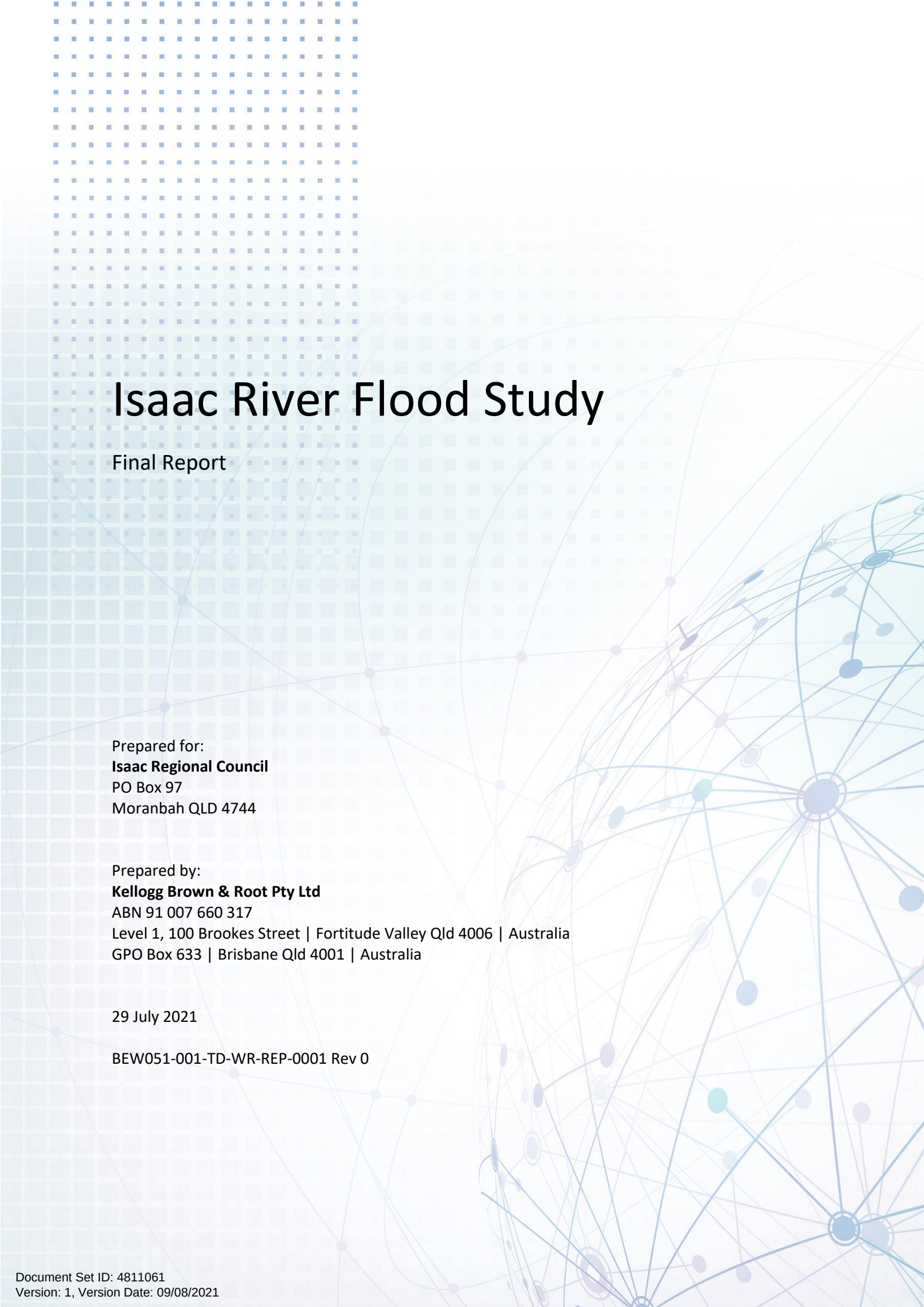


Isaac Regional Council

Isaac River Flood Study

Final Report 1 July 2021





Isaac River Flood Study

Final Report

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29 July 2021

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Acknowledgments

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Limitations Statement

The sole purpose of this report and the associated services performed by Kellogg Brown & Root Pty Ltd (KBR) is to describe flooding behaviour in the Isaac River catchment in accordance with the scope of services set out in the contract between KBR and Isaac Regional Council ('the Client'). That scope of services was defined by the requests of the Client, by the time and budgetary constraints imposed by the Client, and by the availability of access to the site.

KBR derived the data in this report primarily from visual inspections, examination of records in the public domain and interviews with individuals with information about the site. The passage of time, manifestation of latent conditions or impacts of future events may require further exploration at the site and subsequent data analysis, and re-evaluation of the findings, observations and conclusions expressed in this report.

In preparing this report, KBR has relied upon and presumed accurate certain information (or absence thereof) relative to the site and existing infrastructure provided by government officials and authorities, the Client and others identified herein. Except as otherwise stated in the report, KBR has not attempted to verify the accuracy or completeness of any such information.

The findings, observations and conclusions expressed by KBR in this report are not, and should not be considered, an opinion concerning flood risk and resilience in the catchment. No warranty or guarantee, whether express or implied, is made with respect to the data reported or to the findings, observations and conclusions expressed in this report. Further, such data, findings, observations and conclusions are based solely upon information and data supplied by the Client in existence at the time of the investigation.

This report has been prepared on behalf of and for the exclusive use of the Client and is subject to and issued in connection with the provisions of the agreement between KBR and the Client. KBR accepts no liability or responsibility whatsoever for or in respect of any use of or reliance upon this report by any third party.

Revision History

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			Originated by	Checked by	Technical Approval	Project Approval
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1 Introduction

The Isaac River Flood Study (herein this study) has been prepared for Isaac Regional Council (Council) care of Central Highlands Regional Council to define the flood behaviour within the Isaac River catchment. The flood study will establish the basis for subsequent floodplain risk management activities and to assist in future land use planning controls to mitigate against future risk and improve community resilience.

The objectives of this study are the:

- Compilation and review of existing information pertinent to the study.
- Development and calibration of appropriate hydrologic and hydraulic modelling.
- Determination of design flood conditions for design events - including the 5%, 2%, 1%, 0.5%, 0.1% Annual Exceedance Probability (AEP) and Probable Maximum Flood (PMF) events.
- Presentation of flood hazard determined by design event modelling.

The models and results produced in this study are intended to outline the flood behaviour within the study area to aid in Council's management of flood risk.

1.1 STUDY LOCATION

The Isaac River catchment contains several population centres with Moranbah located approximately 295 km north west of Rockhampton. The main industries in the study area are mining and agriculture with the catchment containing several mine sites as well as facilitating agricultural practices.

The catchment contains several significant tributaries including:

- Connors River
- Lotus Creek
- Bee Creek
- Funnel Creek.

These tributaries combine into the Isaac River flowing south prior to joining the Mackenzie River, draining a total catchment area of some 22,500 km². A more detailed description of the study area is presented in Section 2.1.

1.2 REPORT STRUCTURE

The report is structured in the following Sections to address each of the study objectives.

- Section 1 – Introduction of the study
- Section 2 – Description of the catchment and historical flooding
- Section 3 – Review of all available data
- Section 4 – Detailing the development of the model
- Section 5 – Detailing model calibration to Tropical Cyclone Debbie
- Section 6 – Detailing the simulated design flood conditions
- Section 7 – Sensitivity Analysis
- Section 8 - Summary of the study conclusions
- Section 9 – Recommendations
- Section 10 – Listing limitations and exclusions of the study.

2 Study Area

2.1 THE STUDY AREA

2.1.1 Catchment Description

The Isaac River with a total catchment area of 22,324 km² encompasses all points of interest for this study as shown in Figure 2-1. The Isaac River is 475 km long traversing the catchment just north east of Moranbah, Dysart and Middlemount. The Isaac River is a part of the Fitzroy River drainage basin and joins into the Mackenzie River south east of the Junee State Forest.

The highest point in the Isaac River Catchment is at Crediton State Forest, at around 1000 m AHD. The lowest point in the catchment region is at the outlet of the catchment at approximately 100 m AHD. The significant change in elevation is primarily within the far upper catchment. The majority of defined streams grade from approximately 200 m AHD down to the catchment outlet. The local catchments and major overflow flow paths are shown in Figure 2-2

Isaac River Catchment is comprised of a variety of land uses such as mining, crop farming and grazing. The study area contains residential suburbs, major infrastructure, multiple local schools, and open recreational areas.

The study area also includes Conservation Areas including Dipperu National Park and State Forests such as Rosedale and West Hill. Of which, Dipperu National Park is used solely for controlled scientific study and the monitoring of natural and cultural resources.

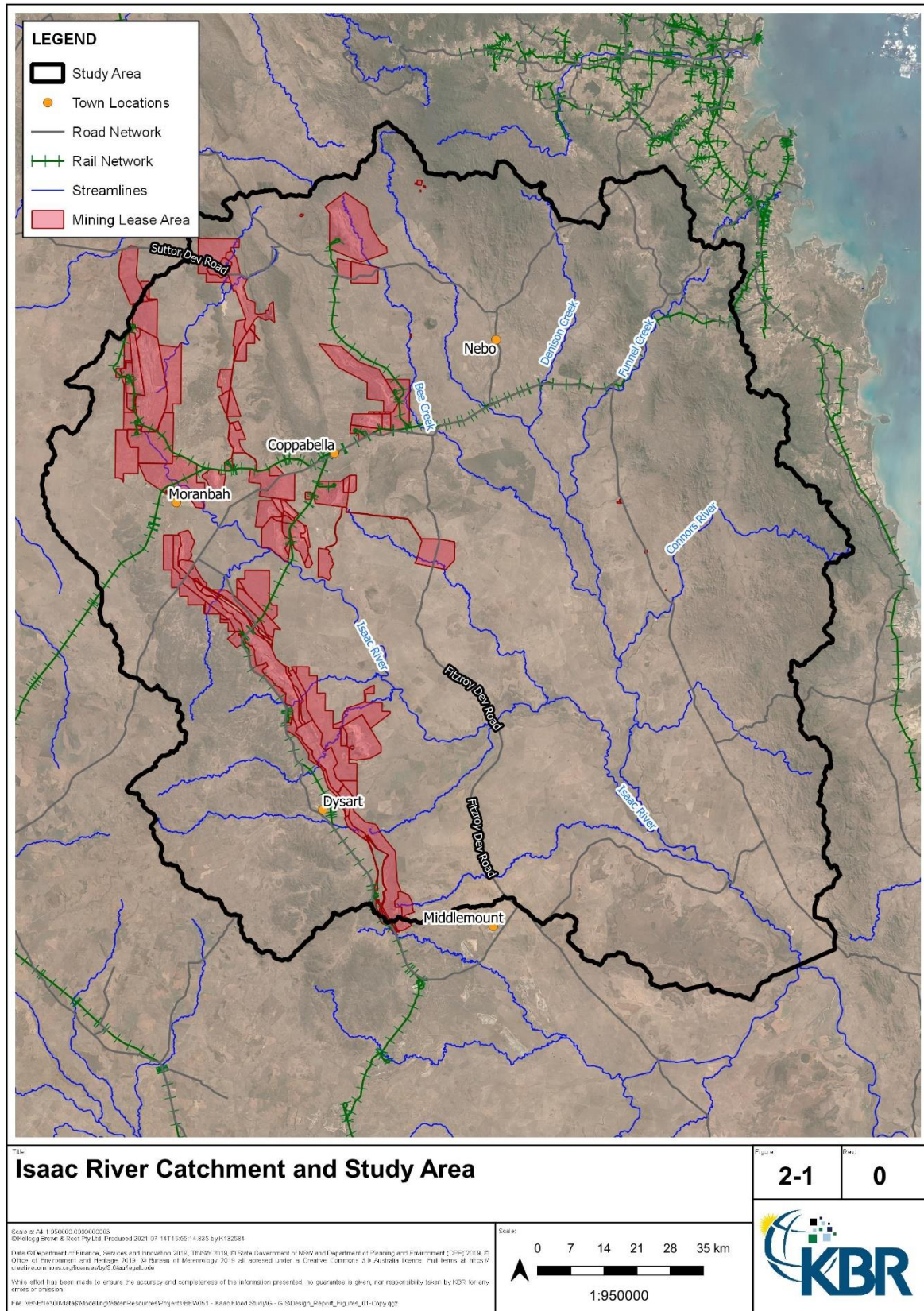


Figure 2-1 Isaac River Catchment and Study Area

2.1.2 Major Tributaries

The Isaac River has four main tributaries that convey flood water from the upper reaches of the catchment. They are outlined below and displayed in Figure 2.2.

Connors River

Connors River with a reach of some 301 km, is the most significant tributary of the Isaac River, receiving water from Bee Creek, Funnel Creek and Lotus Creek prior to joining the Isaac River. The total sub catchment area is 9,527 km². The Connors River catchment is located in the north east region of the total Isaac River catchment and includes the towns of Nebo and Coppabella.

Lotus Creek

Lotus Creek with a length of 65 km has a catchment area of 2,543 km². Lotus Creek is located towards the central eastern region of the catchment and is a tributary of Connors River.

Bee Creek

At a length of 183 km long Bee Creek begins at Mount Lookout and discharges into Funnel Creek. Bee Creek is located in the northern region of the catchment. Bee Creek traverses quite close to both the Bee Creek mine and the township of Nebo.

Funnel Creek

Funnel Creek is a tributary of Connors River, located to the east of Bee Creek with an approximate sub catchment size of 1,580 km². Funnel Creek is located in the north east region of the catchment and has a length of 266 km.

2.1.3 Major Townships

There are several townships and population centres within the catchment. Of these Moranbah, Nebo, Dysart and Coppabella are most notable. In addition to the townships there is a significant mining presence and in association, the provided accommodation for workers.

Moranbah

Moranbah which was founded in 1969 is one of the youngest towns in Queensland and is home to 8,735 people. Despite being one of the newer townships, Moranbah is considered the 'hub' of the Isaac Region, with a variety of services and recreational facilities. It is located in the western region of the Isaac River catchment and covers an area of 3,293km².

Nebo

The town of Nebo is located in the northern region of the catchment adjacent to Nebo Creek and covers an area of 877 km². It has a population of 753 residents.

Dysart

Dysart is also a relatively young town and was initially constructed as a service town for the neighbouring Norwich Park coal mine. It is situated in the western region of the catchment and is a relatively large distance from nearest defined water course. Dysart has an area of 3,764 km² and a population of 2,991.

Coppabella

Coppabella is a small town of 466 residents and is owned and operated by Queensland Rail. It is in the central northern section of the catchment, 159 km south-west of Mackay.

2.1.4 Mining Activities Within the Catchment

The Isaac Region economy is largely driven by the mining and resource sector, which contributes \$5.9 billion (over 78%) to the region's total GRP and produces 54% of QLD's saleable coal.

The sector is the largest employer of the region directly employing 37.7% of the Isaac region's workforce. Additionally, the Isaac Region's population is boosted by approximately 10,600 resource sector workers who travel into the region for work and are housed in temporary accommodation.

The footprint areas of the mines are located in Figure 2 1. The highest contributing mine is the Broad sound-Nebo SA2 area, outputting an equivalent total of \$3.953 Billion.

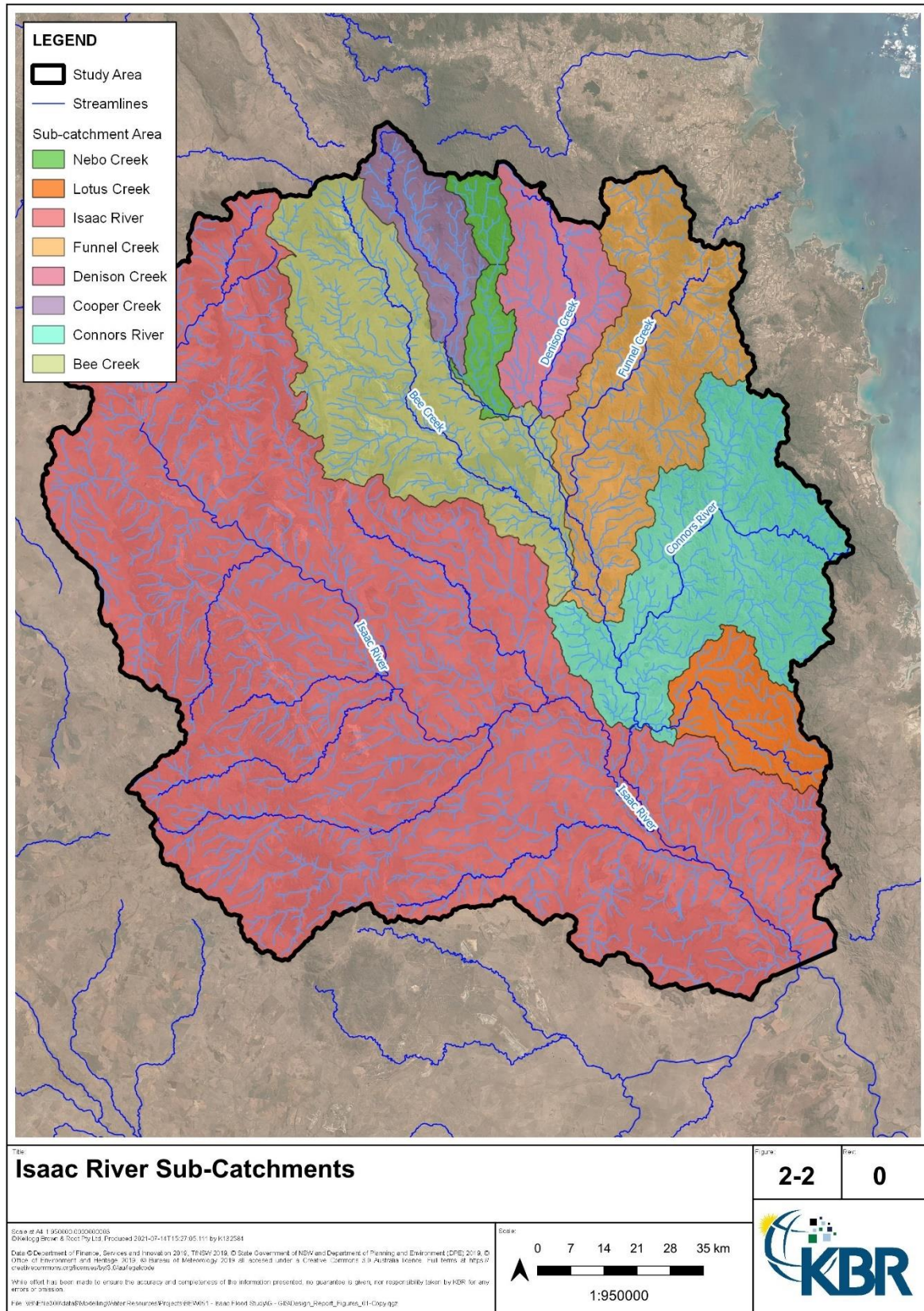


Figure 2-2 Isaac River Sub-Catchments

2.1.5 History of Flooding

The Isaac River Catchment has had several large floods that have impacted residents significantly. A summary of historical flood events in the Isaac River catchment and surrounding areas is provided in Table 2-1. Recently, Tropical Cyclone Debbie, occurred from the 25 to the 29 March 2017, affecting the study area on the 28 onwards. According to data from the Bureau of Meteorology, several locations within the Fitzroy River basin, including the study area, in excess of 1000 mm in rainfall in two days, and the Fitzroy River went into major flood warning at Rockhampton during the following week. Debbie intensified to a category four severe tropical cyclone when the eye passed over the mainland directly over Airlie Beach.

Tropical Cyclone Debbie impacted many residents in the catchment with some having lost their homes due to flooding. Over 85% of Isaac's road network was also damaged due to Cyclone Debbie. Many homes, infrastructure and agriculture suffered significant damage. Thus, the necessity for this flood study and the subsequent recommendations for floodplain risk management activities is evident for the residents of the Isaac River catchment region.

Previous major rain events include Tropical Cyclone Oswald which affected the study area on the 25 and 26 January 2013. Areas west of Rockhampton experienced over 1000 mm of rainfall during this period, leading to significant flooding and damage to infrastructure. Additionally, Tropical Cyclone Marcia affected the Isaac River Catchment from the 20 February 2015 and had major impact upon infrastructure due to flood waters.

Due the severity of Tropical Cycle Debbie as well as the availability of information from the event, it will be utilised as the calibration event for the modelling.

The flood warning network in the region is relatively young and lacked coverage prior to the 2010/2011 event. Most gauges before then belonged to Department of Natural Resources and Mines (DNRME).

Table 2-1 Historical Regional Flooding

Year	Location	Summary
1896	Sandy Creek, Clermont	3 lives were lost and there was widespread damage and destruction to property.
1870	Sandy Creek, Clermont	15 lives were lost and there was widespread damage and destruction to property.
1916	Sandy Creek, Clermont	61 Lives were lost and there was widespread damage, destruction to property and loss of stock.
1918	Fitzroy River Basin.	30 lives were lost in the cyclone and the subsequent floods in Central Queensland.
1928	Fitzroy River Basin.	Widespread damage, destruction to property and loss of stock.
1940	Connors River and Funnel Creek.	Widespread damage and destruction to property.
1951	Isaac River	Isaac River received over 1000 mm of rainfall causing extensive flooding in Rockhampton. There was widespread damage and destruction to property.
1958	Funnel Creek and Connors and Isaac Rivers.	Heavy flooding in lower reaches of Fitzroy River due to near record river heights in the northern tributaries, particularly Funnel Creek and Connors and Isaac Rivers. Funnel Creek recorded highest flood levels for 40 years.

Year	Location	Summary
1959	Clermont	Clermont experienced the worst floods since 1916 with widespread damage, destruction to property and loss of stock.
1960	Connors River and Funnell Creek	Reported heavy runoff from Connors River and Funnell Creek causing considerable dislocation of traffic on the Bruce Highway where motorists were stranded for periods up to 2 days.
1970	Isaac and Connors Rivers and Funnell Creek.	As a result of Cyclone Ada, major flooding occurred in the upper catchments of the Isaac and Connors Rivers and Funnell Creek causing widespread damage and destruction to property.
1979	Connors River and Funnell Creek.	Significant flooding of the Connors River and Funnell Creek caused serious delays to traffic, damage to roads, bridges and other property.
1989	Connors River and Funnell Creek.	Major flood levels were reached in Connors River and Funnell Creek causing minor to moderate flooding in Rockhampton.
1991	Connors and Isaac Rivers and Funnell Creek.	Extensive flooding occurred across Rockhampton following Cyclone Joy in December 1990 and subsequent heavy rainfall in January 1991. 4 lives were lost due to the flooding and there was widespread damage and destruction to property costing more than \$10 million.
1993	Connors and Isaac Rivers and Funnell Creek.	Heavy rainfall caused moderate to major flooding in the Connors River and Funnell Creek, resulting in moderate flooding downstream along the Isaac River.
1997	Fitzroy Catchment and Connors River.	Heavy rainfall caused moderate flooding in the Connors and Isaac Rivers. Floods which commenced in the Connors River in February continued into March due to several periods of heavy rainfall resulting in minor to moderate flooding throughout the Fitzroy catchment and Connors River.
1998	Fitzroy River Basin.	Heavy rainfall resulted in rapid river rises in the Isaac and Connors Rivers and Funnell Creek. Moderate to major flooding occurred with main floodwaters approaching Connors Junction.
2000	Connors and Isaac Rivers.	Intense rainfall was recorded along the coast between Mackay and Rockhampton causing moderate flooding in the Connors and Isaac Rivers.
2010	Connors and Isaac Rivers.	Moderate to heavy rainfall South of Mackay caused moderate flooding along Connors and Isaac Rivers.
2013	Fitzroy River, Rockhampton.	6 lives were lost due to extreme weather over the course of the week. Areas west of Rockhampton received over 1000 mm of rainfall leading to widespread damage and destruction to property.
2017	Isaac River.	Tropical Cyclone Debbie caused over 1000 mm of rainfall to fall over the catchment area creating significant flooding. Several lives were lost and there was widespread damage and destruction to property.

3 Available Data

3.1 INTRODUCTION

Numerical models are heavily dependent on the quality of data utilised in their development. At the inception of this study a data review process was undertaken, following the data review the study approach could be refined to utilise the highest quality and most appropriate datasets.

This review included as follows.

- Previous Studies within the catchment including those for:
 - Connors Dam and Pipeline EIS (SunWater, 2009)
 - Queensland Reconstruction Authority Flood Mapping for the Fitzroy Basin (KBR, 2015)
 - Tropical Cyclone Debbie Technical Report (BoM, 2017)
 - Arrow Energy Major Pipelines: ABP Flood Impact Assessment Study (GHD, 2011)
 - Flood Hydrology Technical Report: Red Hill Mining Lease EIS (URS, 2013)
 - Grosvenor Mine Flood Modelling Report (Alluvium, 2016).
- Data Relating to:
 - Available data from gauges in the Bureau of Meteorology (BoM) and Queensland's Department of Resources (DRNME) Water Monitoring Information Portal (WMIP) networks
 - Australian Water Availability Project (AWAP)
 - Topographical Data, both regional photogrammetry as well as local LiDAR
 - Information and evidence of flooding as acquired by CHRC from the Isaac community.

3.2 PREVIOUS STUDIES AND INVESTIGATIONS

3.2.1 Connors Dam and Pipeline EIS (SunWater, 2009)

SunWater is currently completing a project that includes the construction and operation of Connors River Dam and associated water distribution infrastructure. The Dam is to be located approximately 274 km upstream of the junction of the Connors/Isaac/Mackenzie River system with the Fitzroy River, at the location of the Connors River at Mount Bridget gauge. The construction of the dam is not expected to have discernible impacts to flow in the Fitzroy River. However, changes to catchment areas and the water stored and released by the dam during rain events are anticipated to impact on the Isaac River region.

3.2.2 Flood Mapping for the Fitzroy Basin (KBR, 2015)

Queensland Reconstruction Authority engaged KBR to complete The Flood Mapping Report for the Fitzroy Basin. KBR undertook this mapping through the construction of a course Rainfall on Grid TUFLOW hydraulic model using SRTM elevation data. However, since the model was not validated against a rainfall event on a course grid it provides a high-level overview of major road and rail networks that are vulnerable to flooding. There are also known problems with the vertical accuracy of the SRTM. As such constitutes Level 2 Flood Mapping by QRA standards, as such requires a more detailed study for Level 3.

3.2.3 Tropical Cyclone Debbie Technical Report (BoM, 2017)

The Bureau of Meteorology completed a report to summarise the meteorological and hydrological data associated with Severe Tropical Cyclone Debbie. However, this report is limited

to the gauges available for this report, primarily those operated by BoM and DRNME, additionally several of such gauges within Isaac River Catchment were unable to provide data during the rain event. As such this report contains a coarse resolution of flooding especially within the eastern upper catchment. Therefore, KBR will consider the coverage of this data in the model calibration in this report.

3.2.4 Arrow Energy Major Pipelines: ABP Flood Impact Assessment Study (GHD, 2011)

GHD's ABP Flood Impact Assessment Study used industry accepted hydrologic and hydraulic methods on the first approximate 610 km of the proposed Arrow Bowen Pipeline to identify locations where significant lengths of the pipeline may be flooded. From the information gathered, buoyancy controls for the pipeline were assessed. 11 locations of significant lengths of pipelines were identified to be potentially inundated by floodwaters.

3.2.5 Flood Hydrology Technical Report: Red Hill Mining Lease EIS (URS, 2013)

BHP Billiton Mitsubishi Alliance (BMA), through its joint venture manager, BM Alliance Coal Operations Pty Ltd, conducted a hydrology study for the tributaries of the Isaac River to assist in the assessment of the proposed Red Hill Mine underground longwall mine operation.

3.2.6 Grosvenor Mine Flood Modelling Report (Alluvium, 2016)

Alluvium Consulting Australia was commissioned to complete a Flood Modelling Assessment to predict the flooding and drainage conditions of the Isaac River and its floodplain within the vicinity of the Moranbah and Grosvenor Mining areas. This study was conducted for the purpose of confirming the viability of extending longwall mining into an area west of the previously approved Grosvenor mining area.

3.2.7 Australian Water Availability Project (AWAP) Data

The Australian Water Availability Project run by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) projects an extensive dataset of daily rainfall, temperatures and soil moisture content spatially distributed on approximately a 5 km grid. This dataset is derived from a series of model and analysis of local gauge records, as well as BoM satellite data. As such data from the AWAP is largely consistent with the findings of the Tropical Cyclone Debbie Technical Report (BoM, 2017).

AWAP data for Tropical Cyclone Debbie was extracted from 26 March to 31 March 2017. The AWAP data included 1480 tiles within the catchment ranging from total rainfall of 121.0 mm to 802.4 mm with a median of 258.1 mm.

Contours of total rainfall across the catchment from Tropical Cyclone Debbie are presented within.

3.3 RAINFALL GAUGE DATA

Daily and sub-daily rain gauges provide information of historic event rainfall intensity and duration forming the basis for model calibration. From such gauge's historic hyetographs can be estimated for simulating these events through both hydrologic and hydraulic models.

Within the Isaac River catchment there is an extensive network of gauges publicly and privately owned. Many of which are operated by BoM and DRNME. Sixty-six daily rainfall gauges were extracted from BoM within 170 km to 30 km of the study area for Tropical Cyclone Debbie. Three stand-alone pluvio gauges operated by DRNME were operational during Tropical Cyclone Debbie in addition to the stream gauges listed within Section 3.2.7 which also recorded rainfall at sub-daily intervals. Further discussion of the Tropical Cyclone Debbie is presented within Section 5. Spatial distribution of the rainfall gauge network is presented in Figure 3-1.

Recorded total rainfall across gauges local to the catchment from Tropical Cyclone Debbie are presented within.

In addition, Isaac Regional Council owns several gauges within the catchment, however the majority of these gauges are for the purpose of warnings for road closures due the significant portion of the workforce being drive in-drive out. There are multiple rain gauges in the catchment operated by landholders, records from these gauges were collected and used to assist the calibration process. It is noted that the land holder rain gauge records are incomplete due to the extreme intensity of Tropical Cyclone Debbie and dangers that landholders faced throughout the event.

See Appendix B for a table of relevant daily rainfall gauges.

3.4 STREAM GAUGE DATA

Several DRNME gauges were operational within the catchment at the commencement of the events, however a number of them failed over the course of TC Debbie due to induction from flood waters and instrumentation failure under harsh conditions. Of those with a complete water level record for the event, KBR has reviewed the location and data provided by each gauge as well as the basis of their associated rating curves. Isaac Regional Council gauges are linked to roads to determine road closures not for the purpose of estimating flow. They are in bad locations for rating curve development. Six gauges were considered for the calibration of Tropical Cyclone Debbie as well as for Flood Frequency Analysis for design event modelling, including:

- 130401A – Isaac River at Yatton
- 130410A – Isaac River at Deverill
- 130413A – Denison Creek at Braeside
- 130406A – Funnel Creek at Main Road
- 130403A – Connors River at Mt Bridget
- 130404A – Connors River at Pink Lagoon.

A summary of the active stream gauges during Tropical Cyclone Debbie and their metadata are presented within Table 3-1.

Active stream gauges during Tropical Cyclone Debbie within the Isaac River catchment are presented within Figure 3-1.

Table 3-1 Active Stream Gauges During Tropical Cyclone Debbie

Gauge ID	Gauge Name	Extent of Record	Number of Gauging's	Zero Gauge (m AHD)	Tropical Cyclone Debbie	
					Peak Water Level (m AHD)	Estimated Peak Flow (m3/s)
130401A	Isaac River at Yatton	1/10/196–ongoing	280	89.146	16.69	23,839
130410A	Isaac River at Deverill	20/5/68–ongoing	268	169.304	11.41	1,625
130413A	Denison Creek at Braeside	12/12/17–ongoing	222	167.406	8.40	3,781
130406A	Funnel Creek at Main Road	8/12/65–ongoing	273	158.296	8.14	9,388

Gauge ID	Gauge Name	Extent of Record	Number of Gauging's	Zero Gauge (m AHD)	Tropical Cyclone Debbie	
					Peak Water Level (m AHD)	Estimated Peak Flow (m ³ /s)
130403A	Connors River at Mt Bridget	12/12/65–ongoing	218	138.702	13.67	21,135*
130404A	Connors River at Pink Lagoon	11/12/65–ongoing	225	111.666	13.77	14,306

**Denotes a value determined based off a model derived rating curve, refer to Section 7.1.2*

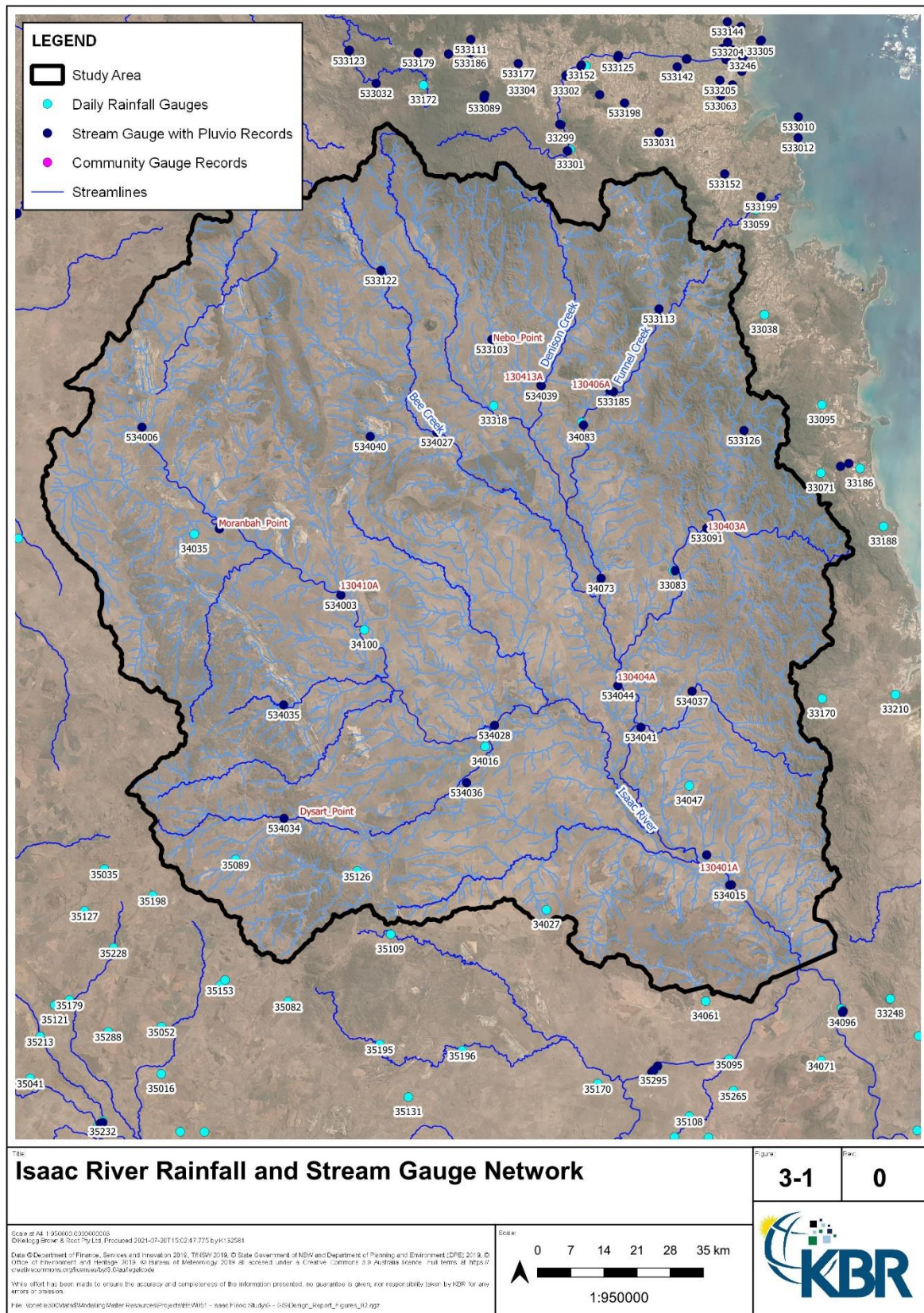


Figure 3-1 Rainfall and Stream Gauge Network

3.5 TOPOGRAPHIC DATA

Due to the expansive area of the Isaac River catchment, multiple elevation datasets were compiled for developing the hydraulic model. Datasets relied upon are listed below from most accurate to least:

- Multiple Light Detection and Ranging (LiDAR) datasets were available covering areas around the townships of Clermont, Dysart, Moranbah and Nebo. This LiDAR data has an accuracy of ± 0.15 m in the vertical direction and ± 0.45 m in the horizontal direction. LiDAR data used for the development of the model was the latest available at the commencement of the assessment and was flown over December 2011.
- On behalf of the Queensland Department of Natural Resources and Mines (DNRM), Aerometrex sampled a photogrammetry dataset in the Bowen geological basin. This photogrammetric dataset was processed into a 20 m resolution with a confidence level of 68%. Whilst an expansive dataset, this does not cover the entire Isaac River catchment. Although KBR records include the tiles for the northern section of the DEM, there is no available grid for the corresponding tiles on file. Additionally, although the southern tiles cover much of the south-east of the study area, there is no metadata available to ensure accuracy. DNRME completed a DEM out of the best data across the whole region.

3.6 COMMUNITY CONSULTATION AND AVAILABLE DATA

Community consultation has taken place in a number of forms over the course of this study, firstly in a briefing held by Isaac Regional Council, secondly through letters to the community to inform of them of the study as well as notifying of visits and thirdly the visits themselves to gather some of the wealth of knowledge the community has of the catchment and historical flood behaviour and consequence.

Representatives from Central Highlands Regional Council on behalf of Isaac Regional Council, undertook the property visits within the catchment. Outcomes of these visits includes gathering of key information including:

- Indicative Flood Extents
- Indicative Flood Depths
- Photographs of the Events
- Historical Records
- Anecdotal Records of the Tropical Cyclone Debbie Event.

Data acquired from the community consultation process has been used to assist in the calibration of the models to Tropical Cyclone Debbie.

3.7 DESIGN RAINFALL DATA

The design rainfall data for the study was obtained from the Bureau of Meteorology and the Australian Rainfall and Runoff 2019 (ARR19) Data Hub and is outlined in Section 6.2.

4 Model Development

4.1 MODELLING APPROACH

Runoff within the floodplain is typically considered in two key components:

- Hydrology, estimating rainfall-runoff. Commonly a separate hydrologic model is developed by simulating runoff from a sub-catchment into a series of hydrographs at respective outlets. Hydrological modelling allows for rapid assessment of flood events simulating the propagation or attenuation of a flood wave through the catchment.
- Hydraulics consider the hydrodynamics of the flood wave through the catchment. Hydraulic modelling allows for a detailed understanding of the risk associated with flooding.

Given the extent of spatial variability within Isaac River catchment regarding experienced weather events, topography and land use, a single model was developed simulating both hydrologic and hydraulic components of flood modelling. As such a Rainfall-on-Grid (RoG) approach has been adopted, representing the entire catchment within a combined hydrologic/hydraulic model.

A separate XP-RAFTs hydrological model was considered and built at the commencement of the study using CatchmentSIM delineation software, however due to the uncertainty within the calibration process of the input storms a combined hydrological and hydraulic approach was found to better represent catchment conditions. This approach allows the representation the complex relationships between input storms and runoff with rapid assessment of the consequence to hydraulic behaviour. Additionally, this approach allows for an increase in the detail within the distribution of rainfall inputs and manipulation of these inputs.

4.2 TUFLOW MODEL

A TUFLOW RoG model was developed for this study with a fully two-dimensional (2D) representation of the floodplain. 2D flood modelling requires spatial distribution of topography and land use categorisation as well as the spatial distribution of storm events. Major hydraulic structures can also be represented within the catchment, including dams, levees and weirs.

Outcomes from hydraulic model includes spatial representation of peak flood levels, depths, velocity and presented flood hazard within the catchment.

KBR has applied the 2D software modelling package TUFLOW (Release 2020-10-AA-iSP-w64). TUFLOW has the capability to simulate the dynamic interaction of in-bank flows in open channels, major underground drainage systems, and overland flows through complex overland flow paths using a linked 1D/2D flood modelling approach. The TUFLOW Heavily Parallelised Compute (HPC) engine was utilised for the study.

To consider hydrologic elements within the model the following information was included in the model:

- Localised storms based off either AWAP rainfall tiles for the calibration event or IFD tiles for the design events.
- Soil type and associated properties to simulate losses to infiltration within the model.
- To represent the hydraulics of the flood wave through the catchment the following information was included within the model:
- Topographic information to represent the landform of the catchment informing slope and storage of the catchment

- Hydraulic roughness retarding flow through the catchment
- Downstream boundary to represent the flow out of the model.
- Underling all the inputs into the model consideration was also given to:
 - Required accuracy and resolution of the model
 - Computational limitations for efficient simulation without excessive runtimes as well as model configuration viable for relatively standard computers to facilitate.

4.3 CATCHMENT DELINEATION AND MODEL DOMAIN

The Isaac River catchment was delineated using CatchmentSIM software. The study area includes the delineated Isaac River catchment, across an active 2D domain of a total area of 22,500 km². The modelling boundaries defined as the catchment area includes the major tributaries such as Connors River, Funnel Creek, Lotus Creek and Bee Creek and others that combine into the Isaac River flowing south prior to joining the Mackenzie River.

For the catchment area a TULOW 2D domain model resolution of 60 m was adopted. Due to the finer resolution of topography, a Sub-Grid-Sampling approach was undertaken. A sub-grid sampling distance of 15 m was adopted based on the resolution of the base model topography.

By employing a sub-grid-sampling approach flow width at cell sides is represented with a depth-flow width relationship based of the sampled every 15 m, as such each cell side's depth-flow width relationship contains 5 points on the curve. Similarly, storage in each cell is represented by a depth-storage volume relationship, with points sampled on a 15 m grid within each cell.

This resolution was selected to optimise run times whilst maintaining the detail necessary to accurately represent the topography of the study area and major hydraulic controls.

4.4 RAINFALL ON GRID SEGMENTISATION

Using the Rainfall on Grid approach each active cell within the catchment has rainfall applied. Details on the adopted hydrology at each Rainfall-on-Grid storm are provided in Section 5 for the calibration event and Section 6 for design event modelling.

4.5 DOWNSTREAM BOUNDARY CONDITIONS

The downstream boundary of the model adopted an automatically generated head-flow boundary based on the input of slope. The average slope local to the boundaries was calculated and input into the model.

No consideration of coincident flooding has been included within this flood study. From studies in the neighbouring catchments of the Makenzie River, it is apparent there will be some affectation particularly in the lower Isaac River catchment from the effects of coincident flooding.

4.6 GREEN-AMPT INFILTRATION MODEL PARAMETERS

Losses within the model were accounted for through the continuous infiltration functionality of TUFLOW, which was incorporated into the Isaac River catchment model. This approach assigns parameters based on the soil's hydraulic conductivity (mm/h), suction (mm), porosity (fraction) and initial moisture content, thus allowing the initial and continuing rainfall losses to be determined using the Green-Ampt methods.

As mentioned previously, soil data for the region was obtained from the Australian Soil Resource Information System (ASRIS). This data demonstrated two distinct soil types across the catchment area: well-drained sandy/loam soils and less well-draining clay soils. The distribution of the soils is illustrated in Figure 4-1, shows that upland areas of the catchment are generally sandy/loam soils and flat areas such as those along the major watercourses are generally clay based soils.

Green-Ampt infiltration parameters developed by the United States Department of Agriculture (USDA) for standard soil types (see Table 6-14 of the TUFLOW manual 2018-03-AC) was used for defining the suction, hydraulic conductivity, and porosity of the soil types. For the clay soils the standard parameters for 'sandy clay' were used, therefore providing a suction of 240 mm, hydraulic conductivity of 0.6 mm/h and a porosity of 0.3. For the sandy/loam soils the standard parameters for sandy loam/loam soil were used, therefore providing a suction of 110 mm, hydraulic conductivity of 5 mm/h and a porosity of 0.4.

Due to variability in hydraulic conductivity between soil types it was expected that selected parameters would need to be adjusted to fit calibration data. Additionally, the Green-Ampt method also has the ability to model groundwater interaction, however for the purpose of this study it was not utilised, rather hydraulic conductivity has been used to compensate for this.

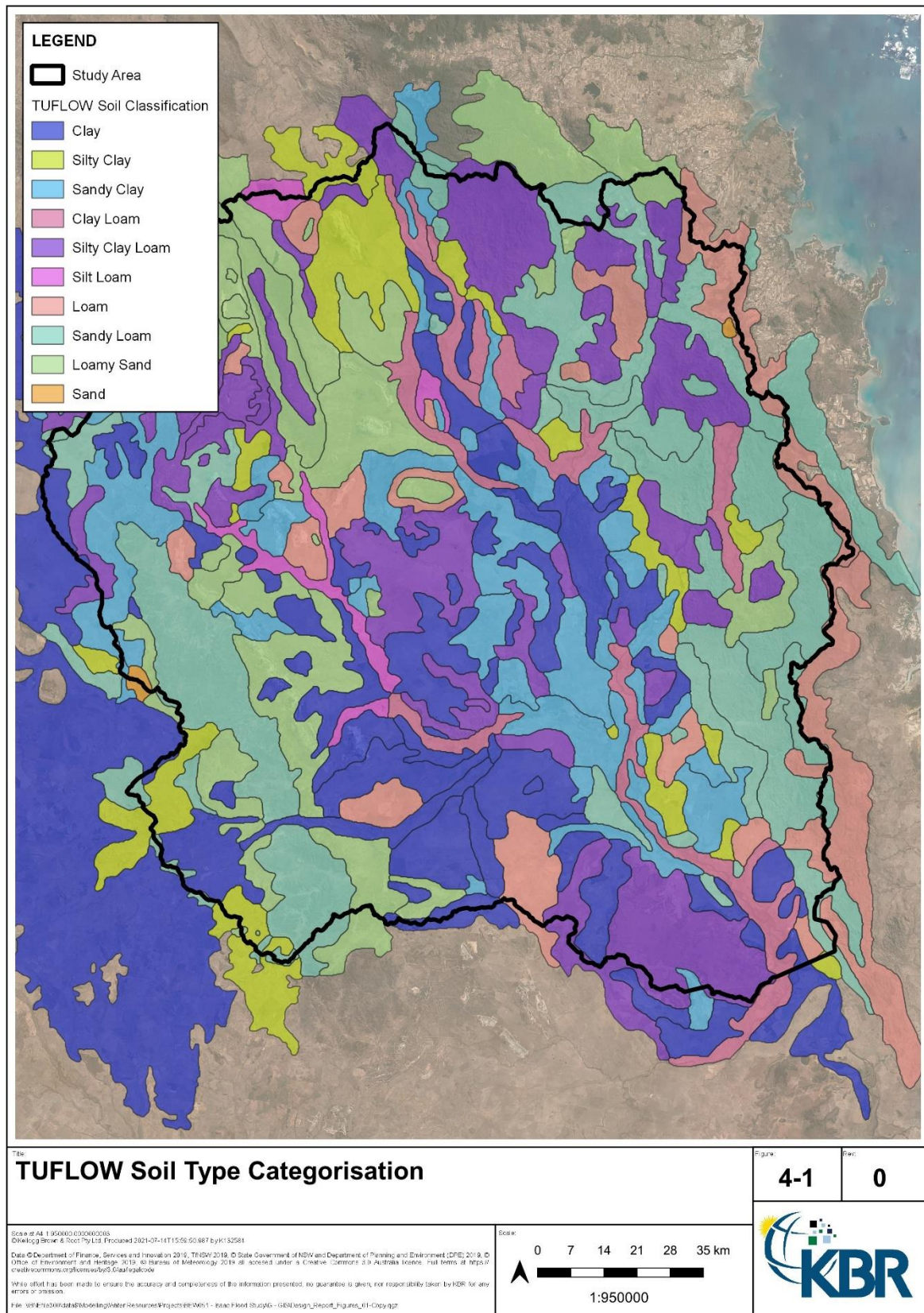


Figure 4-1 Soil Type Classifications

4.7 MODEL TOPOGRAPHY

As discussed within Section 3.5, a combined photogrammetry dataset covered the extent of the catchment, this dataset was utilised as a basis of the model elevation. LiDAR datasets were sampled where available. Alterations to model topography were included to ensure the different datasets merged cohesively as well as to enforce local hydraulic controls. Adopted model elevations are presented in Figure 4-2.

4.8 HYDRAULIC ROUGHNESS

To develop a TUFLOW model, a hydraulic roughness, known as a 'Manning's (n)' value is assigned to each material zone. These zones are identified using ariel photography and cadastral data for modelling variations in flow resistance across natural environments, agricultural regions, intensive uses such as mine sites and buildings and waterways.

Queensland Government maps were used to generate land use surface types and roughness zones in the catchment area. The material distribution has been displayed in Figure 4-3. The Manning's 'n' values adopted are presented in Table 4-1.

Localised obstructions or obstructions within or around private property, for example wood paling fencing, were not represented within the hydraulic model. Conversely, these obstructions were incorporated into the Manning's 'n' roughness value termed 'intensive' which was used for urban areas as they are likely to fail during large flood events.

Table 4-1 Manning's 'n' Value Adopted for Each Land Use Category

Description of Land Use	Manning's 'n' Value
Conservation and natural environments	0.100
Production from relatively natural environments	0.080
Production from dryland agriculture and plantations	0.060
Production from irrigated agriculture and plantations	0.060
Intensive Land Uses	0.080
Watercourse	0.035
Road Corridors	0.025

4.9 RESULT FILTERING

Unfiltered Rainfall on Grid results depict a significant amount of noise within the result due to the nature of Rainfall on Grid models placing water across all active cells. As such filtering of results is undertaken to depict developed flow paths without the shallow depths across the entire active model domain. As such the following process was undertaken on the raw outputs from TUFLOW to provide a filtered result:

- Cells with depths less than 0.1 m were removed from all results.
- Cells with a velocity depth product greater than 0.1 m were reinstated from the depth filtered regions.
- Isolated regions of flood water less than 60 pixels were removed from the above filtered results.

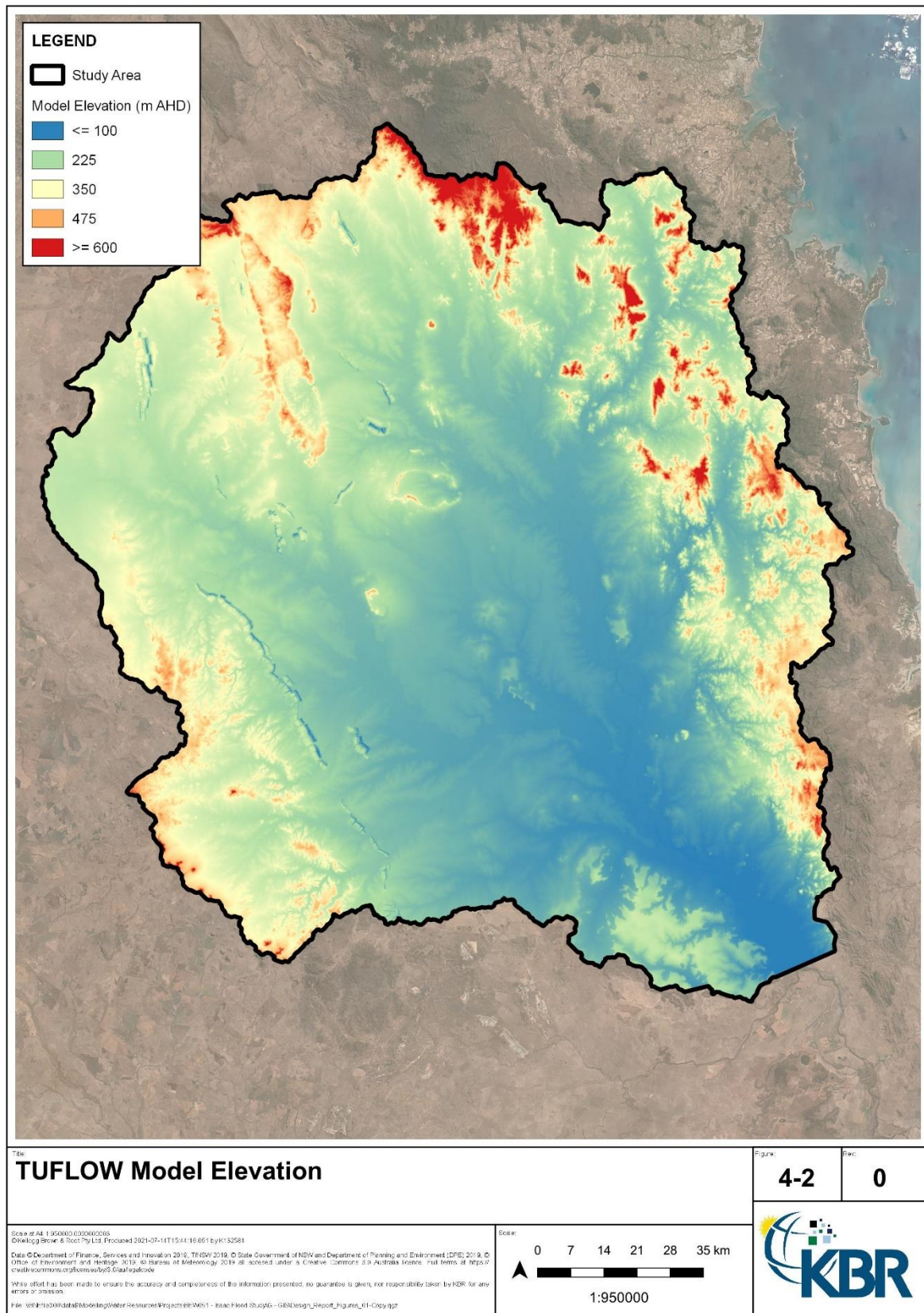


Figure 4-2 TUFLOW Model Elevation

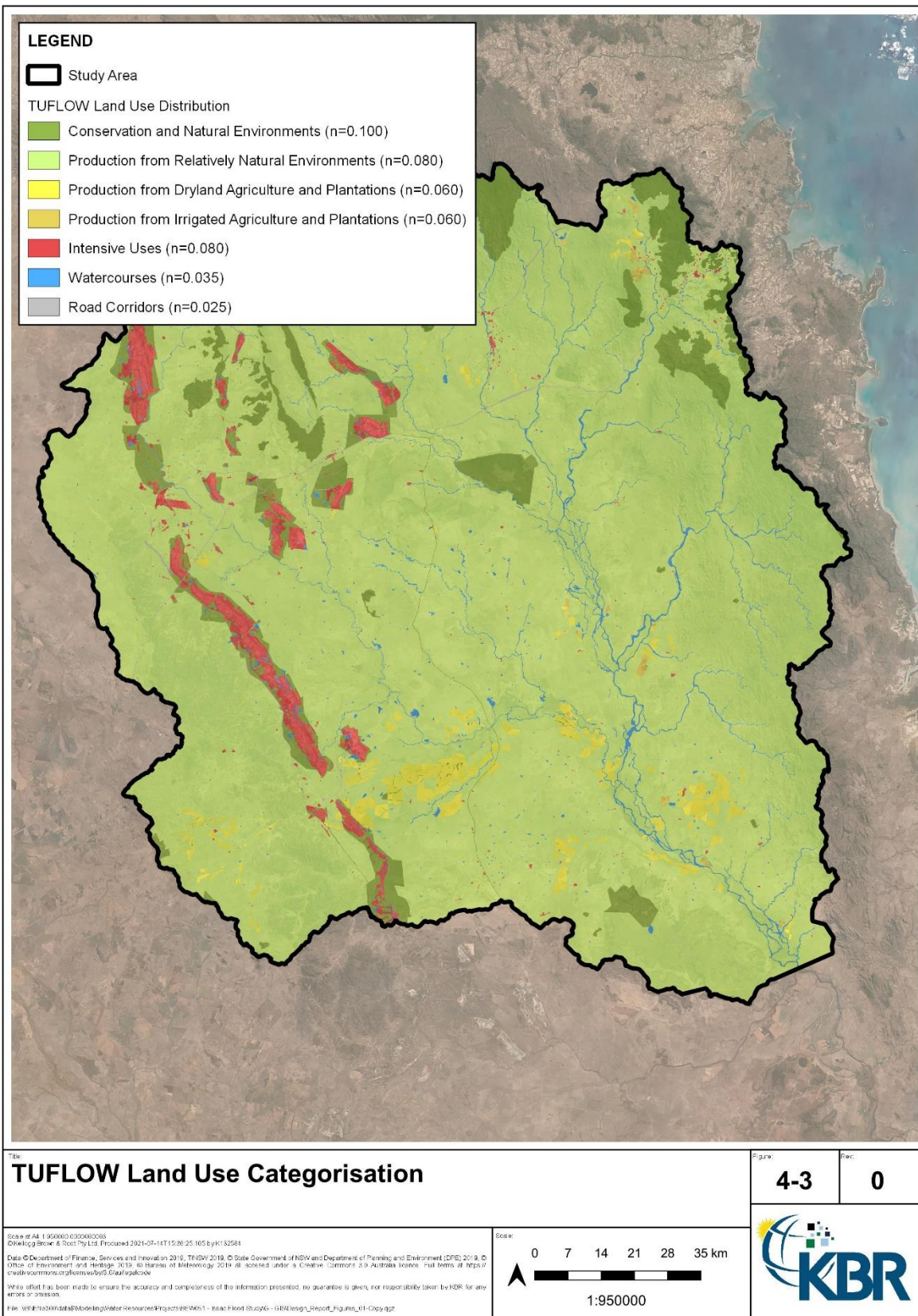


Figure 4-3 TUFLOW Land Use Categorisation

5 Model Calibration

To calibrate the TUFLOW RoG model, the historical Tropical Cyclone Event was simulated through the model. To define the historical event a series of data sources were combined to derived inputs into the model including:

- Local total daily rainfall gauges
- Local gauge records kept from residents within the catchment
- Pluvio-gauge data
- AWAP data.
- The performance of the model was assessed in comparison to:
- Recorded Stream Gauge Data
- Surveyed Flood Marks
- Historical Photography
- Anecdotal Evidence of peak flood extent, depth and overall flood behaviour.

5.1 CALIBRATION DATA

The March 2017 flood event resulted from widespread and prolonged rainfall across the Isaac River Catchment and wider region over a period of three days, from the 28 March–30 March 2017. However, the catchment was mainly affected on the 29–30 March. Several data sources were utilised to derive the calibration event inputs into the model.

The calibration process was undertaken with two key components. Firstly, hydraulic performance of the model was assessed against gauging's at the three eastern upper catchment stream gauges. To undertake this process a reduced model domain was adopted as well as decreasing the model cell size to 15 m. Secondly due to the uncertainty in several rating curves at high flow, the model inflows were adjusted to correlated with the water level time series. The subsequent tropical cyclone event was compared to surveyed peak flood levels as well as indicative flood depths and extents.

5.1.1 Stream Gauges

A number of DRNME stream gauges were active during the 2017 event. Six of which are considered reliable for calibration. The six gauges represent the areas of most intense rainfall as well as outlets to major sub-catchments. The Isaac gauges were not used as there are no stream ratings for these gauges and the project team could not confirm the survey accuracy.

Due to the extensive record of gauging's at the stream gauges, the upper catchment gauges of 130413A – Denison Creek at Braeside, 130406A – Funnel Creek at Main Road and 130403A – Connors River at Mt Bridget were used to calibrate the model based off recorded gauging's as well as to validate the high flow rating curves provided by DRNME.

Time series of the water level at each of the gauges and performance of the model in respected to the observed timeseries is presented within Section 5.4.

5.1.2 Daily Rainfall Data

During the event there was a range of active BoM rainfall gauges within, or in the vicinity of the Isaac River catchment. The recorded daily totals for the at each of these gauges as well as their

coordinated are recorded within Appendix B. The spatial distribution and the total rainfall over the course of the event are presented in Figure 5-2.

There is significant spatial variation within the total recorded depths across the catchment with the most intense rainfall occurring in the far north eastern reaches of the catchment. Notably in this area there is no data within the upper catchments themselves rather on either side of the ranges.

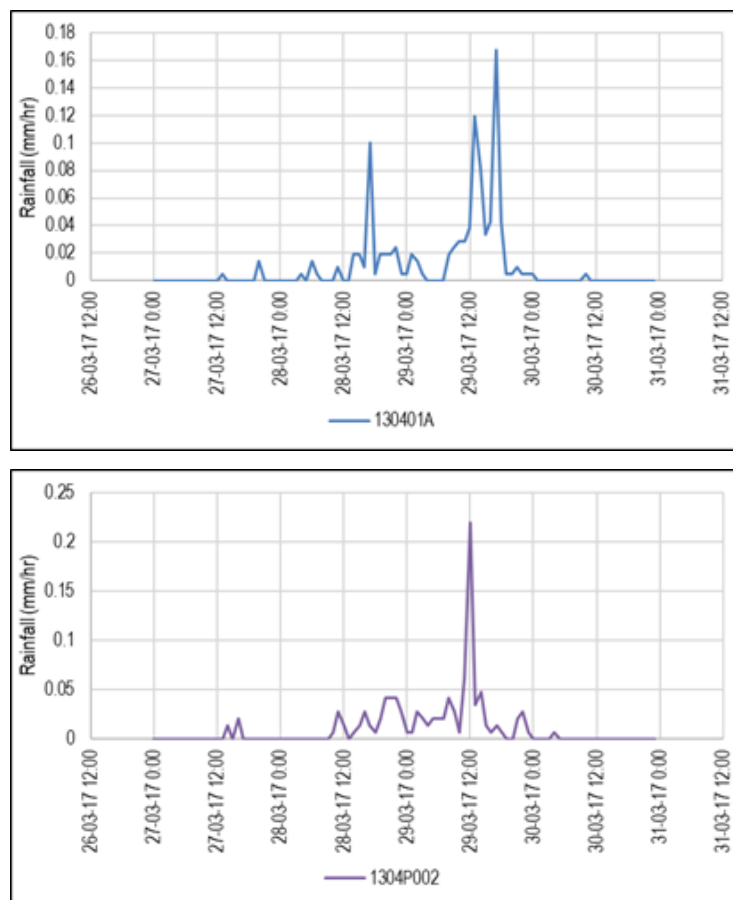
Due to the basis of the AWAP data the total daily gauges rainfall distribution matches that of the AWAP distribution. Total rainfall contours of the AWAP data is similarly presented in Figure 5-2

5.1.3 Sub-Daily Rainfall Data

Each of the active stream gauges as well as three standalone DRNME pluvio-gauges were active during Tropical Cyclone Debbie. Each of the records were considered in light of the gauge location as well as the completeness of the dataset with several gauges ceasing records due to the gauge becoming 'drowned'. The location and total rainfall recorded at these gauges is presented in Figure 5-2.

A key element of the temporal patterns is the highly spatially varying nature of the tropical cyclone with the ranging intensity and spiralling of the cyclone bands. This is evident with the large rainfall peaks within the recorded hyetographs. Due to this highly spatially varying nature of the rainfall event and the significant distance between sub-daily gauges, the adopted temporal patterns will not reflect the actual distribution at locations away from the immediate vicinity of the gauge.

Selected records for distributing total rainfall into model input storm events are presented in Figure 5-1.



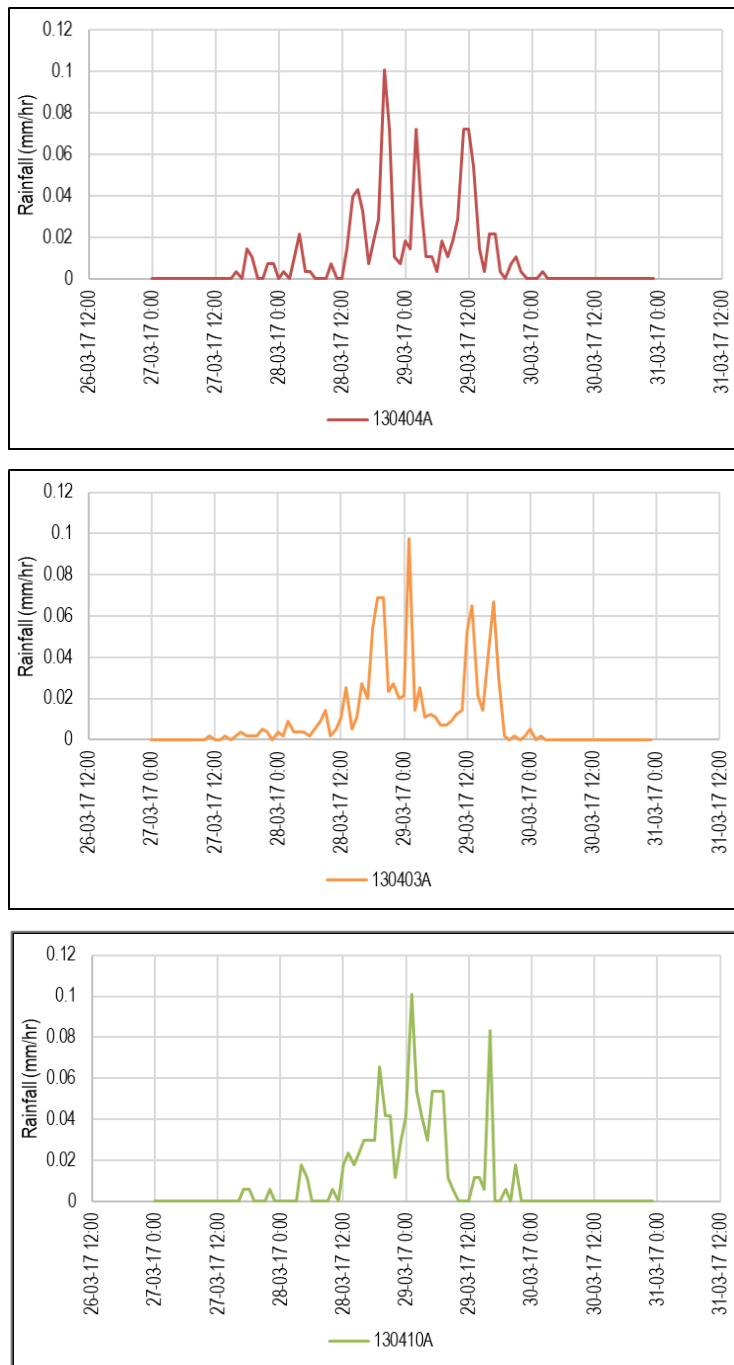


Figure 5-1 Select Pluvio-Graphs from Tropical Cyclone Debbie

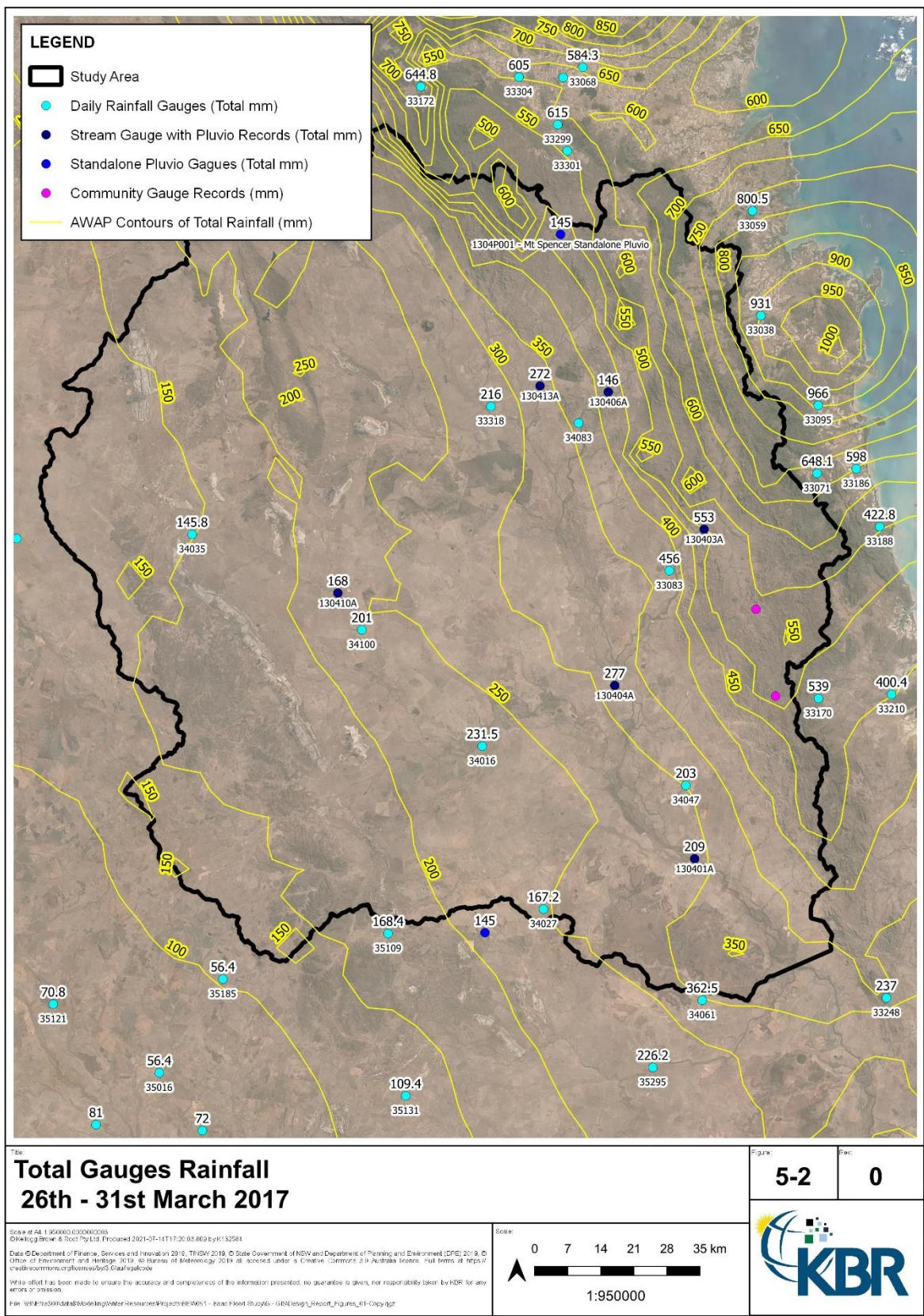


Figure 5-2 AWAP Data for Tropical Cyclone Debbie

5.1.4 Antecedent Conditions

Prior to Tropical Cyclone Debbie, a series of lower order rainfall events were recorded, and anecdotal evidence records the catchment of being fully saturated prior to the commencement of Tropical Cyclone Debbie. This would have been a contributing factor to the severity of the event in the catchment. As such, all soils at the commencement of the simulation are simulated as fully saturated.

5.1.5 Peak Flood Level and Flood Extent Data

As discussed within Sections 3.4 and 3.6 peak flood level and flood extent data is provided through community consultation with multiple survey marks as well as the peak water level within the stream gauge time series.

5.2 ADOPTED CALIBRATION EVENTS STORM INPUTS

5.2.1 Calibration Storm Segmentation

Due to the scale of the catchment and ranging AWAP data the allocated storms were based of rainfall data-tiles. As such a unique storm was applied to each AWAP tile, as presented in Figure 5-3.

The model area was considered in regard to each of the stream gauges. Local storms were applied based on the following:

- Temporal patterns were selected from sub-daily gauges, these temporal patterns were then normalised in order to scale to local rainfall intensity. Selected temporal patterns are presented in Figure 5-1.
- The total rainfall for each AWAP tile was distributed across the selected normalised temporal pattern for the respective stream gauge region shown in Figure 5-4.
- Peak water level time series were used to inform scaling of rainfall in each of the respective stream catchments. Adopted scaling is presented in Table 5-1.

Table 5-1 AWAP Total Rainfall Scaling by Stream Gauge Catchment

Gauge	Scaling
130401A - Isaac River at Yatton	80%
130403A - Connors River at Mt Bridget	310%
130404A - Connors River at Pink Lagoon	50%
130406A - Funnel Creek at Main Road	175%
130410A - Isaac River at Deverill	90%
130413A - Denison Creek at Braeside	160%

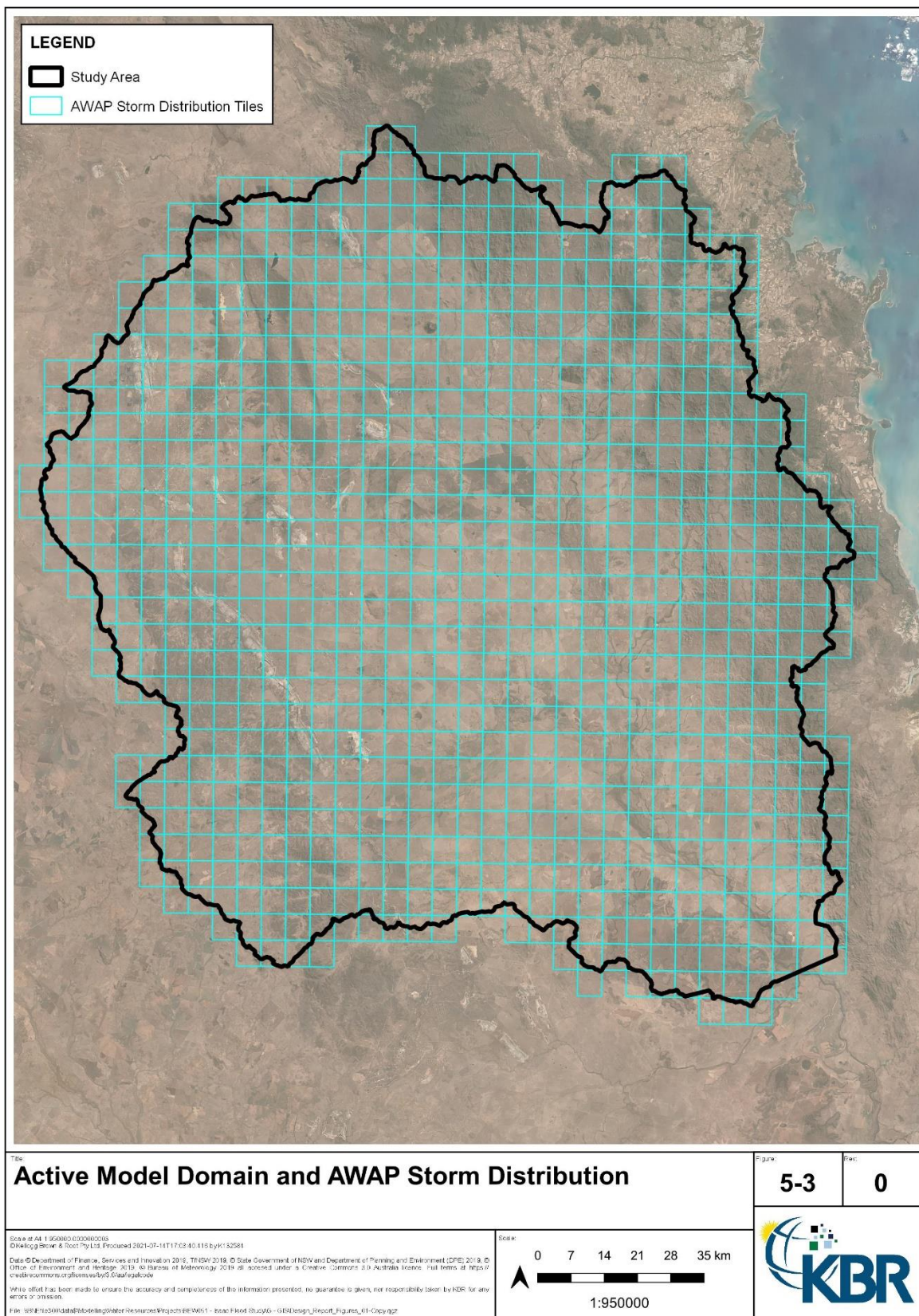


Figure 5-3 AWAP Storm Distribution



5.3 RAITING CURVE CALIBRATION

Each of the DRNME rating curves, observed gauging's as well as KBR TUFLOW model results are presented in Figure 5-5, Figure 5-7 and Figure 5-8. On the left in each figure, the 15 m grid cell size TUFLOW model result is presented, on the right both the 15 m and 60 m cell size TUFLOW results are presented for comparison in high flow scenarios. Across all gauges, the finer 15 m grid TUFLOW model and the courser catchment wide 60m grid model align well.

5.3.1 130403A - Connors River at Mount Bridget

It was requested as part of this study that the rating curve at Mount Bridget be reviewed and updated. The modelled results at Connors River at Mount Bridget are capturing the observed gauging's, noting all of the gauging's above 6.14 m were sampled from the one event with levels sampled from the 9 March 1977 to 10 March 1977. Given the time of these gauging's over the single event 44 years ago, as well as the lack of bathymetry data upstream and downstream of the gauge, this is considered a reasonable fit. Notably all of the gauging's were below the upper banks of Connors River, as such the flows in the DRNME curve above $\sim 3000 \text{ m}^3/\text{s}$ are interpolated from the in-bank flows. The TUFLOW model is simulating higher flow for this out of bank flow, as such the implication of revising the rating curve is higher flows than previously inferred off the DRNME curves.

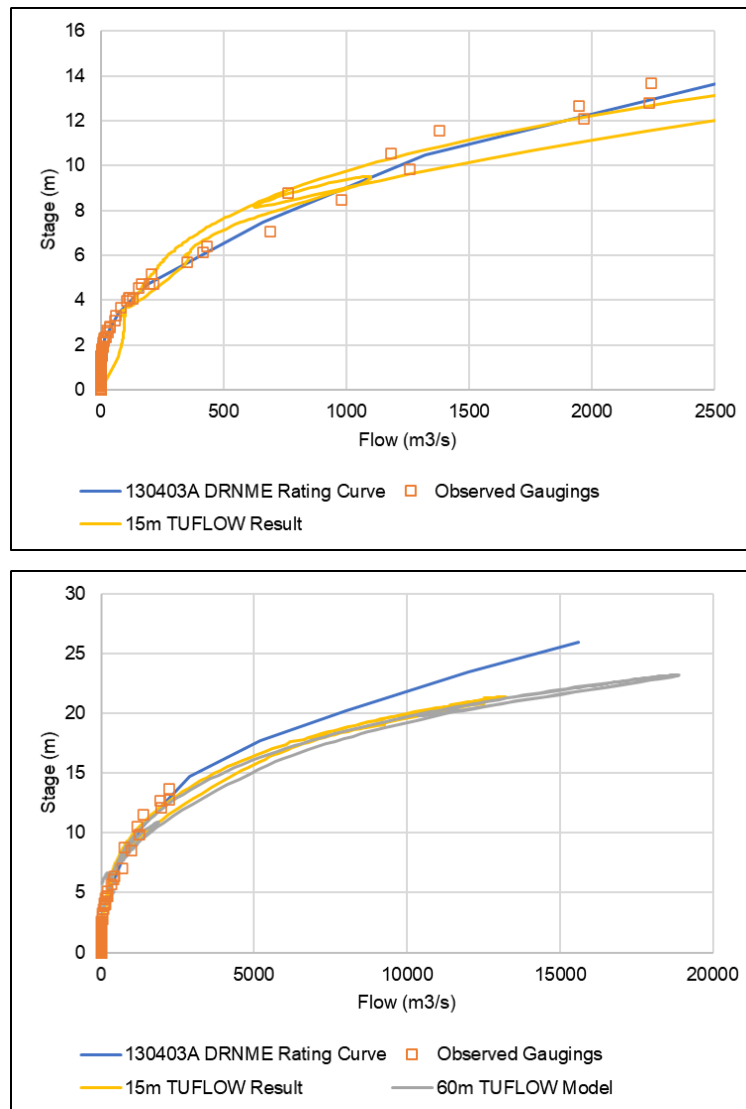


Figure 5-5 130403A - Connors River at Mount Bridget Rating Curve Calibration

The modelling results for Connors River at Mount Bridget were used to create a model derived rating curve. Due to the hysteresis in the model results the average flow at 0.25m water level intervals were extracted, with a log curve fitted to the averaged results.

The produced rating curve is presented in Figure 5-6. The model derived curve indicates higher flow for equivalent stage then that of the DRNME curve, most notably in higher stages.

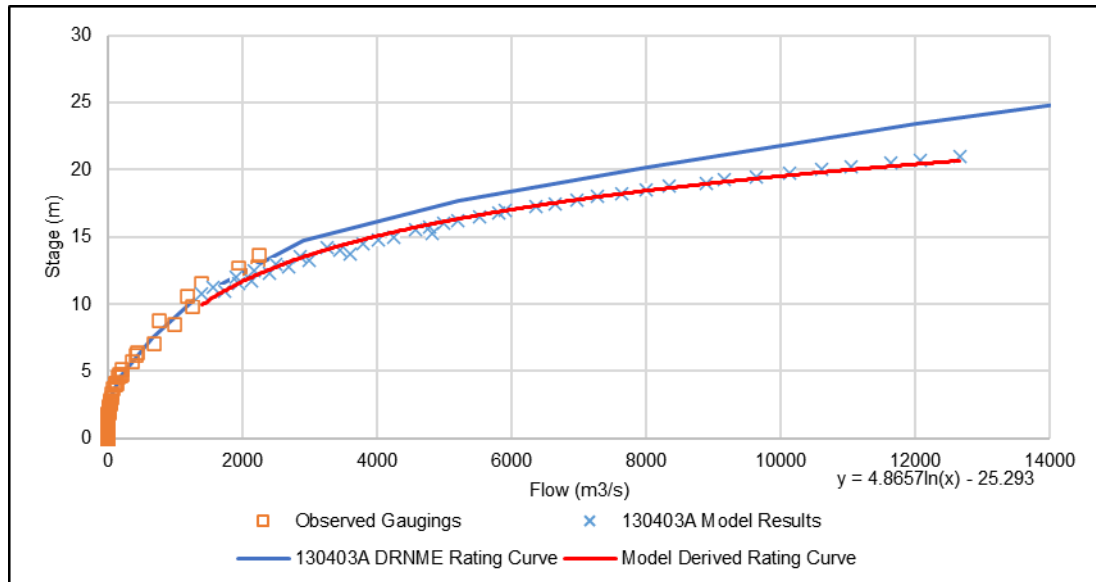


Figure 5-6 130403 – Connors River at Mount Bridget Model Derived Rating Curve

5.3.2 130406A - Funnel Creek at Main Road

Local to the Funnel Creek gauge there are several limitations to matching the low flow gauging's. Notably is the enforcement of the low flow control weir at the gauge, and the gauge is upstream of an area with vegetated channels too fine for the photogrammetry elevation dataset to adequately capture.

Beyond the channel the TUFLOW model results reflect the high flow gauging's, additionally the TUFLOW derived depth-discharge relationship aligns well with the DRNME generated curve as shown in Figure 5-7.

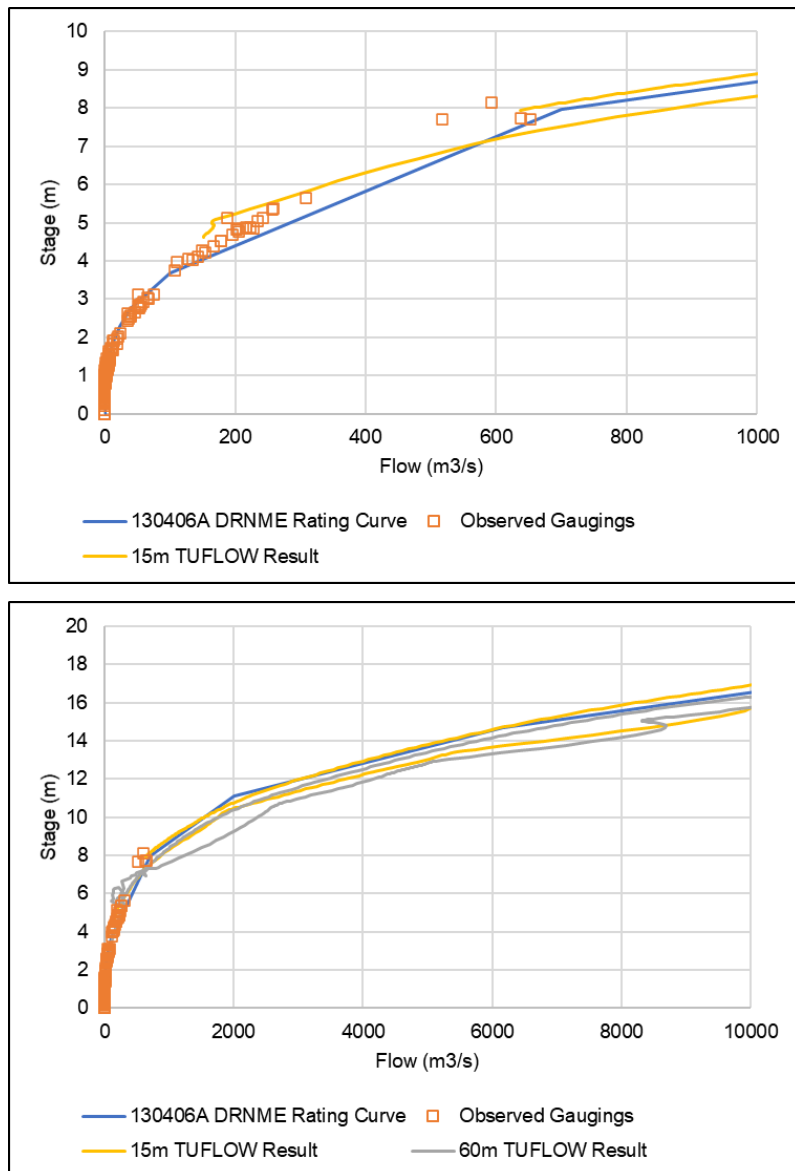


Figure 5-7 130406A – Funnel Creek at Main Road Rating Curve Calibration

5.3.3 130413A - Denison Creek at Braeside

The Denison Creek at Braeside matches gauging's and DRNME rating curve for all flows as shown in Figure 5-8. This gauge is the key driver to limiting the floodplain roughness's, in the broader Tropical Cyclone Debbie calibration. The presented figures are the highest Manning's Roughness adopted to maintain the matching of the curve with the gauging's, noting the gauging's are aligned primarily with the rising limb of the flood wave.

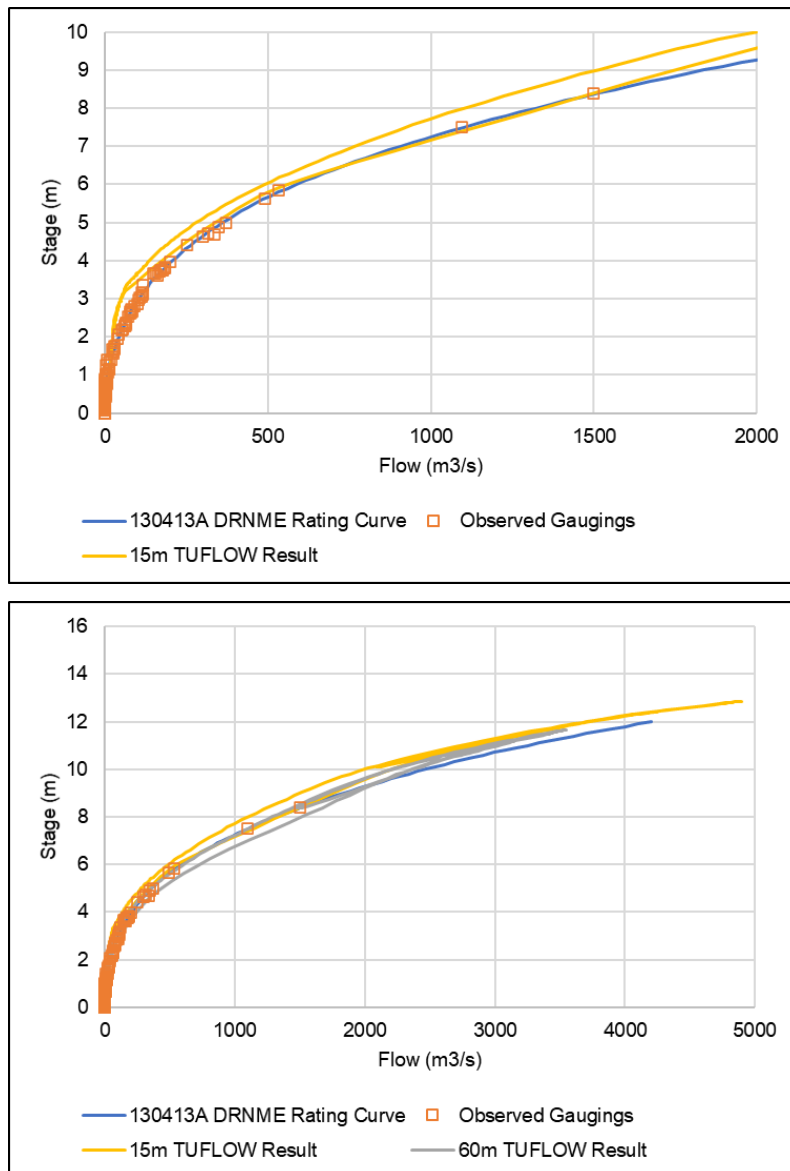


Figure 5-8 130413A - Denison Creek at Braeside Rating Curve Calibration

5.4 TROPICAL CYCLE EVENT RESULTS

Modelled peak flood depths and calibration point locations are displayed Figure 5-9. Water level times series are presented in Figure 5-10. Gauges within the eastern upper catchments, there is some disparity between the observed and simulated water level time series, this is primarily driven by the temporal patterns of the storms simulated in each region. The double peak hydrographs in the upper catchment were difficult to replicate due to the available rain gauge data not recording the shifting storm cell along the escapement. Additional gauge information within this region would enable more accurate calibration of the time series results. Downstream gauges perform well matching the time series distribution.

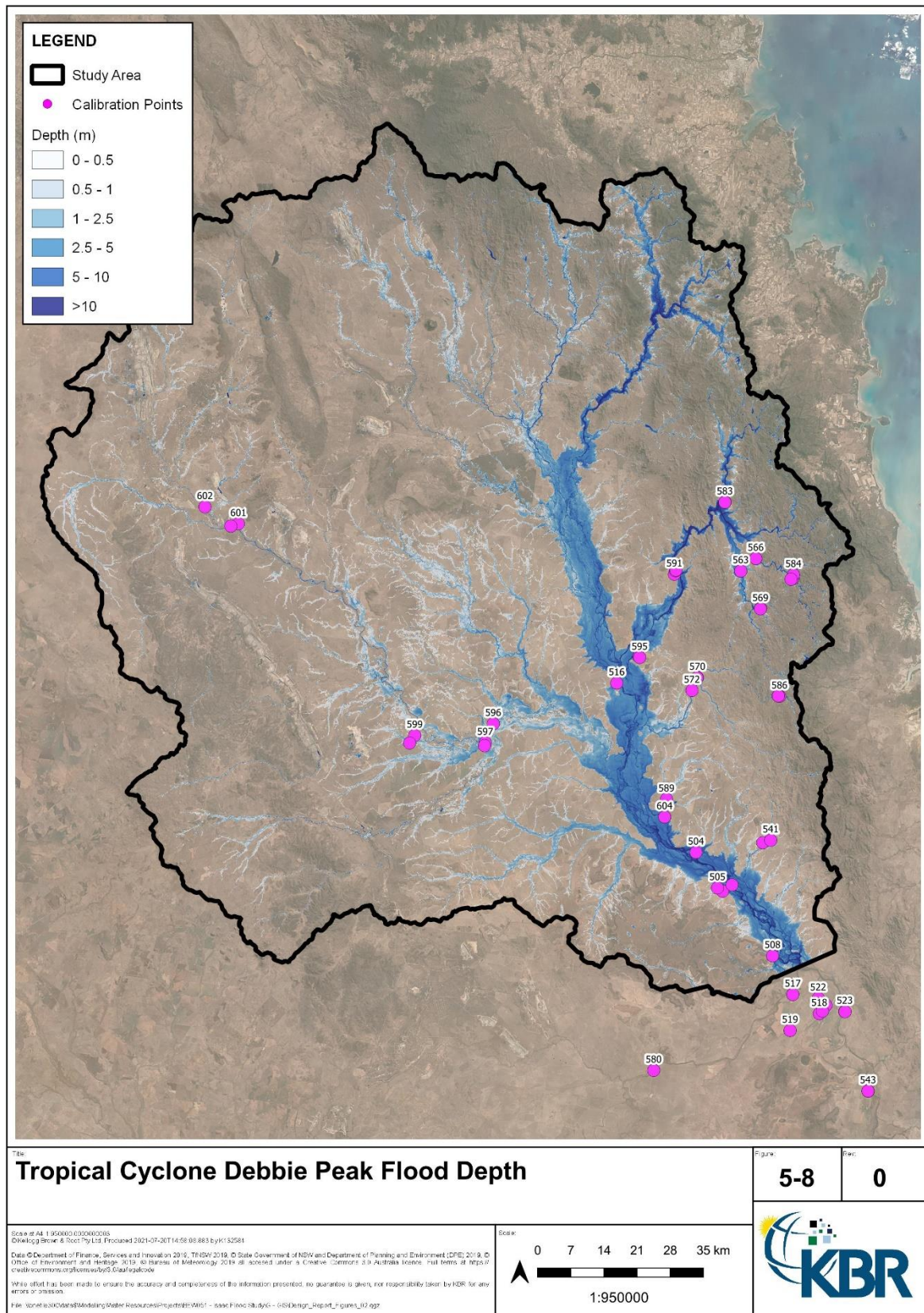


Figure 5-9 Tropical Cyclone Debbie Flood Depths

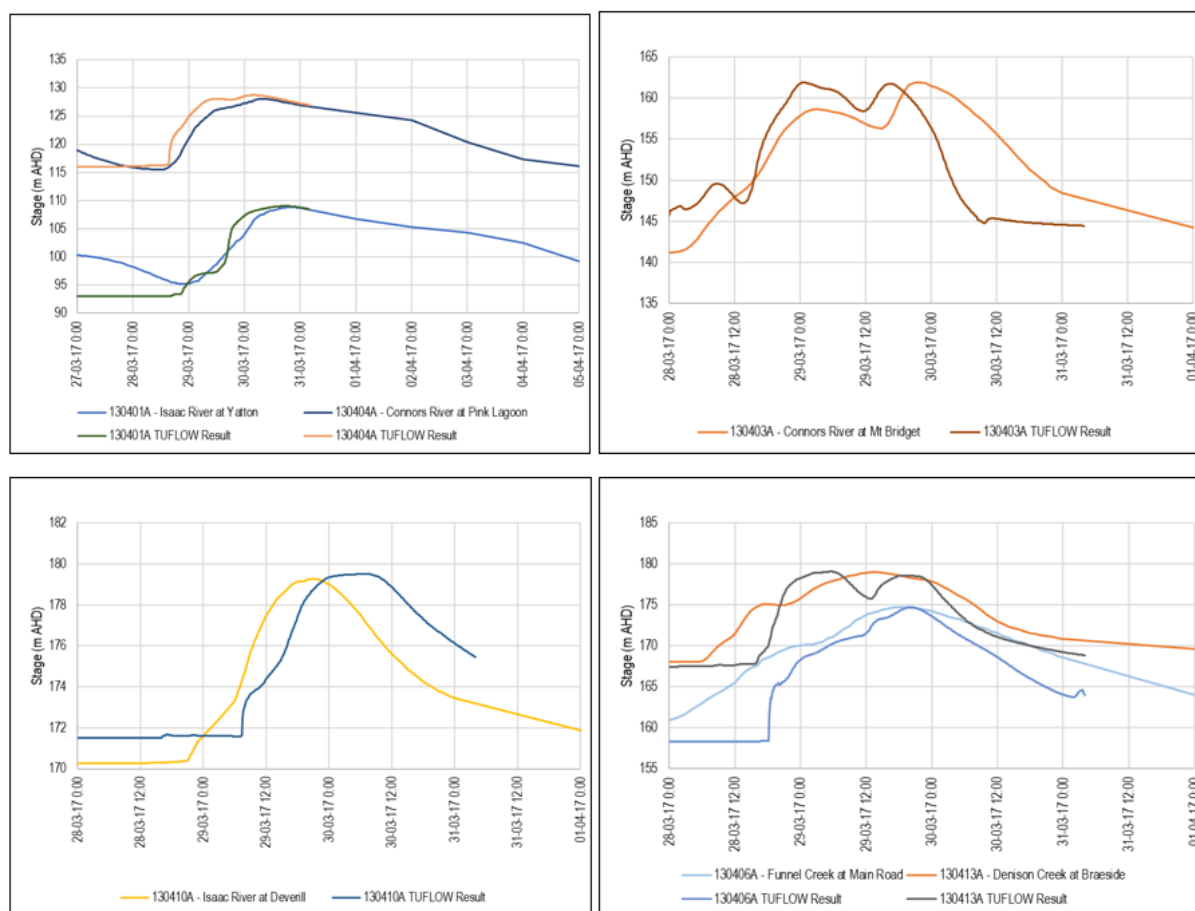


Figure 5-10 Tropical Cyclone Debbie Stream Gauge Hydrographs

The observed and simulated peak flood levels are summarised in Table 5-2. With the exception of Connors River at Pink Lagoon the simulated peak flood level select gauges are within 300 mm of the observed levels. The Connors River at Pink Lagoon peak flood level difference is considered reasonable given the well-matched levels at upstream gauges and a scaling factor of 50% applied to local storms to the gauge catchment.

Table 5-2 Stream Gauge Maximum Observed Peak Flood Levels with Isaac Catchment

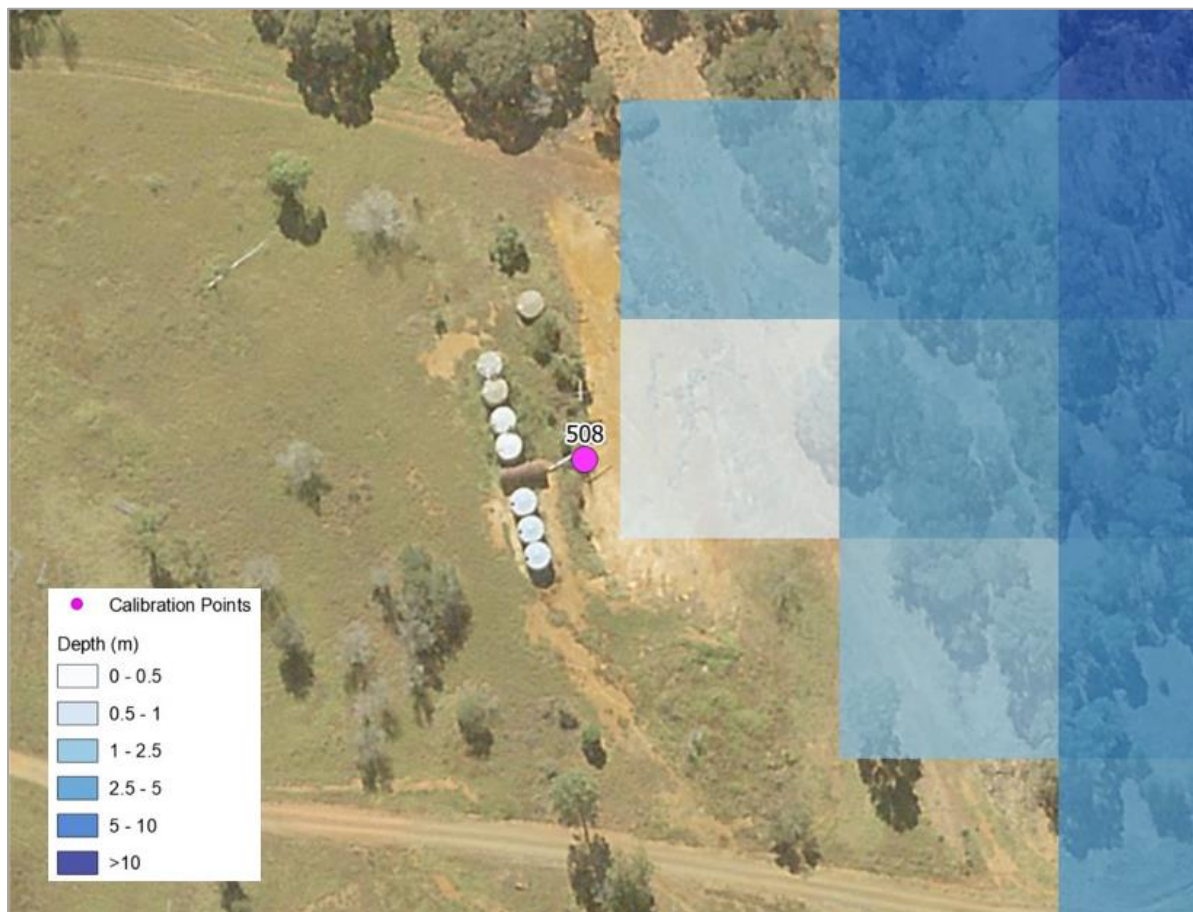
Gauge	Observed Maximum Peak Flood Level	Simulated Maximum Peak Flood Level (m AHD)	Difference (m)
130401A - Isaac River at Yatton	108.82	109.04	0.22
130403A - Connors River at Mt Bridget	161.87	161.89	0.03
130404A - Connors River at Pink Lagoon	128.07	128.73	0.66
130406A - Funnel Creek at Main Road	174.71	174.71	0.01
130410A - Isaac River at Deverill	179.27	179.53	0.26
130413A - Denison Creek at Braeside	178.99	179.06	0.08

Surveyed flood levels as well as ground levels at the peak flood extent are presented in Table 5-3. At surveyed locations differences in peak flood level are larger than that simulated at the gauges. This is driven by several factors most notably the base elevation data coarseness and accuracy. For the given model resolution and accuracy of the base elevation data the levels match well.

Table 5-3 Surveyed Peak Flood Levels Comparison

ID	Surveyed Peak Flood Level (m AHD)	Simulated Peak Flood Level (m AHD)	Difference in Peak Flood Level (m AHD)
500	106.07	106.59	0.52
504	108.69	109.48	0.79
505	106.28	106.81	0.53
506	105.52	106.23	0.71
508	100.22	98.39	-1.84

Two of the surveyed levels above indicate the peak flood extent, Figure 5-11 and Figure 5-12 presents the peak flood extent at these locations. The extents align well with the surveyed marks. Notably point 508 is simulated to have the largest difference in peak flood level, this is driven by the influence of the downstream water level boundary that is driven by the Mackenzie River. The extent aligns well due to the steep gradient in the area. In order to calibrate this level well, detailed water level time series information would need to be provided for the flooding conditions within the Mackenzie River for the Tropical Cyclone Debbie event. There are multiple surveyed flood levels in the Mackenzie River catchment downstream of the Isaac River catchment that could be used if calibration of TC Debbie on the Mackenzie River was to be undertaken. The nearest time series gauge data on the Mackenzie River is the Bingegang (130106A) gauge approximately 43 km upstream of the confluence with the Isaac River, which is too far away to be used in calibration of the Isaac River catchment.

**Figure 5-11** Survey Point 508

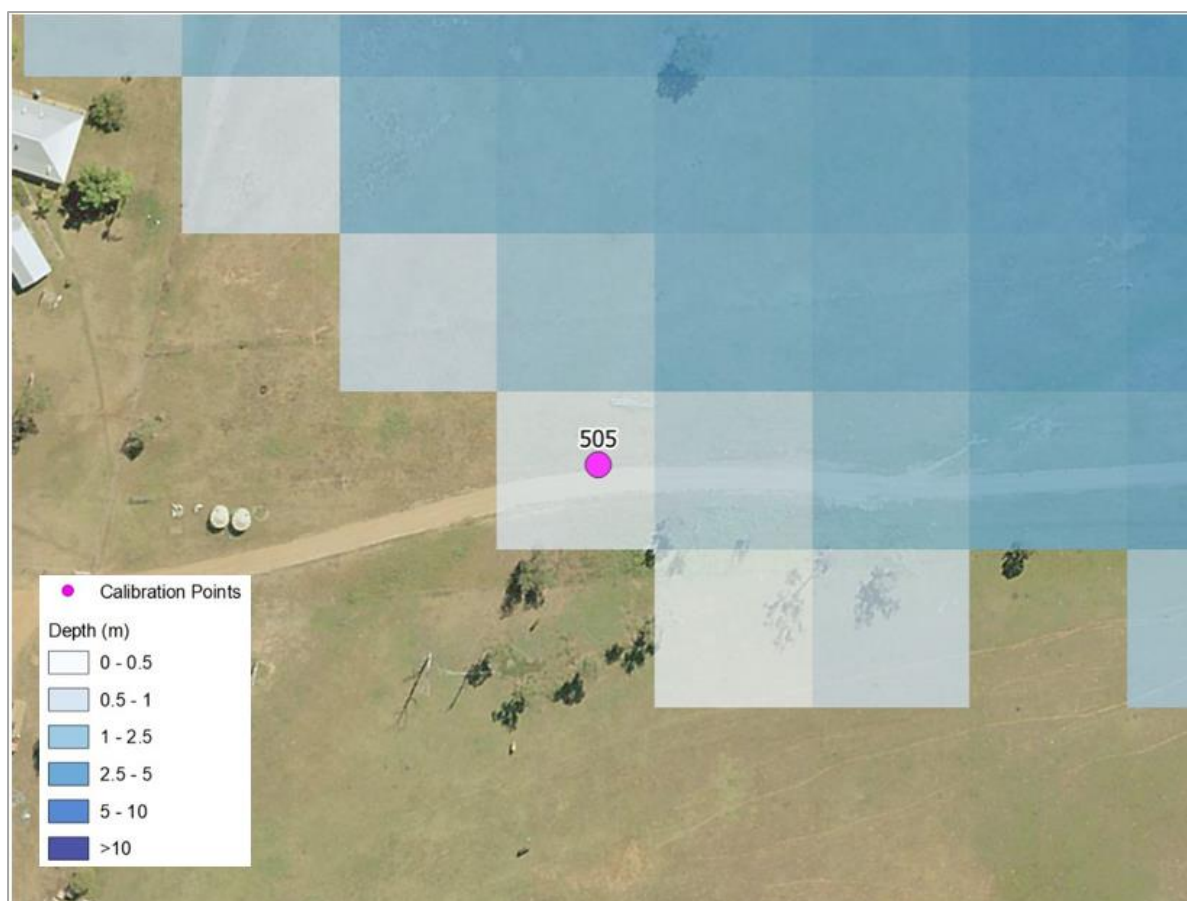


Figure 5-12 Survey Point 505

Indicative peak flood depths gathered from community consultation and the respective simulated peak flood depth are presented in Table 5-4. This model employed sub-grid-sampling as such the reported levels are only sampled at the 60 m grid resolution, however the model is solving for a finer resolution, not conveyed in the coarser final resultant grid.

Table 5-4 Indicative Peak Flood Depth Comparison

ID	Indicative Peak Flood Depth (m)	Simulated Peak Flood Depth (m)	Difference in Peak Flood Depth (m)
566	2.96	2.41	-0.55
568	1.19	1.38	0.19
571	2.79	0.49	-2.30
572	1.64	NFI	N/A
581	0.80	3.98	3.18
582	0.28	NFI	N/A
584	2.90	4.25	1.35
585	10.5	9.07	-1.43
588	0.88	NFI	N/A
589	1.52	1.22	-0.30
590	6.60	6.39	-0.21

ID	Indicative Peak Flood Depth (m)	Simulated Peak Flood Depth (m)	Difference in Peak Flood Depth (m)
599	0.55	0.18	-0.37
507	1.39	NFI	N/A
516	[128.03]	[128.78]	0.74
562	1.25	1.97	0.72
541	1.30	NFI	N/A
566	2.96	2.41	-0.55

NFI – No Flooding Indicated.

N/A – Not Applicable due to one of the two datasets with no flooding indicated.

[] – Indicated calculated peak flood levels from DRNME and respective simulated peak flood level at that location.

Five of the indicative responses provided an estimated flood extent. Figure 5-13 to Figure 5-17 presents the peak flood extent at these locations. Several of these points align well, however locations 570 and 592 demonstrate some deviation from the observed flood extents to the simulated. At both locations, the peak water level aligns with the lowest water within the respective cell however this is not presented within the depth result due to the depth result being represented based off the exact elevation of the cell corners and cell centre. As such the model does simulate flood extents up to this location however it will not be presented within depth result. This is a known constraint with the current release of TUFLOW and will be address in the next release. Survey point 570 shown in Figure 5-15 is located in Markwell where the heaviest storm cell moved through the bottom end of Connors River catchment and across Lotus and Clarke Creek catchments. It is difficult for a regional RoG model to replicate the rainfall intensities in the small creek catchments.



Figure 5-13 Survey Point 586

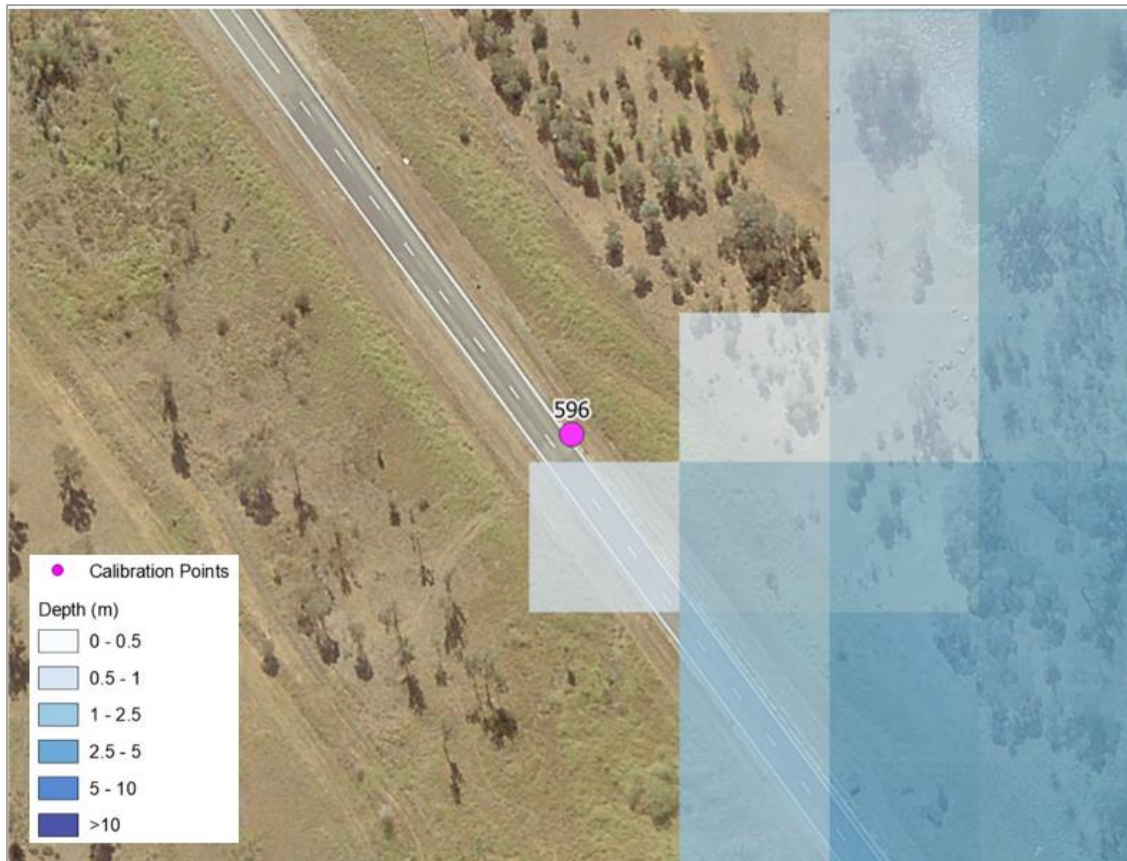


Figure 5-14 Survey Point 596



Figure 5-15 Survey Point 570



Figure 5-16 Survey Point 592

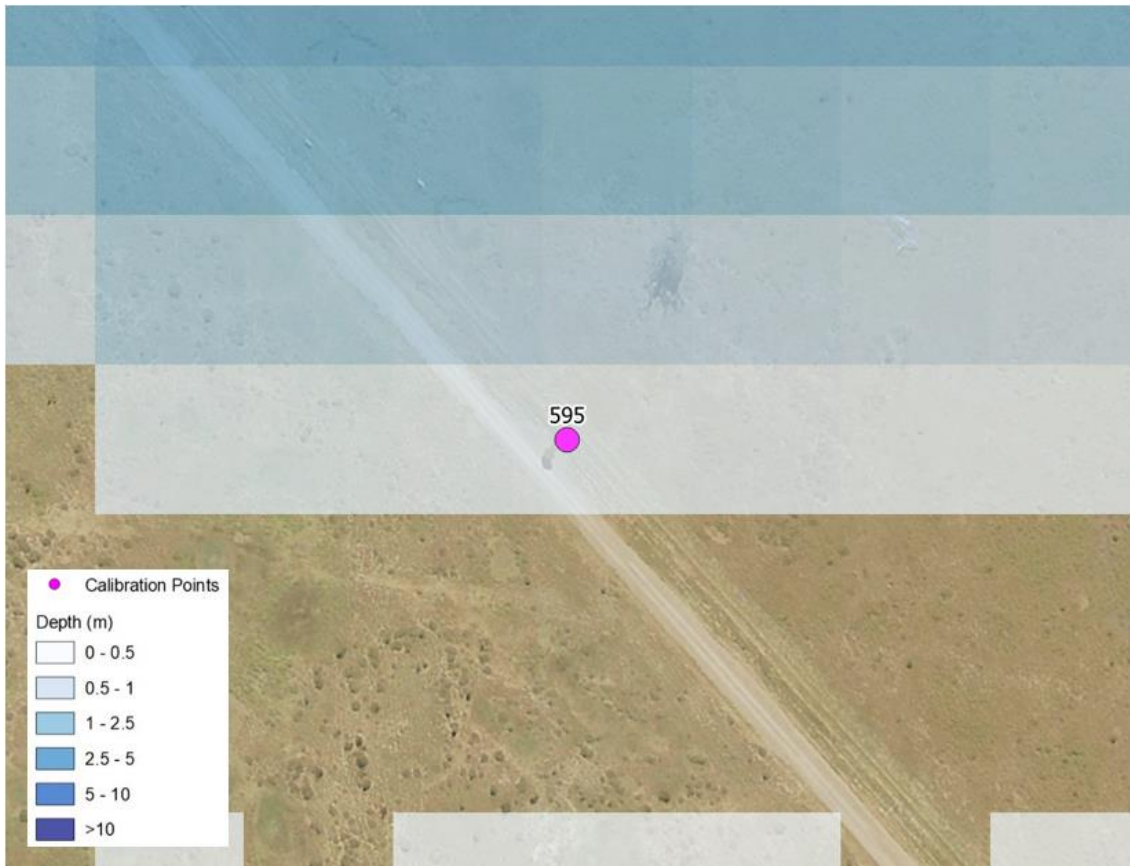


Figure 5-17 Survey Point 595

Hydrographs from DRNME data and the simulated hydrograph at each of the gauges are presented in Figure 5-18. These hydrographs are significantly affected from both the temporal patterns as well as the deviation of the DRNME rating curves and the simulated depth-discharge relationships under high flow conditions. Further refinement to the hydrographs below is possible provided more sub-daily rainfall data and further investigation and adoption of model derived rating curves.

Gauges most significantly affected from the disparity of DRNME rating curves and simulated depth-discharge relationships include Connors River at Pink Lagoon, Connors River at Mt Bridgett and Isaac River at Deverill.

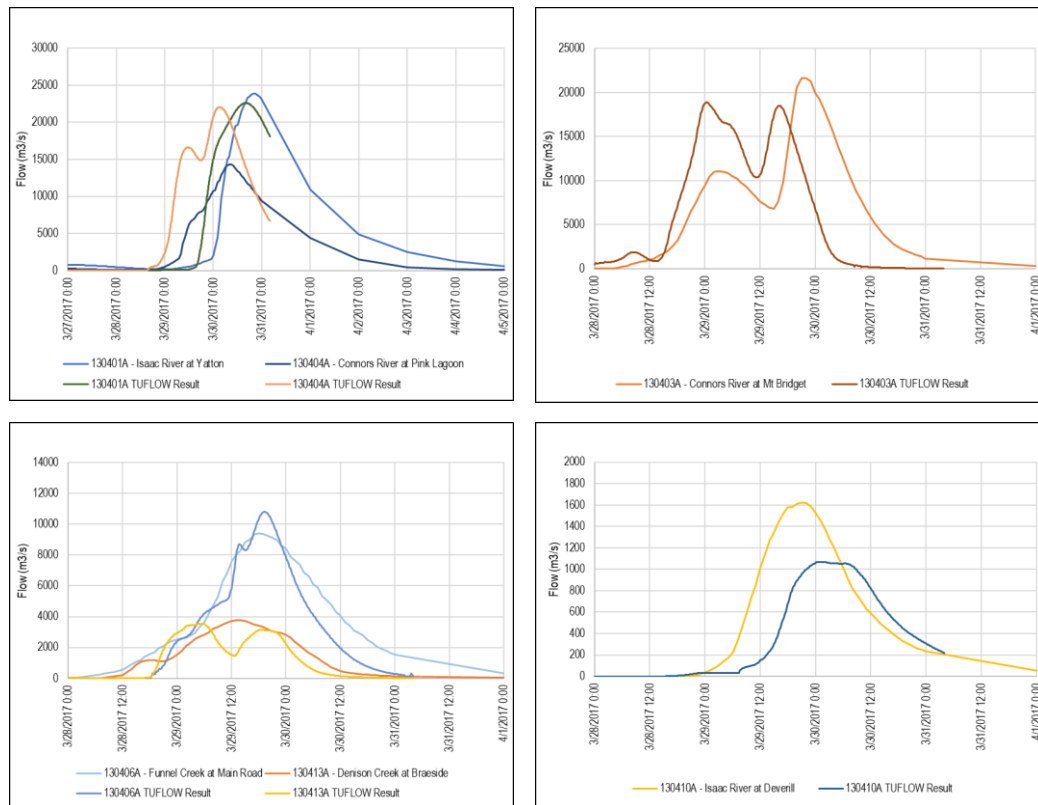


Figure 5-18 Tropical Cyclone Debbie Stream Gauge Hydrographs

5.5

CALIBRATION CONCLUSION

The derived model has matched peak flood levels within the catchment for the 2017 Tropical Cyclone Debbie event. The available rainfall gauges within the catchment did not record the extreme rainfall intensity of Tropical Cyclone Debbie due to the storm cell shifting along the escapement missing the rainfall gauges. Significant scaling of input rainfall was required to match gauge levels and estimated flow hydrographs.

The Mount Bridgett rating curve was the only rating curve revised as part of this assessment, therefore there is still a level of uncertainty of estimated flows at the remaining gauges for the Tropical Cyclone Debbie event. If further analysis and revisions of rating curves in the catchment are undertaken, this calibration should be revised.

6 Design Event Modelling

For this study the design rainfall estimates are in accordance with Geoscience Australia's 2019 release of Australian Rainfall and Runoff (ARR). The design flood conditions form the basis for floodplain management in the catchment, including flood planning levels for future development controls. The predicted design flood conditions are presented in Section 6.3.

Design event modelling simulated synthetic storms at varying degrees of likelihood of occurring. ARR 2019 provides extensive guidance as well as several datasets to derive design events for any given catchment in Australia. Such datasets include:

- Intensity-Frequency-Duration Curve
- Temporal Patterns
- Catchment Antecedent Conditions and Associated Losses
- Areal Reduction Factors.

Due to the broad scale in which this data is provided, ARR 2019 emphasises the value of local gauge data to provide historical temporal patterns if appropriate as well as Flood Frequency Analysis (FFA) to determine what flow or water level within a water course has a given probability of occurring. This significantly increases the reliability of the study with the adjustment of storms to suite reflect the FFA.

Given the size of the Isaac Catchment and the nature of design event modelling. Adopted design events and proposed methodology was driven by the locations of gauges, township centres as well as the overall flood mechanics within the catchment. As such design rainfall was considered in eight sub-catchments as presented in Figure 6-2. Design rainfall inputs were derived for each of these locations then scaled to match the local FFA's.

KBR has simulated the 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and 0.1% AEP design events as well as the PMF.

6.1 FLOOD FREQUENCY ANALYSIS

At each of the gauges discussed within Section 5 a FFA was undertaken within TUFLOW FLIKE on both the annual peak water level and annual peak flow. Due to significant width of the floodplain in several locations within the Isaac Catchment, the focus of the study and scaling of design rainfall was to match the peak water level FFA. Discussion of the adoption of FFA on peak flood level over the industry standard FFA on peak flow is provided within Section 7.2.

GEV probability distributions performed best on the annual maximum gauge stage series. Inference methods as well as outlier censoring was undertaken on a gauge-by-gauge basis. Adopted inference method, probability distribution and censored datasets for the FFAs are presented in Table 6-1.

Table 6-1 FFA Parameters on Gauge Annual Maximum Stage

ID	Name	Inference Method	Probability Distribution	Censored	Total AMAX	AMAX Excluding Outliers
130401A	Isaac River at Yatton	LH H+0	GEV	NO	59	-
130403A	Connors River at Mt Bridget	LH H+2	GEV	NO	56	-
130404A	Connors River at Pink Lagoon	LH H+1	GEV	YES	56	40

ID	Name	Inference Method	Probability Distribution	Censored	Total AMAX	AMAX Excluding Outliers
130406A	Funnel Creek at Main Road	LH H+1	GEV	NO	56	-
130410A	Isaac River at Deverill	LH H+4	GEV	NO	53	-
130413A	Denison Creek at Braeside	LH H+1	GEV	YES	50	40

Results from the FFA on annual peak gauge stage are presented in Table 6-2 and a graphical representation of the FFA undertaken in TUFLOW FLIKE is presented in Figure 6-1.

In comparing the Tropical Cyclone Debbie event, the peak flood level in the majority of the catchment is representative of the 2% AEP event with the exception of the Connors River at Mount Bridget which on peak flood level alone was between the 0.5 and 0.1% AEP event.

Table 6-2 FFA on Gauge Annual Maximum Stage

ID	Name	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	TC Debbie
130401A	Isaac River at Yatton	18.9	19.8	20.1	20.4	20.7	19.7
130403A	Connors River at Mt Bridget	19	20.6	21.5	22.2	23.4	23.2
130404A	Connors River at Pink Lagoon	16	16.4	16.7	16.9	17.2	16.4
130406A	Funnel Creek at Main Road	13.7	15.2	16.2	17.2	19.5	16.4
130410A	Isaac River at Deverill	11.2	11.6	11.8	11.9	12	10.0
130413A	Denison Creek at Braeside	11.3	12	12.4	12.6	13	11.6

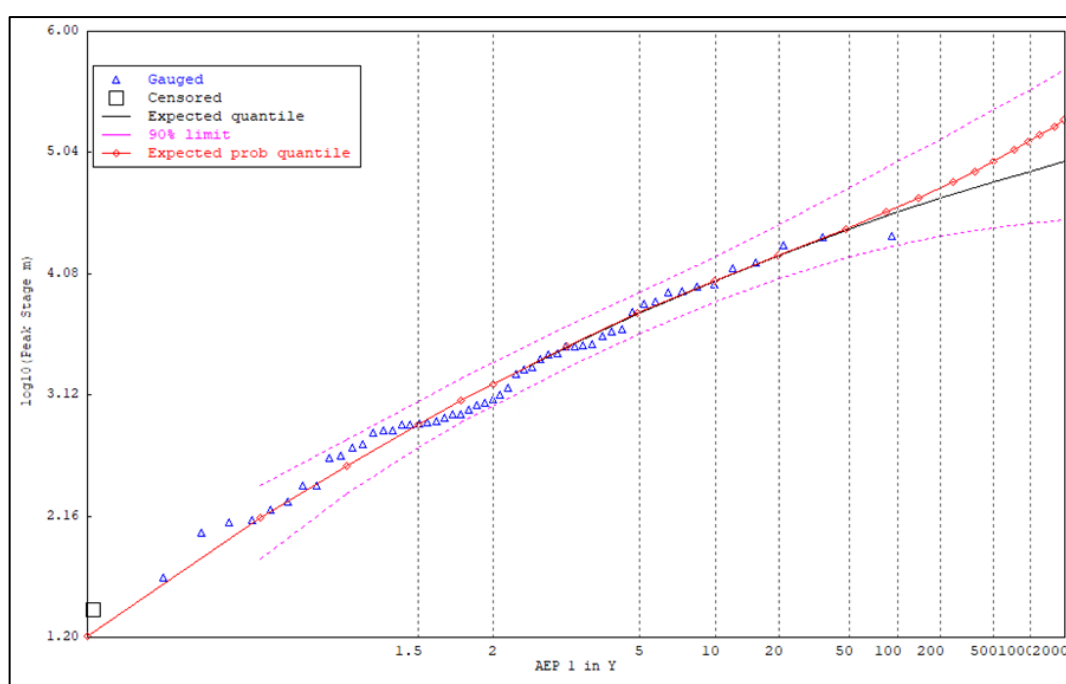


Figure 6-1 130401A Isaac River at Yatton

6.2 DESIGN EVENT MODEL INPUTS

Design input schematisation is orientated around 8 local storm inputs to townships and major gauges. These local storms extract from the ARR 2019 datahub at the centroid of each of the total upstream area of each outlet. Each storm is named after the outlet adjacent at either the township or major gauge. Spatial distribution of the local storms is presented in Figure 6-2.

- Dysart Local Storm
- Funnel Creek Local Storm (at gauge 130406A)
- Denison Creek Local Storm (at gauge 130413A)
- Connor River at Mount Bridget Local Storm (at gauge 130403A)
- Nebo Local Storm
- Moranbah Local Storm (Upstream of gauge 130410A)
- Connor River at Pink Lagoon Local Storm (at gauge 130404A)
- Isaac River at Yatton Local Storm (at gauge 130401A)

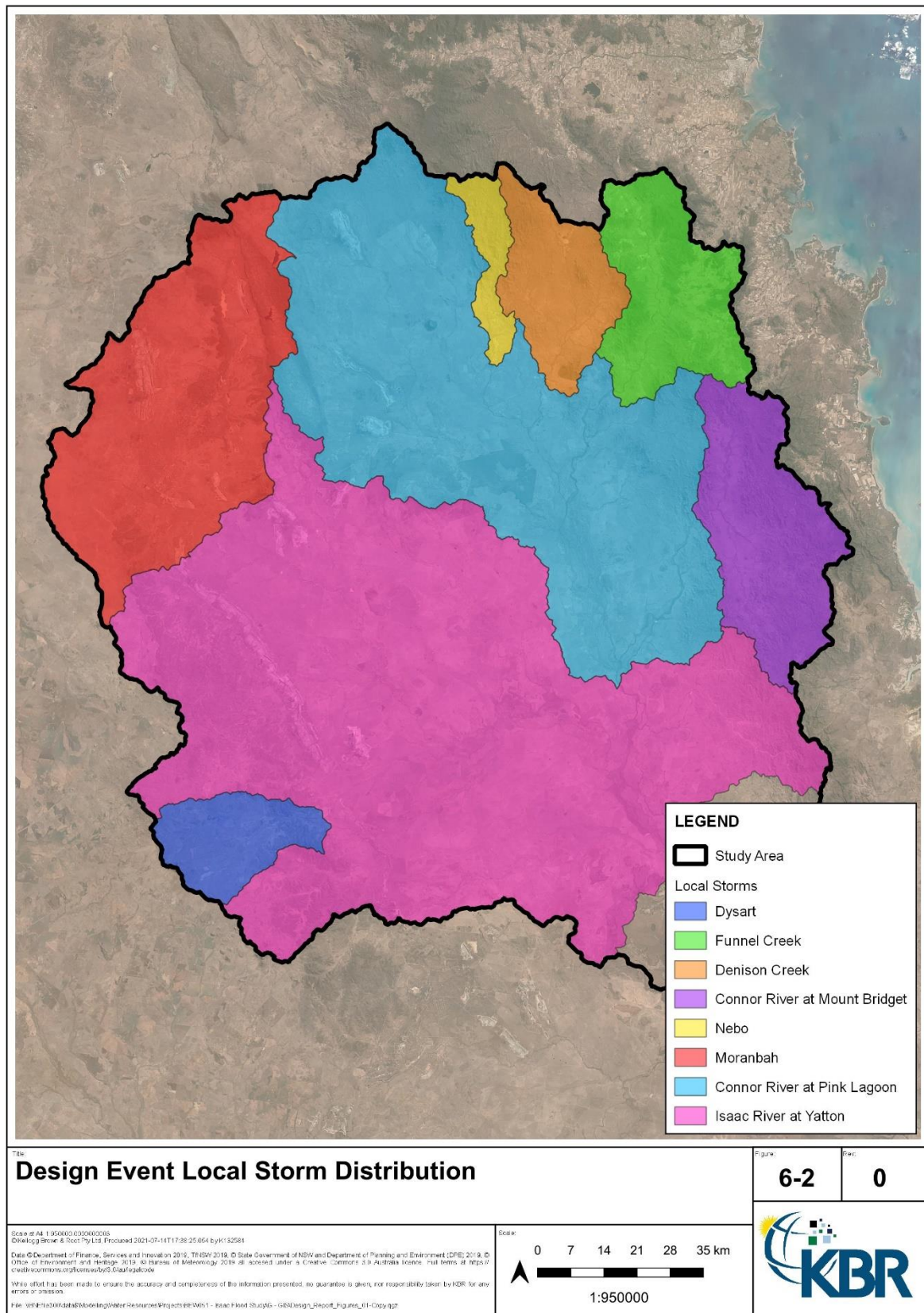


Figure 6-2 Design Event Local Storm Distribution

6.2.1 Design Rainfall Depth

Design rainfall depths were extracted using the centroid of the entire contributing catchment. Extracted rainfall depths for the 1% AEP are presented in Table 6-3. As presented in Table 6-3 storms in the upper regions of the catchment design rainfall depths are significantly larger than that of the western and lower reaches of the catchment.

Table 6-3 1% AEP IFD Data at Each Extraction Location (m)

Duration (min)	Connor at Bdgt	Connor at Pink	Denison	Dysart	Funnel	Moranbah	Nebo	Yatton
720	254.6	159.2	219.8	160.6	271	139.9	240.6	113.3
1080	333.1	210	281.7	187.2	359.6	172.8	309	146.2
1440	405.2	259.4	338.5	211.5	443.9	203.4	369.2	178.8
1800	459.8	294.2	382	228.5	508.2	223.9	417	200.6
2160	506.9	324.7	419.7	242.6	565.7	242.3	459	219.7
2880	584.8	375.3	482.3	265.8	663.7	272.7	526.5	251.2
4320	695.6	448.1	571.5	300.2	805.4	317.3	620.1	298.4
5760	765.8	494	633.2	322.7	900.8	345.7	679.6	329.9
7200	810.6	522.4	676.1	338.3	963.2	363.6	718.9	350.7
8640	837.7	537.9	709.1	347.9	1005	374.7	747	364.3
10080	852.8	543.9	733.1	354.5	1027.2	380	766	370.7

6.2.2 Areal Reduction Factor

Similarly, to the design rainfall depths, areal reduction factors were determined on the total upstream catchment to each respective local storm. As such the further downstream in the catchment the larger the areal reduction factor to the applied storm.

6.2.3 Rainfall Losses

Green-Ampt soil infiltration was maintained to account for rainfall losses, refer Section 4.6. Given design events are largely reflective of systems driven by cyclones, design events are assumed to occur during the wet season. As such, all soils are simulated as saturated at the start of the simulation.

6.2.4 Temporal Patterns

Isaac Catchment is located at the juncture of several ARR 2019 temporal pattern regions. Whilst the majority of the catchment is located within the East Coast North region, the north eastern sub-catchments cross over the Wet Tropics region and the north western reaches fringe on the Monsoonal North region.

Due to the minimal coverage of the Monsoon North region, these areas were assumed to be represented by the East Coast North temporal patterns.

Due to this historical effect of tropical cyclones on the catchment, both the Wet Tropics and the East Coast North were extracted for sub-catchments along the eastern boundary of the catchment. These included the following areas:

- Funnel Creek Local Storm (at gauge 130406A)
- Denison Creek Local Storm (at gauge 130413A)
- Connor River at Mount Bridget Local Storm (at gauge 130403A)

- Nebo Local Storm.

Due to the extent of the catchment area temporal patterns were adopted.

6.2.5 Critical Duration Assessment

The critical duration assessment takes into consideration the upper and lower catchments. With a separate simulation to capture the critical durations at the areas of interest. The upper catchment local storms include:

- Dysart Local Storm
- Funnel Creek Local Storm (at gauge 130406A)
- Denison Creek Local Storm (at gauge 130413A)
- Connor River at Mount Bridget Local Storm (at gauge 130403A)
- Nebo Local Storm
- Moranbah Local Storm (Upstream of gauge 130410A).

For the lower catchment two local storms were considered for their proximity to major gauges, as follows:

- Connor River at Pink Lagoon Local Storm (at gauge 130404A)
- Isaac River at Yatton Local Storm (at gauge 130401A).

To define the critical duration of each storm a rapid assessment was undertaken within the XP-RAFTs model built in the early stages of the flood study to define the median and mean temporal patterns. For simulation through TUFLOW either the mean or median was selected with the exception of temporal patterns which the median and mean temporal patterns produced an artificially high peak, in these cases an alternative temporal pattern was then manually selected.

Each of the selected temporal patterns were simulated for all durations through TUFLOW, the critical duration for each storm was then selected based on the duration with the highest peak flow out of the associated catchment. The critical duration assessment for the lower catchment storms assumed a universal upstream storm using the total area for the aerial reduction factor and adopted East Coast North temporal patterns.

Adopted critical durations are presented within Table 6-4.

Table 6-4 Critical Duration and Associated Temporal Pattern and Selection Method

Name	Critical Duration (min)	Temporal Pattern	Selection Method
Dysart Local Storm	720	10	Median
Funnel Creek Local Storm	5760	10	Selected
Denison Creek Local Storm	1440	6	Mean
Connor River at Mount Bridget Local Storm	2880	2	Selected
Nebo Local Storm	2880	9	Mean
Moranbah Local Storm	1440	4	Mean
Connor River at Pink Lagoon Local Storm	7200	1	Median
Isaac River at Yatton Local Storm	4320	1	Mean

These individual storm critical durations were used to inform the adopted temporal pattern and duration combinations for design event modelling. As all the upper catchment storms are independent of one another, each of these storms are simulated concurrently within the one simulation. This efficiency significantly reducing the number of simulations required with no effect to the results within the catchment.

For the lower catchment storms an alternative approach must be considered. Due to the four upper catchments within the Wet Tropic region, these regions design rainfall events were re-defined with the East Coast North temporal pattern to maintain consistency in the storms being simulated in the lower catchment. As such all catchments were simulated with East Coast North temporal patterns, IFD and aerial reduction factors for the total upstream area of each catchment, noting these are to be scaled to match the FFA. Through defining this process, it was determined that the Isaac River at Yatton storm was representative of the conditions of the Connors River at Pink Lagoon as such the 4320min temporal pattern 1 event was simulated in the entire lower catchment, whilst noting the storm will be locally scaled to the FFA's.

6.2.6 Scaling to FFA Results

Following the derivation of the critical duration, each of the design events were iteratively run scaling the inputs storms to match the peak flood levels derived from the FFA on gauge stages.

Adopted scaling factors for each design event AEP are presented in Table 6-5.

Table 6-5 Local Storm Scaling Factors for Each Design Event

Name	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP (Lower)	0.1% AEP (Upper)
Dysart Local Storm	1.05	1	1	1	1	0.85
Funnel Creek Local Storm	2.45	2.3	2.2	2.1	1.9	1.5
Denison Creek Local Storm	1.9	1.75	1.65	1.5	1.2	1.1
Connor River at Mount Bridget Local Storm	2.55	2.45	2.3	2.15	1.8	1.45
Nebo Local Storm	1.9	1.75	1.65	1.5	1.2	1.1
Moranbah Local Storm	1.05	1	1	1	1	0.85
Connor River at Pink Lagoon Local Storm	1	0.5	0.5	0.5	0.5	0.5
Isaac River at Yatton Local Storm	1.4	1.5	1	0.7	0.7	0.5

6.3 PROBABLE MAXIMUM FLOOD

Within Australia there are several methodologies to modelling a Probable Maximum Flood (PMF). Due to the location, size and critical durations simulated for design event modelling, only the Generalised Tropical Storm Method (GTSMR) was deemed appropriate.

The GTSMR was developed by BoM and initially released in 2003 with further guidance provided in 2005. The GTSMR like other PMF derivation methodologies characterises extreme historical events produce a represented event for inputs into hydrological models.

To characterise a catchment for the GTSMR several inputs are required, including three factors spatially distributed across GTSMR relevant regions as well as an area dependant probable maximum precipitation (PMP).

The raw PMP was calculated based of a total catchment area of 22,437 km². An average of the spatial distribution of Moisture Adjustment Factor (MAF), Decay Adjustment Factor (DAF) and

Topographic Adjustment Factors (TAF) were extracted for each of the design rainfall regions as well as for the entire catchment. PMP for each region was scaled based off the ratio of the local regions average TAF compared to the catchment average TAF. For the final adopted PMP the regional PMP was scaled by the regional average MAF, DAF and TAF.

Input GTSMR parameters and adopted PMP depths are presented in Table 6-6 and Table 6-7 respectively.

All GTSMR durations were simulated through TUFLOW with the 36-hour event being critical at all location except 130406A - Funnel Creek at Main Road where the 36-hour event was 19mm below the 24 hours. As such the 36-hour event was adopted as being the critical duration on a catchment wide basis

The provided PMF event is on a catchment wide basis, individual catchment PMF events should be considered local to towns for planning purposes.

Table 6-6 GTSMR Input Parameters

Catchment	Area (km2)	DAF	TAF	MAF
Dysart	548.0	1.00	1.00	0.75
Funnel	1058.7	1.00	1.46	0.83
Denison	757.4	1.00	1.30	0.81
Connor River at Mount Bridget	1276.1	1.00	1.46	0.81
Nebo	268.4	1.00	1.48	0.81
Moran	2672.2	1.00	1.00	0.77
Connor River at Pink Lagoon	5278.7	1.00	1.09	0.80
Yatton	9139.2	1.00	1.05	0.77
Entire Study Area	22437.2	1.00	1.12	0.78

Table 6-7 Adopted PMP Depths (mm) for Each Duration

Catchment	24 Hour	36 Hour	48 Hour	72 Hour	96 Hour	120 Hour
Dysart	481	582	676	843	949	981
Funnel	1137	1375	1597	1990	2240	2316
Denison	882	1067	1239	1545	1739	1798
Connor River at Mount Bridget	1115	1349	1566	1952	2197	2271
Nebo	1135	1373	1595	1988	2237	2313
Moran	495	599	695	867	976	1009
Connor River at Pink Lagoon	603	730	848	1057	1190	1230
Yatton	543	657	763	951	1070	1106

6.4 DESIGN FLOOD RESULTS

Design flood results have been compared against the FFA peak flood level to confirm scaling factors as well as peak conditions at key locations. Additionally, mapping of key model outputs such as hazard are presented in Appendix A.

6.4.1 Match to FFA

Differences between the maximum peak flood level between the upper and lower catchment flooding scenarios for each AEP and the FFA on gauge stage is presented in Table 6-8.

Differences from the FFA at Connors River at Pink Lagoon, ranges from +0.32 to +0.66 m, this deviation is largely consistent across the design events. The final differences are driven by the adoption of scaling factors matching upstream gauges, to achieve lower differences at this location would require significant scaling at rainfall local to Connors River at Pink Lagoon.

At two key locations, Funnel Creek a Main Road and Isaac River at Deverill, deviation from the FFA levels is presented at the more frequent and rarer events respectively. This is driven by the adoption of maximum of peak flood level from the upper scenario at a location which should be driven the lower event and visa versa. While the deviation is noted, the adopted scaling factors were selected to maintain overall scenario scaling accuracy and the relatively minor deviation from the FFA level.

Table 6-8 Simulated Peak Flood Level Comparison to FFA on Gauge Annual Maximum Stage

ID	Name	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
130401A	Isaac River at Yatton	-0.07	-0.08	-0.01	0.06	0.00
130403A	Connors River at Mt Bridget	0.04	0.05	-0.03	-0.06	0.01
130404A	Connors River at Pink Lagoon	0.32	0.33	0.48	0.66	0.53
130406A	Funnel Creek at Main Road	0.35	0.00	0.06	0.09	0.05
130410A	Isaac River at Deverill	-0.04	0.06	0.05	0.16	0.31
130413A	Denison Creek at Braeside	0.03	0.00	0.00	-0.01	-0.01

6.4.2 Peak Flood Conditions

Peak flood depth and level at several key locations are presented in Table 6-9 and Table 6-10.

Range in peak flood levels between the 5% to 0.1% AEP events varies from 1.16 m at locations of broad floodplains such as Isaac River at Yatton and up to 5.5m at locations of channelised flow such as Funnel Creek at Main Road.

PMF Levels are demonstrated to be above the 0.1% AEP at all locations. Additionally, it should be noted the PMF event is a catchment wide assessment, local PMF events such as within the Nebo catchment would result in more extreme PMF levels.

Table 6-9 Peak Flood Depths at Key Locations

Location	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	PMF
Nebo Creek - Nebo	5.09	5.65	6.10	6.36	6.72	8.05
Isaac River – Peak Downs Highway	8.30	9.35	9.97	10.58	11.57	12.99
Stephens Creek Dysart	5.97	6.55	6.96	7.38	8.26	8.65
Connors River at Pink Lagoon	11.73	12.14	12.59	12.97	13.14	14.80
Funnel Creek at Main Road	14.06	15.21	16.26	17.29	19.55	17.62
Isaac River at Deveril	8.95	9.46	9.65	9.86	10.11	10.98
Denison Creek at Braeside	8.44	9.10	9.51	9.70	10.09	11.35
Connors River at Mt Bridget	19.06	20.67	21.49	22.16	23.44	22.68
Isaac River at Yatton	13.45	14.35	14.72	15.08	15.33	18.86

Table 6-10 Peak Flood Levels at Key Locations

Location	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP	PMF
Nebo Creek - Nebo	195.66	196.21	196.67	196.93	197.29	198.61
Isaac River – Peak Downs Highway	206.55	207.60	208.23	208.84	209.82	211.25
Stephens Creek Dysart	214.60	215.18	215.58	216.00	216.88	217.28
Connors River at Pink Lagoon	127.99	128.40	128.84	129.23	129.39	131.06
Funnel Creek at Main Road	172.35	173.50	174.56	175.59	177.85	175.92
Isaac River at Deveril	180.48	180.99	181.18	181.39	181.64	182.52
Denison Creek at Braeside	178.71	179.38	179.78	179.97	180.36	181.66
Connors River at Mt Bridget	157.77	159.37	160.19	160.87	162.14	161.38
Isaac River at Yatton	107.97	108.87	109.24	109.60	109.85	113.38

6.4.3 Flood Hazard

Flood hazard is typically derived from a combination of peak flood depth and velocity. The visualization of flood hazard provides for a better understanding of the potential flood risk within the study area. Handbook 7 - Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (2013) provides revised hazard classifications which add clarity to the hazard categories and what they mean in practice. The classification is divided into six categories shown in Figure 6-3 which indicate the restrictions on people, buildings and vehicles:

- H1 – No constraints
- H2 – Unsafe for small vehicles
- H3 – Unsafe for all vehicles, children and the elderly
- H4 – Unsafe for all people and all vehicles
- H5 – Unsafe for all people and all vehicles. Buildings require special engineering design and construction
- H6 – Unsafe for people and vehicles. All building types considered vulnerable to failure

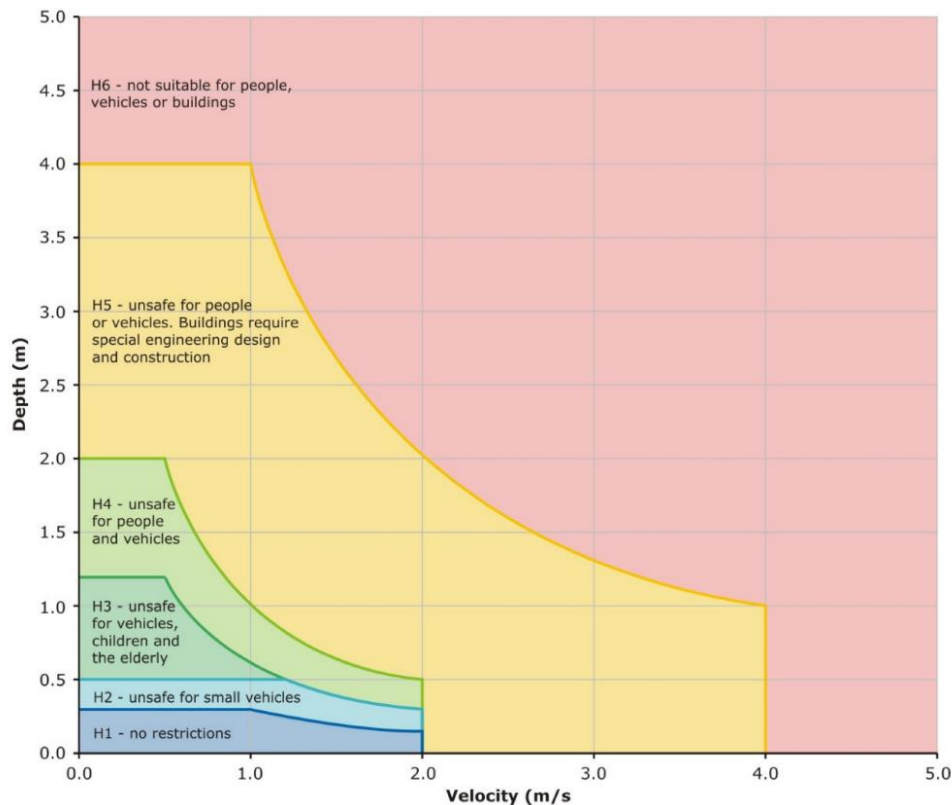


Figure 6-3 Combined Flood Hazard Curves (AIDR, 2017)

Mapping of the flood hazard is presented within Appendix A.

6.4.4 Flood Mapping

Mapping of the flooding results are is presented within Appendix A. Mapping is presented on all simulated events, the 5%, 2%, 1%, 0.5%, and 1% AEP events as well as the PMF event, and at a catchment wide scale.

Provided mapping includes two sets of information:

- Peak Flood Depths with Peak Water Level Points
- Peak Flood Velocity
- Flood Hazard – According to Handbook 7 - Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (2013).

7 Sensitivity Testing

Due to rating curves and FFA's being critical to this study, sensitivity testing focuses on these elements, with sensitivity undertaken on;

- Rating Curves – Particularly with their implications for flow.
- FFA on Flow – Given the significant scaling adopted and the uncertainty within the high flow rating curves.
- Plotting Positions of Historical Events – Underlying the FFA at several gauges, the plotting position of TC Debbie has significant effects on the extreme event range of the FFA.

7.1 RATING CURVE SENSITIVITY

Due to the critical nature of the gauge data with associated rating curves, the FFA sensitivity of the adopted rating curves is considered. Whilst this section does not include extensive modelling to support the sensitivity of the modelling outcomes, these should be noted to be key limitations in the accuracy of the modelling undertaken.

7.1.1 Sensitivity in Rating Curve Calibration

Through the calibration process matching model stage-discharge results to gaugings at the major gauges were a key consideration. Due to the scope of this assessment individual catchment Manning's values were not considered and catchment wide adoption of Manning's values was undertaken.

As presented in Figure 7-1, this resulted in minor under and over estimation of stage-discharges at different gauge sites. As such a Manning's value that resulted in the best suited all gauge relationships was adopted. By adopting catchment local Manning's values, subtle variations in adopted values would be extrapolated to higher order flows.

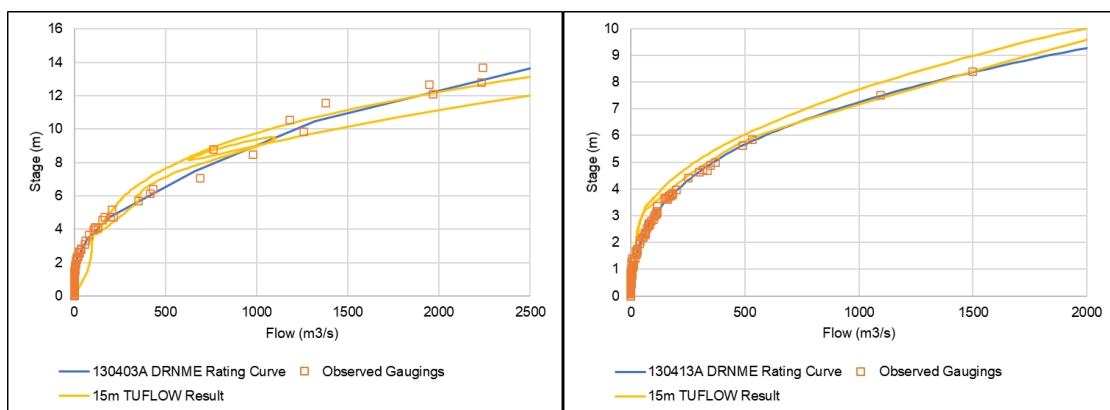


Figure 7-1 (L) Low Stage Rating Curve at 130403A (R) Low Stage Rating Curve at 130413A

7.1.2 Sensitivity to High Flow at Major Gauges

At a number of key gauges such as Connors River at Pink Lagoon and Isaac River at Yatton, the out of bank flow occurs across an exceptionally wide floodplain. Due to this breadth of the floodplain and significant safety risk few if any sampled gaugings are undertaken for out of bank flows. As such these rating curves are highly dependent on extrapolation of what gaugings are available as well as assumed relationships.

This becomes problematic with high order events and adoption of an appropriate flow. Uncertainty within these rating curves extends to the subsequent FFA on flow. Figure 7-2 presents the DRNME rating curves and the gaugings for each of these gauges. These present the high level of extrapolation of high order events.

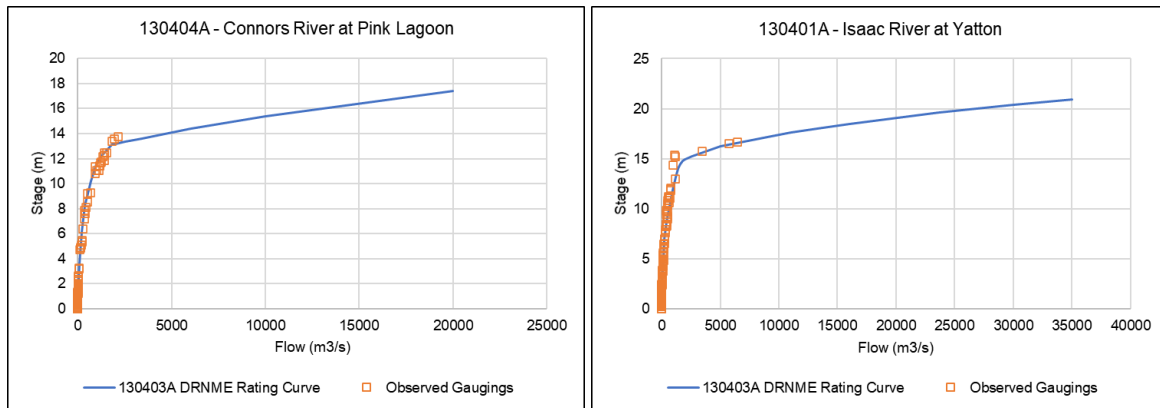


Figure 7-2 (L) Connors River at Pink Lagoon Rating (R) Isaac River at Yatton Rating

7.1.3 Mount Bridget Rating Curve

Following the outcomes of the Connors River at Mount Bridget rating curve validation in Section 5.3.1, the modelling results were used to create a model derived rating curve. Due to the hysteresis in the model results the average flow at 0.25m water level intervals were extracted, with a log curve fitted to the averaged results.

The produced rating curve is presented in Figure 7-3. The model derived curve indicates higher flow for equivalent stage than that of the DRNME curve, most notably in higher stages. This will significantly skew the outcomes of the FFA on flow at the gauge.

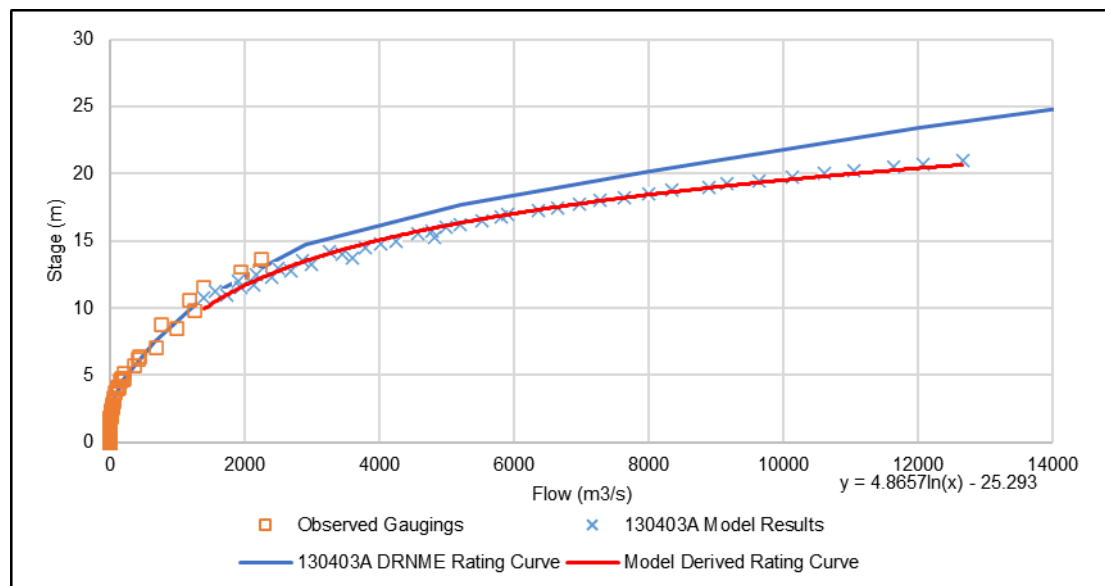


Figure 7-3 130403 – Connors River at Mount Bridget Model Derived Rating Curve

7.2 FFA ON FLOW SENSITIVITY

As discussed within Section 6.1, FFA was also undertaken on peak flow at each of the gauges. The Log-Pearson III distribution performed best for the annual gauge peak flow. Similarly, to the peak gauge stage FFA, inference methods as well as outlier censoring was undertaken on a gauge by gauge basis.

For the FFA of flow at the Mount Bridget gauge, the annual peak water level services were converted into flows using the rating curve.

Adopted inference method, probability distribution and censored datasets for the FFAs are presented in Table 7-1, and results presented in Table 7-2. A percent difference between the simulated flow for the design events and the FFA on flow is presented in Table 7-3.

As presented in these tables, the FFA on flow significantly increases the flow at major gauges such as Isaac River at Yatton and Connors River at Mount Bridget. In order to match these FFA flows, rainfall inputs would need to be significantly scaled beyond their adopted values in the order of three times the IFD derived events.

Table 7-1 FFA Parameters on Gauge Annual Peak Flow

ID	Name	Inference Method	Probability Distribution	Censored	Total AMAX	AMAX Excluding Outliers
130401A	Isaac River at Yatton	Bayesian	LP3	YES	59	54
130403A	Connors River at Mt Bridget	LH H+0	LP3	YES	56	42
130404A	Connors River at Pink Lagoon	Bayesian	LP3	YES	56	44
130406A	Funnel Creek at Main Road	LH H+0	LP3	YES	56	44
130410A	Isaac River at Deverill	LH H+0	LP3	YES	53	41
130413A	Denison Creek at Braeside	LH H+0	LP3	YES	50	41

Table 7-2 FFA on Gauge Annual Peak Flow

ID	Name	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
130401A	Isaac River at Yatton	16846	27281	36821	47748	64241
130403A	Connors River at Mt Bridget	10385	15236	19716	25000	40982
130404A	Connors River at Pink Lagoon	11731	16868	20968	25173	30792
130406A	Funnel Creek at Main Road	4092	5955	7697	9779	16250
130410A	Isaac River at Deverill	2337	2578	2684	2749	2820
130413A	Denison Creek at Braeside	3423	3833	4018	4136	4268

Table 7-3 Simulated Peak Flow Comparison to FFA on Gauge Annual Peak Flow

ID	Name	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
130401A	Isaac River at Yatton	3%	21%	35%	45%	56%
130403A	Connors River at Mt Bridget	9%	18%	28%	36%	52%
130404A	Connors River at Pink Lagoon	-27%	-10%	-9%	-7%	7%
130406A	Funnel Creek at Main Road	-62%	-42%	-35%	-27%	-8%
130410A	Isaac River at Deverill	39%	27%	21%	0%	-50%
130413A	Denison Creek at Braeside	5%	17%	-11%	-15%	-26%

Table 7-4 presented the conversion of FFA on gauge stage converted to flow through the gauge rating curves. Table 7-5 presents the percent difference between the modelled flow and the

converted peak flow of the stage FFA. There is a reasonable match across most gauges except Connors River at Pink Lagoon and Isaac River at Deverill.

Table 7-4 FFA on Gauge Stage Converted to Flow

ID	Name	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
130401A	Isaac River at Yatton	18,549	24,918	27,459	30,000	33,000
130403A	Connors River at Mt Bridget	9,077	12,631	15,211	17,576	22,519
130404A	Connors River at Pink Lagoon	13,000	15,000	16,500	17,500	19,000
130406A	Funnel Creek at Main Road	5,004	7,203	9,289	11,374	16,171
130410A	Isaac River at Deverill	2,467	2,800	2,967	3,050	3,133
130413A	Denison Creek at Braeside	3,516	4,200	4,412	4,818	5,303

Table 7-5 Simulated Peak Flow Comparison to FFA on Stage Converted Flow

ID	Name	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
130401A	Isaac River at Yatton	12%	13%	13%	12%	15%
130403A	Connors River at Mt Bridget	-4%	1%	6%	9%	13%
130404A	Connors River at Pink Lagoon	-15%	-24%	-39%	-54%	-51%
130406A	Funnel Creek at Main Road	-33%	-18%	-12%	-9%	-9%
130410A	Isaac River at Deverill	43%	33%	29%	10%	-35%
130413A	Denison Creek at Braeside	7%	24%	-1%	1%	-2%

7.3 PLOTTING POSITION OF TROPICAL CYCLONE DEBBIE

Due to the significance of Tropical Cyclone Debbie on the records of Connors River at Mount Bridget and Funnel Creek at Main Road, the position of the event within the FFA has significant consequence to the extrapolation of extreme events for both the FFA on gauge stage and FFA on gauge flow.

As presented in Table 7-6 the removal of Tropical Cyclone Debbie significantly reduces the peak flow from the FFA. A 29% reduction in flow is observed between the Connors River at Mount Bridget with and without the Tropical Cyclone Debbie for the 1% AEP FFA flow.

For other gauges due to similar historical events to Tropical Cyclone Debbie, the results vary significantly less.

Table 7-6 Comparison of Flow FFA with the Removal of Tropical Cyclone Debbie

ID	Name	5% AEP	2% AEP	1% AEP	0.5% AEP	0.1% AEP
130403A	Connors River at Mt Bridget	10,385	15,236	19,716	25,000	40,982
130403A	Connors River at Mt Bridget (TC Debbie Removed)	8,424	11,420	13,921	16,636	23,794
130404A	Funnel Creek at Main Road	4,092	5,955	7,697	9,779	16,250
130406A	Funnel Creek at Main Road (TC Debbie Removed)	3,298	4,398	5,321	6,327	9,013

8 Conclusion

The primary objective of this study has been to develop a flood model to inform the catchment wide risk associated with flooding. Outcomes of this assessment can inform decision making processes within the council as well as to form the basis of later more detailed flood studies as well as

As a part of this study KBR has;

- Undertaken a review of available information and derived a suitable methodology to the scope of the study.
- Used outcomes of community consultation to inform key historical events as well as to ensure adopted methodology is suitable to the community needs.
- Developed TUFLOW model combining hydrologic and hydraulic representation of the Isaac River catchment. The modelling package has been set up so that additional topographic of calibration data can be easily assessed in the future
- Calibrated the TUFLOW model to local gauge gaugings as well as to the 2017 Tropical Cyclone Debbie event.
- Completed FFA on gauge data to inform the design event modelling.
- Simulated reflective design events scaled to the FFA at gauges consistent with ARR 2019.
- Sensitivity testing of key factors to the outcomes of the flood study.
- Provided results that can be used to inform future planning decisions in the Isaac Regional Council LGA.

9 Recommendations

Following the completion of the Isaac River Flood Study and following recommendations are provided:

- Provided the outcomes of this study, the Isaac Regional Council Planning Scheme can be amended. Updates to the scheme can draw upon outcomes such as hazard mapping and adopting a design event for assigning flood planning levels with consideration of freeboard.
- With the additional information around catchment response to flood events, Isaac Regional Council and Central Highlands Regional Council can lead more informed discussions with emergency services. Consultation with emergency services can help both councils refine emergency response planning for their residents.
- Installation of rain gauges in the upper reaches of the Connors River, Funnel Creek and Denison Creek catchments. The gauges should be installed at the greatest height above sea level as practicably possible.
- It is recommended that local catchment flood studies be undertaken in the future for the following scenarios. The results from the local model can be feed back into the regional model.
 - Proposed major development
 - Major infrastructure projects
 - Flood mitigation projects
- If local catchment flood studies are to be undertaken it is recommended LiDAR survey be flown to provide accurate topographic data for future assessments.
- Road closure assessment be undertaken for the Isaac River catchment using the modelled results from this study
- Given the sensitivity of the modelling to the limitation of rating curves as discussed within Section 7.1, further rating curve assessments should be considerate at the remaining major gauges.
- Following the additional refinements detailed above and additional rainfall data particularly in the upper catchment areas, re calibration should be undertaken to a future event as well as refining the calibration to Tropical Cyclone Debbie.
- The provided PMF event is on a catchment wide basis, individual catchment PMF events should be considered local to towns for planning purposes. Consideration of local PMF events could also allow for alternate methods such as the Generalised Short Duration Method (GSDM)

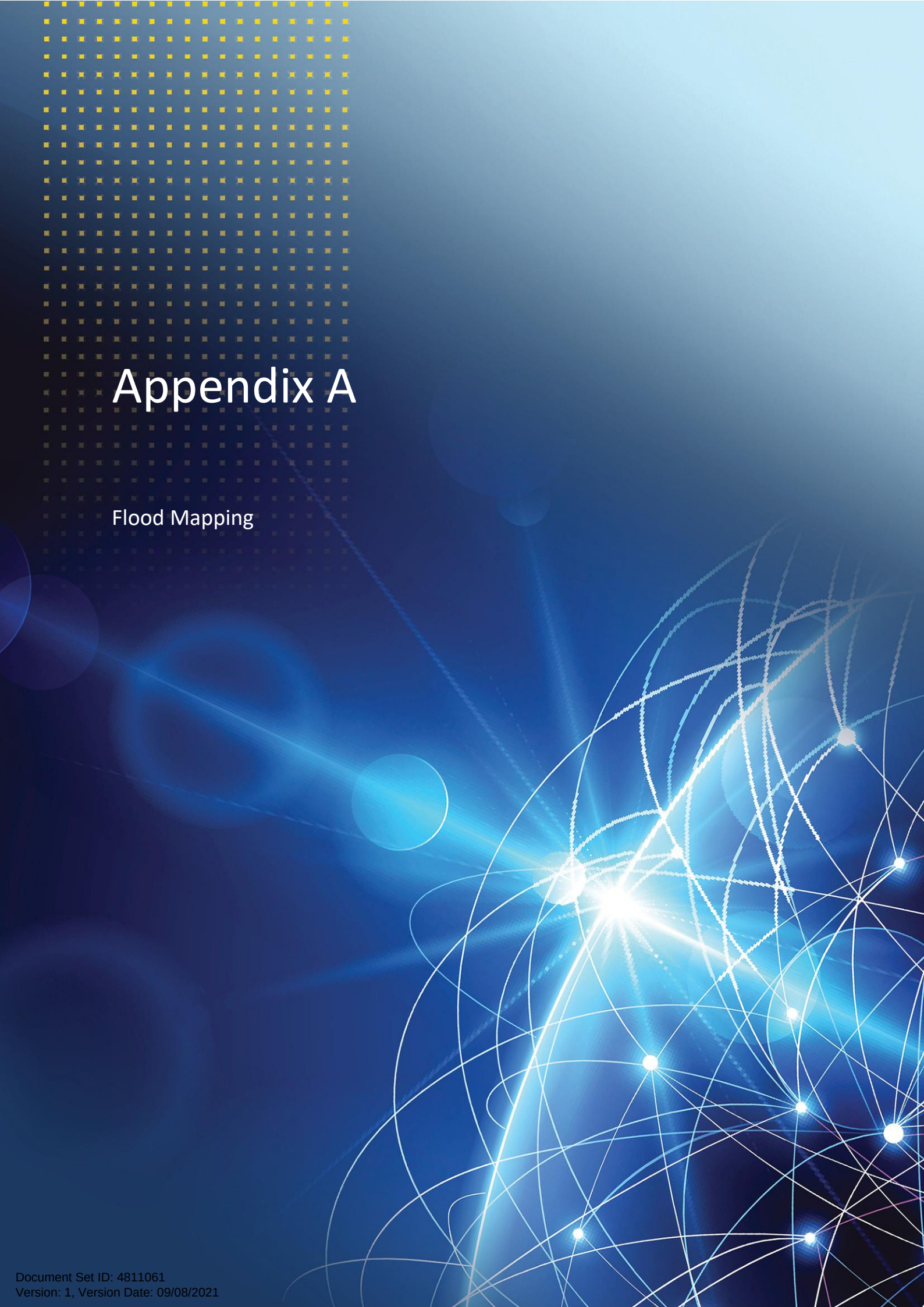
10 Limitations and Exclusions

This report and associated modelling contain but not limited to the following limitations and exclusions:

- The purpose of this study is to reflect the high-level risk presented by flooding within the catchment. For site specific information and understanding further detailed modelling should be undertaken. Due to the scope of the study being catchment wide, adopted parameters were on a catchment wide basis. The adopted IFD scaling factors with associated matching to FFA results were similarly considered on the scale of the entire Isaac River catchment.
- All modelling has been undertaken with the best available elevation datasets available to KBR at the commencement of the study, noted accuracy of the datasets must be taken into consideration in comparison to surveyed levels and noting the cumulative effect of inaccuracies within the base elevation dataset.
- The modelling undertaken places confidence in a number of unofficial rainfall records observed during the TC Debbie event. There was a lack of rainfall records within the catchment with suitable confidence. The outcomes of this assumption are reflected in the scaling required to match recorded flood levels in TC Debbie. However, in the event more data were to become available specifically to rainfall, this should be considered, and recalibration undertaken of the model. Similarly, if additional gauges are installed and another large event were to occur in which more suitable rainfall and stream gauge records were available recalibration should be undertaken. KBR does wish to note the significant safety concern associated with gaining and maintaining gauge data in the region and would like to acknowledge the gauge information provided by the community for Tropical Cyclone Debbie.
- As highlighted within this report there is some uncertainty with a number of the rating curves at a number of the gauges within the catchment. Due to the scope of this study limited investigation could be undertaken into these gauges. Undertaking a FFA on stage is noted as not being industry standard approach with the distribution of flows being more favourable to statistical probability analysis. The adoption of stage was undertaken in consideration of the considerable uncertainty with the gauge flows.
- The PMF analysis was undertaken on an Isaac River catchment wide storm. If local catchment flood studies are undertaken the local PMF analysis is likely to produce peak flood levels and flows greater than the modelled results in this study.
- All presented results are the identified critical durations as specified within Sections 6.2.5 and 6.3.

11 References

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Appendix A

Flood Mapping

LEGEND

● Peak Flood Levels (mAHD)

Study Area

Depth (m)

0 - 0.5

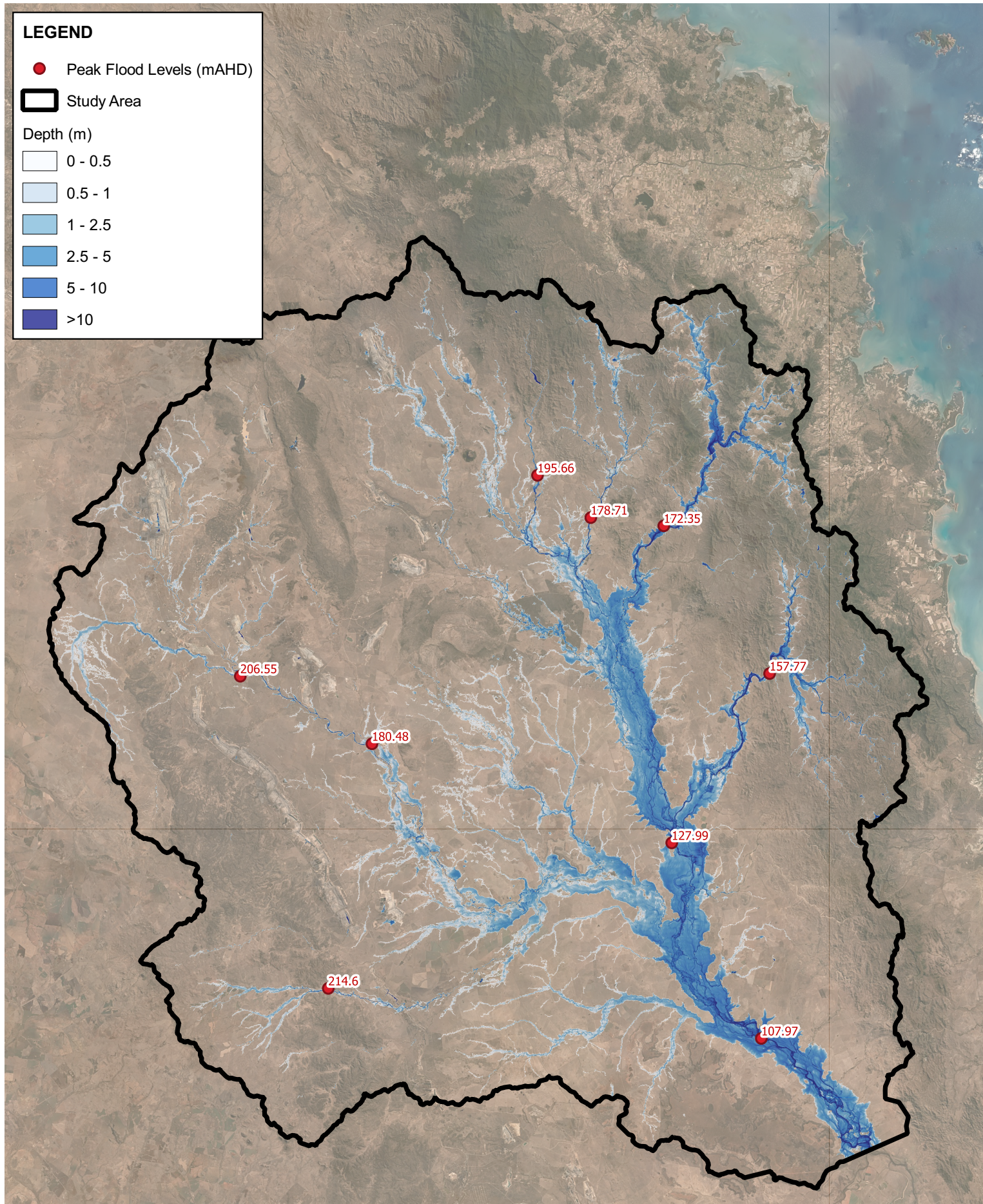
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1 - 2.5

2.5 - 5

5 - 10

>10



Peak Flood Depths and Levels Isaac River Catchment 5% AEP Event

Figure:

A-1

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Scale at A4 1:950000.0000000003
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Scale:

0 7 14 21 28 35 km



1:950000



LEGEND

● Peak Flood Level (mAHD)

▭ Study Area

Depth (m)

0 - 0.5

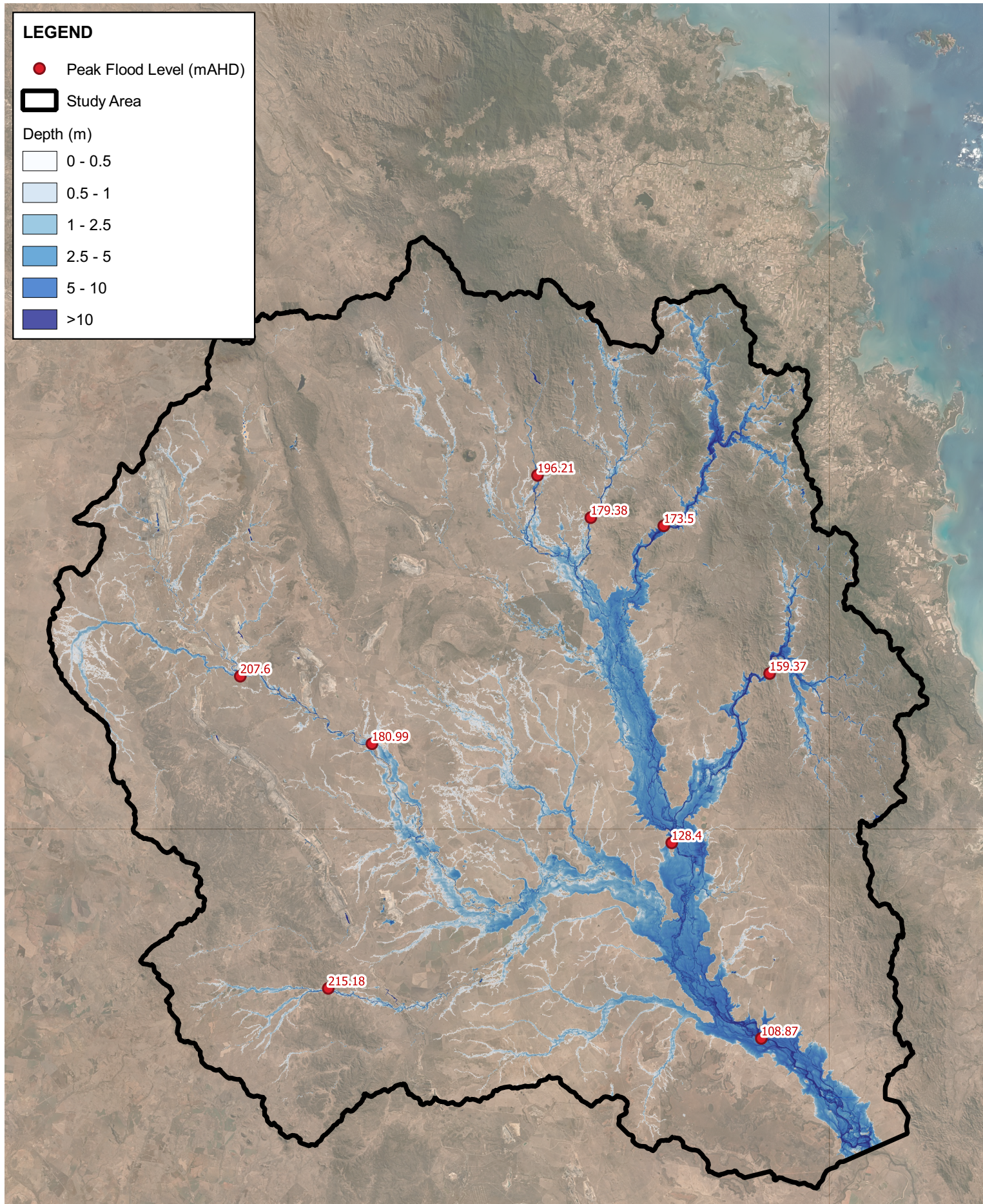
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2.5 - 5

5 - 10

>10



Peak Flood Depths & Levels Isaac River Catchment 2% AEP Event

Figure:

A-2

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Version: 1, Version Date: 09/08/2021

Scale:

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1:950000



LEGEND

● Peak Flood Levels (mAHD)

▭ Study Area

Depth (m)

0 - 0.5

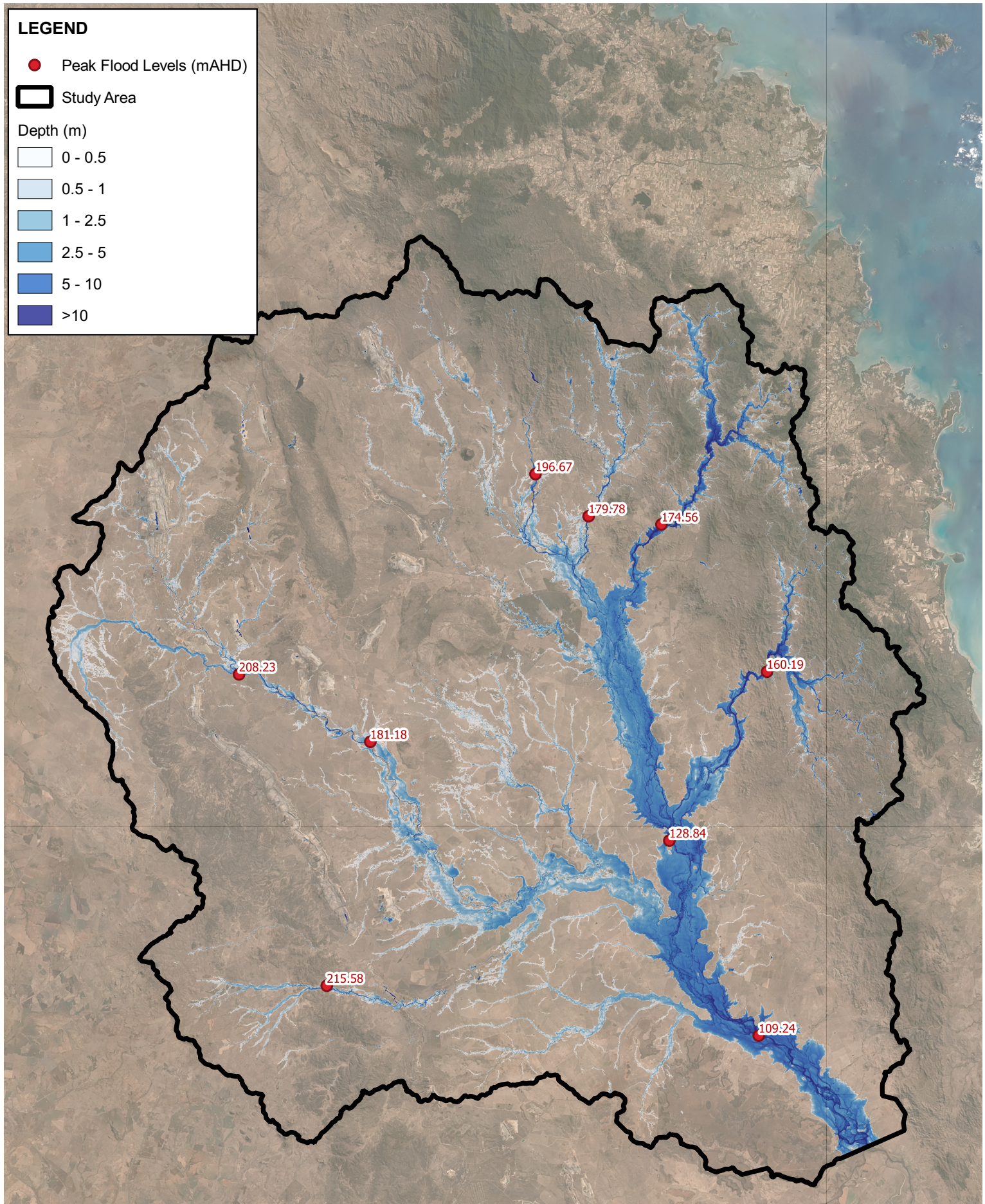
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1 - 2.5

2.5 - 5

5 - 10

>10



Peak Flood Depths & Levels Isaac River Catchment 1% AEP Event

Figure:

A-3

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Version: 1, Version Date: 09/08/2021

Scale:

0 7 14 21 28 35 km



1:950000



LEGEND

● Peak Water Levels (mAHD)

Study Area

Depth (m)

0 - 0.5

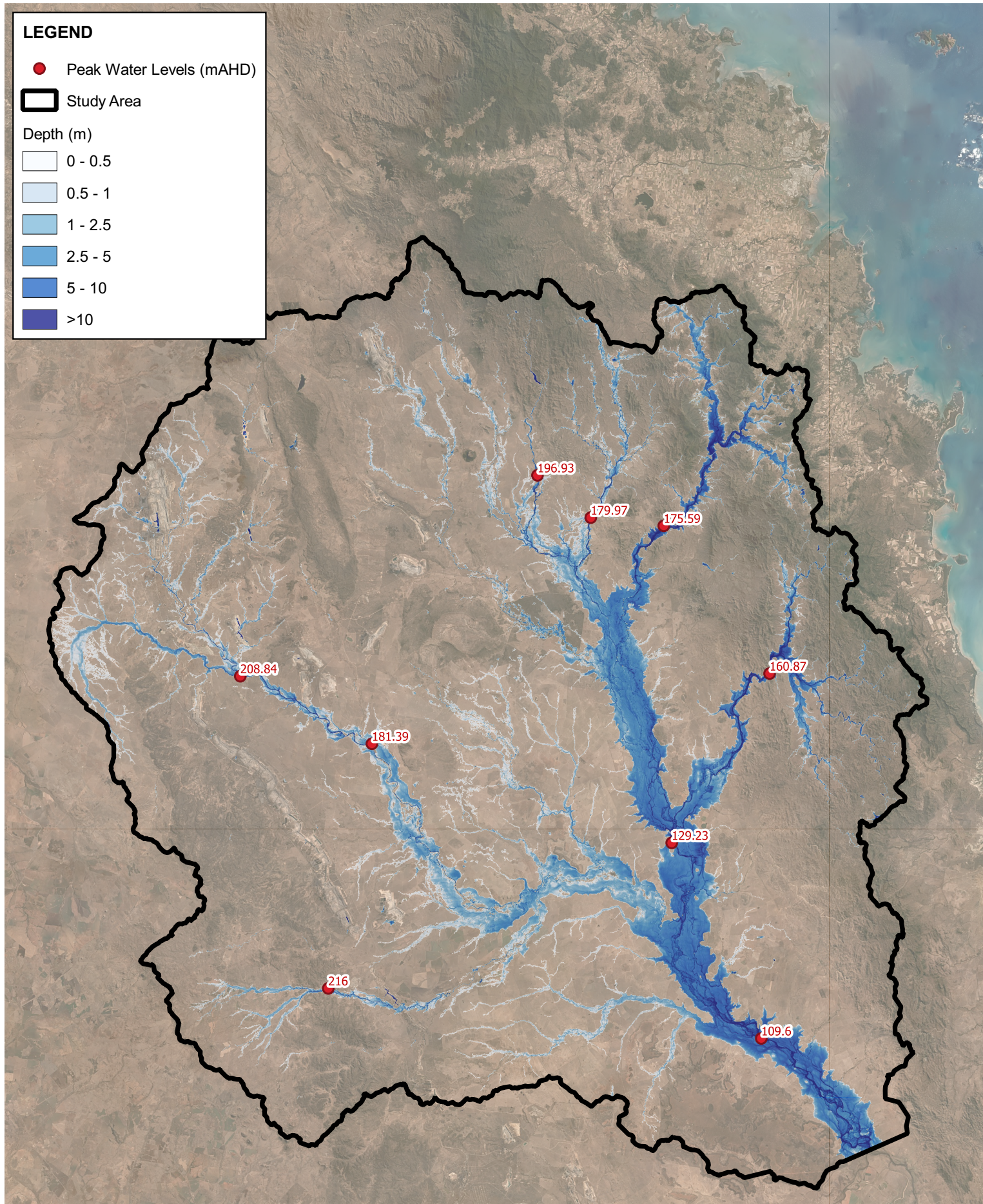
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1 - 2.5

2.5 - 5

5 - 10

>10



Peak Flood Depths & Levels Isaac River Catchment 0.5% AEP Event

Figure:

A-4

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0

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Version: 1, Version Date: 09/08/2021

Scale:

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1:950000



LEGEND

● Peak Flood Level (mAHD)

Study Area

Depth (m)

0 - 0.5

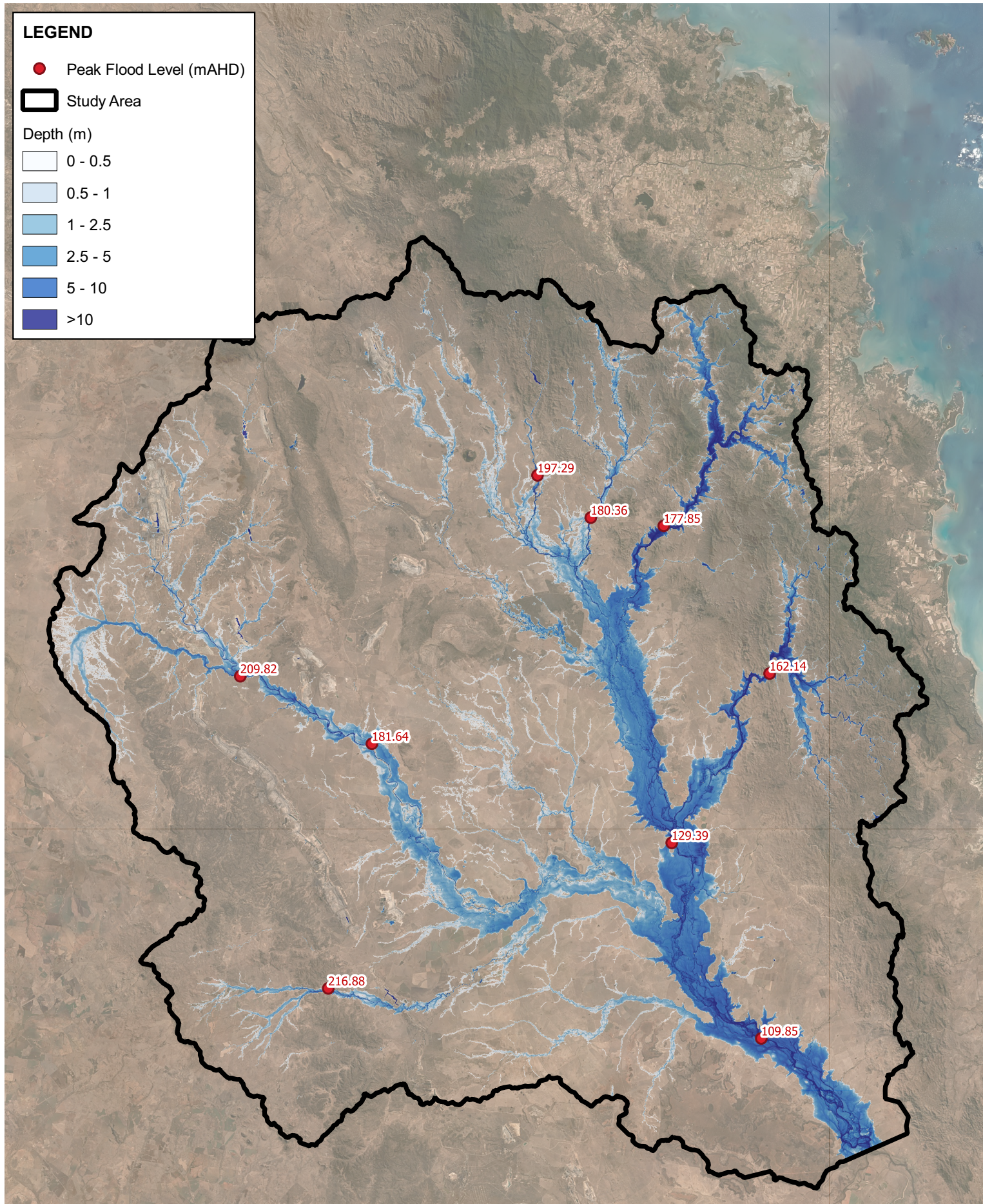
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1 - 2.5

2.5 - 5

5 - 10

>10



Peak Flood Depths & Levels Isaac River Catchment 0.1% AEP Event

Figure:

A-5

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LEGEND

● Peak Water Level (mAHD)

Study Area

Depth (m)

0 - 0.5

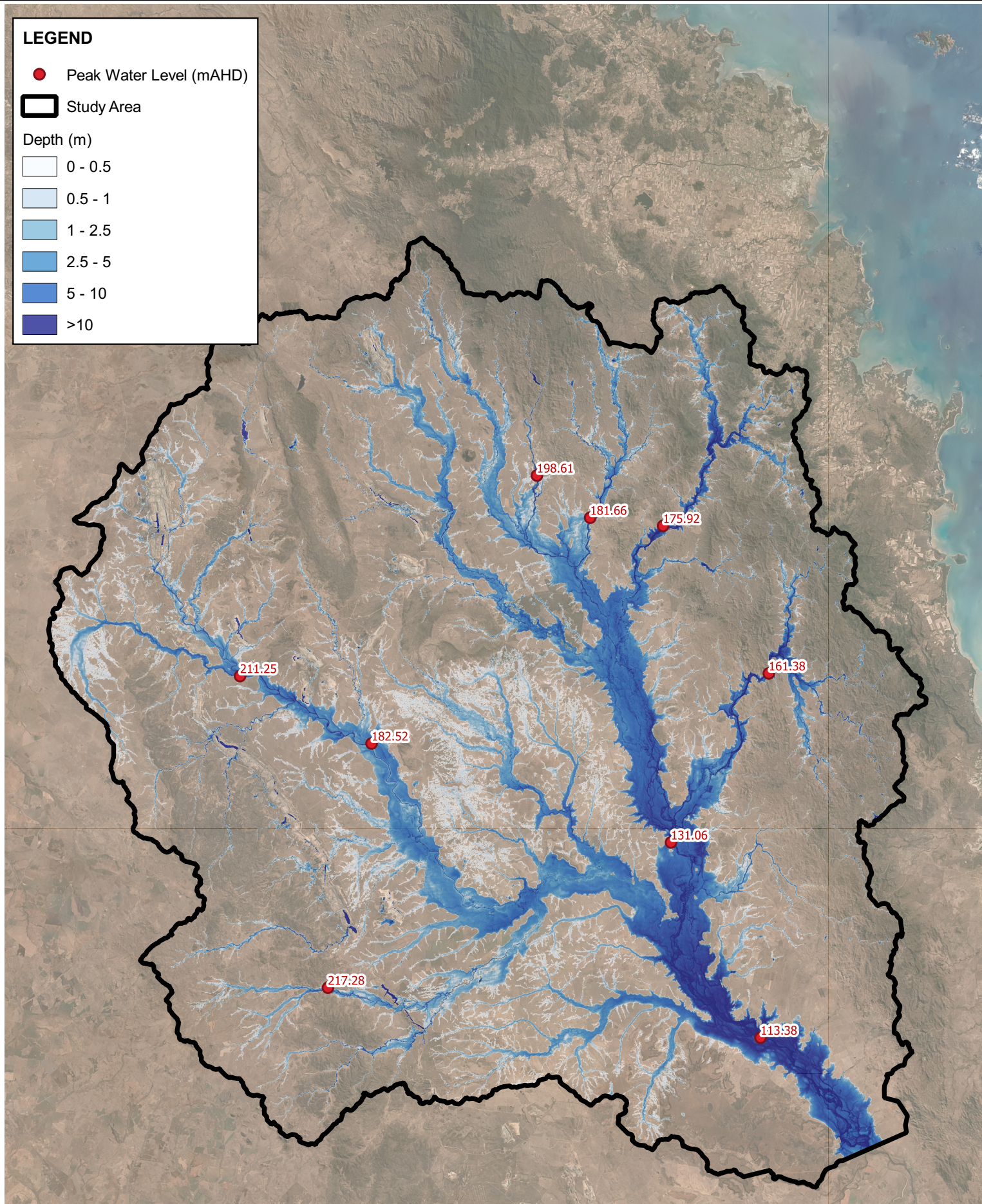
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1 - 2.5

2.5 - 5

5 - 10

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Peak Flood Depths & Levels Isaac River Catchment PMF Event

Figure:

A-6

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Version: 1, Version Date: 09/08/2021

Scale:

0 7 14 21 28 35 km



1:950000



LEGEND

 Study Area

Velocity (m/s)

 0 - 0.25

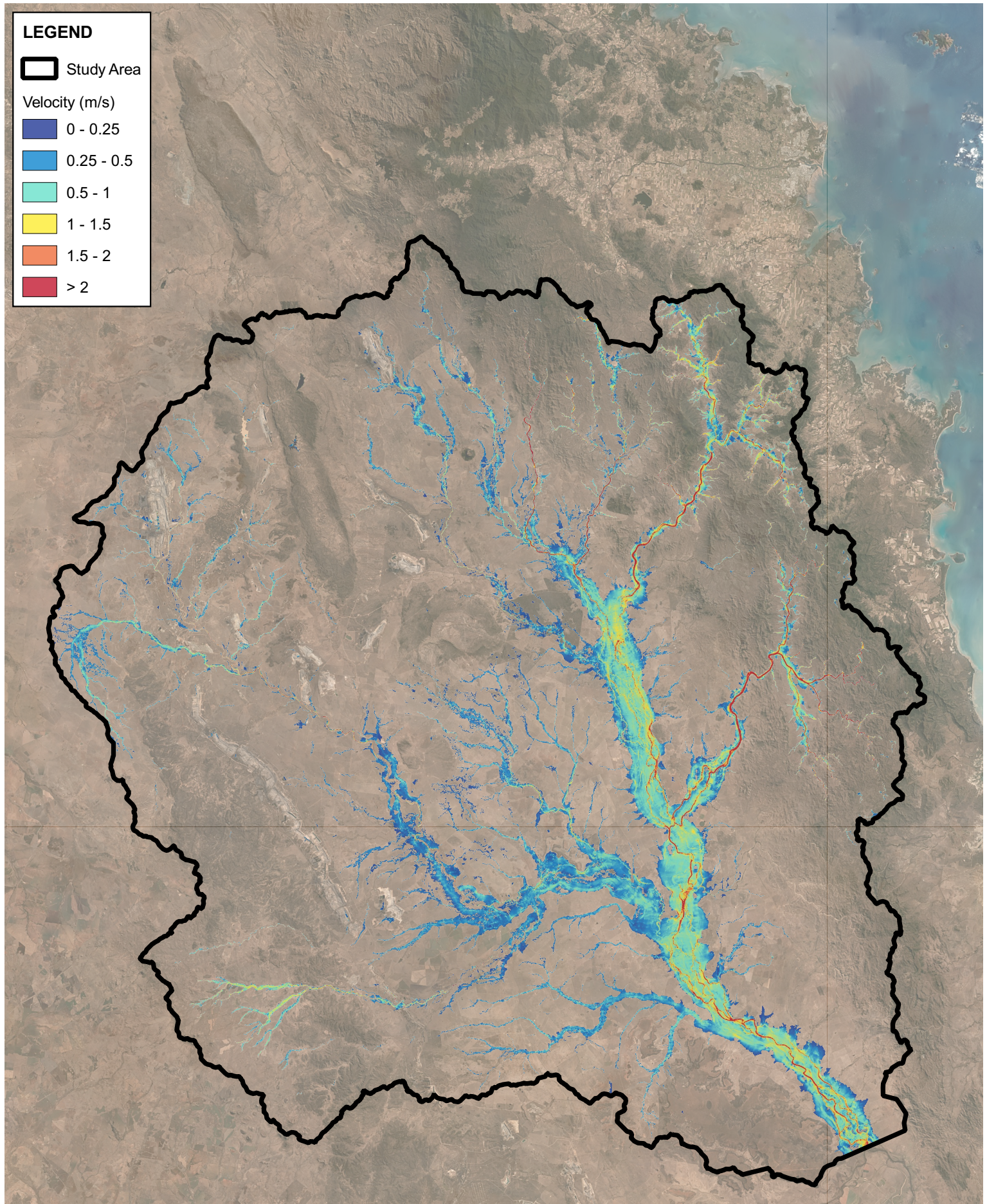
 0.25 - 0.5

 0.5 - 1

 1 - 1.5

 1.5 - 2

 > 2



Title: Peak Flood Velocities Isaac River Catchment 5% AEP Event

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Version: 1, Version Date: 09/08/2021

Scale:

0 7 14 21 28 35 km



1:950000

Figure:

A-7

Rev:

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LEGEND

 Study Area

Velocity (m/s)

 0 - 0.25

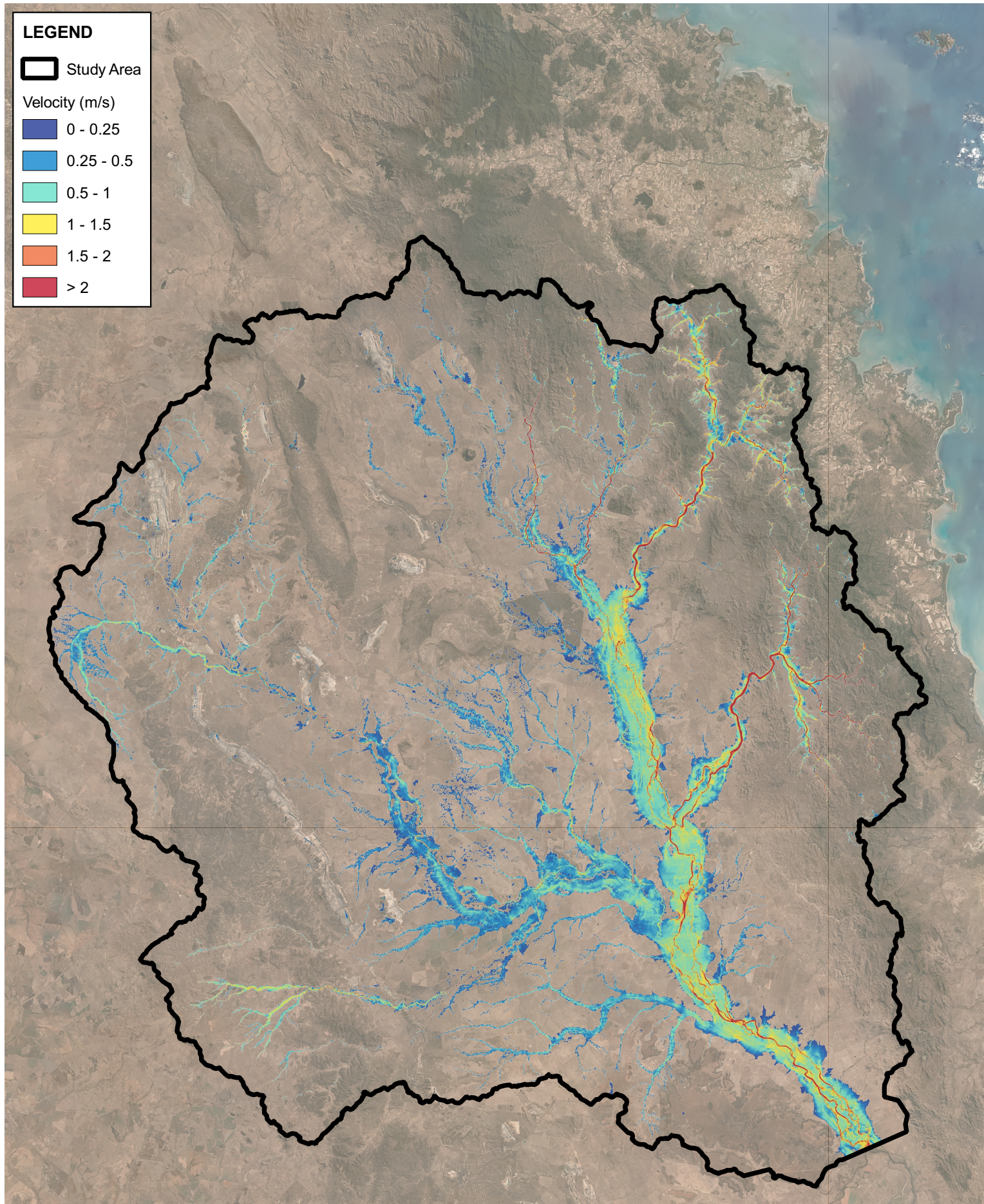
 0.25 - 0.5

 0.5 - 1

 1 - 1.5

 1.5 - 2

 > 2



Title: Peak Flood Velocities Isaac River Catchment 2% AEP Event

Scale at A4 1:950000.0000000003
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Version: 1, Version Date: 09/08/2021

Scale:

0 7 14 21 28 35 km



1:950000

Figure:

A-8

Rev:

0



LEGEND

 Study Area

Velocity (m/s)

 0 - 0.25

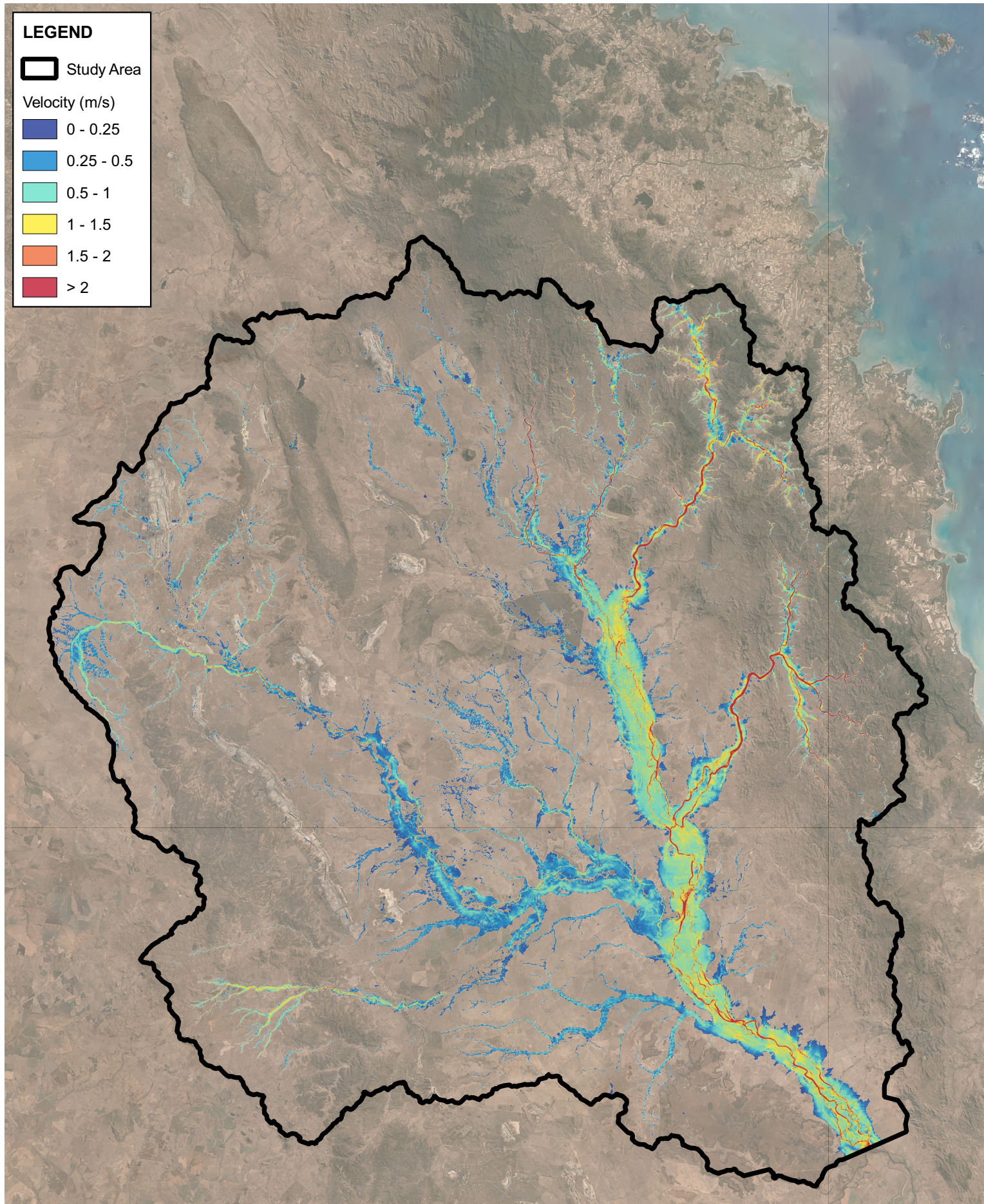
 0.25 - 0.5

 0.5 - 1

 1 - 1.5

 1.5 - 2

 > 2



Peak Flood Velocities Isaac River Catchment 1% AEP Event

Figure:

A-9

Rev:

0

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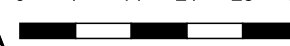
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Scale:

0 7 14 21 28 35 km



1:950000



LEGEND

 Study Area

Velocity (m/s)

 0 - 0.25

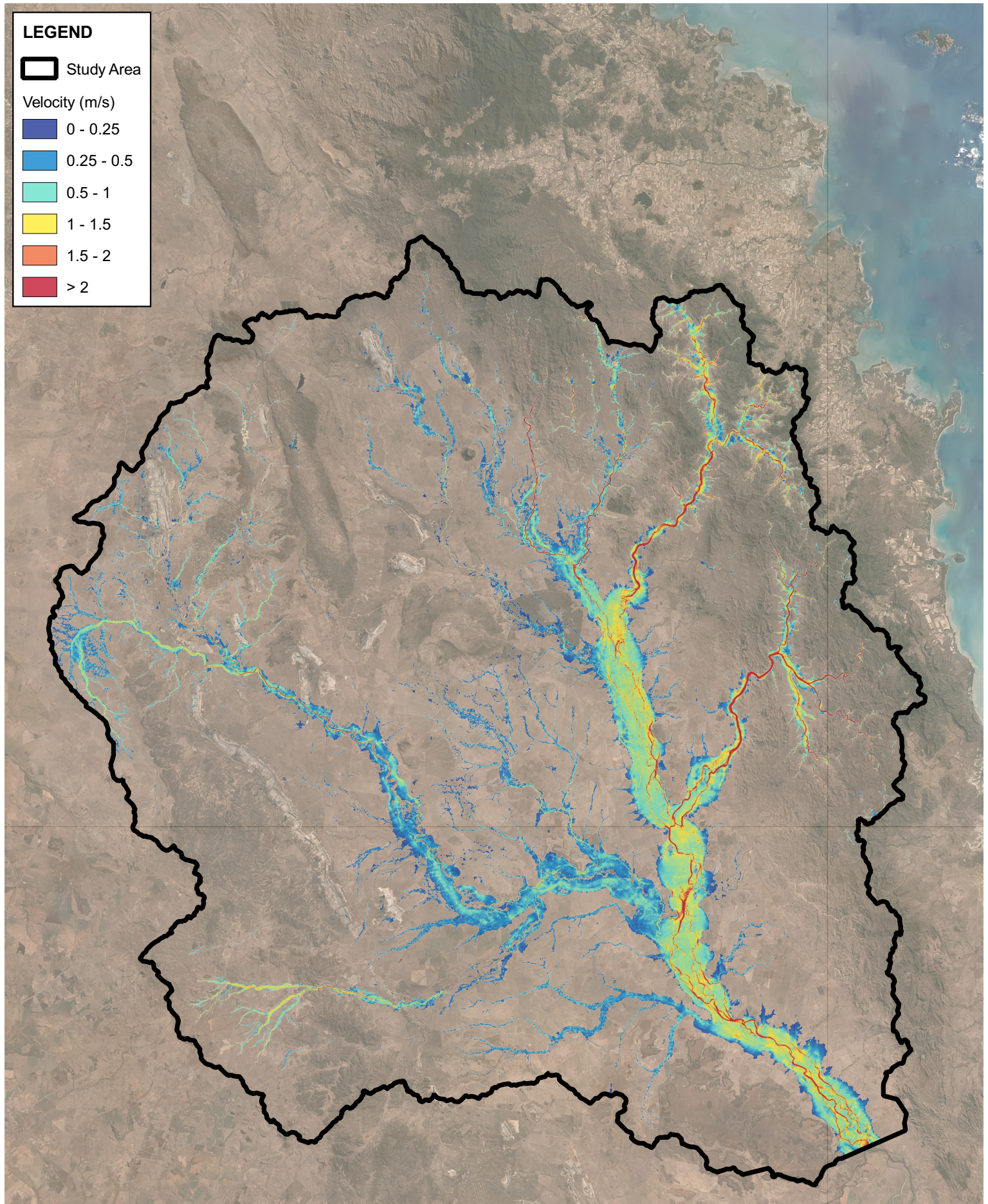
 0.25 - 0.5

 0.5 - 1

 1 - 1.5

 1.5 - 2

 > 2



Title

Peak Flood Velocities Isaac River Catchment 0.5% AEP Event

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Version: 1, Version Date: 09/08/2021

Scale:

0 7 14 21 28 35 km



1:950000

Figure:

A-10

Rev:

0



LEGEND

 Study Area

Velocity (m/s)

 0 - 0.25

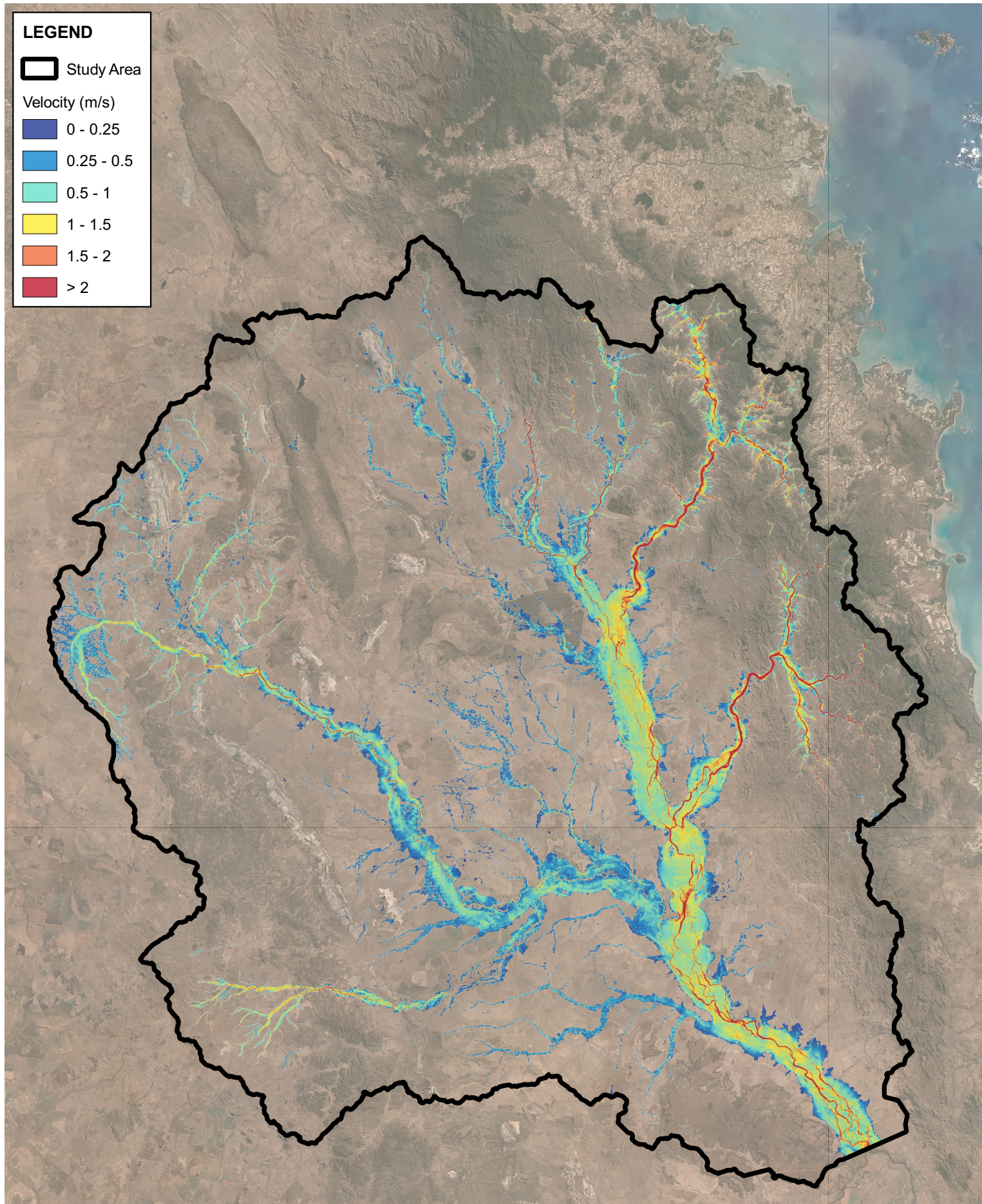
 0.25 - 0.5

 0.5 - 1

 1 - 1.5

 1.5 - 2

 > 2



Title Peak Flood Velocities Isaac River Catchments 0.1% AEP Event

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Version: 1, Version Date: 09/08/2021

Scale:

0 7 14 21 28 35 km



1:950000

Figure:

A-11

Rev:

0



LEGEND

 Study Area

Velocity (m/s)

 0 - 0.25

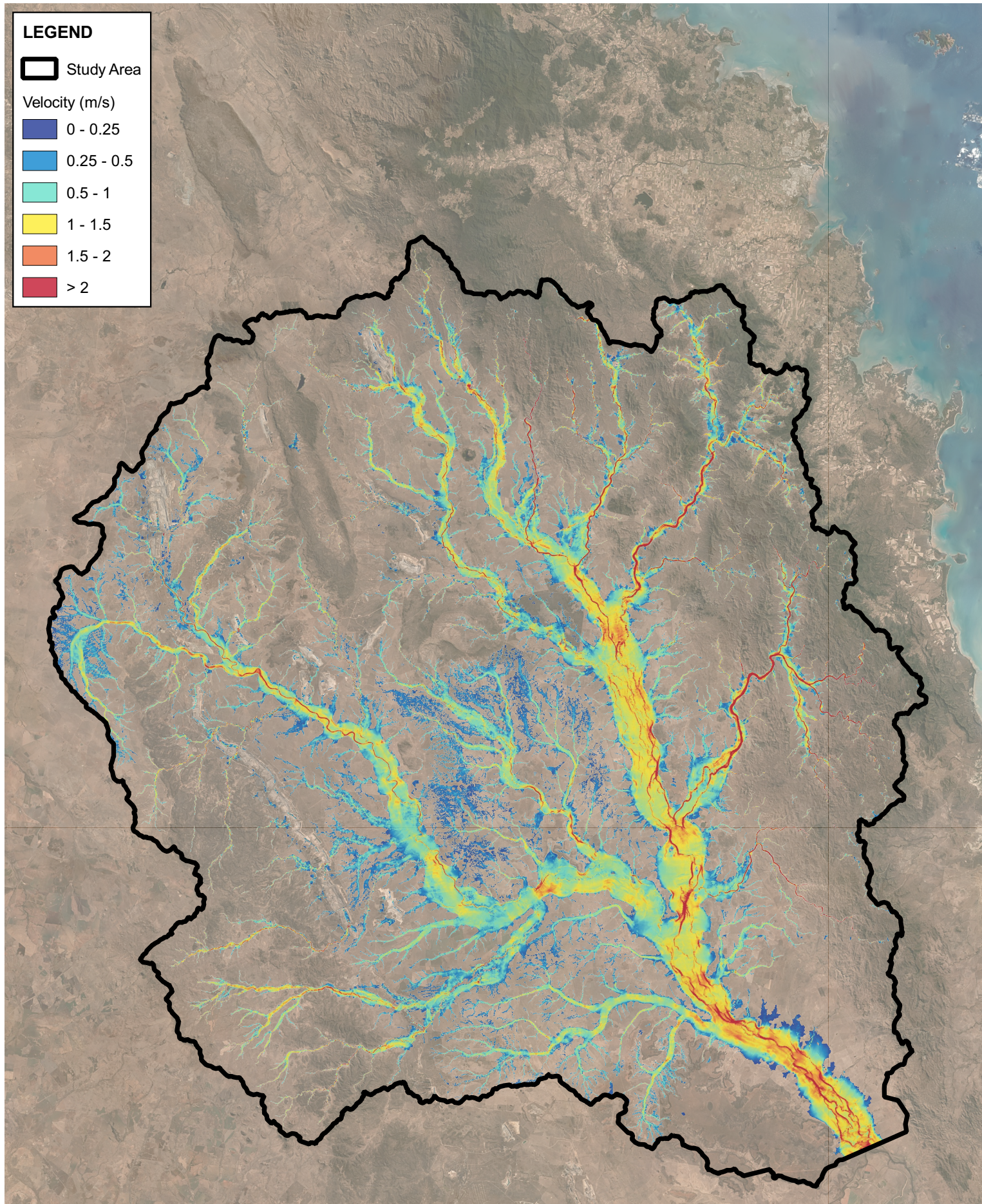
 0.25 - 0.5

 0.5 - 1

 1 - 1.5

 1.5 - 2

 > 2



Title Peak Flood Velocities Isaac River Catchment PMF Event

Figure:

A-12

Rev:

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Scale at A4 1:950000.0000000003
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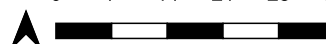
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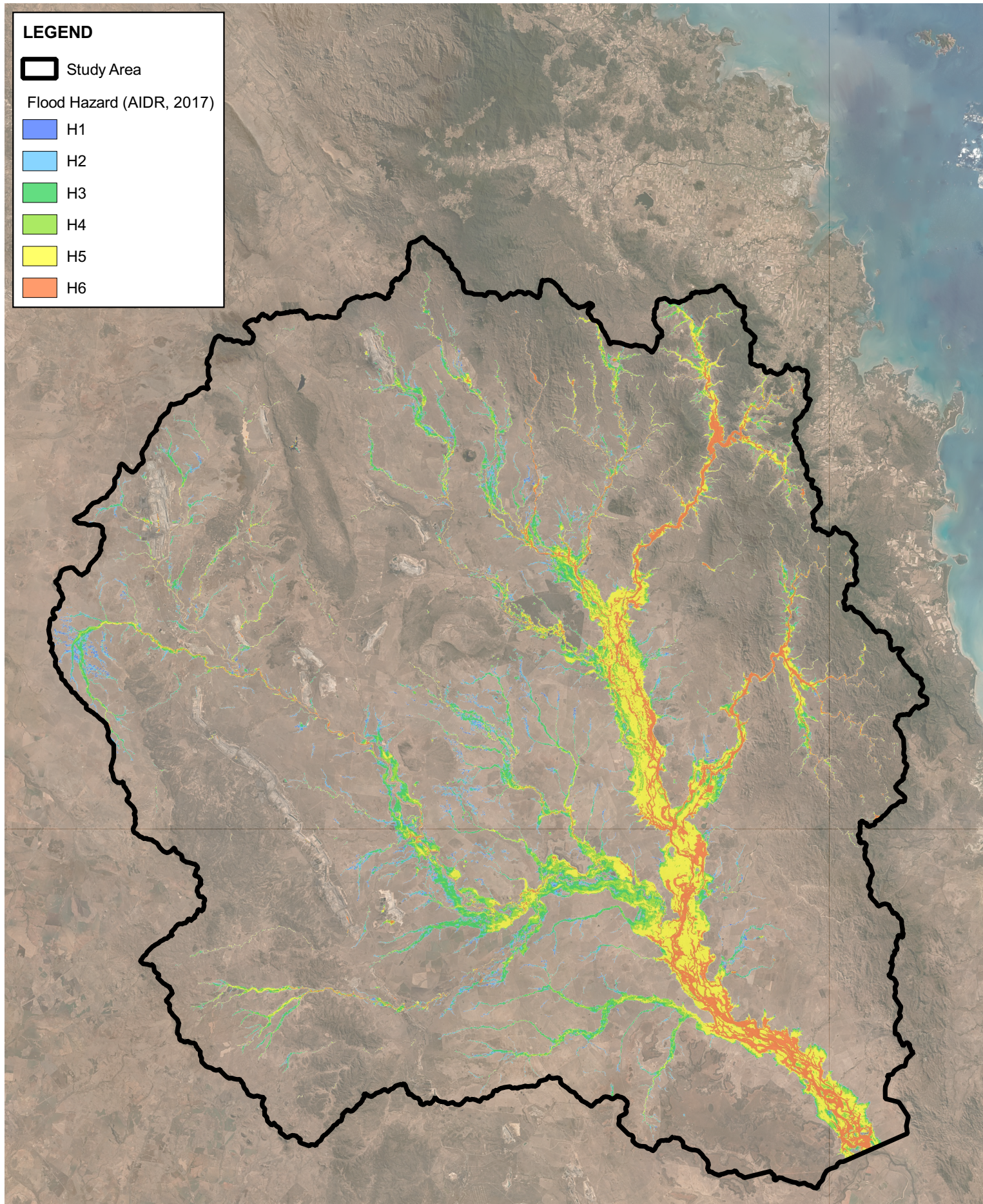


LEGEND

 Study Area

Flood Hazard (AIDR, 2017)

-  H1
-  H2
-  H3
-  H4
-  H5
-  H6



Title Flood Hazard (AIDR, 2017) Isaac River Catchment 5% AEP Event

Figure:

A-13

Rev:

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Scale at A4 1:950000.0000000003
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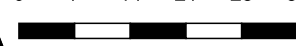
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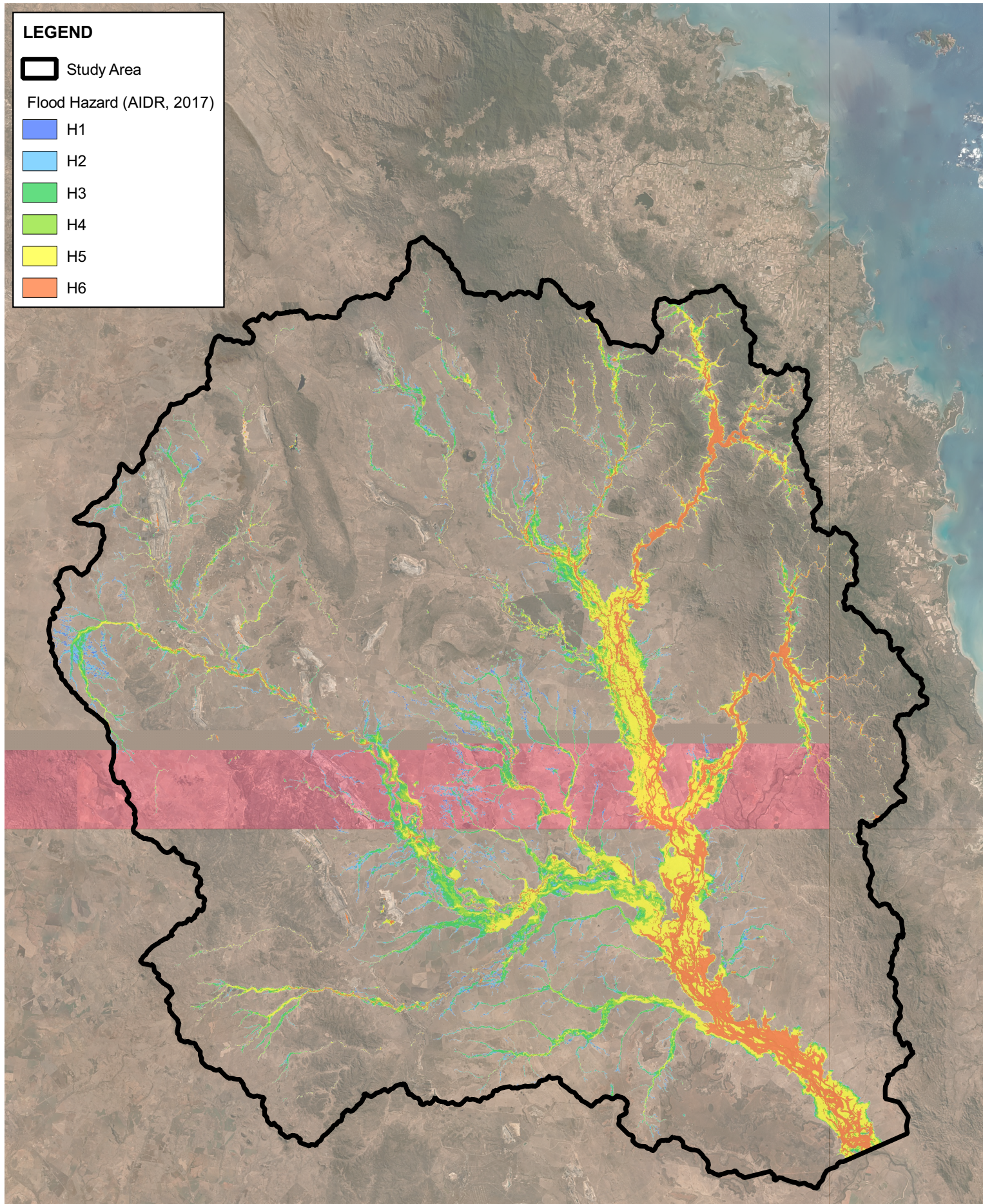


LEGEND

 Study Area

Flood Hazard (AIDR, 2017)

-  H1
-  H2
-  H3
-  H4
-  H5
-  H6



Title Flood Hazard (AIDR, 2017) Isaac River Catchment 2% AEP Event

Figure:

A-14

Rev:

0

Scale at A4 1:950000.0000000003

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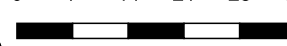
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Version: 1, Version Date: 09/08/2021

Scale:

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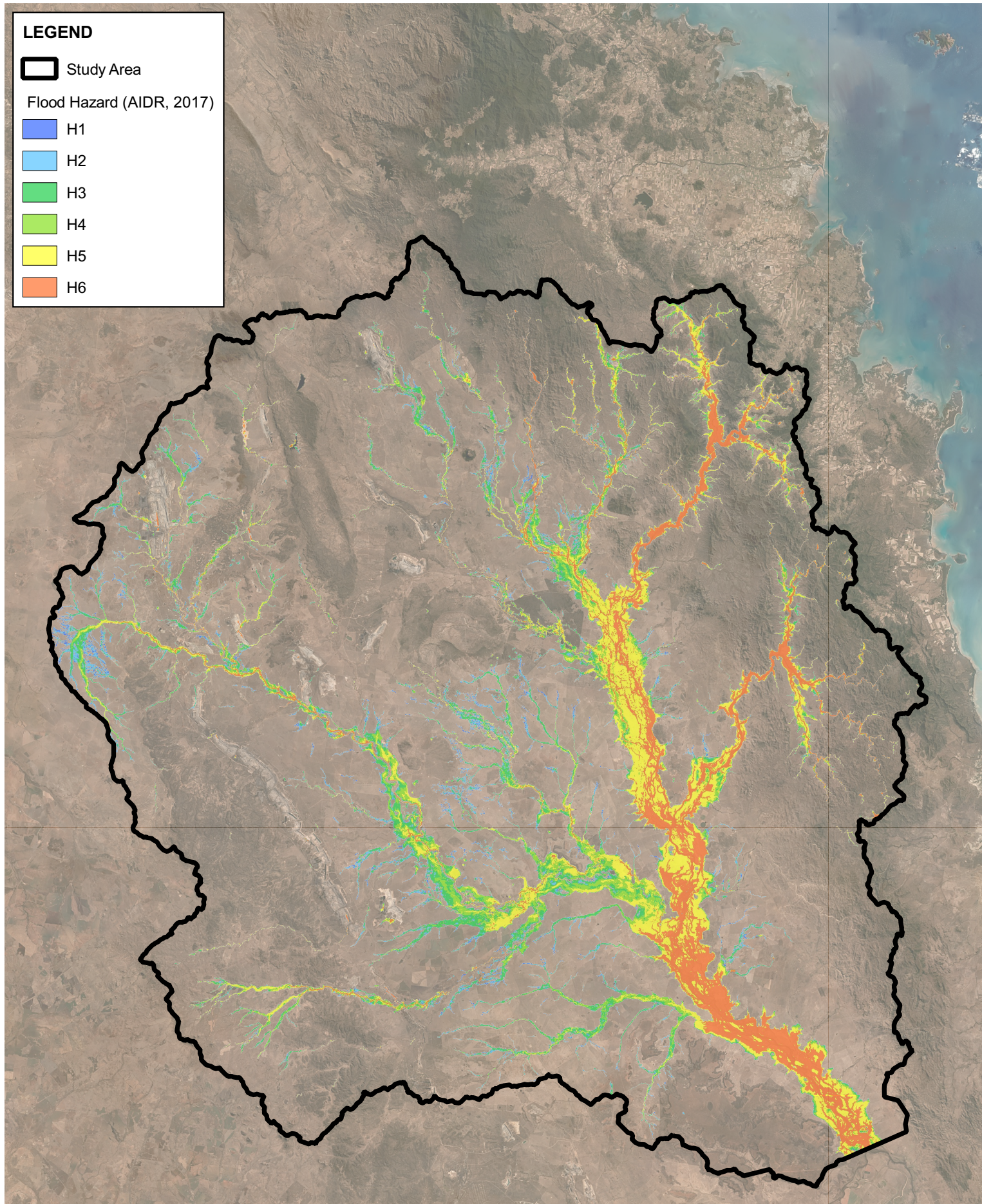


LEGEND

 Study Area

Flood Hazard (AIDR, 2017)

-  H1
-  H2
-  H3
-  H4
-  H5
-  H6



Title

Flood Hazard (AIDR, 2017) Isaac River Catchment 1% AEP Event

Figure:

A-15

Rev:

0

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Version: 1, Version Date: 09/08/2021

Scale:

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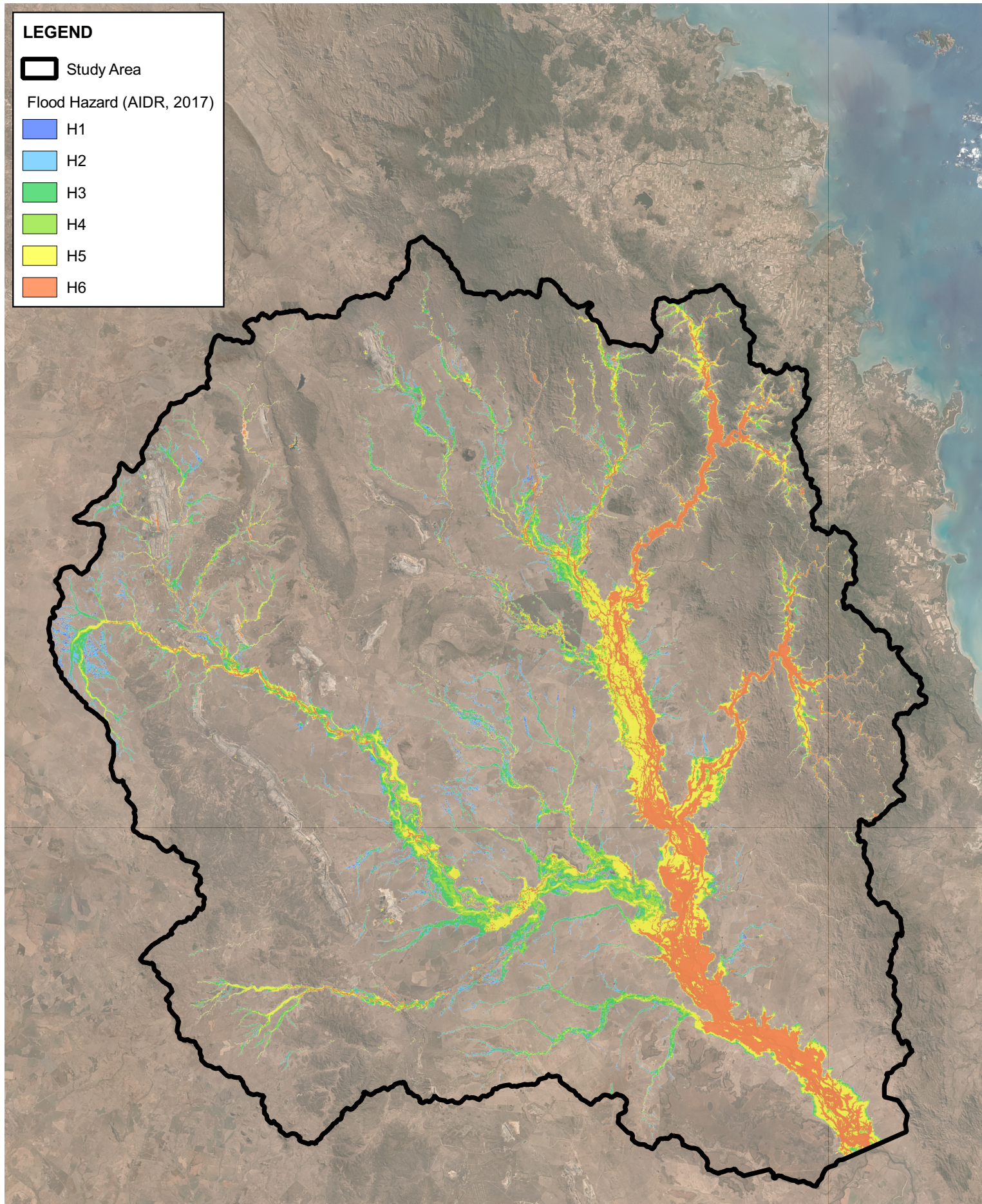


LEGEND

 Study Area

Flood Hazard (AIDR, 2017)

-  H1
-  H2
-  H3
-  H4
-  H5
-  H6



Title

Flood Hazard (AIDR, 2017) Isaac River Catchment 0.5% AEP Event

Figure:

A-16

Rev:

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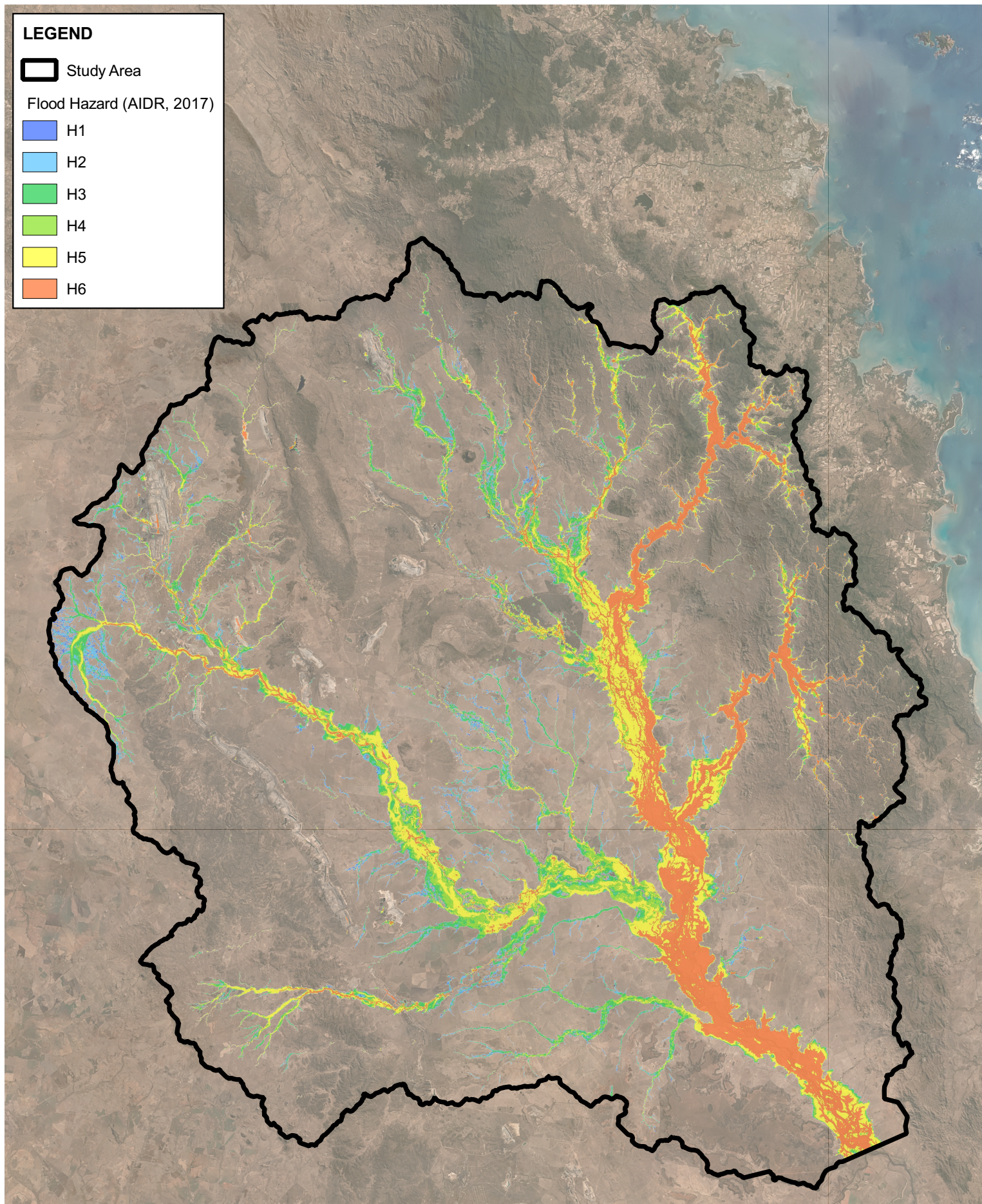


LEGEND

 Study Area

Flood Hazard (AIDR, 2017)

-  H1
-  H2
-  H3
-  H4
-  H5
-  H6



Title

Flood Hazard (AIDR, 2017)

Isaac River Catchment

0.1% AEP Event

Figure:

A-17

Rev:

0

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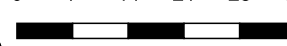
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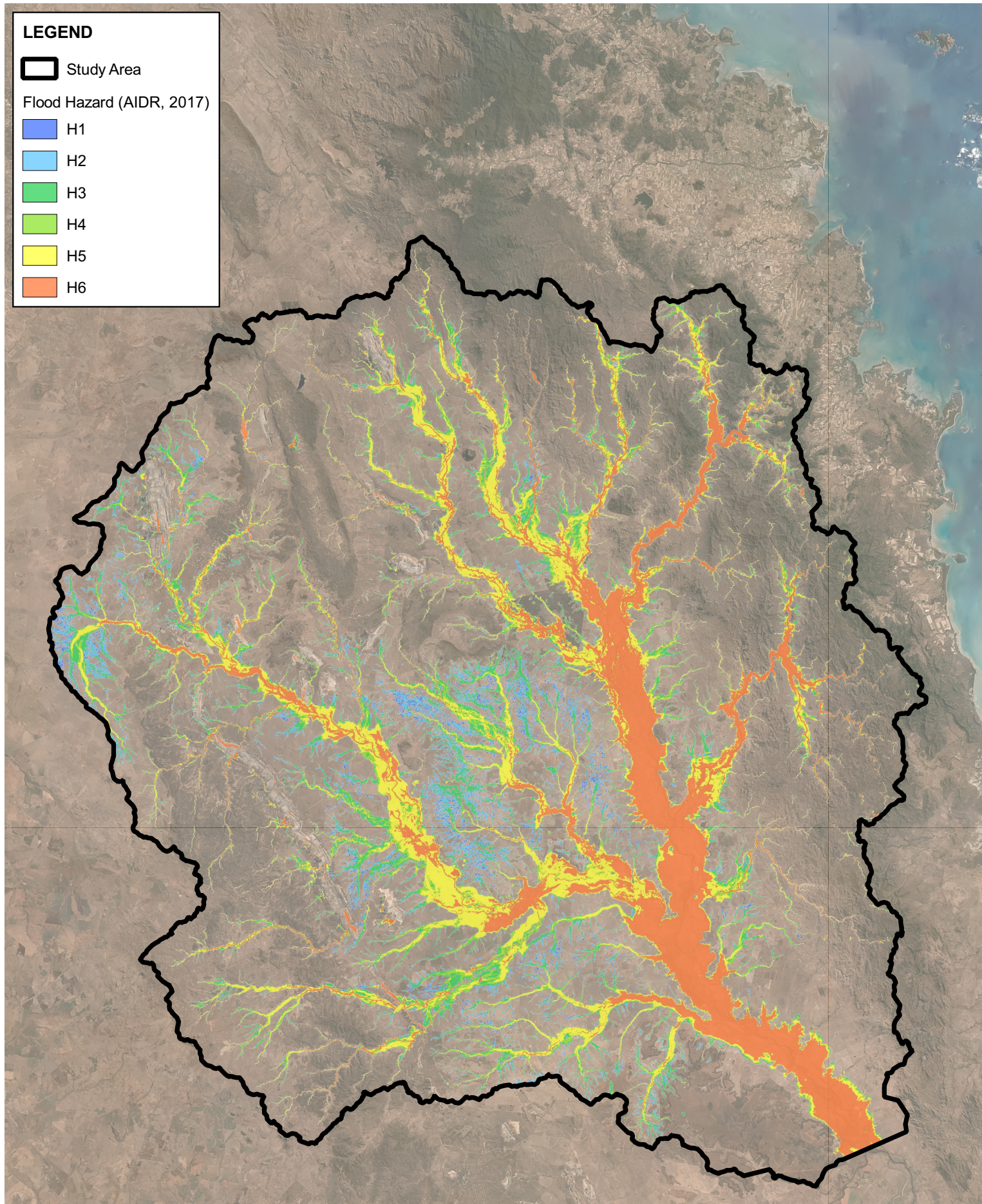


LEGEND

 Study Area

Flood Hazard (AIDR, 2017)

-  H1
-  H2
-  H3
-  H4
-  H5
-  H6



Title Flood Hazard (AIDR, 2017) Isaac River Catchment PMF Event

Figure:
A-18

Rev:
0

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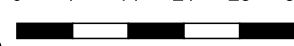
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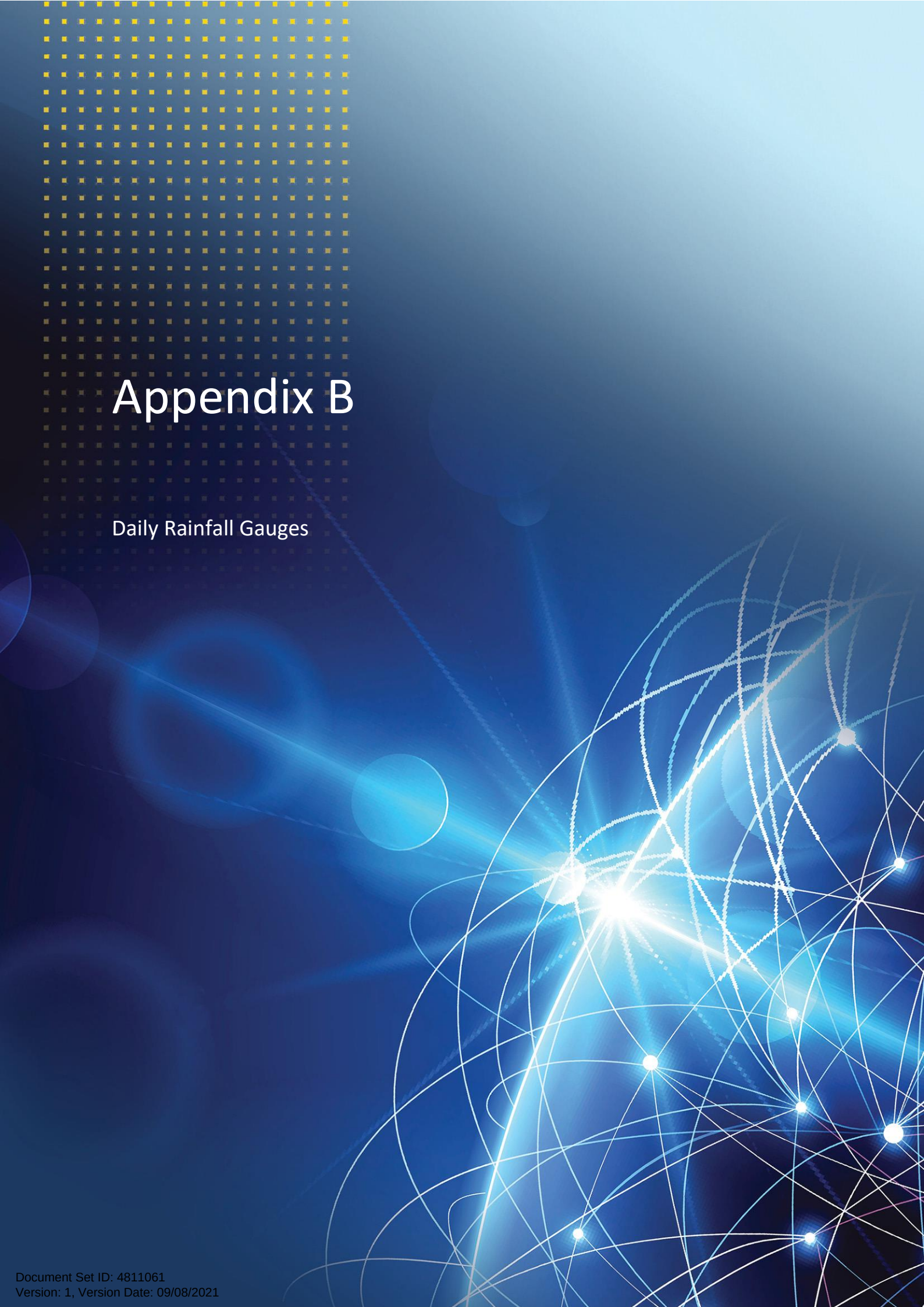
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Appendix B

Daily Rainfall Gauges

Site Number	Site Name	26-03-17	27-03-21	28-03-21	29-03-17	30-03-17	31-03-17	01-04-17	02-04-17	03-04-17	04-04-17	Sum	Latitude	Longitude
33083	Cardowan	0	0	43	209	204	0	0	0	0	0	456	- 22. 12	149 .06
33172	Crediton	2.2	6.8			638	0		0.4	0	0	644 .8	- 21. 2	148 .54
33189	Strathmuir	0	0	42	69	245	0	0	0	0	0	356	- 22. 71	149 .73
33210	St Lawrence	0	0	119 .2	145 .4	135 .8	0	0	0	0	0	400 .4	- 22. 35	149 .52
33248	Cerberus	0	0.4	23. 4	110	103 .2	0	0	0	0	0	237	- 22. 93	149 .52
33285	The Gap Tm	0	0	28	24	128	0	0	0	0	0	180	- 23. 09	150 .11
33301	Whiteford's Alert	0	0	108	337	154	0	0	0	0	0	599	- 21. 32	148 .84
33318	Dilkera	0	0	18. 6	163	34. 4	0	0	0	0	0	216	- 21. 81	148 .69
34015	Wentworth	0	0	0		35. 6	0	0	0	0	0	35. 6	- 22. 07	147 .72
34016	Carfax	0	0	7	165 .5	59	0	0	0	0	0	231 .5	- 22. 46	148 .68
34027	Essex	0	0	6.8	87	73. 4	0	0	0	0	0	167 .2	- 22. 77	148 .81
34035	Moranbah Airport	0	0	5.4	115 .4	25	0	0	0	0	0	145 .8	- 22. 06	148 .08
34044	Bruslee	0	0	0	26	13	0	0	0	0	0	39	- 21. 08	146 .51
34047	Barmount	0	0	19. 5	79	104 .5	0	0	0	0	0	203	- 22. 53	149 .1
34078	Greenmantle	0	0	0	55	42	0	0	0	0	0	97	- 22. 52	147 .69

Site Number	Site Name	26-03-17	27-03-21	28-03-21	29-03-17	30-03-17	31-03-17	01-04-17	02-04-17	03-04-17	04-04-17	Sum	Latitude	Longitude
34083	Waitara	0	0	17.2	226.6	191	0	0	0	0	0	434.8	- 21.84	148.87
34094	Taemas	0	0	0	13	0	0	0	0	0	13	-21		146.43
34100	Iffley	0	0	8	157	36	0				201	- 22.24		148.43
35000	Alpha Post Office	0	0	0	9	21.2	0	0	0	0	30.2	- 23.65		146.64
35016	Capella Post Office	0	0	0	29	27.4	0	0	0	0	56.4	- 23.09		148.02
35053	Peakvale Station	0	0	0	24	53	0	0	0	0	77	- 23.19		247.35
35062	Sapphire Post Office	0	0	0	19	56	0	0	0	0	75	- 23.46		147.72
35094	Winvic	0	0	0	48	58					106	- 22.48		147.52
35109	Booroondarra	0	0	4.4	80	84	0	0	0	0	168.4	- 22.82		148.49
35121	Valencia	0	0	0	32.6	38.2	0	0	0	0	70.8	- 22.96		147.8
35124	Clermont Airport	0	0	0	36.6	40.2	0	0	0	0	76.8	- 22.78		147.62
35131	Talagai	0	0	0	55	54.4	0	0	0	0	109.4	- 23.13		148.53
35143	Maryvale Springs	0	0	0	0	12.6	0	0	0	0	12.6	- 24.06		145.91
35164	Monklands	0	0	0	9	19	0	0	0	0	28	- 23.41		146.46
35185	Capella (Rowe's Hill) Alert	0	0	0	30	26.4	0	0	0	0	56.4	- 22.91		148.15
35187	Valeria Alert	0	0	0	38	43	0	0	0	0	81	- 23.19		147.89

Site Number	Site Name	26-03-17	27-03-21	28-03-21	29-03-17	30-03-17	31-03-17	01-04-17	02-04-17	03-04-17	04-04-17	Sum	Latitude	Longitude
35199	Mount Wilkin	0	0	0	43	49	0				92	- 22.28	147.44	
35211	Kurrajong	0	0	0	52.4	35.2	0	0	0	0	87.6	- 22.62	147.66	
35219	Cairo	0	0	0	46	52	0	0	0	0	98	- 22.44	147.38	
35221	Lucknow	0	0	0	25	47	0	0	0	0	72	-23.2	148.11	
35224	Karmoo	0	0	0	26.6	71.2	0	0	0	0	97.8	- 23.08	147.38	
35267	Coovin	0	0	0	72.6	54	0	0	0	0	126.6	- 22.43	147.55	
35275	Islay Plains	0	0	0	4	17	0	0	0	0	21	- 23.21	146.88	
35286	Glencoe	0	0	0	0	13	0				13	- 23.71	146.17	
36050	Ulcanbah	0	0	0	9.4	18	0	0	0	0	27.4	- 22.02	145.98	
36074	Jochmus	0	0	0	0	27	0	0	0	0	27	-22.3	145.99	
36083	Albro Station	0	0	0		15	0	0	0	0	15	-22.7	146.57	
36160	Frankfield Station	0	0	0	36	34	0	0	0	0	70	- 22.27	147.09	
39035	Melrose	0	0	31.7	26	137	0	0	0	0	194.7	- 23.14	149.97	
39200	Redbank	0	0	18	30.2	125.2	1.2	0	0	0	174.6	- 23.11	149.91	
33071	The Valley	0	4.3	66.4	277	300.4	0	0	0	0	648.1	- 21.93	149.36	
33170	Mystery Park	0	0	110	179	250		0	0	0	539	- 22.36	149.37	

Site Number	Site Name	26-03-17	27-03-21	28-03-21	29-03-17	30-03-17	31-03-17	01-04-17	02-04-17	03-04-17	04-04-17	Sum	Latitude	Longitude
33095	Orkatie West Hill	0	0	105	452	409	0	0	0	0	0	966	-21.8	149.36
33038	Koumala Hatfields Road	0	6	138	287	500		0	0	0	0	931	-21.63	149.24
33195	Williamson	0	1.4	74	53	136.2	0.2	0	0	0	0	264.8	-22.47	150.18
33059	Plane Creek Sugar Mill	0	28	226	191	355.5	0	0	0	0	0	800.5	-21.43	149.22
33111	Marlborough H Helipad Tm	0	0.2	38	80.8	115.8	0	0	1.2	0	0	234.8	-22.82	149.89
200001	Middle Percy Island	0.2	33.6	46.2	119.4	157.4	9.4	0	0	0	0	366	-21.66	150.27
33129	Tilpal Station	0	0			177	0	0	0	0	0	177	-22.8	150.14
34061	Junee Station	0	0	11	95	255	1.5	0	0	0	0	362.5	-22.94	149.14
33188	Belgamba	0	12	47.2	194.2	169.4	0	0	0	0	0	422.8	-22.03	149.49
33186	Carmila Beach Road	0		83.6	350.4	164	0	0	0	0	0	598	-21.92	149.44
33304	Gargett Alert	0	2	152	291	160	0	0	0	0	0	605	-21.18	148.74
35295	Bingegang Weir Hw Alert	0	0	2.6	75.4	147	1.2	0	0.2	0	0	226.2	-23.07	149.04
33158	Hecate	0	7.2		337.6	114	0	0	0	0	0	458.8	-20.5	148.34
33284	Bloomsbury	1	6	50	358	135	0	0	0	0	0	549	-20.75	148.58
33176	Gatton Vale	0	0	11	129	31	0	0	0	0	0	171	-20.78	147.95
33053	Mount Jukes	4	38	206	565	380	0	0	0	0	0	1189	-21	148.94

Site Number	Site Name	26-03-17	27-03-21	28-03-21	29-03-17	30-03-17	31-03-17	01-04-17	02-04-17	03-04-17	04-04-17	Sum	Latitude	Longitude
33292	Myuna Alert	0	0	8	59	10	0	0	0	0	0	77	- 20.58	147.6
33320	Mt Jukes	1	33	232	325	635	0	0	0	0	0	1225	- 21.01	148.91
33013	Collinsville Post Office	0	0		188.4	29.8	0	0	0	0	0	218.2	- 20.55	147.85
33068	Mirani Mary Street	0	7	90.8	352.5	134	0	0	0	0	0	584.3	- 21.16	148.87
33302	Minari Weir TW Alert	0	7	151	304	132	0	0	0	0	0	594	- 21.18	148.83
33299	Sarich's Alert	0	3	162	322	128	0	0	0	0	0	615	- 21.27	148.82