BUSINESS PAPER

Extraordinary Meeting of Council

Council Chambers
13 August 2025

6.30pm

BROKEN HILL
CITY COUNCIL

AUSTRALIA'S FIRST
HERITAGE LISTED CITY

Notice is hereby given, in accordance with the provisions of the *Local Government Act 1993*, that an Extraordinary Meeting of the Broken Hill City Council will be held in the Council Chambers on **Wednesday 13 August 2025** commencing at **6:30pm** to consider the following business:

AGENDA

1	Opening the Meeting
2	Apologies
3	Leave of Absence Applications
4	Prayer
5	Acknowledgement of Country
6	Acknowledgement of Broken Hill's Mining History
7	Public Forum Session
8	Disclosure of Interest
9	Reports a) Draft Broken Hill Flood Study Report and Flood Mapping for Public Exhibition
10	Public Forum Session
11	Confidential Matters a) Proposed Sale of 232 Morgan Street - CONFIDENTIAL
12	Conclusion of the Meeting

STATEMENT OF ETHICAL OBLIGATIONS
All Councillors undertook an Oath or Affirmation at the beginning of their term of office and declared to undertake the duties of the office of Councillor in the best interests of the people of the Broken Hill Local Government Area and the City of Broken Hill; and that they will faithfully and impartially carry out the functions, powers, authorities and discretions vested in them under the *Local Government Act 1993* or any other Act to the best of their ability and judgment.

LIVE STREAMING OF COUNCIL MEETINGS
This Council meeting is being streamed live on Youtube, recorded and published on Council's website. To those present in the gallery today, by attending or participating in this public meeting you are consenting to your image, voice and comments being recorded and published.
The Mayor and/or General Manager have the authority to pause or terminate the stream if comments or debate are considered defamatory or otherwise inappropriate for publishing.
Attendees are advised that they may be subject to legal action if they engage in unlawful behaviour or commentary.

JAY NANKIVELL
GENERAL MANAGER

REPORTS

EXTRAORDINARY MEETING OF THE COUNCIL

August 8, 2025

ITEM 1

BROKEN HILL CITY COUNCIL REPORT NO. 146/25

SUBJECT: DRAFT BROKEN HILL FLOOD STUDY REPORT AND FLOOD MAPPING FOR PUBLIC EXHIBITION D25/35991

Recommendation

1. That Broken Hill City Council Report No. 146/25 dated August 8, 2025, be received.

2. That Council endorses the Draft Flood Study Report and Flood Mapping for the purpose of public exhibition.

3. That the Draft Flood Study Report and Flood Mapping be placed on public exhibition for submissions to be received for a period of 28 days.

4. That Council receives a further report after the public exhibition period has ended, outlining all submissions received and any recommended amendments, to support the adoption of the final Flood Study report and its recommendations.

Executive Summary:

Broken Hill City Council, in collaboration with Torrent Consulting, Department of Climate Change, Energy, the Environment and Water (DCCEEW) has completed the Draft Flood Study for Broken Hill's urban catchments, as part of its obligations under the NSW Flood Prone Land Policy. The study provides a detailed understanding of existing and potential flood risks, supporting planning decisions, infrastructure design, emergency response, and flood risk management strategies.

The study covers approximately 60 square kilometres of urban land within Broken Hill and incorporates key infrastructure, residential, commercial, and community assets. Using a high-resolution 2D TUFLOW model calibrated against real flood events (September 2020, March 2022, and January 2024), the study offers flood mapping, hazard classification, and flood function zoning for a range of design storms including the 1% (100-year event) Annual Exceedance Probability (AEP) and Probable Maximum Flood (PMF).

Community engagement has played an important role in validating the modelling outcomes. Engagement included a media release, community survey, and an information session. Further engagement and feedback are planned during the public exhibition phase.

As per the established protocol, it's recommended to place the Draft Flood Study Report on public exhibition for 28 days. A further report will be presented to Council at the conclusion of the exhibition, summarising submissions and proposing any amendments prior to adoption of the Final Flood Study Report.

Report:

Background

Council has engaged Torrent Consulting to undertake a Flood Study for Broken Hill's urban catchments, aligning with the NSW Government's Floodplain Risk Management Process. The study is part-funded by the NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW).

The five key stages of the study are:

1. Stage 1: Data Collection and Initial Community Consultation – *Completed*
2. Stage 2: Model Development and Validation – *Completed*
3. Stage 3: Design Flood Modelling and Mapping – *Completed*
4. Stage 4: Draft Flood Study and Public Exhibition – *This stage will commence following Council's endorsement.*
5. Stage 5: Final Flood Study and Council Adoption – *To be completed*

Study Area and Objectives

The study area covers approximately 60 km² of Broken Hill's urban landscape, including residential areas, commercial zones, schools, hospitals, aged care, and critical infrastructure. The objective is to simulate flood behaviour under various design rainfall events to:

- Inform land use and development controls
- Support infrastructure and drainage planning
- Assist in emergency response
- Guide future flood mitigation options

Modelling and Methodology

The TUFLOW 2D hydraulic model was developed using:

- LiDAR-derived topography
- Local land use and drainage data
- Site inspections and field observations
- A rain-on-grid modelling approach

Validation was carried out using flood data from three recent events. Community-provided photographic and video evidence was used to match simulated flood depths and extents. Model refinements were made to better represent obstructions such as fences and buildings, ensuring accurate representation of flood pathways.

Explanation of AEP and PMF

The Annual Exceedance Probability (AEP) is a statistical measure used to describe the likelihood of a flood occurring in any given year. For example, a 1% AEP flood, commonly referred to as a "100-year flood", has a 1 in 100 chance of occurring in any single year, not once every 100 years as the name may suggest.

This terminology is consistent with current best practice under Australian Rainfall and Runoff 2019 (ARR2019) guidelines.

The Probable Maximum Flood (PMF) represents the most extreme flood that could theoretically occur, based on the maximum possible rainfall and catchment conditions. While its likelihood is extremely low (often less than a 1 in 10,000,000 chance per year), PMF modelling is important for planning critical or high-risk infrastructure and ensuring public safety in rare catastrophic scenarios.

Key Findings

- Flood maps have been developed for 10% AEP to PMF events
- Outputs include peak flood depths, velocities, hazard classification (H1–H6), and flood function zoning
- Areas of increased flood risk have been identified for further planning and mitigation considerations

Public Exhibition

The Draft Flood Study Report will be placed on public exhibition for a period of 28 days, providing the community and stakeholders with an opportunity to review the study findings and make formal submissions.

As part of the exhibition, Council will present the results of the 1% Annual Exceedance Probability (AEP) flood modelling, commonly referred to as the “100-year flood”. This scenario is the standard reference point used in floodplain risk management across New South Wales, as it represents a significant flood event for planning, development control, infrastructure design, and emergency response purposes.

The exhibition materials will include:

- Online access to the full Draft Flood Study Report and accompanying flood maps.
- A comprehensive set of approximately 140 high-resolution maps illustrating outcomes from the 1% AEP scenario, including:
    - Model calibration results
    - Peak flood depth
    - Velocity of floodwaters
    - Flood hazard classifications (H1 to H6)
    - Flood function zoning (e.g. floodway’s, storage areas, fringe)
- An opportunity for residents, landowners, and stakeholders to provide submissions and feedback on the draft findings.
- Provision for a second Community Information Session, if required, to support further engagement during the exhibition period.

Following the exhibition, a further report will be presented to Council summarising all submissions received, recommending any amendments, and seeking adoption of the final Flood Study Report.

Next Steps

Following Council’s endorsement, the Draft Flood Study Report will be placed on public exhibition for a period of 28 days. During this time, community members, stakeholders, and affected property owners will be invited to review the report, access the supporting flood maps, and provide formal submissions.

At the conclusion of the exhibition period, all feedback received will be reviewed and considered. A further report will then be presented to Council, summarising the submissions and recommending any necessary amendments to the Draft Flood Study.

Subject to Council's consideration of the feedback and recommended changes, the final Flood Study Report will be adopted. This will complete Stage 5 of the flood study process and enable Council to proceed with the next phase, preparation of a Floodplain Risk Management Plan, to identify and prioritise practical flood mitigation and adaptation measures.

Community Engagement:

Community engagement has been an integral part of the Broken Hill Flood Study process to date. During the early stages of the study, Council conducted a media release in October 2023 and invited residents to participate in an online questionnaire to share their experiences with local flooding. A Community Information Session was also held, providing an opportunity for residents, Council staff, Torrent Consulting, and representatives from the NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW) to engage directly.

The community provided flood photos, videos, and feedback played a valuable role in validating the flood model and informing local assumptions.

The Draft Flood Study Report will now be placed on public exhibition for a period of 28 days. During this time, the community and stakeholders will have the opportunity to review the findings, access flood maps and reports online and make formal submissions. A second Community Information Session may be held if and as required.

All submissions received during the exhibition period will be reviewed and considered in the finalisation of the Flood Study.

Strategic Direction:

Key Direction:	3	Our Environment
Objective:	3.3	Proactive, innovative and responsible planning supports the community, the environment and beautification of the City.
Strategy:	3.3.4	Advocate for improved storm water management within the City.

Relevant Legislation:

- NSW Flood Prone Land Policy
- NSW Government's Floodplain Risk Management Framework
- Australian Institute for Disaster Resilience (AIDR) – Hazard Classification Standards
- Australian Rainfall and Runoff 2019 (ARR2019)
- Department of Climate Change, Energy, the Environment and Water (DCCEEW) Guidelines

Financial Implications:

The preparation of the Flood Study has been jointly funded by Broken Hill City Council and the NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW) under the NSW Government's Floodplain Management Program. The total funding was approved as part of the 2023/2024 Annual Budget for $154,000 in a 4:1 funding model, with Council contributing $30,800.

There are no additional direct financial implications associated with placing the Draft Flood Study on public exhibition. Any further financial considerations, including implementation of future flood mitigation measures or preparation of a Floodplain Risk Management Plan, will be subject to separate reports and funding strategies following the adoption of the final Flood Study.

Attachments

1. ⇩ Flood Study Report

CODIE HOWARD
DIRECTOR INFRASTRUCTURE AND ENVIRONMENT

JAY NANKIVELL
GENERAL MANAGER

Torrent Consulting

Broken Hill Flood Study

R.T2422.001.03

Progress Report - Design Flood Modelling

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Wallsend NSW 2287

ABN 11 636 418 089

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Document:	R.T2422.001.03_progress_report
Title:	Broken Hill Flood Study – Design Modelling Report
Project Manager:	Darren Lyons
Author:	Dan Suvaal / Darren Lyons
Client:	Broken Hill City Council
Client Contact:	Faisal Salah

Prepared: Verified:

[redacted]

Synopsis

Progress Report for the Broken Hill Flood Study.

Revision History

Revision	Description	Date
01	Progress Report	25/03/2024
02	Calibration and Preliminary Design Report	19/12/2024
03	Design Modelling Report	05/08/2025

Cover photo: "A flood at Broken Hill, New South Wales" (circa 1915), State Library South Australia.

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1 Introduction

The Broken Hill Flood Study is being prepared for Broken Hill City Council (Council) to define the existing flood behaviour in the city overland flow catchment areas and establish the basis for subsequent flood risk management activities.

The project delivery incorporates a series of milestone reports as outlined in Table 1-1. This report addresses Stage 1 to Stage 3 of the Milestone and Deliverable Package and documents the data collection, data review, community consultation, model development and calibration, and design flood modelling progress to date. The Stages 1-3 progress report will form the basis of the Draft Flood Study report to be issued following progress report review, feedback and update.

Table 1-1 Project Milestone Reporting

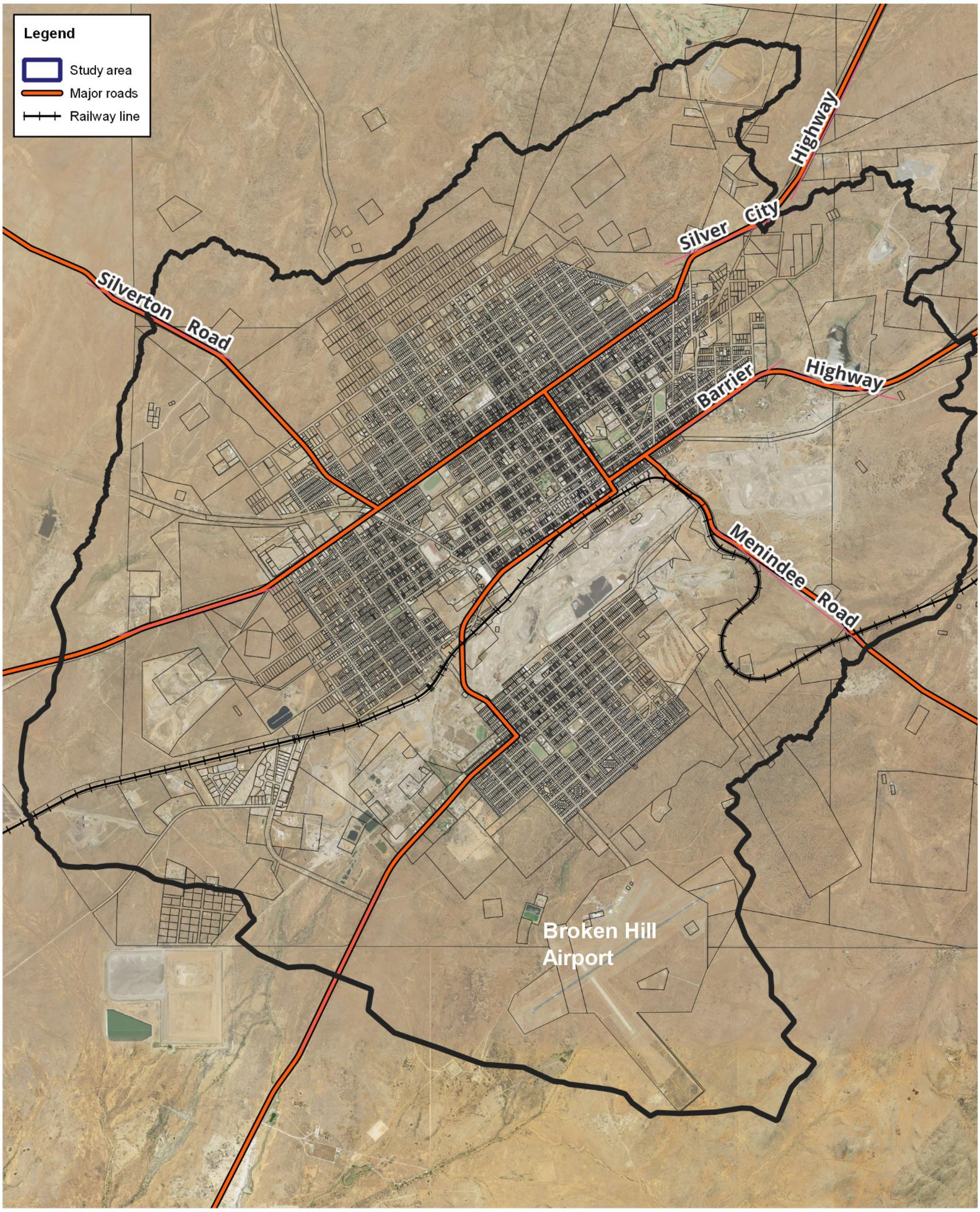
Stage	Milestone and Deliverable Package
Stage 1	Data Collection, Review and Community Consultation progress report
Stage 2	Model Development & Calibration/Validation progress report
Stage 3	Design flood modelling and damages assessment progress report
Stage 4	Draft Flood Study report & Public Exhibition
Stage 5	Final Flood Study report & Council adoption

1.1 Study Location

The City of Broken Hill is located in far western New South Wales, approximately 50 kilometres east of the South Australian border. The study catchment situated within the boundaries of the Broken Hill City Council represents an area of approximately 60 km^2 as shown in Figure 1-1.

Regional access to Broken Hill is via the Barrier Highway from the west and east, the Silver City Highway from the north and south, with Silverton Road and Menindee Road connecting to the adjacent towns of Silverton and Menindee, respectively. Rail access to Broken Hill is available via the Peterborough Broken Hill Railway, and Broken Hill Airport also allows air travel from major cities.

The Study Area is broadly defined as the local urban drainage catchments within the City of Broken Hill.



Title:

Study Locality

0 1 2 km

approx. scale

Figure: **1-1**

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1.2 The Floodplain Risk Management Process

The NSW Government has worked in partnership with councils to understand and manage flood risk to communities across New South Wales under the NSW Flood prone land policy (the policy) since 1984. The primary objective of the policy is to reduce the impacts of flooding and flood liability on communities and individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible. The *Flood risk management manual: the policy and manual for the management of flood liable land* (NSW Dept. Planning & Environment, 2023) and its toolkit support the implementation of the policy.

Under the policy the management of flood liable land remains the responsibility of Councils, with the State Government providing specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities and may subsidise flood mitigation works to alleviate existing problems. Councils are encouraged to develop and implement Floodplain Risk Management (FRM) plans through the FRM process outlined in Figure 1-2.

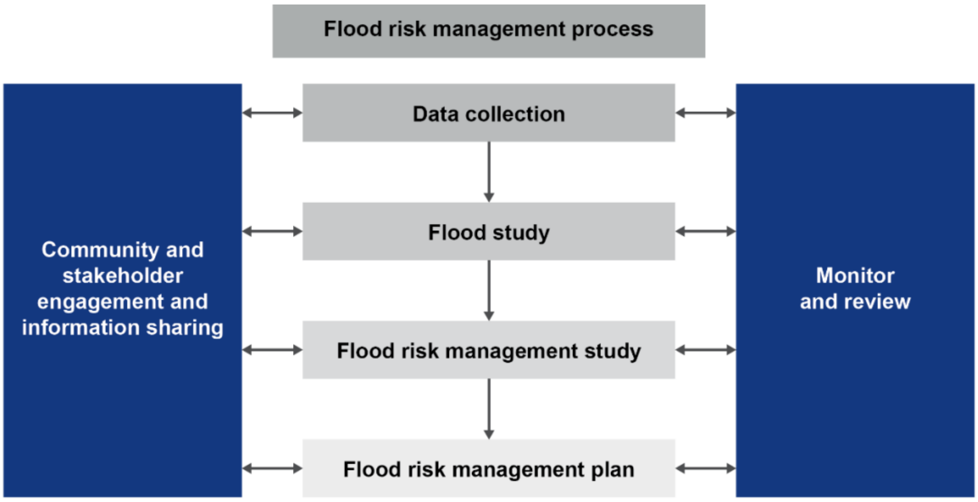


Figure 1-2 - Flood risk management process (NSW Floodplain Risk Management Manual)

This study represents the "Flood Study" stage of the above process and aims to provide an understanding of flood behaviour within the Broken Hill environs.

1.3 Study Objectives

The primary objective of the Flood Study is to define the flood behaviour within the Broken Hill environs through the establishment of appropriate numerical models. The developed models simulate expected flood behaviour in the local catchment area providing information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment and floodplain conditions. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data as required.
- Development appropriate hydrologic and hydraulic models and calibration to observed historical event data where available.

- Determination of design flood conditions for a range of design magnitude events up to the Probable Maximum Flood (PMF) event, considering also future flooding conditions incorporating potential climate change influence.
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

The principal outcome of the flood study is the understanding of flood behaviour in the catchment and in particular design flood level information to assist in future flood planning and assessment of flood risk management options.

1.4 Report Outline

This report documents the Study's objectives, results and recommendations.

Section 1 introduces the study.

Section 2 provides an overview of the approach adopted to complete the study.

Section 3 outlines the community consultation program undertaken.

Section 4 provides information on the historical flood data collected for this study.

Section 5 details the development of the computer models.

Section 6 details the model calibration and validation process including sensitivity tests.

Section 7 presents the design flood simulation results and associated flood mapping.

Section 8 presents key floodplain risk management considerations

2 Study Background

2.1 The Study Area

The study area catchments comprise the majority of the mixed urban development within the City, and drain in multiple directions to the ephemeral creek systems at the City outskirts. Accordingly, the study focusses on the urban Council area containing a mix of residential, light industrial, and commercial premises, schools, Council reserves, and sports and community facilities. The study area is extended to include important infrastructure and development areas beyond the main urban centre, such as the Broken Hill Airport.

Critical services available within Broken Hill include the following:

- 9 schools
- 5 preschool / childcare centres
- 3 aged care facilities
- Broken Hill Hospital

Critical infrastructure available within Broken Hill includes the following:

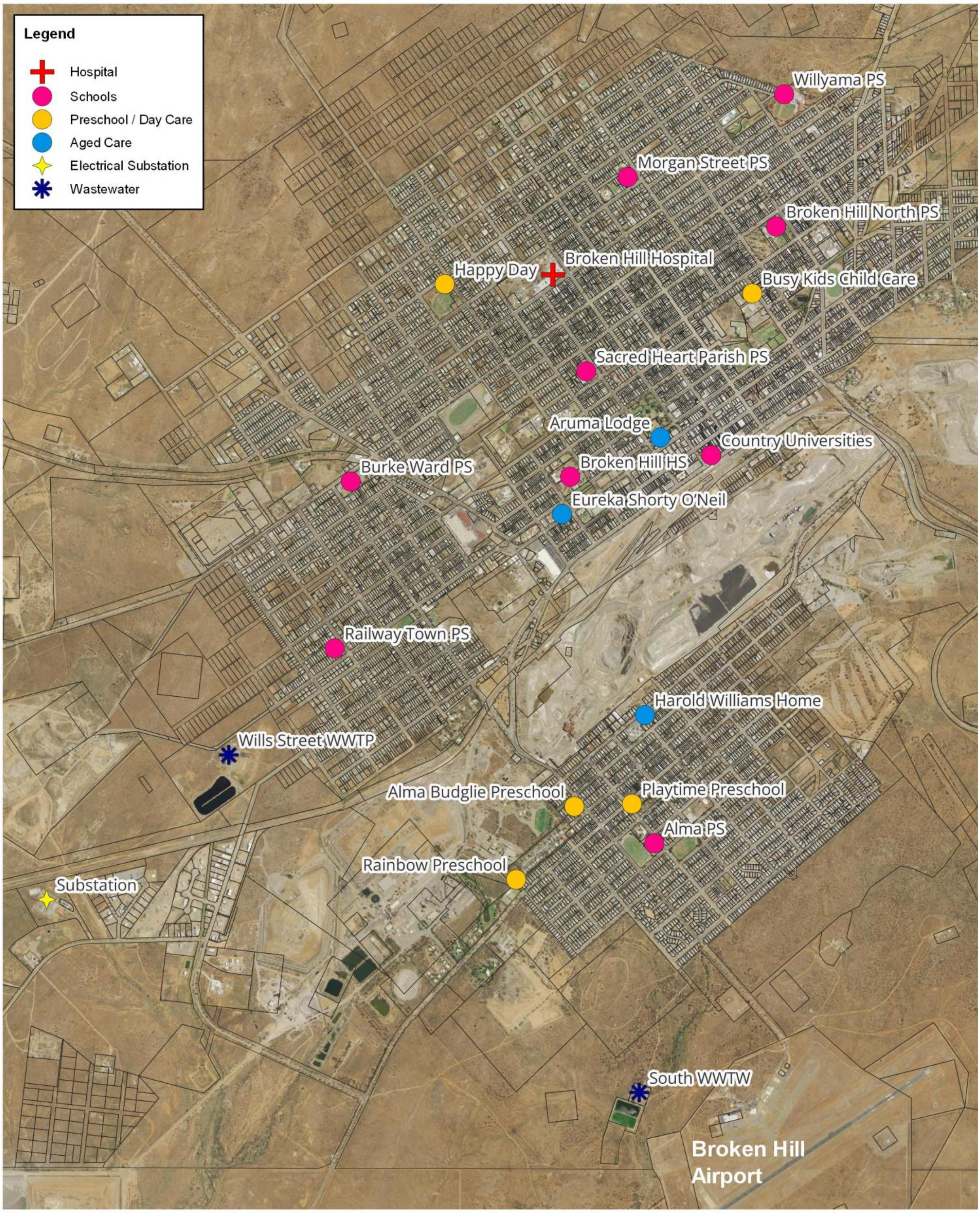
- Broken Hill electrical substation
- Reticulated water supply
- Sewage infrastructure, including 2 Wastewater Treatment Plants (WWTP) and 11 sewage pumping stations

The location of the above key infrastructure is shown in Figure 2-1.

2.1.1 Catchment Description

The study area consists of multiple sub-catchments based on their outlet location. These sub-catchments are readily identifiable in the local topography as annotated on Figure 2-2:

- The Living Desert – located in the northern region of the City draining in a typical north-east direction to an unnamed watercourse and eventually to Willa Willyong Creek.
- Mulga Creek - adjacent to the Living Desert catchment in the eastern region of the city draining via open channel to the east of the city and again to Willa Willyong Creek
- Cemetery Creek – covers the north-west sector of the City and drains in a typical south-westerly direction to Cemetery Creek via a large number of overland flow paths
- Railwaytown – located at the western end of the city between the Cemetery Creek and South Broken Hill catchments, typically draining in a south-westerly direction through the railway line.
- South Broken Hill – the southern portion of the City largely grading in a south-east direction to a number of outlets.



Title:
Key Services and Infrastructure

Figure: **2-1**

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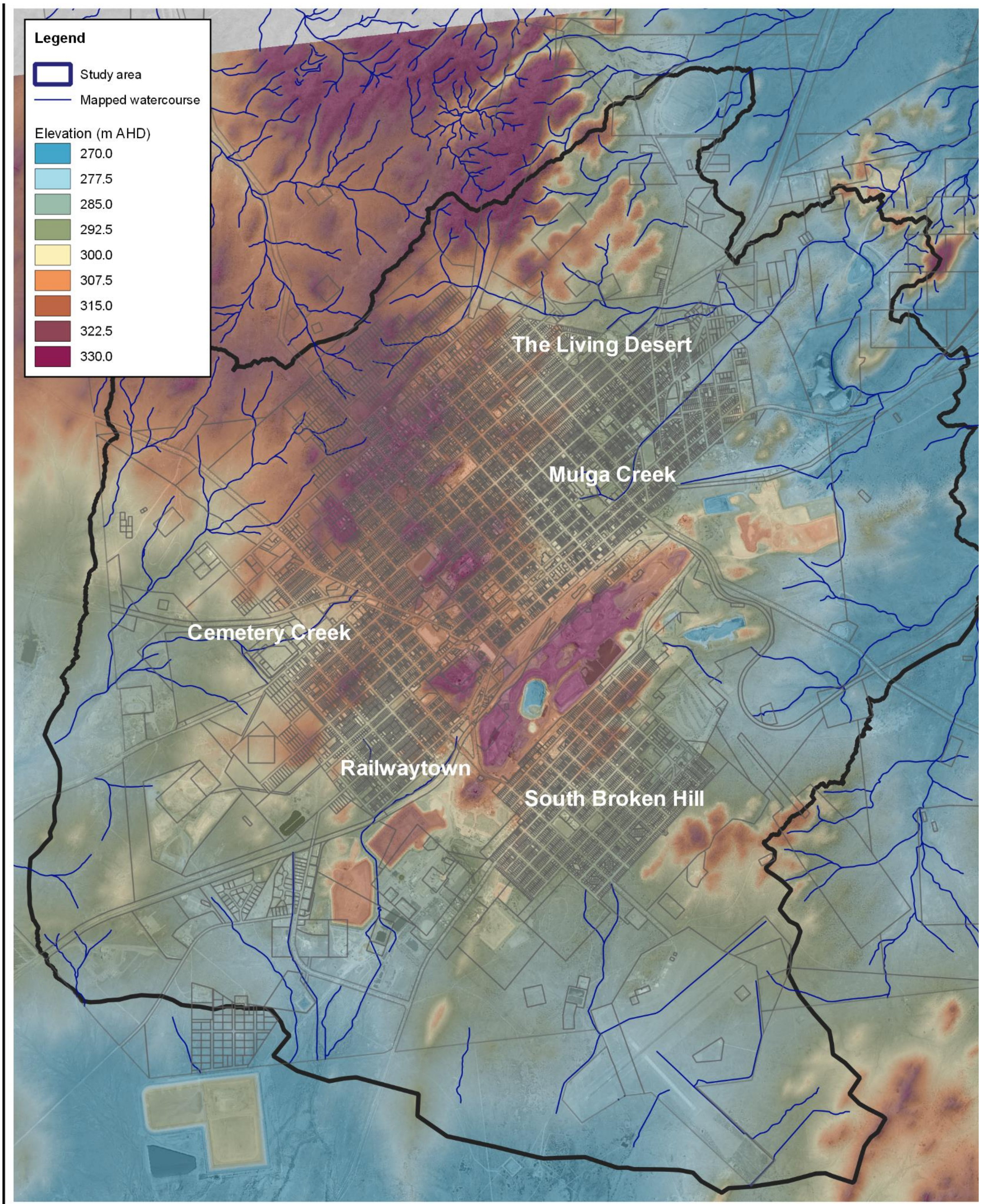

Title:

Local Catchments and Topography

0 1 2 km

approx. scale

Figure: **2-2**

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Urban runoff is primarily conveyed to natural drainage lines at the periphery of the town limits via overland flow paths, with limited sub-surface drainage infrastructure existing within Broken Hill. Roadway formations make up the bulk of the dedicated flow paths, with drainage infrastructure such as culverts and bridges strategically located to limit the impact of floodwater on property and access where required.

2.2 Compilation and Review of Available Data

2.2.1 Land Use Data

Cadastral data for the City of Broken Hill was downloaded from the NSW Spatial Services SIX maps portal. Aerial imagery was used in combination with cadastral data to define land use areas, surface types and buildings. The spatial distribution of land use area, surface type and buildings are incorporated in the model development when considering:

- delineation of impervious and pervious areas for surface water runoff response to rainfall (e.g. variation in initial and continuing rainfall loss rates)
- hydraulic roughness of different surface coverage types for overland and in-channel flows
- flow impedance of building/structure footprints.

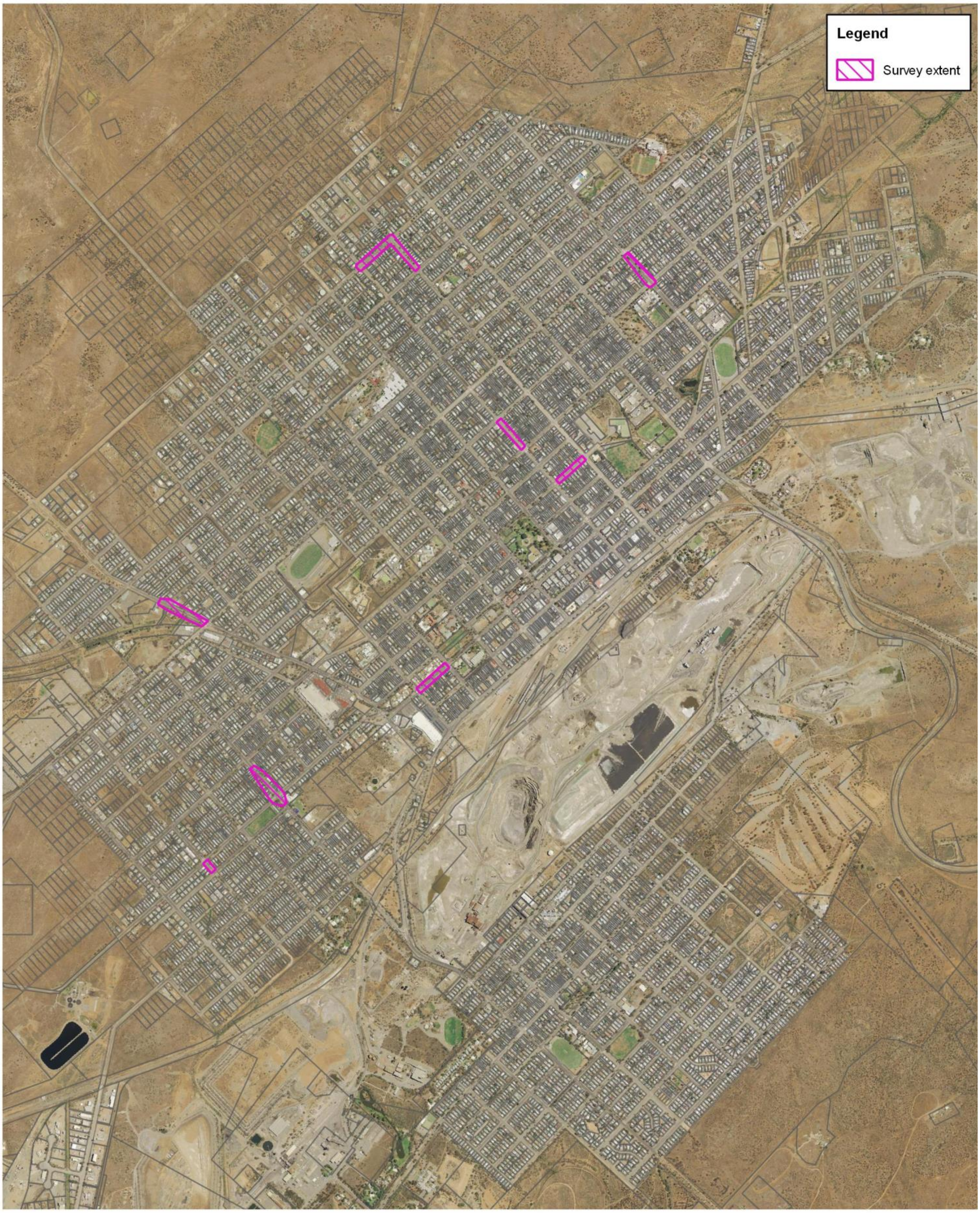
2.2.2 Topographical Data

Topographical data was available from LiDAR survey covering Broken Hill and ground survey provided by Council at several locations across Broken Hill. The NSW Spatial Services LiDAR data product was downloaded via the ELVIS Foundation Spatial Data portal to define the floodplain topography in and around Broken Hill as shown in Figure 2-2. The LiDAR survey was undertaken in February and March 2022, with a Digital Elevation Model (DEM) available at a 1 m resolution. The horizontal spatial accuracy is reported as +/- 0.80 m at 95% confidence interval, with vertical spatial accuracy reported as +/- 0.30 m at 95% confidence interval.

In addition to the derived DEM product, point cloud data was available on the ELVIS Foundation Spatial Data portal. This data is useful for interrogating individual ground level returns to assist in localised topographical adjustment of the DEM where required. The distribution of ground and building returns has also been used to derive building polygons for representation in the developed model.

Survey elevation data was supplied by Council at eight locations across Broken Hill, as presented in Figure 2-3. The survey equipment used for ground surveys such as these typically have a higher accuracy than is available via broadscale LiDAR surveys, and so Council's survey data was useful for confirming the suitability of the existing LiDAR data to be used for terrain representation within the model, and if any terrain reinforcement was required.

Figure 2-4 presents an example survey location on Oxide Street with survey points overlaid on a layer showing the level difference between the LiDAR-derived DEM and the survey-derived DEM. The difference between the LiDAR and survey DEMs is typically within a few centimetres with a general consistency between the two data sets. This demonstrates the LiDAR data is a reasonable representation of the existing terrain. The difference in surface representation is greatest in gutters and crests, indicating that reinforcement of these areas to provide contiguous profiles may be required to provide the best model representation. This can be particularly important for the road corridor which typically conveys a high proportion of the overland flow in urban environments.



Title:

Council Survey Locations

0 0.8 1.6 km
approx. scale

Figure: **2-3**

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Title:

Level Difference Between LiDAR and Survey (Oxide Street)

0 40 80 m

approx. scale

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To further assess the suitability of the available LiDAR data, the surveyed elevation values were subtracted from the underlying LiDAR elevation values to derive an elevation difference for statistical analysis. Due to the potential for vertical discrepancies in areas with sudden level changes, the survey points were filtered so that areas of the LiDAR DEM that exceeded 4% grade were not included in the comparison. Figure 2-5presents a cumulative distribution of the elevation difference between Council's surveyed levels and the LiDAR DEM levels across all eight survey locations.

The LiDAR DEM was interrogated at the position of around 4,000 surveyed points, with 80% of the LiDAR-derived levels within 100 mm of the surveyed levels, and around 95% of the LiDAR-derived levels within 150 mm of the surveyed levels. Accordingly, it is considered the LiDAR DEM is of sufficient accuracy to use in the model representation of the broader study area topography.

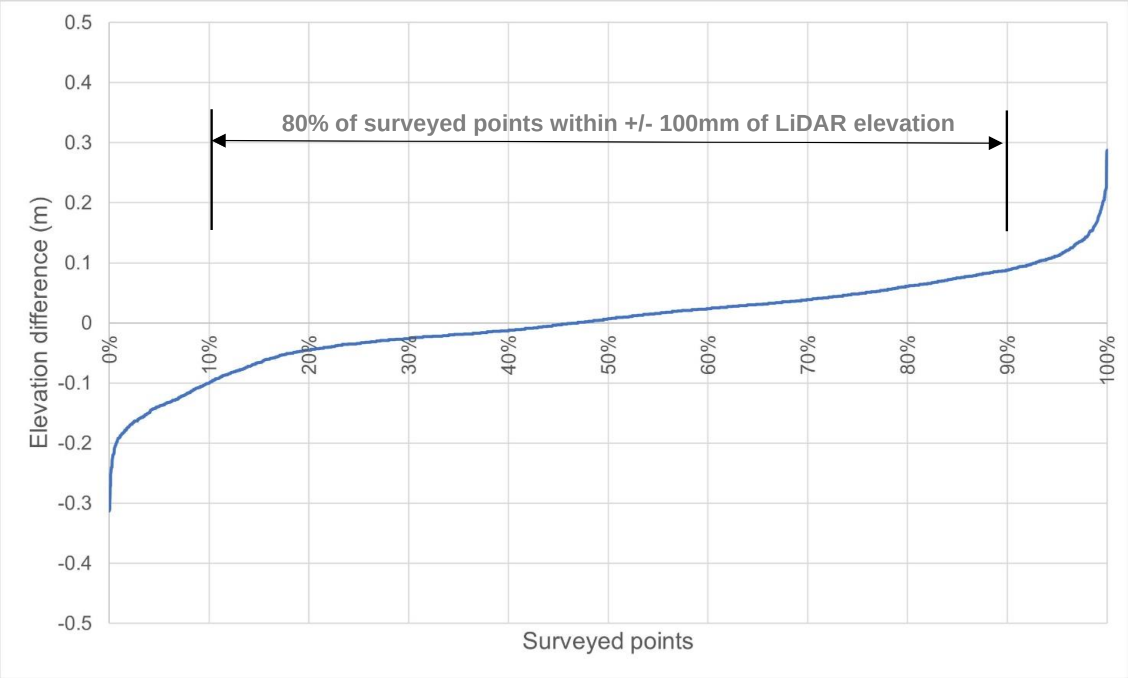


Figure 2-5 – Cumulative distribution of elevation difference between LiDAR and survey data

A cross-section comparison between the Council surveyed road formation in Oxide Street and the LiDAR-derived DEM is shown in Figure 2-6. Generally, it is seen the data sets provide for a similar road profile and corresponding cross-sectional area. However, as expected, there is a larger discrepancy in level values between the surveyed points and the smoothed LiDAR grid values in areas with sudden level changes such as the kerb and gutter profile and the raised median strip.

With respect to the significance to modelled flood conditions, the overall conveyance capacity of the roadway during the peak of design flood events was not expected to be affected, considering that the loss in cross sectional area represented by the level discrepancy at the gutters is relatively small. There is only around a 2% difference in cross-sectional area when comparing the two sections, indicating that the LiDAR DEM can suitably represent the conveyance within the road corridor along major flow paths.

Within the model development phase, preliminary model results were analysed to determine the model performance along the major flow paths. Critical areas were interrogated to ensure that hydraulic controls were captured, with embankments, structures, gutters, and other features reinforced where necessary (refer to Section 5).

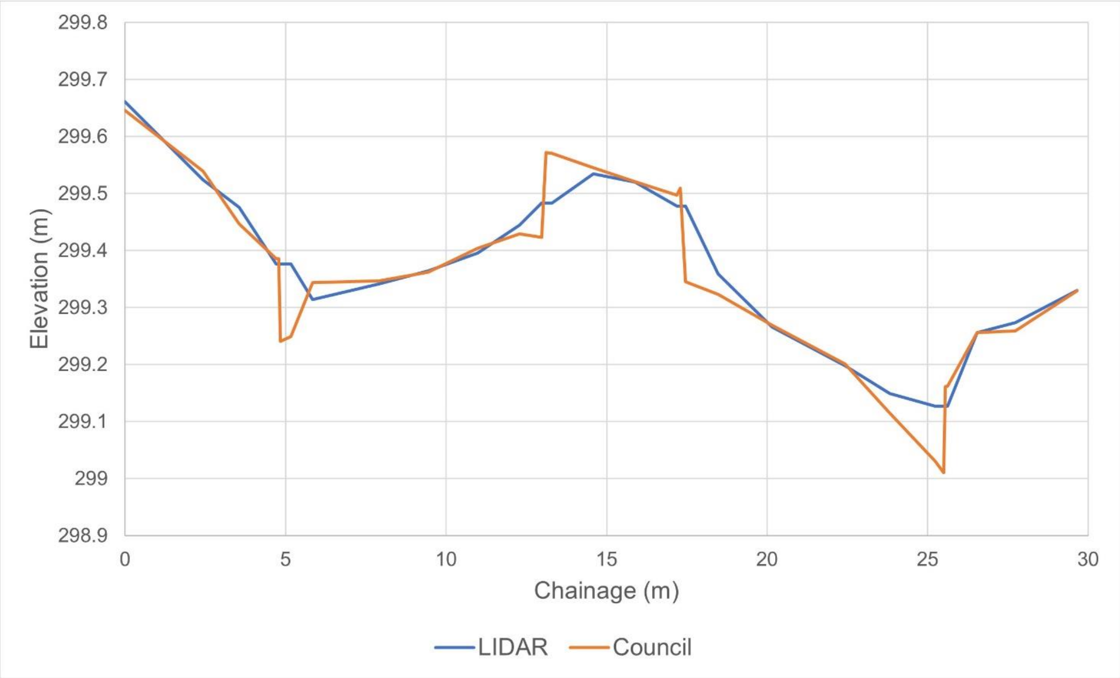
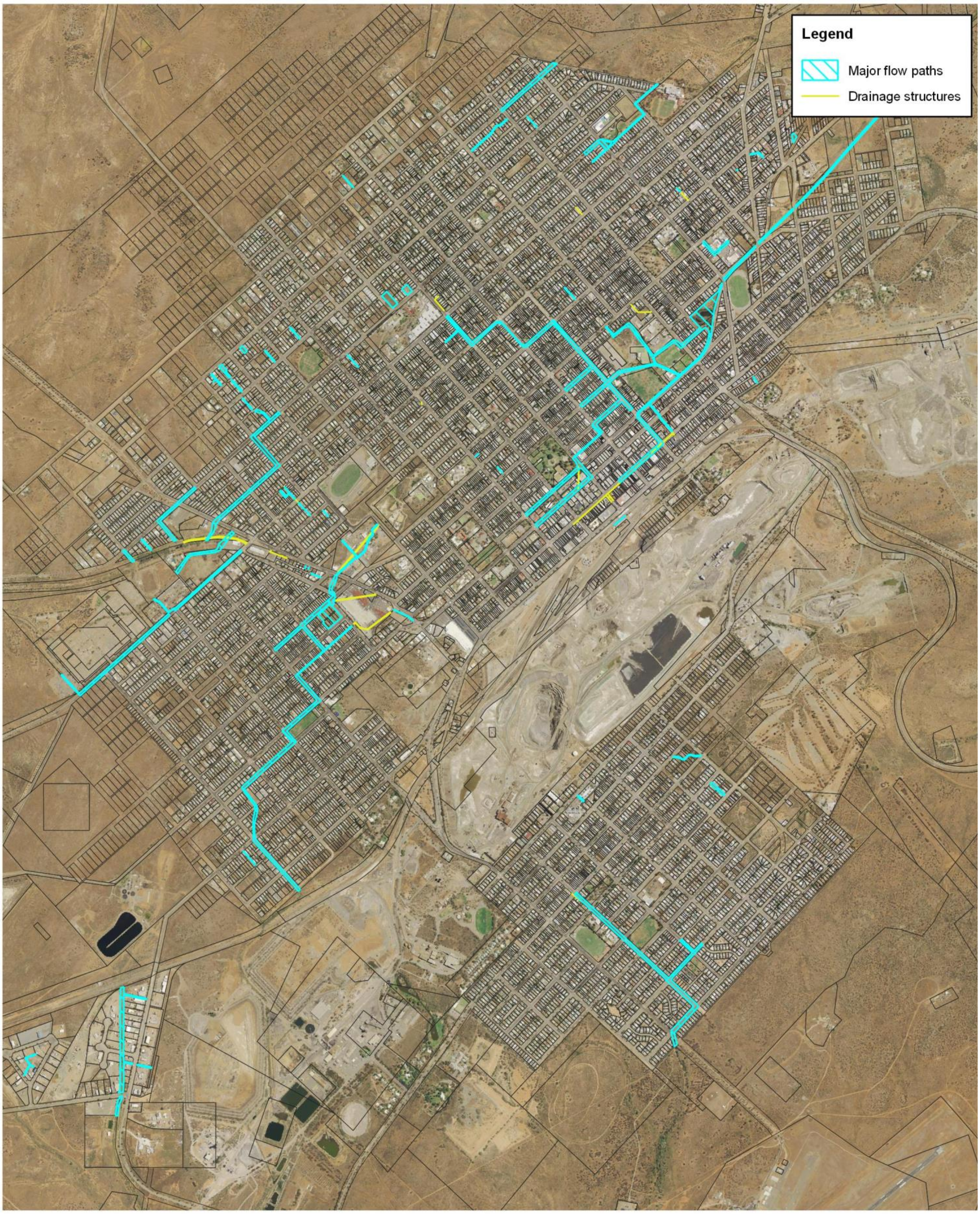


Figure 2-6 - Cross section comparison of LiDAR DEM vs survey DEM at Oxide Street

2.2.3 Drainage Infrastructure

Council supplied a GIS layer of the alignments of known major overland flow paths and location of some drainage infrastructure as shown in Figure 2-7. The data supplied was not comprehensive and did not include sizing or elevation information, with some indicated drainage infrastructure found to be non-existent following a subsequent site inspection. Whilst it is recognised that stormwater drainage infrastructure in the City is somewhat limited, it is understood there is no drainage asset database with relevant configuration details to inform the model representation of this infrastructure. Accordingly, the majority of drainage infrastructure has been identified utilising aerial imagery, Google ‘street view’, and the LiDAR DEM to establish a preliminary list of drainage structure locations and elevations. This data was further ground truthed during site inspections.



Title:

Council Drainage Data

0 0.8 1.6 km

approx. scale

Figure: **2-7**

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2.2.4 Site Visit

A reconnaissance of the study area and local catchment was undertaken during site visit in association with the initial community information session. This provided the opportunity to gain an appreciation of local features influencing flooding behaviour and verify some of the preliminary data collection including local topographic and hydraulic controls, and location and configuration of key stormwater drainage infrastructure.

The site visit included following the route of major flow paths to locate any additional drainage infrastructure not remotely identified, and to inspect the nature of inter-allotment drains and hydraulic controls such as surface roughness, solid fencing, retaining walls, embankments, and Gross Pollutant Traps (GPT's).

The location and configuration of drainage structures identified remotely were confirmed during the site visit. Some 117 structures were identified, measured, and photographed during the site visit. It should be noted that no level survey was carried out. However, all invert levels have been estimated based on the site inspection measurements and interrogation of the LiDAR DEM. In many instances invert levels are readily identified by the LiDAR with clear view of the approach channel or road/gutter profile. Measurement of some structures included the depth from the road/embankment top (with levels well defined in LiDAR) to the obvert and invert of the structure.

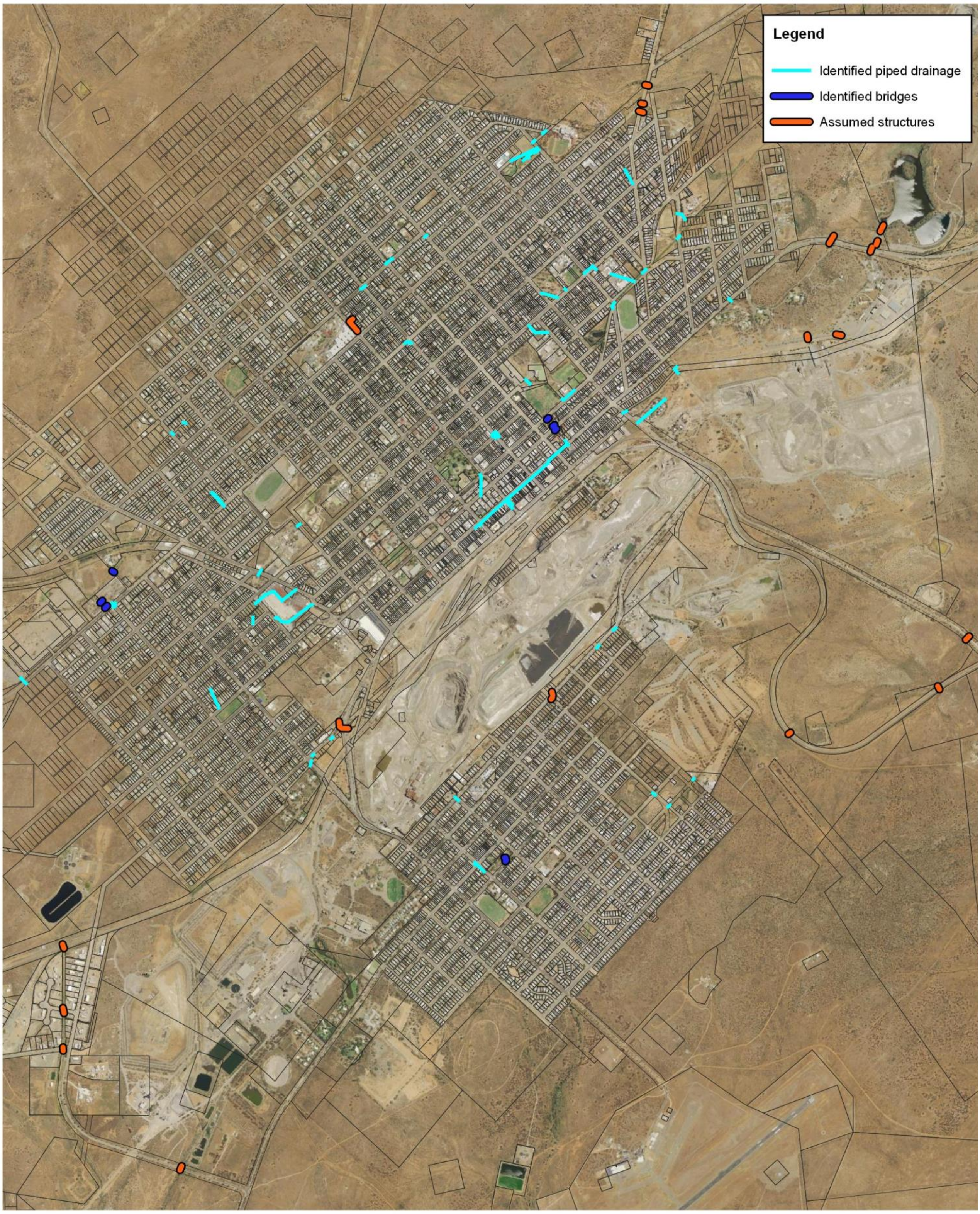
A GIS database of the identified stormwater drainage elements has been established and populated with the relevant configuration and level data. This forms the basis of the one-dimensional (1D) drainage network in the developed TUFLOW model. The location of identified drainage structures is presented in Figure 2-8, with an example site photograph presented in Figure 2-9.

2.2.5 Historical Flood Data

Rainfall data is available via a BoM Automatic Weather Station (AWS) at Broken Hill Airport. This presents a detailed record of rainfall data from 1991 onwards. It is recognised that the airport is around 5 km south of the town centre. Accordingly, recorded rainfall data at the gauge may not represent the rainfall conditions occurring across all the study area catchment during historical flood events.

Weather Underground (https://www.wunderground.com/wundermap) provides community sourced rainfall data with ten gauges listed within Broken Hill. A number of these gauges have records for recent historical events, providing supplementary data to the official BoM gauge in assessing spatial and temporal distribution of rainfall during past events. The suitability of this data is reviewed in Section 4.

There are no officially recorded flood levels or gauge data within the catchment. Accordingly, the majority of historical flood data is anecdotal observations of flooding recorded by community members. In addition to the photo and video evidence provided directly by community members during the initial consultation, online sources such as news articles and social media platforms provide accounts of previous flood events. Photographs and videos such as the example presented in Figure 2-10 provide useful snapshots of observed flood conditions. Timestamps where available on the images also provide an indicator of the relative timing of the inundation during the event to correlate back to the rainfall timing and response. However, in most instances is not possible to determine when the images were taken relative to the peak flood condition at the location.



Title:

Structure Locations

0 0.9 1.8 km

approx. scale

Figure: **2-8**

Revision: **A**

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Figure 2-9 - Site photo of drainage structure at Murton Street and Radium Street

Figure 2-10 - September 2020 event at corner of Gypsum Street and Wills Street

2.2.6 Previous Studies

Previous flood assessments within Broken Hill are limited to the Urban Stormwater Master Plan (Tonkin Engineering Science 2005). This report details the hydrology of the Broken Hill urban catchments and performance of the urban drainage infrastructure. The study used ILSAX hydrology and 1D hydraulic representation of overland flow paths to estimate the Broken Hill flood conditions.

The report and associated modelling techniques are now outdated. Unfortunately, many of the figures are missing from the provided copy of the report, limiting the opportunity for comparison of model results.

2.3 Data Gaps

As noted there has not been any formal survey of the drainage system, with measurements limited to those taken by Torrent Consulting during the site inspection. However, given the reasonable quality of the available LiDAR DEM, it is expected that invert levels derived in combination from the DEM and the site measurement data are a good representation of the structure configurations. It is expected most of these structures will be within a tolerance of around 100 mm to 200 mm plus the general accuracy of the LiDAR data.

The structure sizes will be the main driver of conveyance, with slight adjustments in invert levels not likely to produce any tangible change to structure capacities, or flow conditions around the structures. Accordingly, it considered the derived structure database is adequate for the modelling investigation without the requirement for additional detailed structure survey. If the modelling process identifies any sensitivity in the size, levels, or location of existing drainage structures, then site survey may be requested to ensure accurate model representation.

There are two areas of subsurface stormwater drainage lines which were unable to be accessed during the site inspection. This includes the formalised drainage line along Argent Street in the City Centre and the Westside Plaza drainage. It is expected these drainage lines are of relatively small capacity and have limited influence on the overland flow distribution in major events. However, in the in the absence of data held by Council or the Westfield Plaza operators, Council may wish to consider additional survey to capture these systems.

The lack of gauge data means that model parameters cannot be calibrated to specific water levels, however, validation of the model can be gained from video and photo evidence of significant flood events. Due to the short duration, high intensity nature of flooding within urban areas, the model parameters typically adjusted within a calibration have minimal impact on modelled flood conditions, with the main drivers of the flood conditions being rainfall and topography.

3 Community Consultation

3.1 Consultation Plan

A consultation plan to engage with the community at various stages throughout the project duration is an important component of the study. The key elements of the community consultation plan include:

- Media release at project initiation to inform of the project.
- Community questionnaire at project initiation to garner local flood knowledge and experience.
- Community Information sessions at project initiation and public exhibition phases to inform of study progress and findings.
- Formal Public Exhibition of Draft Flood Study documents and request for feedback.

In addition to the broader community engagement, study progress at key stages is reported to Council's Project Consultative Group (PCG).

A summary of the consultation elements undertaken since the study inception is provided below.

3.2 Media Release and Questionnaire

Council issued a media release on 18 October 2023 to inform the wider community of the study with an invitation to attend the Community Information Session and link to the Community Questionnaire. The media release and questionnaire are included for reference in Appendix A. The questionnaire was hosted on Council's website and was available online for a period of approximately one month from mid-October to mid-November.

The questionnaire sought to collect information on previous flood experience and flooding issues. The focus of the questionnaire was historical flooding information that may be useful for correlating with predicted flooding behaviour from the modelling.

Council provided the collated responses from the online questionnaire completions. There were eight questionnaire responses from residents detailing previous flooding events as follows:

- Chloride Street – March 2022
- Morgan Street – January 2021, March 2022, October 2022
- Town Square – January 2021, March 2022, October 2022
- Ryan Lane - March 2022, October 2022
- Corner Menindee Road and Crystal Lane – no date given
- Oxide Street - no date given
- Finn Street – September 2016, September 2020, January 2021, March 2022, October 2022
- Gaffney Street – January 2010, March 2022, October 2022
- Blende Street - March 2022, October 2022
- Duff Street – January 2021 (note that this was the only response from South Broken Hill)

Five of the respondents reported flooding in their yard, with four respondents having the floodwater enter their shed or garage. Four respondents had above floor flooding occurring within their residence. Two respondents reported witnessing flooding in commercial areas. Four respondents indicated drainage issues due to blocked drainage. Five of the respondents provided photo and/or video evidence, with an example presented in Figure 3-1.

Follow-up contact was made with the respondents to confirm details provided and seek additional anecdotal flood data if available. Several respondents detailed the experience with recent flooding that occurred on 7 January 2024.

Further detail of the historical flooding observations from the community is discussed in Section 4.

3.3 Community Information Session

A Community Information Session was hosted at the Council Chambers on 25 October 2023. The session included representation from:

- Torrent Consulting
- Council's Infrastructure and Environment Team (including flood study project coordinators)
- NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW)
- Community members

Torrent Consulting delivered a presentation to inform those attending of the scope and timeline of the flood study, general study approach and expected outcomes. DCCEEW representatives gave an overview of the NSW Floodplain Management Program and DCCEEW role.

Community members in attendance were invited to share their experience of flooding in Broken Hill. Two of the attendees provided photo and video evidence of past flood events as follows:

- Wills Street – March 2022
- Beryl Lane – March 2022
- Galena Street – October 2022

Examples of the photo evidence is presented in Figure 3-1 and Figure 3-2.

Figure 3-1 - March 2022 event at Chloride Street showing flood mark on gate

Figure 3-2 - March 2022 event at Wills Street showing flooding in rear of property

4 Historical Event Calibration Data

4.1 Historical Events

Identification of historical events was made possible through community consultation, social and news media, and available rainfall data. There are accounts of historical events dating as far back as 1910 in old newspaper reports, however, prior to 1991, the rainfall data was reported daily, and so has little value for model calibration given the flood events in Broken Hill have a typical duration of hours, not days.

The following dates have been identified as significant recent rainfall and flooding events that have are covered by the pluviograph records, with the March 2022 event identified as the most significant recorded event:

- 13 February 2010
- 20 September 2016
- 19 September 2020
- 2 January 2021
- 15 March 2022
- 12 – 13 October 2022
- 7 January 2024

4.2 Recorded Rainfall

The key model driver for the calibration events is the observed rainfall distributions. These can vary both spatially and temporally across the catchment. Historical rainfall data is available for the BoM rain gauge at Broken Hill Airport for each of the events noted above, including the most recent event on 7 January 2024. An example hyetograph for the March 2022 event is shown in Figure 4-1.

Community sourced rainfall data for 10 gauges within the Broken Hill area is available via https://www.wunderground.com/wundermap. Whilst this data is unverified, it can add value to the model calibration process in providing information on spatial and temporal distribution of rainfall across the catchment area.

Figure 4-2 presents a comparison of a single community gauge record with the Broken Hill Airport data showing a general correlation of the timing of the rainfall event. It is notable the community gauge has captured an extended period of rainfall in the initial burst that was not recorded at the airport gauge.

Similar comparison of recorded hyetographs across the catchment can be made for each model calibration/validation event to define the input rainfall distribution for the model simulations. Rainfall amount and timing is likely the main source of potential deviation between observed and modelled flood conditions.

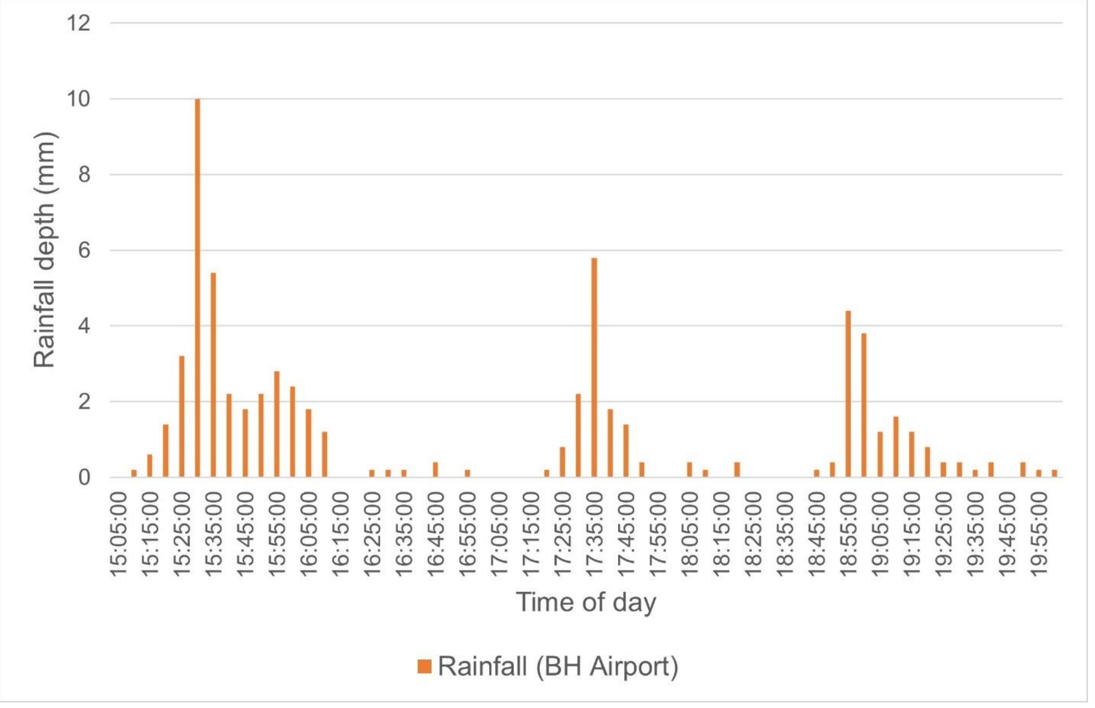


Figure 4-1 - Rainfall hyetograph of March 2022 event

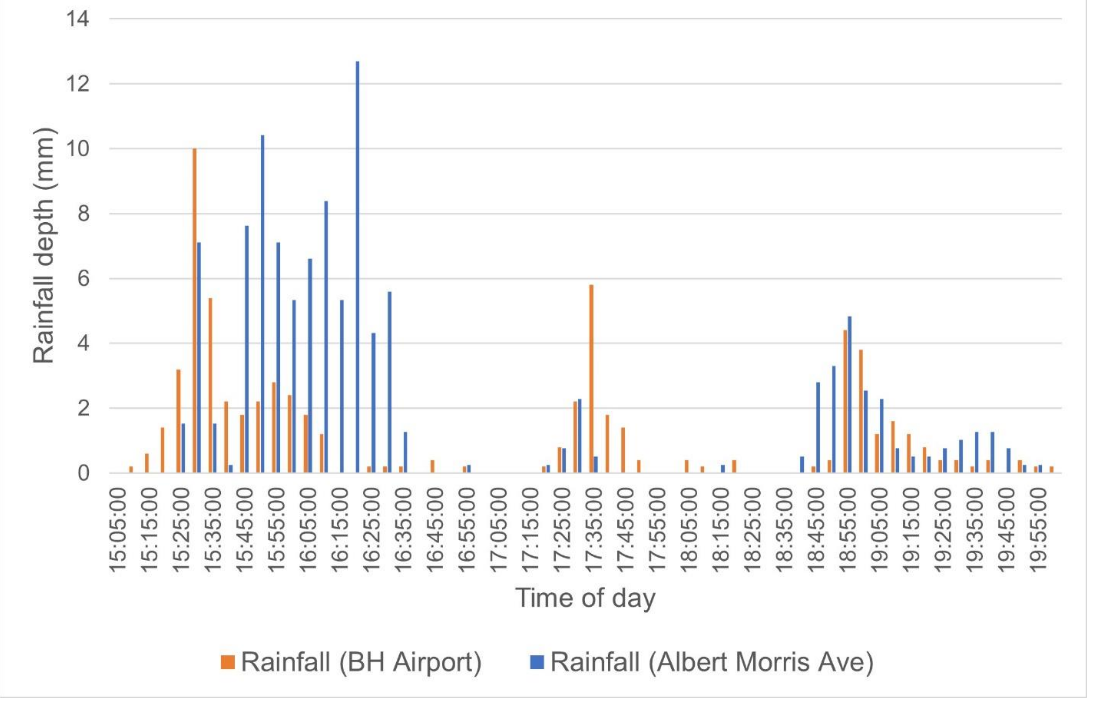
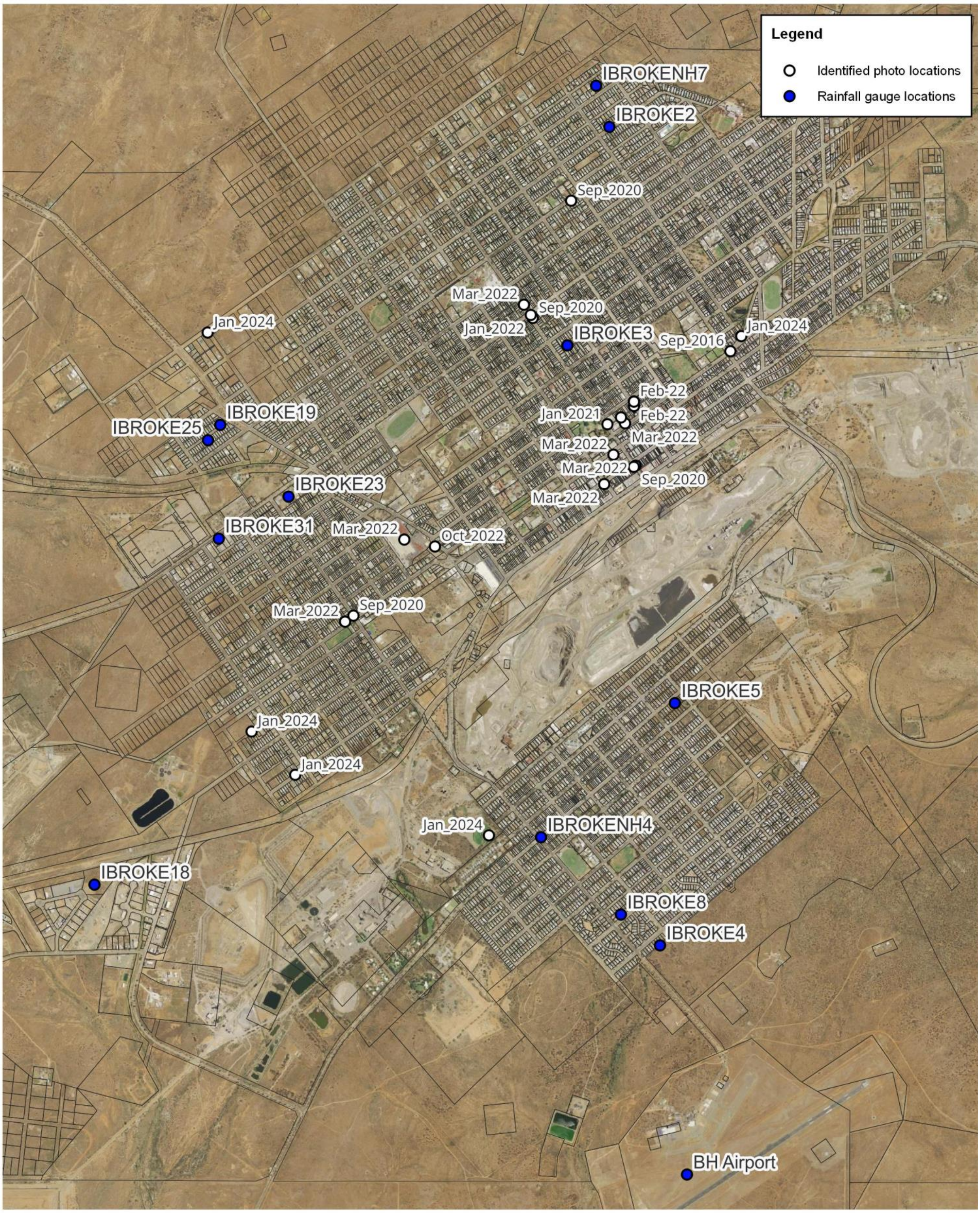


Figure 4-2 – Comparison of rainfall gauge data for the March 2022 event

4.3 Flood Level Observations

The photo and video evidence sourced from community consultation, and online news and social media is the principal source of flood level data for the model calibration. The distribution of the flooding observations across the study area is shown in Figure 4-3 with the relevant event noted. Also shown for reference are the location of the Broken Hill Airport and community rainfall gauges.

There is a concentration of available flood images close to the Town Centre, with scattered data outside of this area. The majority of the flood level observations correspond to the September 2020 and March 2022 events which appear to be the most significant events in recent years.



Title:

Community Sourced Data

0 0.9 1.8 km

approx. scale

Figure: **4-3**

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5 Model Development

5.1 Modelling Approach

The flooding mechanism in the Broken Hill catchments is largely urban overland flow subject to typical short duration flash flooding, with relatively high-density urban development, limited stormwater infrastructure and large road network flood conveyance.

Flood modelling has traditionally consisted of hydrological models to determine catchment runoff at critical locations, with this information input to a hydraulic model to determine flood behaviour within a specified study area. This modelling approach typically uses lumped models to efficiently compute catchment runoff, and effectively limited the hydraulic model area, which can be computationally time restrictive. Recent advancements in computer efficiency and affordability means that full catchment models can simulated using a rain-on-grid method within realistic timeframes previously not achievable.

Add to this the rich data sets now available for topography, soils, land use, rainfall, and infrastructure, full 2D catchment models can be built to simulate catchment flood conditions to a resolution that has many advantages for complex flooding environments.

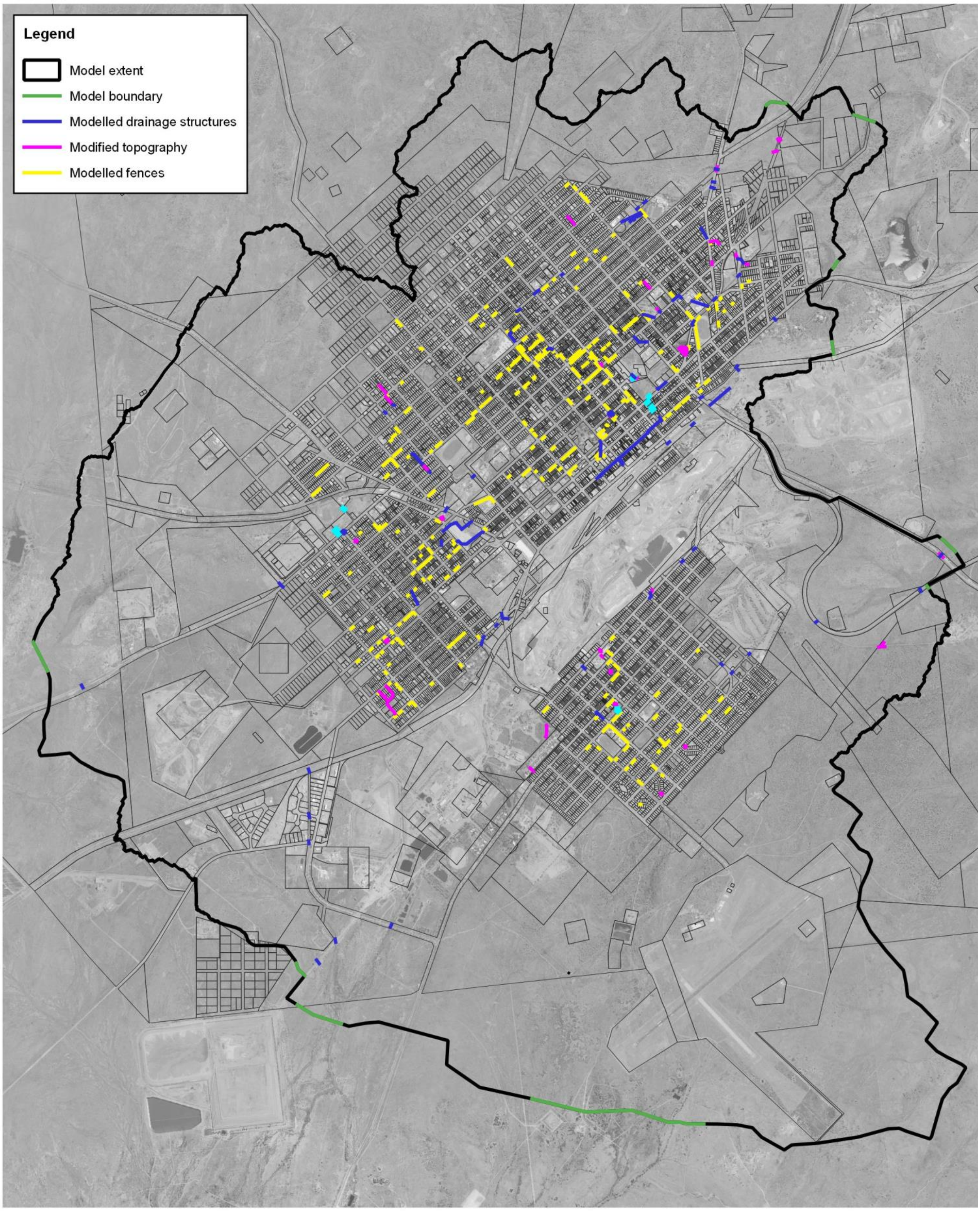
Given the complexity of the urban flooding environment of Broken Hill, a 2D modelling approach is warranted to understand the potential flood conditions within overland flooding areas. The TUFLOW software is well-suited to simulate the dynamic interaction of in-bank flows in open channels, major underground drainage systems, and overland flows through complex overland flowpaths using a linked 1D-2D flood modelling approach.

The direct rainfall (rain-on-grid) approach to simulate the rainfall-runoff process has been adopted which replaces the need for a separate hydrological model. The principal advantage of the direct rainfall approach for the current study is the ability to automatically determine local overland flowpaths. The flooding environment in Broken Hill is characterised by a complex network of overland flow paths, often concentrated in the road network which bifurcates at the many road intersections. Accordingly, the direct rainfall approach enables the accurate simulation of the flow distribution utilising the underlying topography without the need for a pre-determined subcatchments delineation.

5.2 Model Extent and Topography

The model extent covers the urban drainage catchments of Broken Hill draining to the ephemeral watercourses at the City outskirts. The extent of the TUFLOW model, as presented in Figure 5-1, ensured that flooding was assessed in all urban areas of Broken Hill, with several small unnamed sub-catchments around the periphery of town included in the model area.

The model utilises the NSW Spatial Services LiDAR data product, downloaded via the ELVIS Foundation Spatial Data portal to define the local topography. The model was constructed using a 2 m horizontal grid cell resolution, with the sub-grid sampling (SGS) routine enabled to define model elevations from a 1 m resolution LiDAR Digital Elevation Model (DEM), which is a suitable resolution for capturing urban overland flow paths and road formations.



Title:

TUFLOW Model

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Figure: **5-1**

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The LiDAR data was compared with Council survey data at several locations across Broken Hill, with the LiDAR levels considered a good representation of the existing ground surface. The nature of LiDAR survey presents the potential for 'noise' or 'speckling' within the surveyed data, whereby the returned data can fluctuate between high and low margins of error. A multi-directional Lee filter was applied to the topography to smooth the DEM surface. The local statistic Lee filter is one of the most popular and best-known despeckling techniques in radar image processing.

Topographic controls, such as gutters and ridges were reinforced along major flow paths to ensure channel conveyance was accurately represented. Structures such as fences and buildings were reinforced in critical areas to ensure flow path obstructions were represented in the model.

5.3 Drainage Infrastructure

Part of the local pit and pipe drainage network was provided by Council, with additional drainage infrastructure identified by interrogating major flow paths via online mapping. Most of these structures were then located and measured during a site visit to Broken Hill, including structure dimensions and cover depths. This data was incorporated into the model as a 1D element, dynamically linked to the 2D domain. Several identified bridges were represented as 2D Layered Flow Constrictions to allow the modelling of piers, bridge decks, and safety fencing.

The distribution of the modelled drainage network across model domain is shown in Figure 5-1.

5.3.1 Blockage Assumptions

Australian Rainfall and Runoff 2019 (ARR2019) recommends applying blockage to hydraulic structures and outlines a methodology to determine inlet blockage factors by considering debris availability, debris mobility, debris transportability and waterway opening of the structure.

The ARR2019 guideline provides an assessment procedure for estimation of the design blockage condition. The guideline considers the characteristics of the debris source area to assess potential for debris blockage at the structure. The following classifications have been adopted:

- Debris availability – high – channel flows through dense urban area
- Debris mobility – medium – main debris source close to channel
- Debris transportability – medium – deep and wide channel relative to debris dimension

Adopting the above classifications provides for a HMM combination, yielding a MEDIUM 1% AEP Debris Potential at the structure. The L10 value is defined as the average length of the longest 10% of the debris reaching the site. ARR2019 notes that in an urban area the variety of available debris can be considerable with an equal variability in L10. In the absence of a record of past debris accumulated at the structure, an L10 of at least 1.5 m should be considered as many urban debris sources produce material of at least this length such as palings, stored timber, sulo bins and shopping trolleys.

In conjunction with the quantity of debris likely to arrive at the culvert site, Table 5-1 provides an estimate of the 'most likely' inlet blockage level based on the culvert size. Smaller structures are noted as those with a diameter or width less than 1.5 m (the assumed L10), with larger structures with a diameter or width greater than or equal to 1.5 m.

Table 5-1 Blockage Factor Assessment

Design Flood	Small Structures	Large Structures
More frequent than 5% AEP	25%	10%
Between 5% and 0.5% AEP	50%	20%
Less frequent than 0.5% AEP	100%	20%

A simplified approach applying a single blockage factor across the range of design events was considered appropriate for the study. The adopted blockage factors for the culverts and bridge structures are summarised in Table 5-2.

Table 5-2 Adopted Blockage Factor

Land Use	Manning's 'n'
Small culverts (Dia/Width < 1.5m)	50%
Large culverts (Dia/width≥1.5m)	20%
Bridge	5%

5.4 Hydraulic Roughness

Land use coverage in the catchment was separated into cleared or maintained, vegetated, commercial/hardstand, residential, and road reserve areas using aerial imagery, with the cleared and residential areas then assigned a Manning's 'n' roughness within the model of 0.04, the vegetated areas a roughness of 0.06, and the commercial/hardstand and road reserve areas assigned a roughness value of 0.02.

Aside from some large solid commercial buildings, floor levels were not represented in the model as topographical modifications. It is assumed that floodwater will either enter the sub-floor area of buildings with raised floor construction or enter the building itself for slab-on-ground construction.

As such, buildings areas were represented with a high Manning's value to account for the building obstruction to flow without removing the potential for flood storage within building footprints, such as in the sub-floor area. However, the combination of the rain-on-grid approach with high Manning's values in building areas results the perched storage of rainfall that would otherwise drain from roof areas quite rapidly, and so a depth varied Manning's roughness was applied to buildings, with 0.02 applied to water depths less than 0.05 m to approximate the roof runoff at low depths, interpolating to a Manning's value of 2.0 at a depth of 0.1 m, representing the obstruction caused by the building when runoff is passing through the building footprint.

Modelling of buildings in this way results in the apparent inundation of building areas, however this does not indicate that flooding has occurred above the floor level of impacted buildings.

A depth varied Manning's roughness was applied to the cleared and residential areas to better represent the influence of the surface roughness under shallow flow conditions, with a roughness of 0.46 applied to water depths less than 0.01 m, interpolating to a roughness of 0.04 at a depth of 0.33 m.

A depth varied Manning's roughness was also applied to the vegetated areas to better represent the influence of the surface roughness under shallow flow conditions, with a roughness of 0.7 applied to water depths less than 0.02 m, interpolating to a roughness of 0.06 at a depth of 0.83 m.

The Manning's roughness values are summarised in Table 5-3 with the adopted land-use distribution shown in Figure 5-2

Table 5-3 Adopted Mannings 'n' values by land use

Land Use	Manning's 'n'
Cleared/maintained	0.04
Vegetated	0.06
Commercial/hardstand	0.02
Residential	0.04
Road reserve	0.02
Buildings	2.0

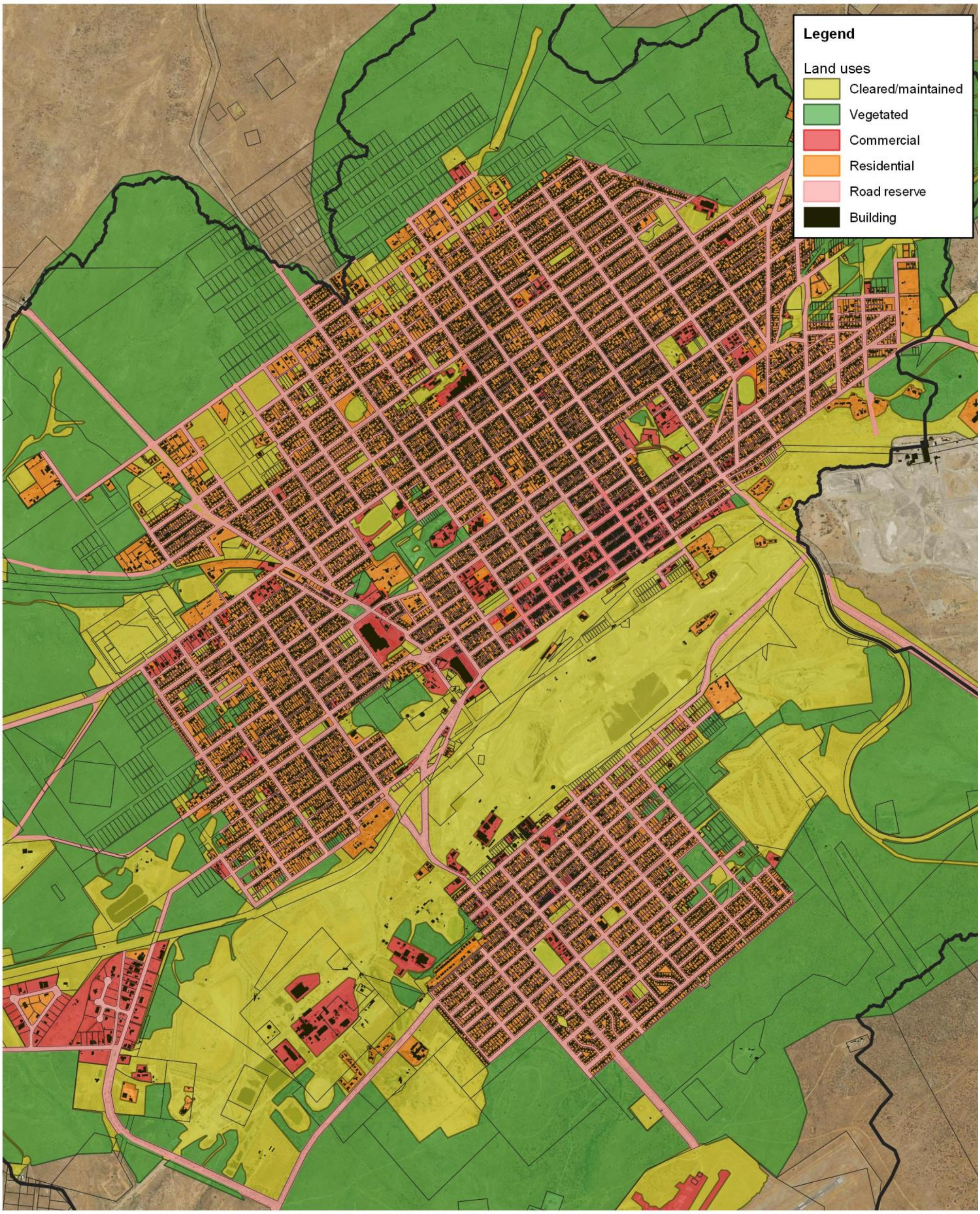
5.5 Rainfall and Losses

Catchment runoff is generated within the model by applying rainfall directly to the modelled area. The release of the Australian Rainfall and Runoff 2019 (ARR2019) guidelines provides updated procedures for design flood estimation. This includes updated intensity-frequency-duration (IFD) rainfall estimates and application of a suite of revised temporal patterns for establishing critical design flood conditions.

The design rainfall depths were sourced from the BoM IFD portal and are summarised in Table 5-4 for various design event magnitudes and storm durations.

Design rainfall was applied directly to the TUFLOW model DEM, generating catchment runoff. Due to the relatively small size of the contributing catchments, no Areal Reduction Factor (ARF) was applied.

The Probable Maximum Precipitation (PMP) for the simulation of the PMF event was derived using the Generalised Short Duration Method (BoM, 2003). The PMP rainfall depths varied from 170mm for the 15-minute duration up to 510mm for the 3-hour duration.



Title:

Modelled Land Uses

0 0.9 1.8 km

approx. scale

Figure: **5-2**

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Table 5-4 Design IFD Rainfall

Duration (mins)	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
10	15.1	18.8	24.1	28.7	33.9	41.1
15	18.7	23.2	29.8	35.5	41.9	50.7
20	21.2	26.3	33.8	40.2	47.5	47.5
25	23.2	28.7	36.9	43.9	51.7	57.4
30	24.7	30.7	39.4	46.9	55.1	62.5
45	28.2	34.9	44.8	53.3	62.6	66.6
60	30.7	38	48.7	57.9	68.0	75.6
90	34.4	42.5	54.5	64.7	76.0	82.0.
120	37.4	46.0	58.9	70.0	82.3	91.7
180	42.0	51.6	65.9	78.3	92.3	99.3

Rainfall losses were modelled using the Green-Ampt infiltration method, with a three-layer soil model comprising a 0.1 m deep topsoil, 0.2 m transition zone and a variable depth subsoil layer. The depth of the subsoil layer was derived from the September 2019 CSIRO gridded soil depth mapping dataset.

Soil types for each layer were derived from the September 2022 NSW DPE gridded soil properties mapping dataset, with classification based on the clay, silt, and sand content. The available water holding capacity for each soil type was based on the MEDLI guidelines. Initial Soil Moisture (ISM) was calculated from data sourced from the Australian Water Outlook website published by BoM. The standard Green-Ampt parameters for suction and hydraulic conductivity were adopted.

Impervious areas were applied to the different land uses, with cleared/maintained and vegetated areas nominated at 100% pervious, commercial/hardstand and buildings nominated at 100% impervious, residential nominated at 20% impervious, and road reserve nominated at 70% impervious (100% in commercial areas), with the Green-Ampt losses interpolated accordingly.

The nominated residential impervious area is lower than typical values, however, as all buildings are represented in the model, the 20% value represents the estimated impervious area of the remaining yard space.

6 Model Calibration

6.1 Selection of Calibration and Validation Events

Model calibration and validation requires suitable records of historical flood events, with data such as surveyed flood levels and stream gauge data used to calibrate model parameters. However, there are no stream gauges within Broken Hill and, due to the dynamic and short-duration nature of flooding within Broken Hill, there are no surveyed flood levels available. The principal source of historical flood data is the anecdotal photographic and video evidence recorded by community members at the time of the events.

Due to lack of accurate data a formal model calibration process to refine model parameters is not possible. Accordingly, the available data was used to validate the model performance to ensure simulation of historical events was consistent with the photographic and video evidence.

Seven significant events have been identified since detailed rainfall data became available at the Broken Hill Airport AWS as detailed in Section 4.1. Three events were chosen for validation due to the availability of photographic or video evidence and the relative magnitude of the events. The selected events include September 2020, March 2022, and January 2024 events, with community feedback indicating the March 2022 event was of particular significance.

Significant events in Broken Hill are characterised by short intense storm bursts that generate flash flooding. This type of storm event is dynamic, with often a high variability in spatial and temporal distribution of rainfall typical across catchments.

The availability of rainfall data from community operated gauges provides some indication of potential rainfall variability across the study area. However, it is noted there is no formal details of the gauge configuration, calibration and quality assurance for these community gauges. Accordingly, the adopted rainfall inputs for the validation event modelling uses only the Broken Hill Airport AWS data.

Further to the uncertainty in quality of community rainfall records, there is not sufficient flood data to support a detailed gauge weighting exercise in deriving rainfall distribution. Variation in rainfall inputs will not result in discernible differences to modelled flood conditions with comparison to the observations from the photographic and video record. Moreover, this would not influence any of the adopted model parameters or inform a robust calibration/validation process.

Notwithstanding, in reviewing model validation results for each event consideration is given to the community data and potential variation in rainfall across the modelled attachments and influence on simulated flood conditions.

A summary of the model validation for each of the adopted events is provided in the following sections. The analysis includes a review of the recorded rainfall data and comparison of observed and simulated flood conditions. Flood photographs are annotated with points of interest and is accompanied by a flood map output showing the modelled flood depth with the corresponding point of interest, the approximate location the photo was taken from, and the direction in which it was taken shown for context.

6.2 Observed and Simulated Conditions September 2020

Figure 6-1 shows a comparison of the recorded rainfall for the September 2020 event and the design IFD data for Broken Hill. The derived depth vs duration profile shows the event was at 10% AEP magnitude up to around a 15-minute duration, then generally tracking at a 20% AEP magnitude for durations longer than 30 minutes.

Figure 6-2 shows a comparison of the cumulative rainfall recorded at the Broken Hill Airport AWS gauge and community gauge locations for the September 2020 event. This event was characterised by a burst of intense rainfall, followed by around 2.5 hours of steady rainfall, as shown in Figure 6-3. There is a general consistency in the timing of the burst and continuing steady rainfall recorded at the gauge locations.

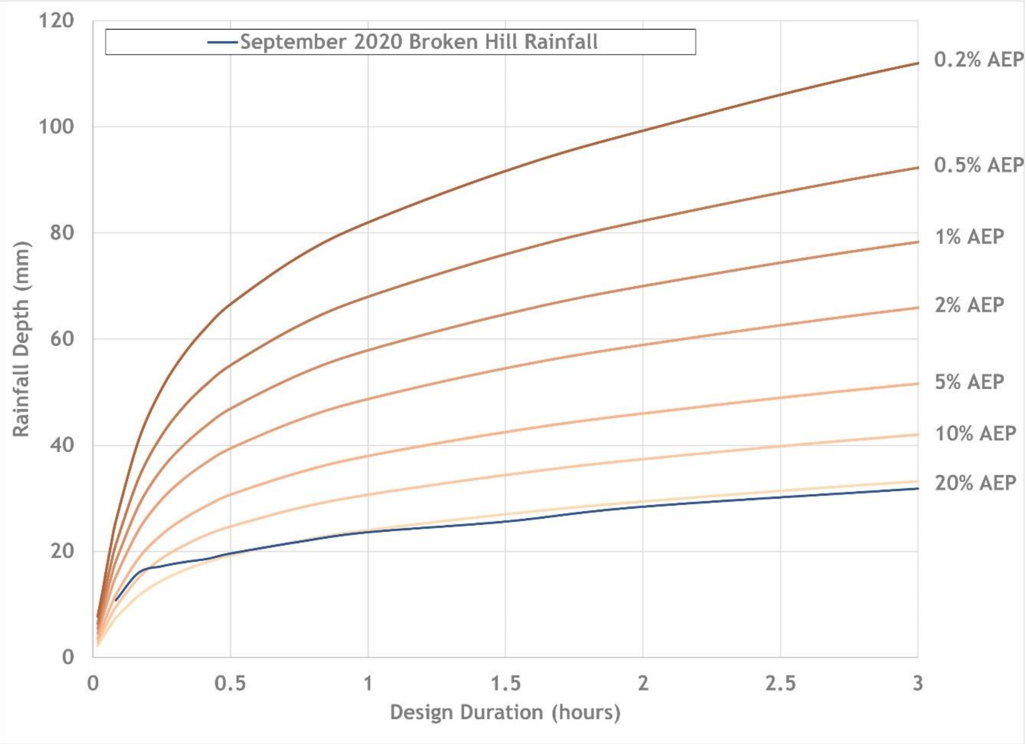


Figure 6-1 – IFD comparison of September 2020 event

The recorded rainfall at community gauge locations IBROKE2 and IBROKENH7 demonstrates the uncertainty in using the data to derive spatial and temporal rainfall distributions. These stations are in very close proximity (~300m apart) as shown in Figure 4-3. However, as shown in Figure 6-2 the adjacent stations provide for the lowest and highest rainfall for the event across the rain gauge network. Given these adjacent stations provide the greatest spread of rainfall across the data set, it demonstrates that any derived distributions for the model input will not be robust and provide no meaningful input into a model validation process. Accordingly, the single adoption of the Broken Hill Airport AWS data across the model area is considered appropriate to represent the validation events.

Table 6-1 provides a summary of the comparison between observed and simulated flood conditions for the September 2020 event, with Figure 6-4 to Figure 6-10 showing the flood photographs and corresponding simulated flood depth and inundation extent at the location.

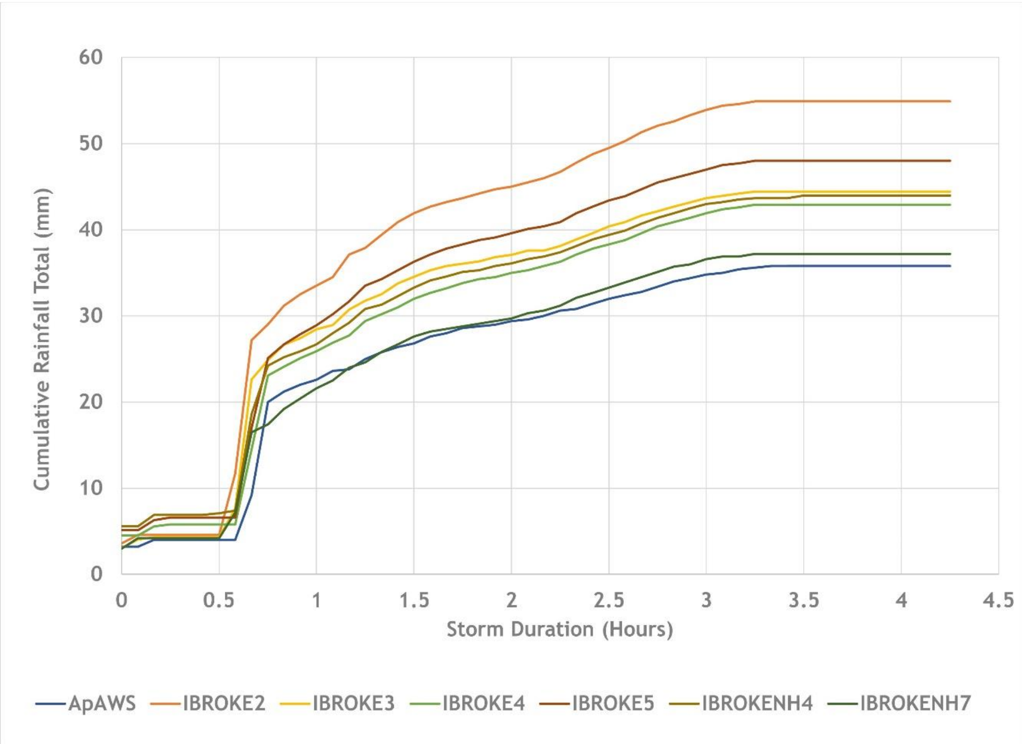


Figure 6-2 -September 2020 event cumulative rainfall across gauge network

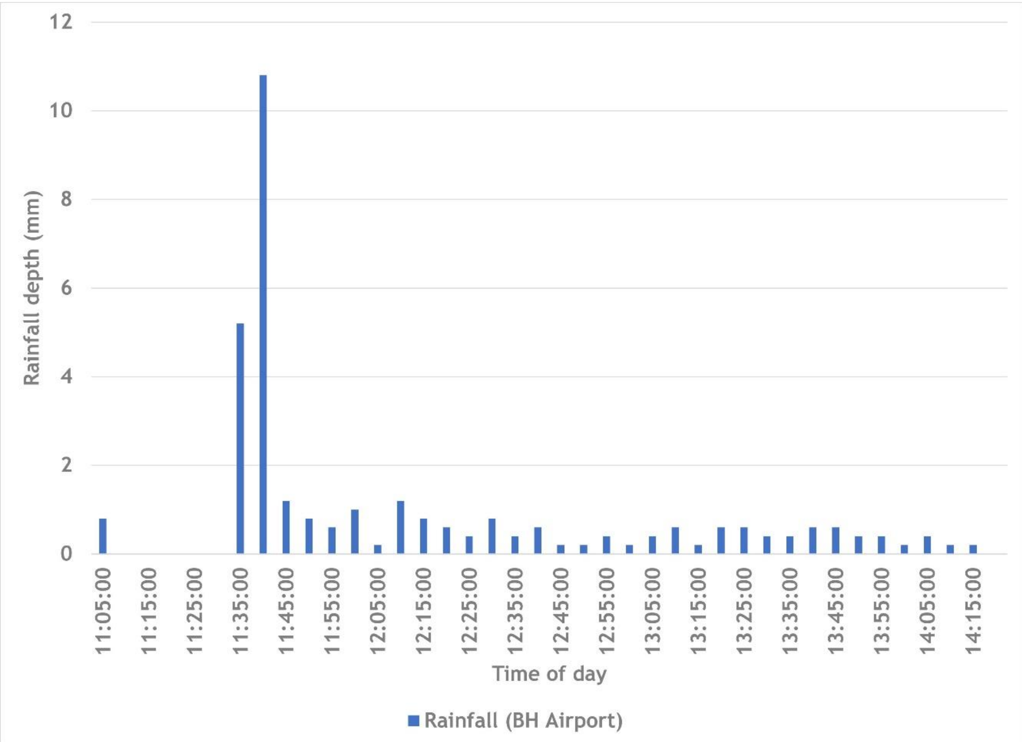
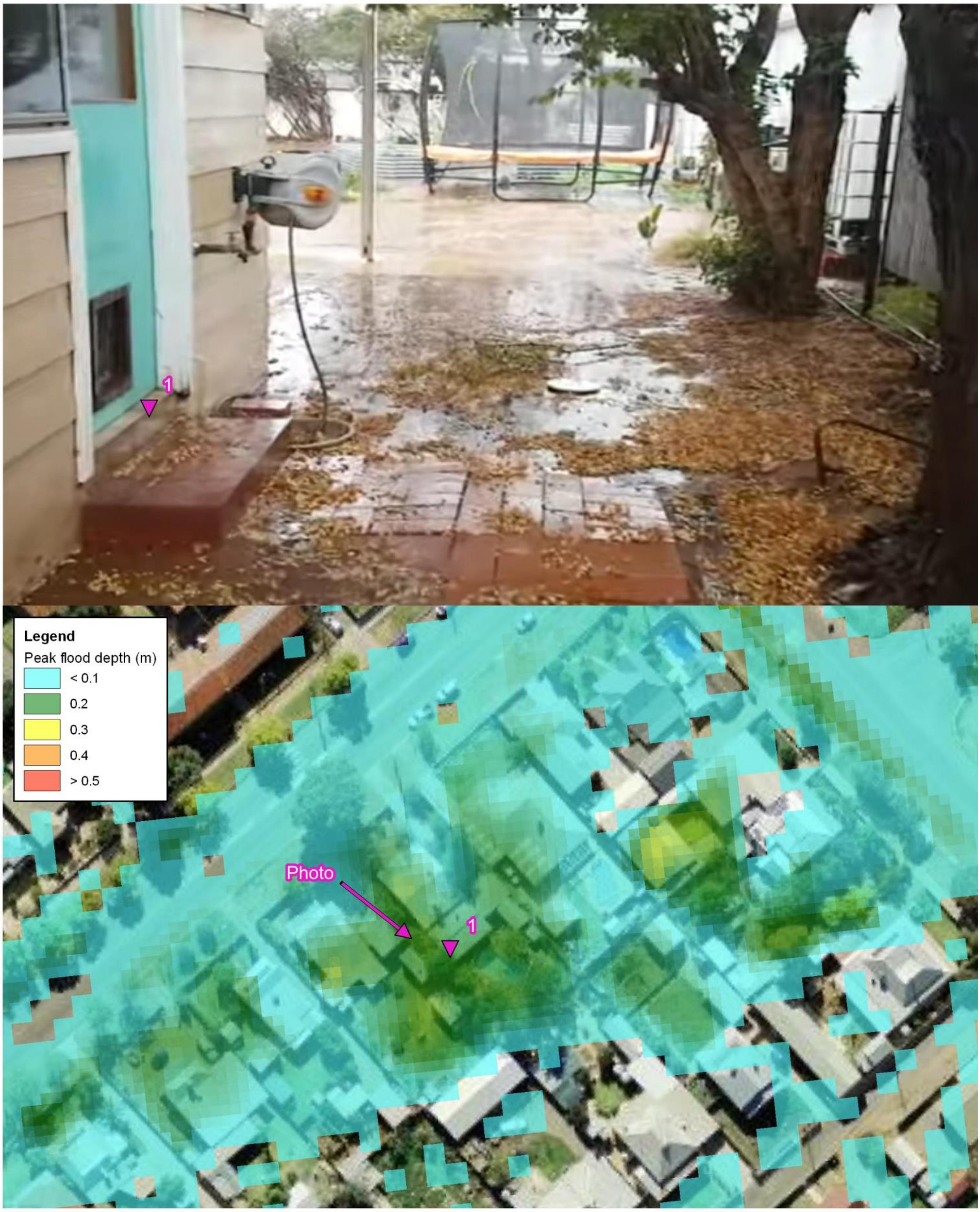


Figure 6-3 - Rainfall hyetograph of September 2020 event

Table 6-1 Model Validation September 2020

Location	Comments
Figure 6-4 - Observed and Simulated Flooding - Morgan Street	• Floodwater spills from Morgan Street into private lots. • Photo shows flooding at the rear of a property on Morgan Street as documented by the owner following the peak of the event. • Owner observed that the flood water came to within 1 to 2 cm of entering the rear room of dwelling (1), with the flood depth estimated at around 0.2 m. • The modelled peak flood depth at the rear door of the dwelling was around 0.2 m, which is consistent with the observed depth.
Figure 6-5 - Observed and Simulated Flooding - Chloride and Williams Street Intersection	• Fast moving floodwater makes a 90° turn from Chloride into Williams Street. • The photo shows the western (2) and southern (1) corners of the intersection experience only shallow depths as indicated by the visible kerb, with shallow depths also shown in the foreground. • Modelled flood depth mapping is consistent with observed depths. • The photo was extracted from footage that shows turbulent flows in the centre of the intersection, indicating a high velocity environment. • The apparent high velocities observed are consistent with model results, with velocities up to 1.9 m/s modelled across the intersection.
Figure 6-6 - Observed and Simulated Flooding - Broken Hill Fire Station	• A sag point on Blende Street fills due to incoming floodwater exceeding the capacity of piped drainage connecting Blende Street to an outlet on Beryl Street. • The peak level is controlled by the spilling of surface flows to the north along Chloride Street. • The photo shows the level of the water on the on the wall tiles at just over two tiles below the white sign. In combination with street view images, the depth of water here is estimated to be around 0.1 m. • The modelled peak flood depth at this location was around 0.1 m, which is consistent with the observed depth.
Figure 6-7 - Observed and Simulated Flooding – Gypsum and Wills Street Intersection	• Floodwater moving at moderate velocity makes 90° turn from Gypsum into Wills Street. • The photo shows that the eastern (1) and southern (2) corners of the intersection experience shallow depths as indicated by the visible kerb. • The vehicle in the foreground shows floodwater reaching to around the bottom of the cabin body, which is estimated to be a depth of around 0.3 m.

	• The modelled shallow flood depths at the kerb corners were consistent with the observed depths. • Modelled flood depths in the vicinity of the vehicle were around 0.25 to 0.3 m, which is consistent with the observed depth.
Figure 6-8 - Observed and Simulated Flooding – Westside Plaza	• A sag point near the main Galena Street entry to Westside Plaza fills due to incoming floodwater exceeding the capacity of piped drainage connecting Galena Street and the plaza carpark to a dedicated detention basin to the west of the plaza complex. • The peak level in Galena Street is controlled by the spilling of surface flows into the plaza carpark. • The photo shows a good match to the modelled flood extent across this area of Galena Street at locations 1, 2, and 4. • The depth at the car front tyre (3), which is approximately at the invert of the gutter, is estimated at around 0.4 m. • The modelled flood depth at the kerb invert in this area (3) is around 0.45 m, which is consistent with the observed depth.
Figure 6-9 - Observed and Simulated Flooding – Discount Tyres	• Another sag point to the south along Galena Street fills due to incoming floodwater exceeding the capacity of piped drainage connecting a table drain adjacent to Galena Street to an outlet on Graphite Street. • The peak level in Galena Street is controlled by the spilling of surface flows into the plaza carpark. • The photo shows a small gap below fencing at the northeast (2) and southeast (1) corners of the Discount Tyre building show that the water is very shallow here, which is consistent with modelled extent.
Figure 6-10 - Observed and Simulated Flooding – Oxide and Cobalt Street Intersection	• Floodwater from Beryl Lane collects behind the Oxide Street and Cobalt Street formation when the culvert capacity is exceeded, eventually spilling across the road in several locations. • The photo shows that the observed flood extent is significantly less than the modelled extent, however, the timing of the observation is unclear and likely not showing the peak extent for this event. • This observation and other events observed at this location indicate that some physical obstructions are not adequately represented, particularly in the CBD where solid buildings are more prevalent.



Title:

Observed and Simulated Flooding
Morgan Street

0 20 40 m

approx. scale

Figure: **6-4**

Revision: **A**

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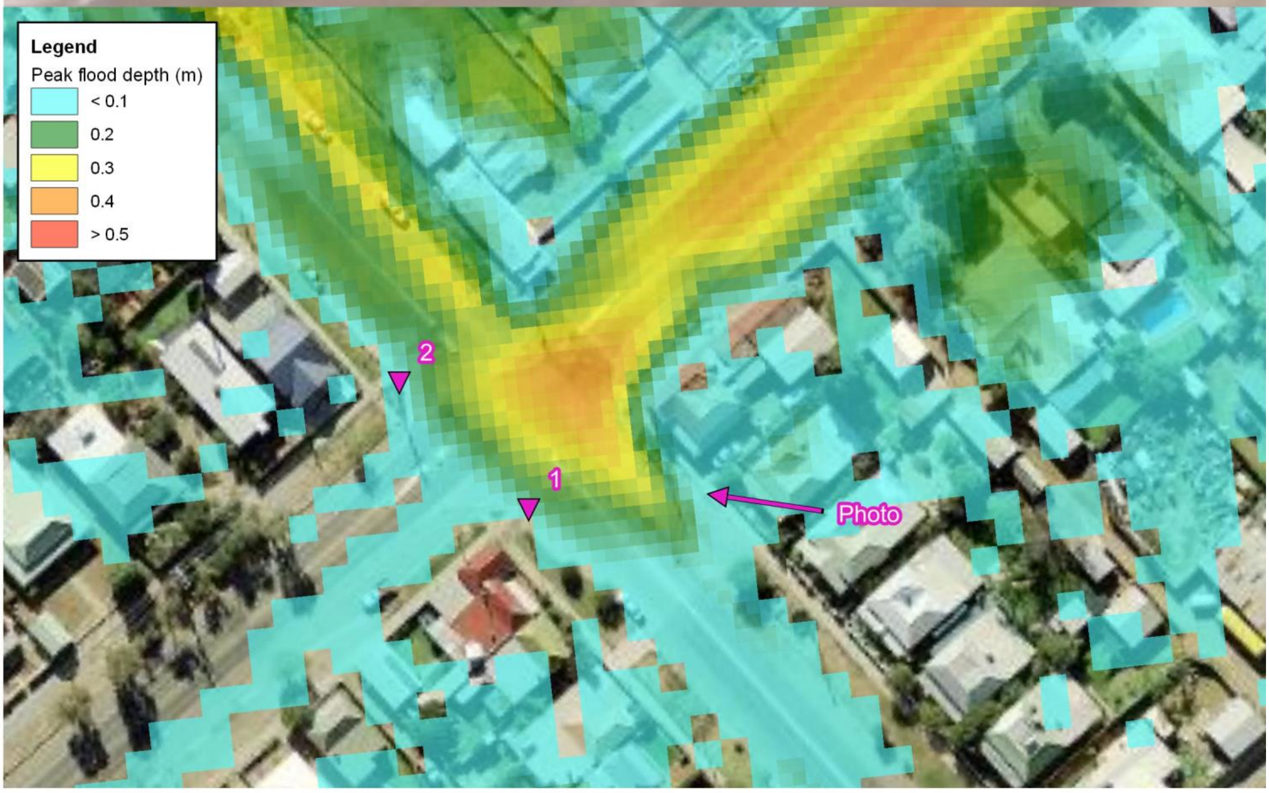
Filepath: Z:\Projects\T2422 Broken Hill\GIS\T2422 Figure 6-4 Validation morgan st.qgz



Title:

Observed and Simulated Flooding
Chloride and Williams Street Intersection

0 20 40 m
approx. scale

Figure:	6-5	*Information shown on this figure is compiled from numerous sources and may not be complete or accurate. Torrent Consulting cannot be held responsible for the misuse or misinterpretation of any information and offers no warranty guarentees or representations of any kind in connection to its accuracy or completeness. Torrent Consulting accepts no liability for any loss, damage or inconvenience caused as a result of reliance on the information.*
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Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-5_Validation_chloride_williams.qgz

Title:

Observed and Simulated Flooding
Broken Hill Fire Station

0 10 20 m
approx. scale

Figure:	6-6
Revision:	A

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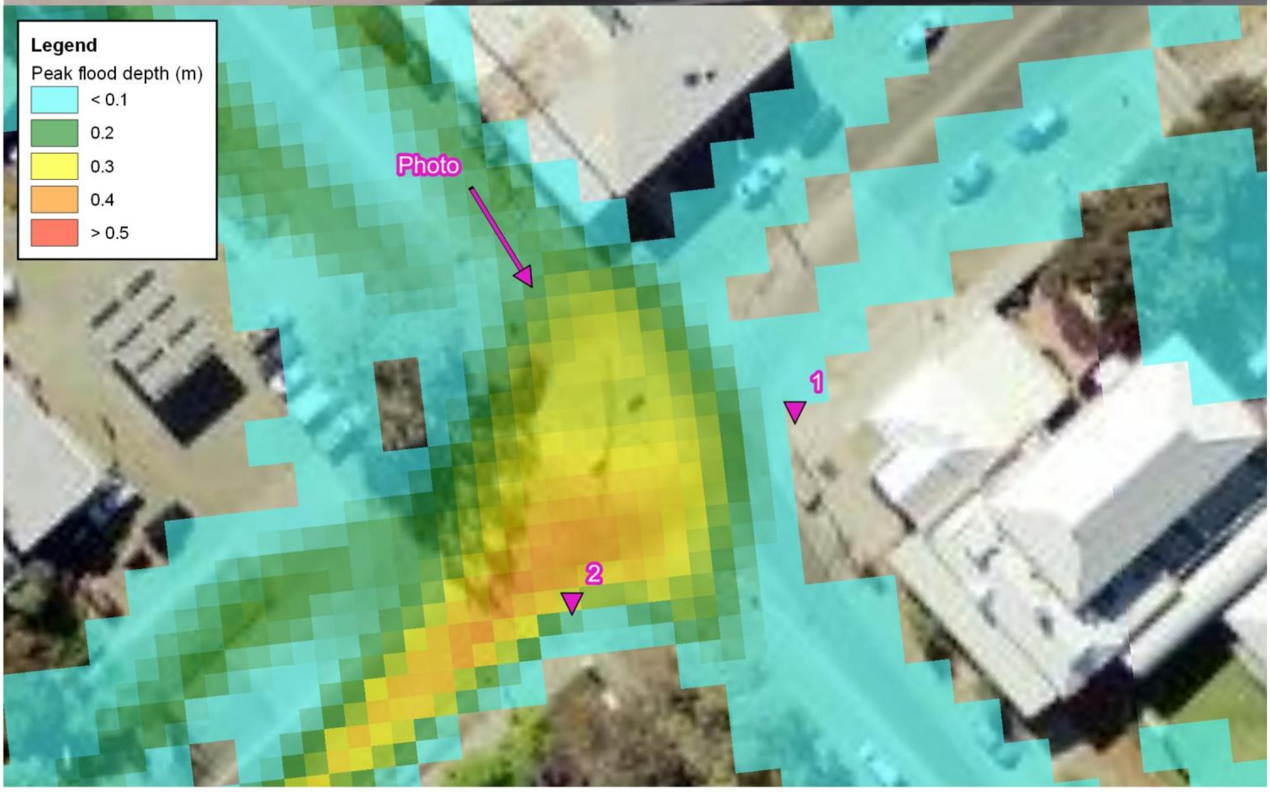
Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-6_Validation_fire_station.qgz



Title:
Observed and Simulated Flooding Gypsum and Wills Street Intersection

Figure: 6-7

Revision: A

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Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-7_Validation_Cnr_gypsum_wills.qgz

Title:

Observed and Simulated Flooding
Westside Plaza

0 30 60 m
approx. scale

Figure: **6-8**

Revision: **A**

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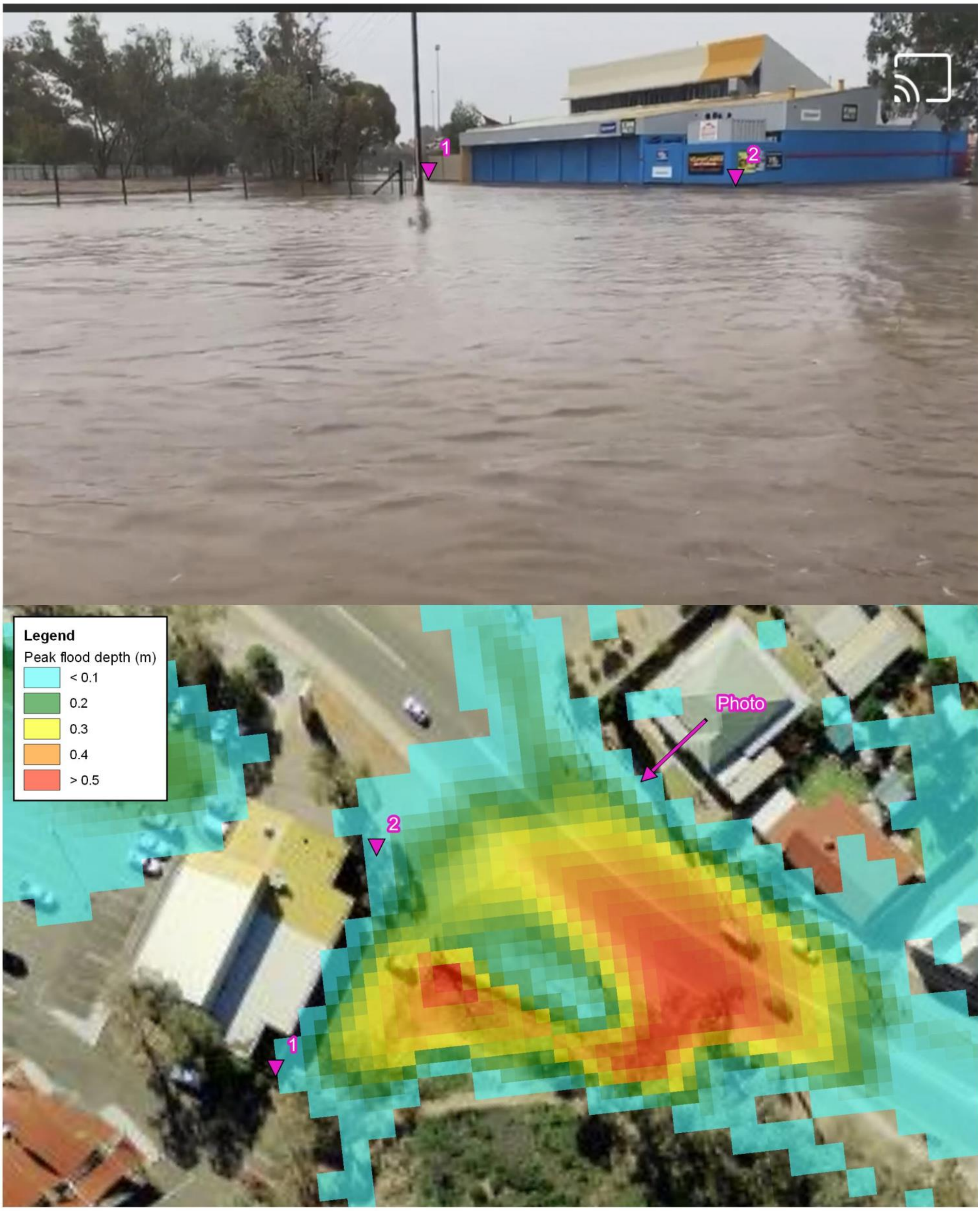
Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-8_Validation_plaza.qgz



Title:

Observed and Simulated Flooding
Discount Tyres

0 20 40 m
approx. scale

Figure: **6-9**

Revision: **A**

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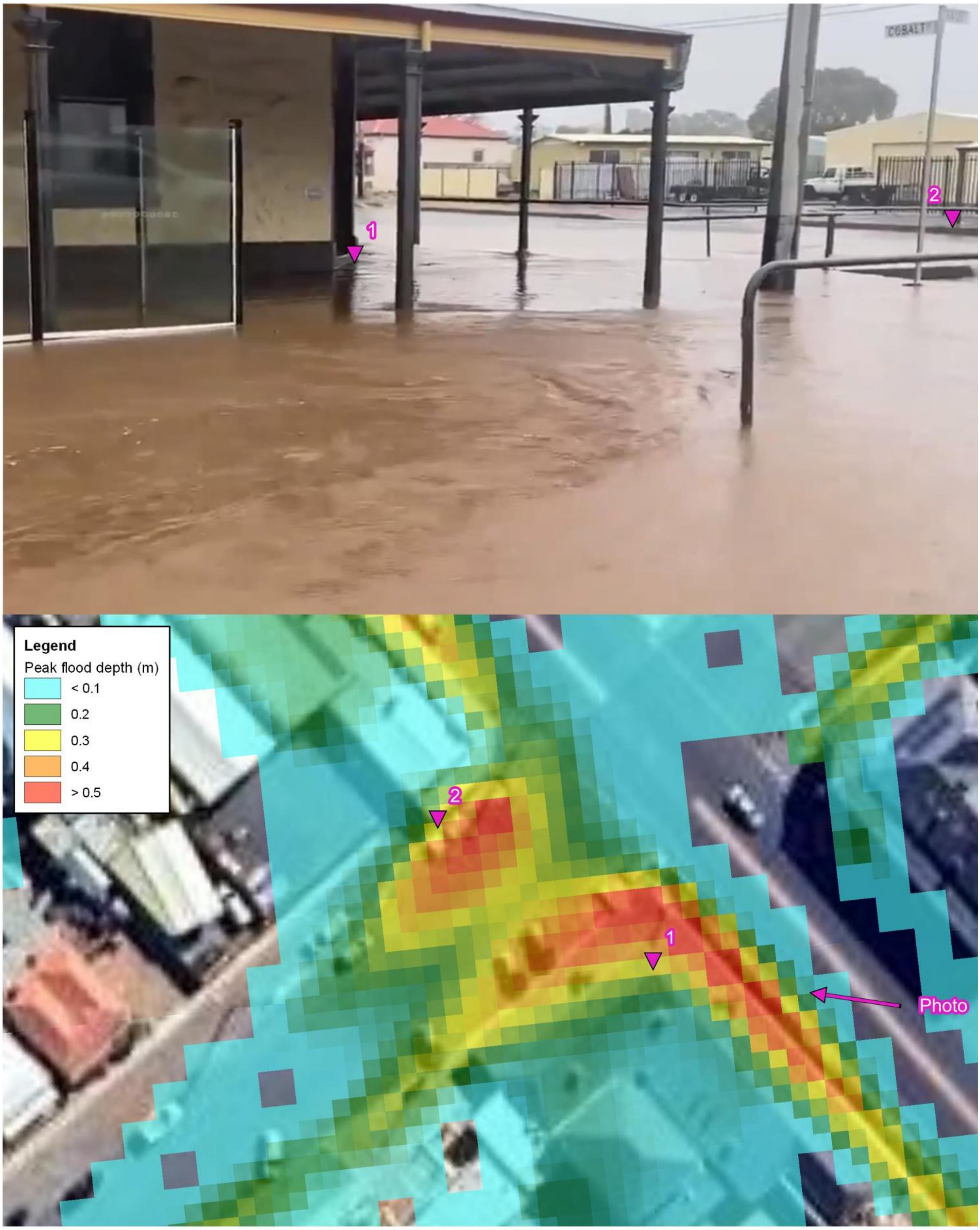
Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-9_Validation_tyre_shop.qgz



Title:

Observed and Simulated Flooding
Oxide and Cobalt Street Intersection

0 10 20 m

approx. scale

Figure: **6-10**

Revision: **A**

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6.3 Observed and Simulated Conditions March 2022

Figure 6-11 shows a comparison of the recorded rainfall for the March 2022 event and the design IFD data for Broken Hill. The derived depth vs duration profile shows the event generally tracking between a 10% and 5% AEP magnitude.

Figure 6-12 shows a comparison of the cumulative rainfall recorded at the Broken Hill Airport AWS gauge and other community gauge locations for the March 2022 event. This event was characterised by three separate periods of rainfall burst as shown in Figure 6-13. These are evident in the steps in the cumulative total rainfall profiles. There is a general consistency in the timing of the bursts recorded at the gauge locations.

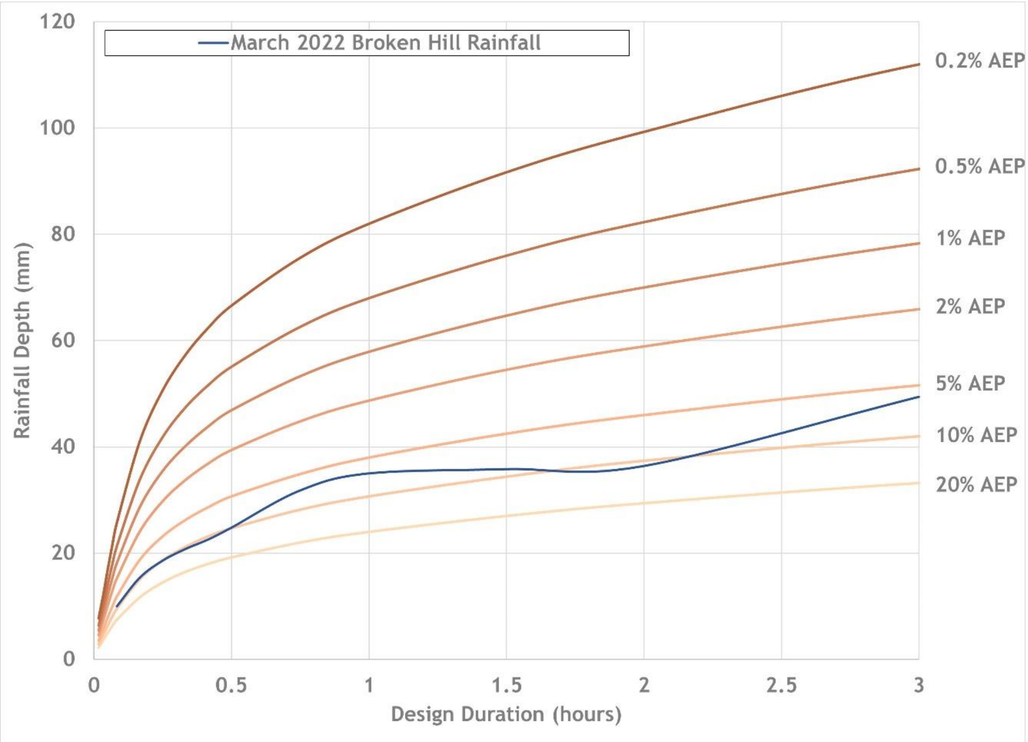


Figure 6-11 – IFD comparison of March 2022 event

Table 6-2 provides a summary of the comparison between observed and simulated flood conditions for the March 2022 event, with Figure 6-14 to Figure 6-21 showing the flood photographs and corresponding simulated flood depth and inundation extent at the location.

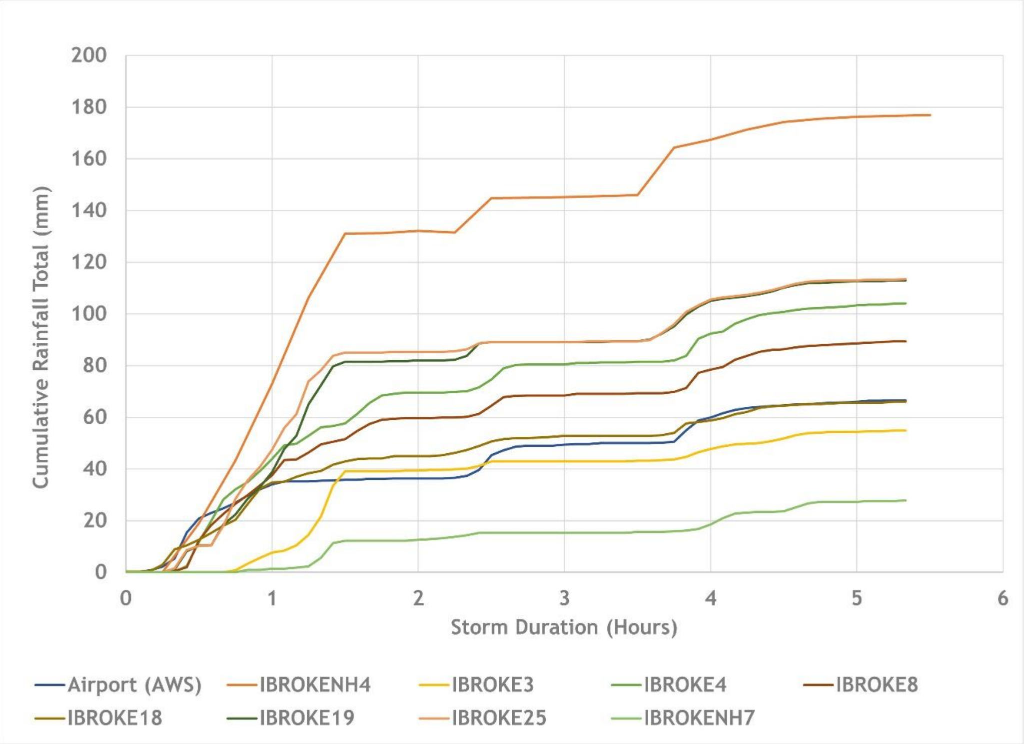


Figure 6-12 –March 2022 event cumulative rainfall across gauge network

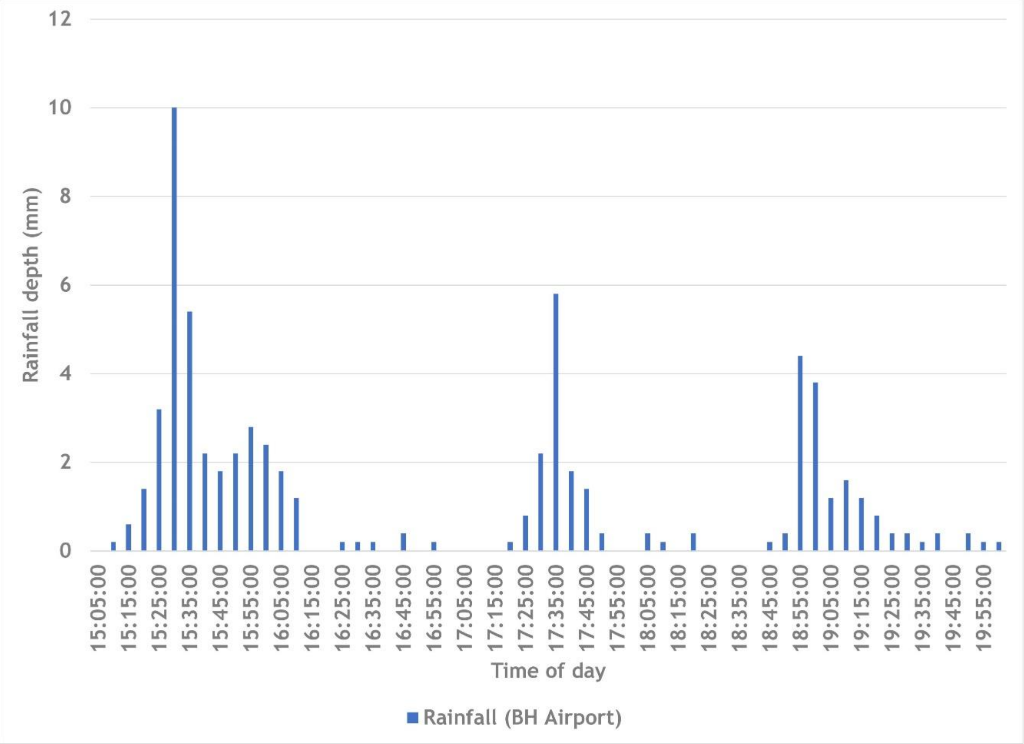
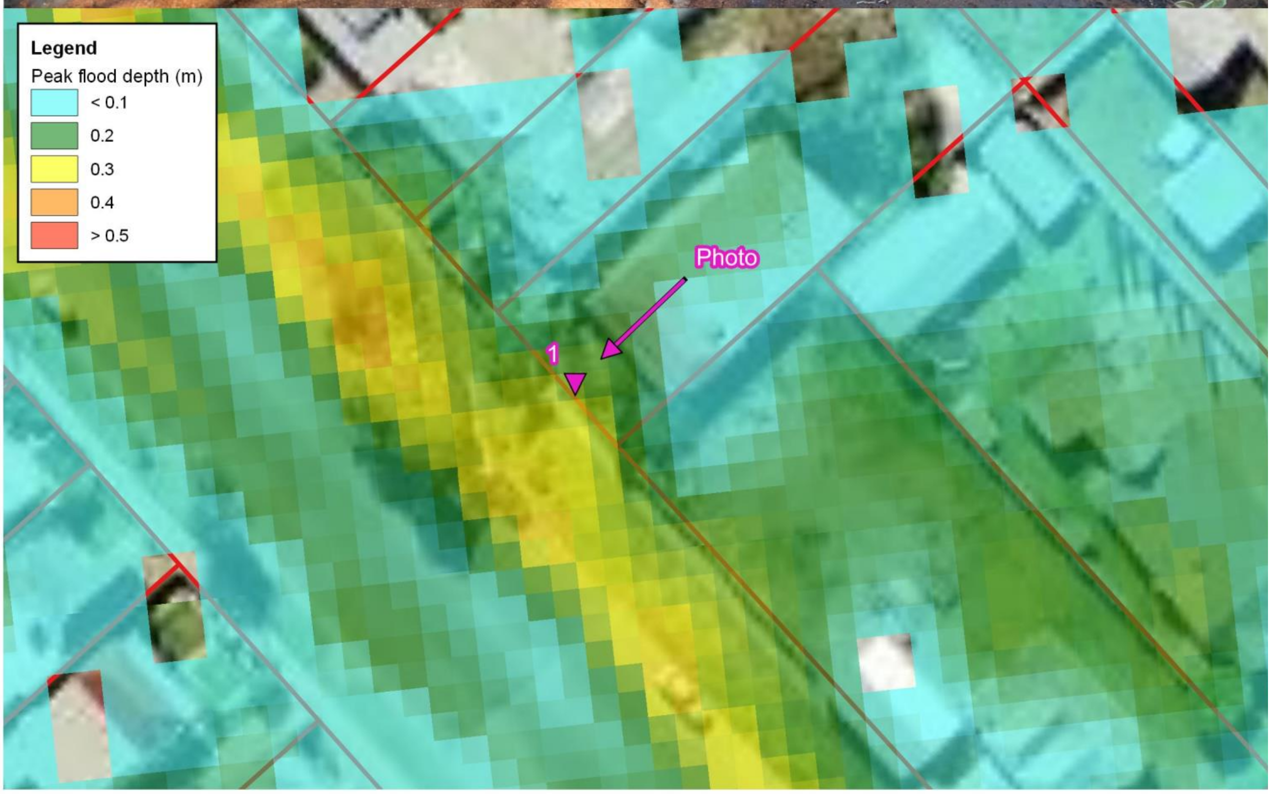


Figure 6-13 - Rainfall hyetograph of March 2022 event

Table 6-2 Model Validation March 2022

Location	Comments
Figure 6-14 - Observed and Simulated Flooding - Chloride Street	• Floodwater spills from Chloride Street into private lots. • The photo shows a debris line indicating the peak depth of flooding at the front of a property on Chloride Street as documented by the owner following the peak of the event. • The observed depth is estimated to be around 0.3 m, which is consistent with the modelled depth of around 0.25 m.
Figure 6-15 - Observed and Simulated Flooding – Beryl Lane	• Beryl Lane forms a major flow path during flood events. • The photo is a still taken from footage of the flooding in Beryl Lane and shows the peak level of the flood within the laneway. • The footage showed turbulent flow, indicative of a high velocity environment. • Still water observed behind the fence, as shown in the top right of the image, indicates that panel fences such as the sheet iron fences in Beryl Lane are acting to contain the high velocity within the main flow path, with non-convective flooding on the adjacent lot. • The estimated depth flooding at the location shown is around 0.4 m, which is consistent with a modelled depth of around 0.5 m. • Peak modelled velocities were around 1.5 m/s, which is consistent with the turbulent flow observed in the footage.
Figure 6-16 - Observed and Simulated Flooding – Beryl Lane and Oxide Street Intersection	• Floodwater discharging from Beryl Lane is directed sharply to the north-west by the Oxide Street formation, with some flows spilling to the northern side of the formation. • The modelled depth at the Give Way sign is around 0.1 m, which is consistent with the depth of around 0.15 m estimated from the photo.
Figure 6-17 - Observed and Simulated Flooding – Beryl Street	• The roundabout at the intersection of Beryl Street and Chloride Street, as well as the entrance to Beryl Lane, causes backwater to pond in Beryl Street on the southern side of the Toyota dealership. • The photo shows that the observed extent of the backwater corresponds with the edge of the brick garden bed, with very shallow depths shown across the front of the two garden beds. This is consistent with the modelled extent.
Figure 6-18 - Observed and Simulated Flooding – Blende Street	• The sag point on Blende Street fills due to incoming floodwater exceeding the capacity of piped drainage connecting Blende Street to an outlet on Beryl Street. • The peak level is controlled by the spilling of surface flows to the north along Chloride Street.

	• The photo shows the floodwater was observed to reach just below the second step (1), which is estimated to be a depth of around 0.3 m, which is consistent with the modelled depth of 0.25 m at this location.
Figure 6-19 - Observed and Simulated Flooding – Town Square	• Town Square is a recessed courtyard that drains via a grated inlet pit to the Argent Street drainage network. The area fills with floodwater when inflows from Crystal Lane exceed the capacity of the outlet. • The photo shows shallow inundation was observed at the edge of the recessed area (1), with shallow overflow to Argent Street at the northern corner of Town Square (2). • This is consistent with the modelled conditions.
Figure 6-20 - Observed and Simulated Flooding – Plaza Car Park	• Depressions within the Broken Hill Plaza carpark become flooded when piped drainage capacity is exceeded. • The photo shows an observed depth of flooding at about 0.1 m near one of the plaza entrances. • This is consistent with the modelled peak depth. • Flood free areas of the carpark can be seen in the background of the photo, which is consistent with the modelled extent.
Figure 6-21 - Observed and Simulated Flooding – Wills Street	• Shallow floodwater spilling from Gypsum Street inundates properties between Wills Lane and Wills Street. • The photo shows that backwater was observed within a property on Wills Street to a depth of around 0.1 m, as indicated on the wheel of the laundry trolley (1). • This is consistent with the peak depth of around 0.1 m modelled at this location.



Title:

Observed and Simulated Flooding Chloride Street

0 10 20 m

approx. scale

Figure: **6-14**

Revision: **A**

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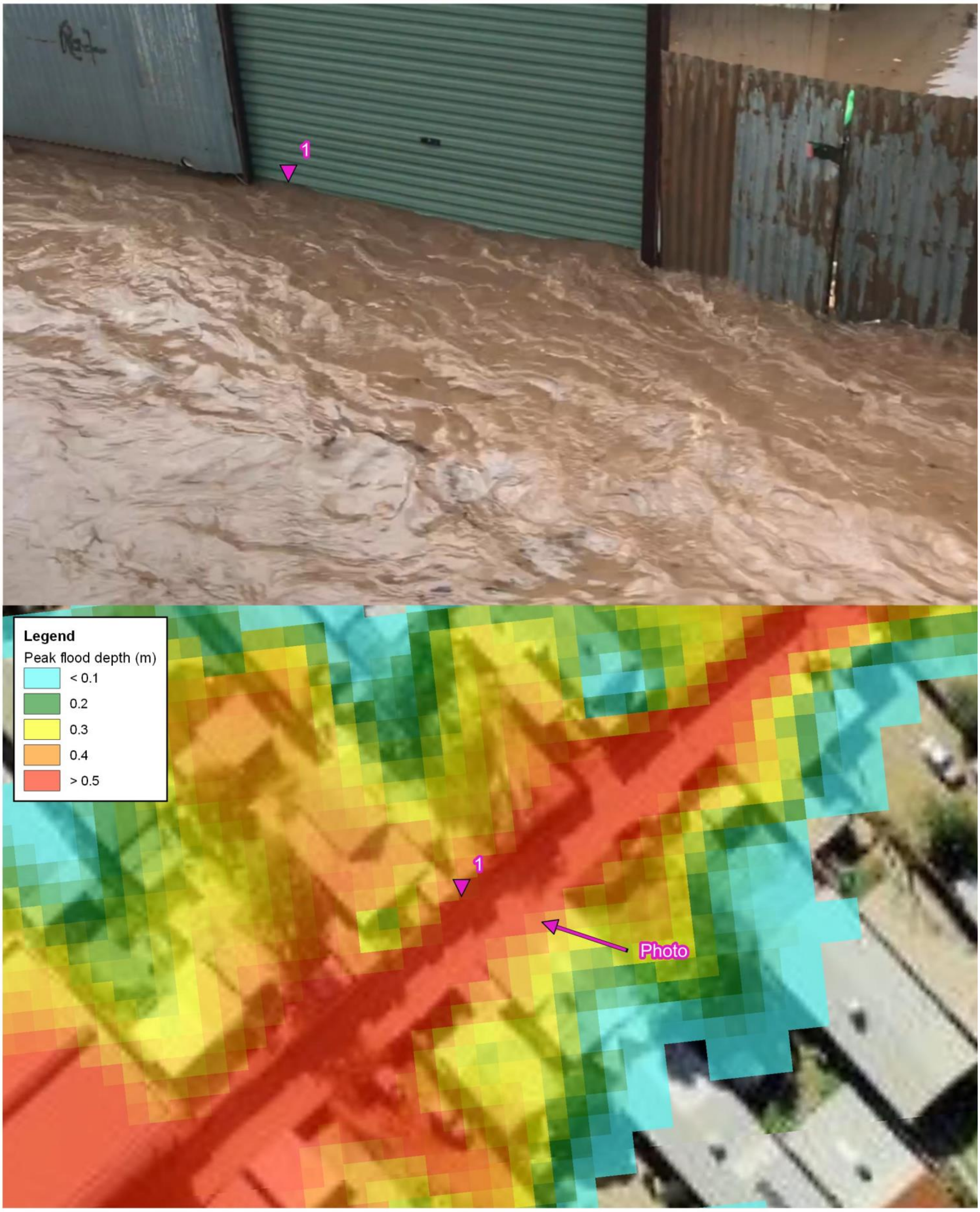

Title:

Observed and Simulated Flooding
Beryl Lane

0 10 20 m
approx. scale

Figure: **6-15**

Revision: **A**

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Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-15_Validation_beryl_lane.qgz

Title:

Observed and Simulated Flooding
Beryl Lane and Oxide Street Intersection

0 10 20 m

approx. scale

Figure: **6-16**

Revision: **A**

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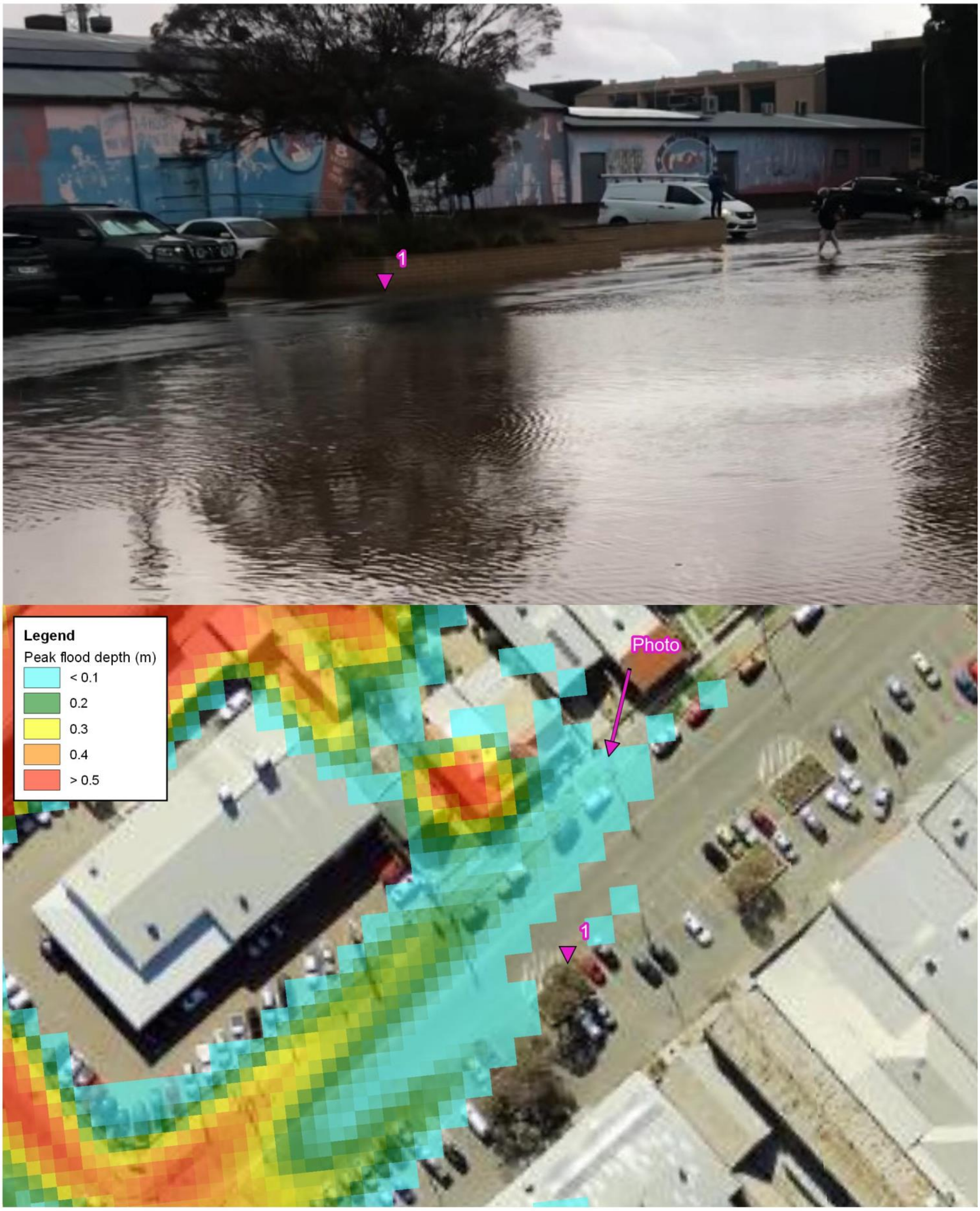
Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-16_Validation_beryl_lane_oxide.qgz



Title:

Observed and Simulated Flooding
Beryl Street

0 20 40 m
approx. scale

Figure: **6-17**

Revision: **A**

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Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-17_Validation_beryl_street.qgz

Title:

Observed and Simulated Flooding Blende Street

0 20 40 m

approx. scale

Figure: **6-18**

Revision: **A**

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Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-18_Validation_blende_street.qgz

Title:
Observed and Simulated Flooding
Town Square

0 10 20 m
approx. scale

Figure: **6-19**

Revision: **A**

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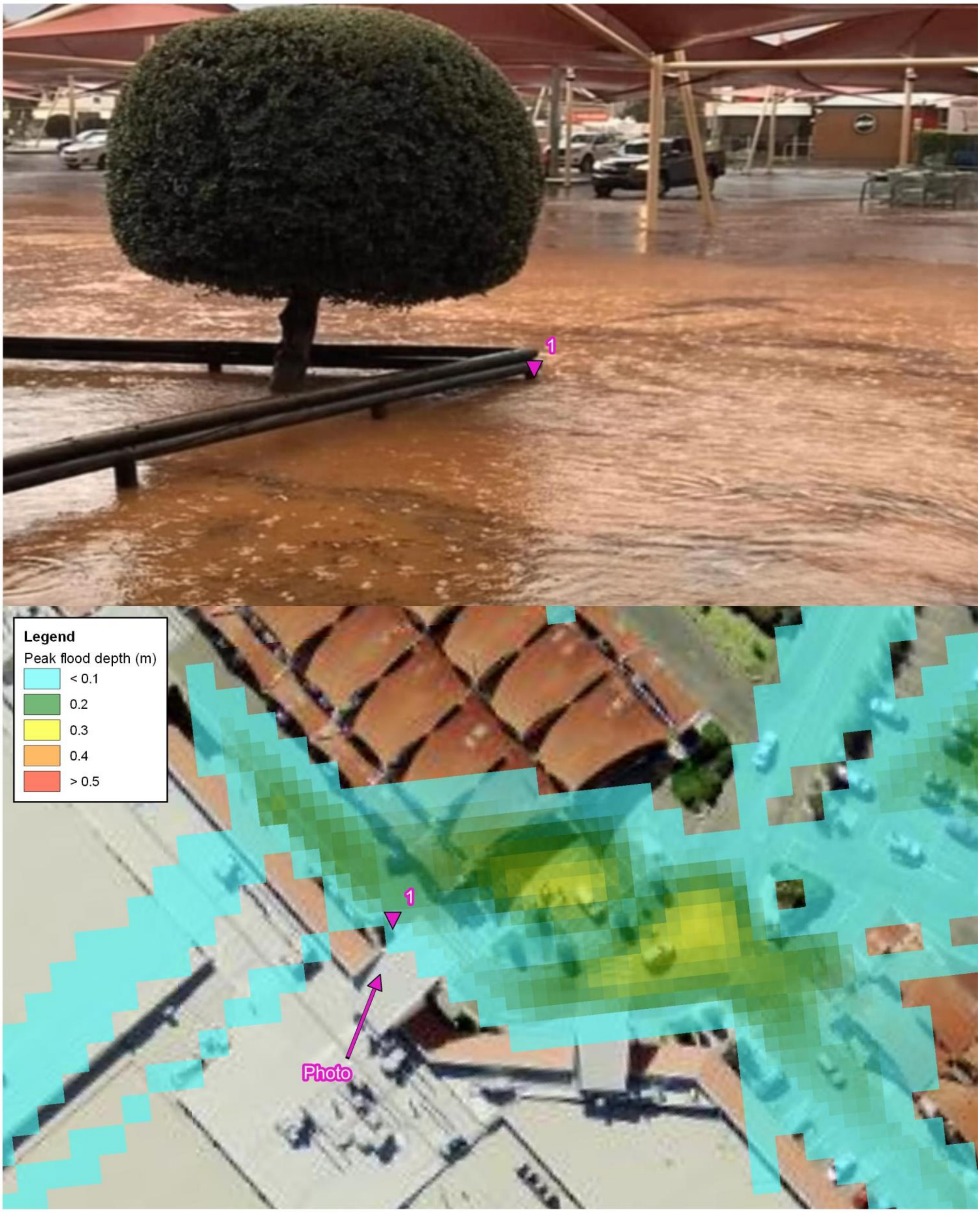
Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-19_Validation_town_square.qgz



Title:

Observed and Simulated Flooding
Plaza Car Park

0 20 40 m
approx. scale

Figure: **6-20**

Revision: **A**

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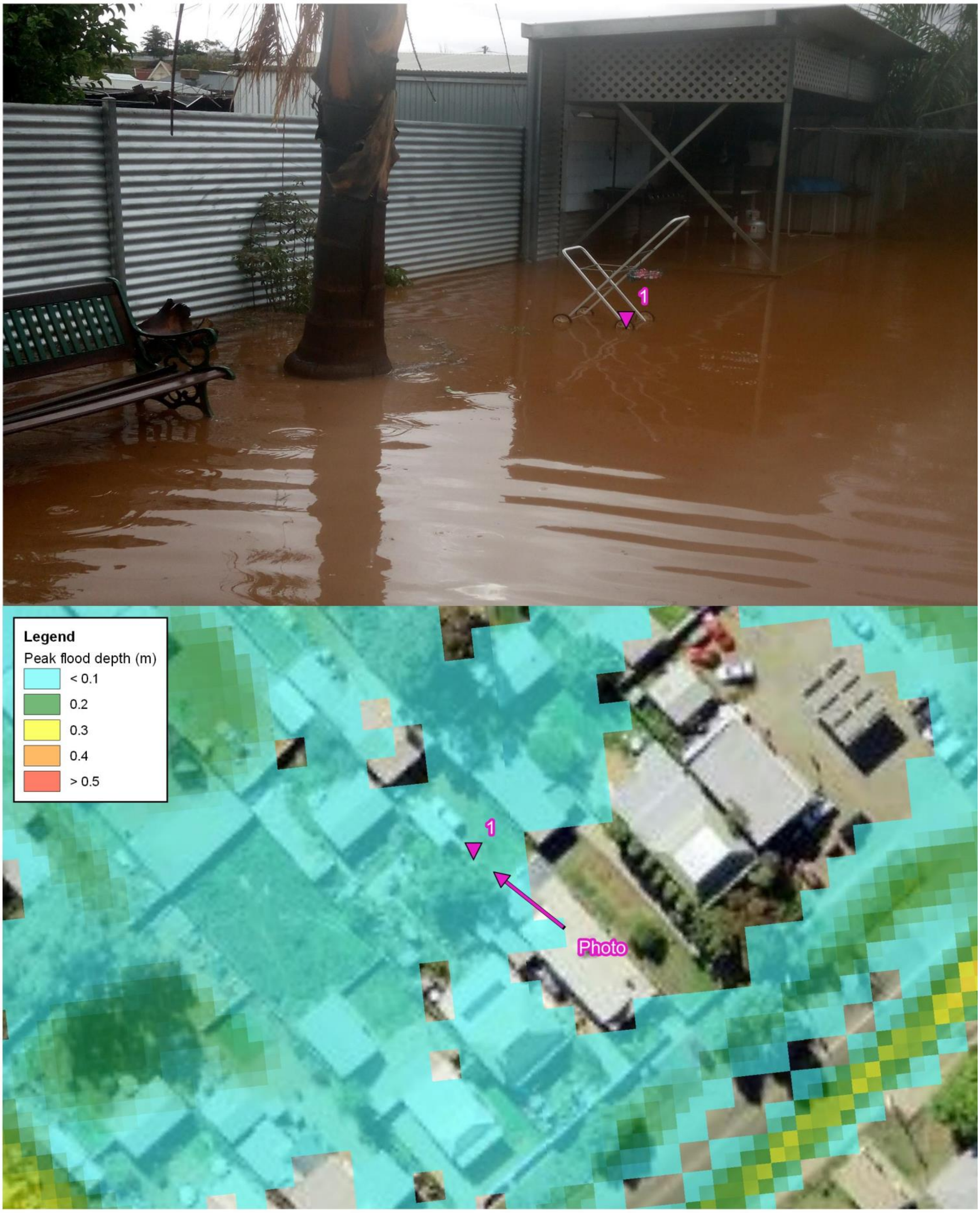
Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-20_Validation_plaza.qgz



Title:

Observed and Simulated Flooding
Wills Street

0 10 20 m
approx. scale

Figure: **6-21**

Revision: **A**

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Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-21_Validation_wills_street.qgz

6.4 Observed and Simulated Conditions January 2024

Figure 6-22 shows a comparison of the recorded rainfall for the January 2024 event and the design IFD data for Broken Hill. The derived depth vs duration profile shows the storm tracking between a 10% and 5% AEP magnitude up to around a 20-minute duration, with the event below a 20% AEP magnitude for durations longer than 1-hour.

Figure 6-23 shows a comparison of the cumulative rainfall recorded at the Broken Hill Airport AWS gauge and the community gauge locations for the March 2022 event. This event was characterised by three separate periods of rainfall burst as shown in Figure 6-24. These are evident in the steps in the cumulative total rainfall profiles. There is a general consistency in the timing of the bursts recorded at the gauge locations.

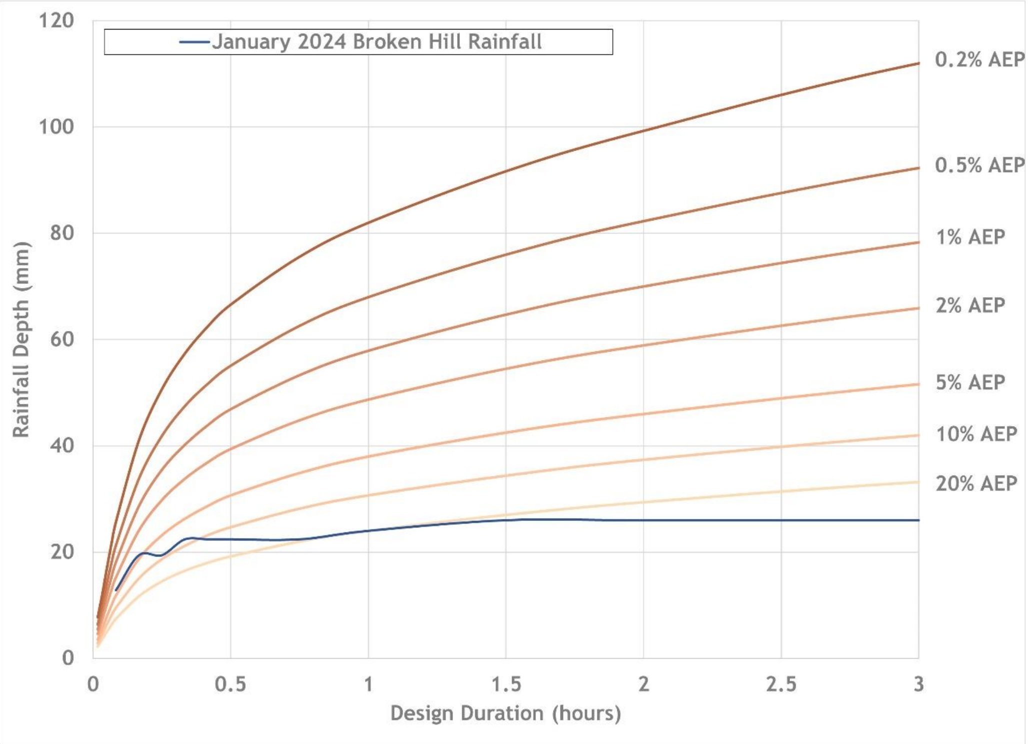


Figure 6-22 – IFD comparison of January 2024 event

Table 6-3 provides a summary of the comparison between observed and simulated flood conditions for the January 2024 event, with Figure 6-25 and Figure 6-26 showing the flood photographs and corresponding simulated flood depth and inundation extent at the location.

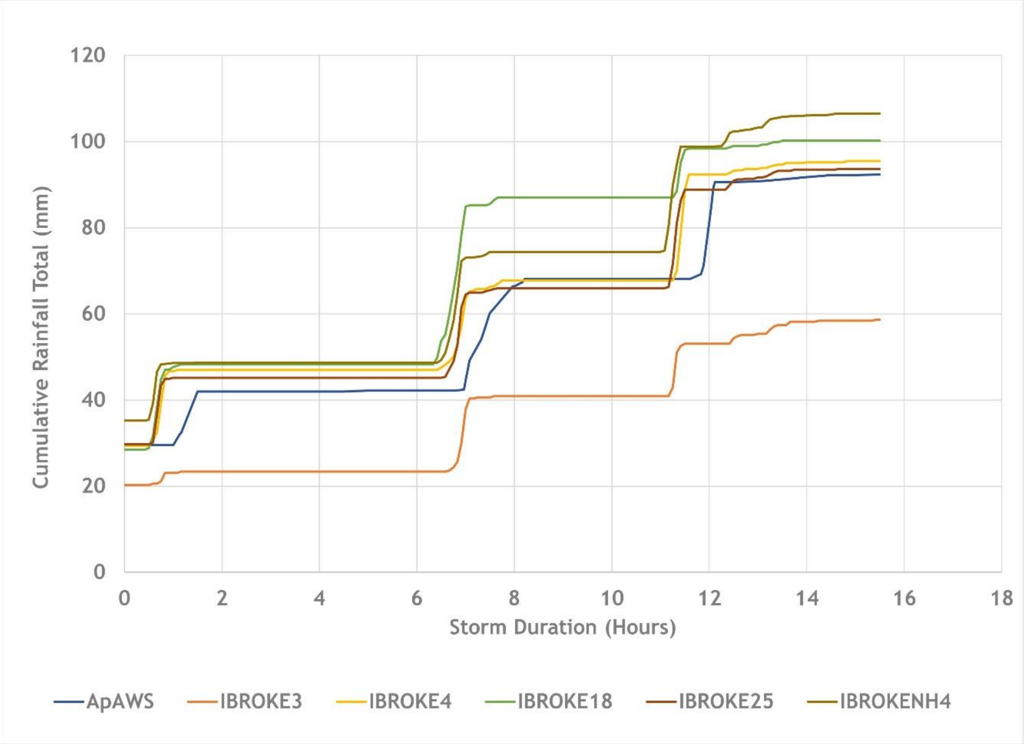


Figure 6-23 – January 2024 event cumulative rainfall across gauge network

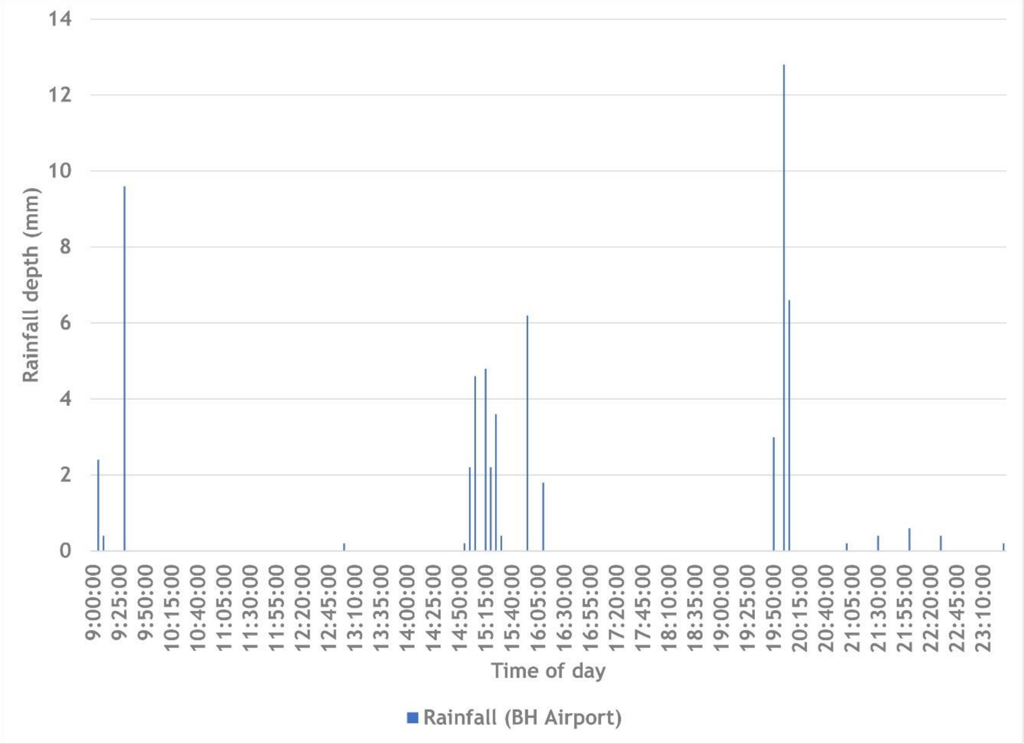
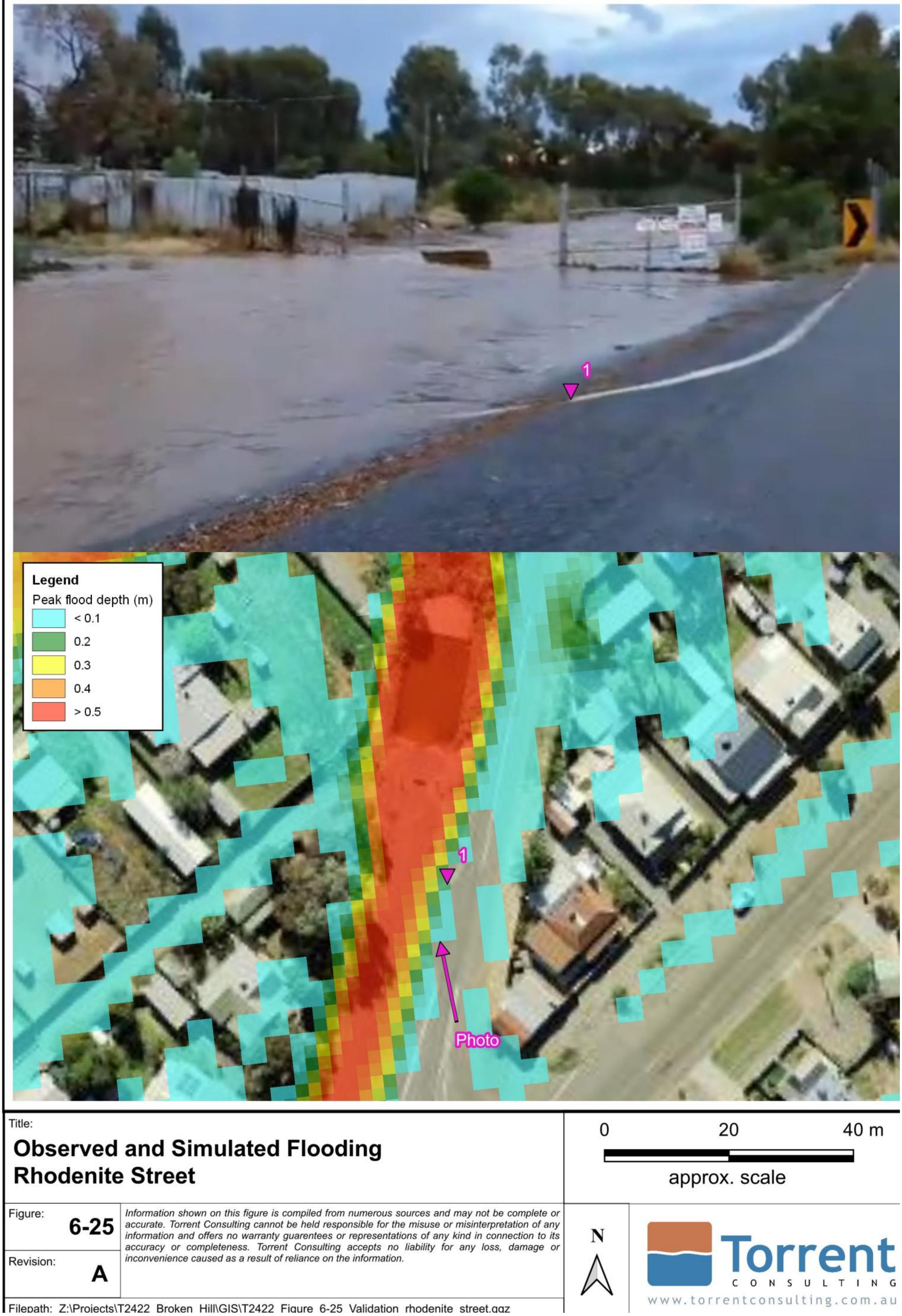


Figure 6-24 - Rainfall hyetograph of January 2024 event

Table 6-3 Model Validation January 2024

Location	Comments
Figure 6-25 - Observed and Simulated Flooding – Rhodenite Street	• Rhodenite Street becomes a major flow path during flood events. • The Photo shows a debris line indicating the peak extent of flooding. • The modelled peak flood extent is shown to be a good match, as shown on the curve of the painted line.
Figure 6-26 - Observed and Simulated Flooding – Zinc Oval	• Zinc Oval partially fills when runoff from the northeast exceeds the capacity of the diversion drain that runs along the eastern side of the oval. The oval fills prior to spilling back into the diversion drain at the southeast. • The photo shows water spilling into the oval from the diversion drain (2) and shows the northern extent of the inundation within the oval (1). • The spill location and extent of flooding are consistent with modelled peak flood conditions.



Title:
Observed and Simulated Flooding Rhodenite Street

Figure: **6-25**

Revision: **A**

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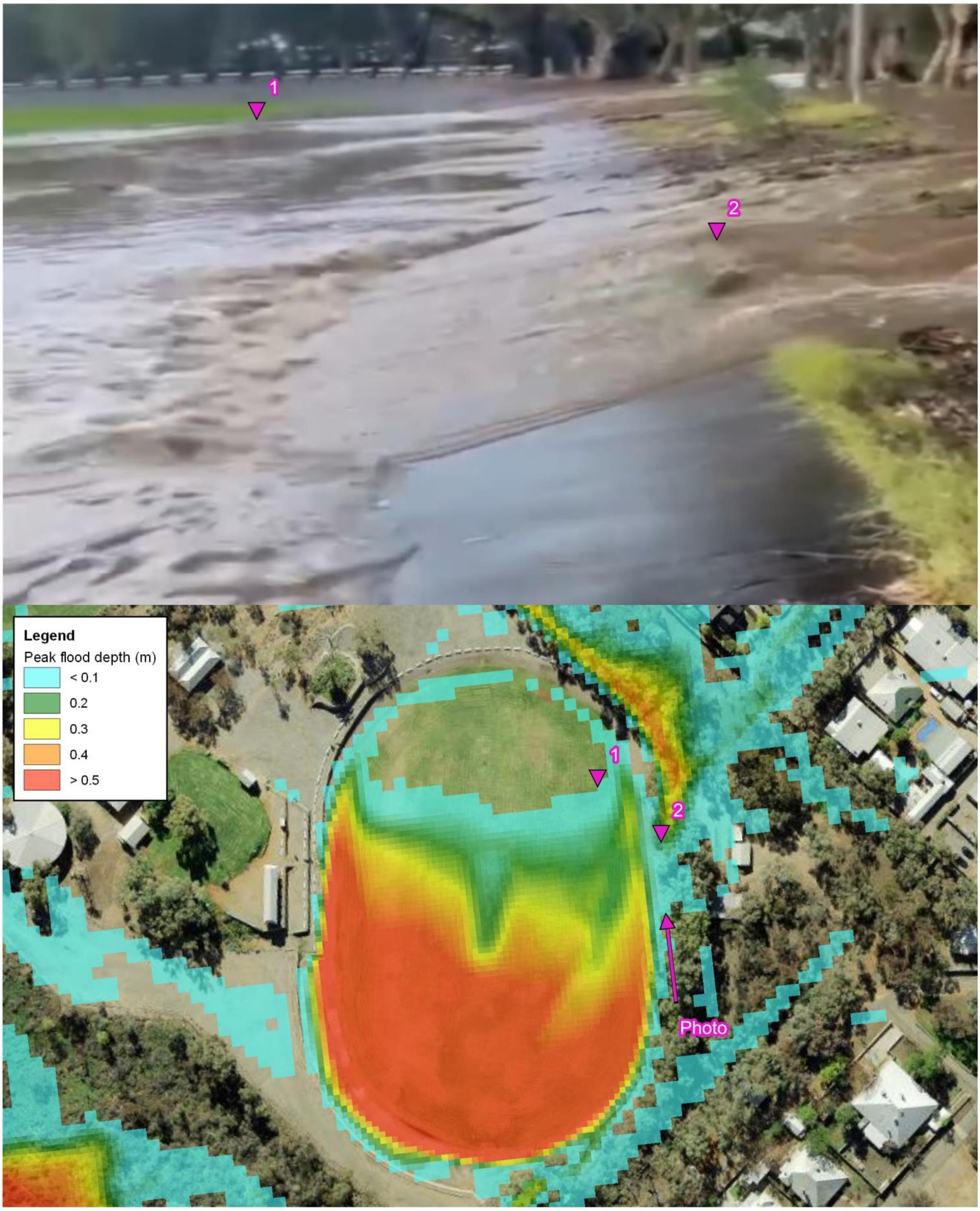
Filepath: Z:\Projects\T2422_Broken_Hill\GIS\T2422_Figure_6-25_Validation_rhodenite_street.qgz



Title:

Observed and Simulated Flooding Zinc Oval

0 40 80 m
approx. scale

Figure: 6-26

Revision: A

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6.5 Validation Summary

The purpose of model validation is to determine that the model is adequately representing the observed conditions for the nominated historical events. As previously stated, the calibration of model parameters such as surface roughness, infiltration, and coverage of assumed pervious and impervious areas is not feasible without detailed information such as surveyed flood levels or stream gauge data. These parameter values are assumed from best practice and previous model experience, with local conditions reviewed to determine suitable values, and are not adjusted for the validation.

There is uncertainty in the temporal and spatial distribution of rainfall across the catchment, and so some difference is expected between the observed and modelled flood conditions. However, the modelled flood depths and extents are generally consistent with the observed conditions across the validation events.

The validation exercise did enable to some local modifications to the model to better represent flow behaviour. Table 6-4 provides a general overview of the types of modifications made based on the observed flood conditions.

Table 6-4 Model Improvements Following Validation

Observation	Model Changes
Floodwater was observed to be static within properties fronting major flow paths (see **Figure 6-15**), indicating that panel fencing was acting to influence the distribution of flow.	Panel fences were represented with 2D layered flow constriction to allow flow under small gaps at the base of the fence panel and exclude flow through the panel. Fences parallel to flow were assumed to remain standing due to equilibrium of static pressure on both sides of the fence. Fences crossing flow paths were reinforced to a height of 0.3 m, assuming failure at around this depth of floodwater.
Floodwater was observed entering structures of solid construction to ground level, such as brick and concrete buildings. These structures would initially obstruct fast moving floodwater, influencing flow distribution.	Solid buildings within overland flow paths were reinforced by raising the area floor level, as estimated from street imagery. Upstream walls were reinforced to redirect deeper flows, but still allow flood storage within the building. Solid fences were reinforced as solid objects to the height of the fence as estimated from street imagery.
In the process of undertaking a detailed review of the flow paths for the reinforcement of fences and buildings, modelled flow paths were found to be obstructed by inaccurate LiDAR surface capture in the vicinity of street trees. This was particularly critical in the upper reaches of the modelled catchments where roads will typically convey low flows, with slightly raised sections of the LiDAR enough to	Sections of the road formation under street trees were reinforced to remove the raised areas.

redirect flows to footways and into adjacent lots.	
Some inter-allotment flow paths and grass-lined channels were not suitably represented due to vegetation 'noise' in the LiDAR.	The bed level was reinforced in these areas within the model.

Figure 5-1 showed the distribution of various topographic controls reinforced across the model domain. Figure 6-27 shows a detail of an area where the multiple types of modifications were made to best represent local topography and influence of structures.

Title:

TUFLOW Model Improvements

0 20 40 m

approx. scale

Figure: **6-27**

Revision: **A**

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7 Design Flood Conditions

7.1 Design Flood Events

Design flood events are hypothetical flood events with a given probability of occurrence. This probability of occurrence is the chance that the flood may occur or be exceeded in any one year and is termed the Annual Exceedance Probability (AEP). A 1% AEP flood is a flood that statistically has a 1% chance of occurring or being exceeded in any given year. This is also sometimes stated as a '1 in 100' chance of occurrence. Prior to ARR2019, design floods were typically referred to by their Average Recurrence Interval (ARI), however this terminology has been phased out in ARR2019.

Table 7-1lists the AEPs considered in this study and their equivalent ARIs. The AEP terminology expressed as a percentage has been used in this report to describe probability of occurrence.

Table 7-1 Design Flood Terminology

AEP %	AEP 1 in Y	ARI (years)
20	5	4.5
10	10	9.5
5	20	19.5
2	50	50
1	100	100
0.5	200	200
0.2	500	500

The Probable Maximum Flood (PMF) event is a function of the Probable Maximum Precipitation (PMP), which is the most rainfall that can be practically considered as being possible to occur over a given location or area. It is an extreme event with an approximate probability of between a 1-in-10,000 and a 1-in-10,000,000 AEP, dependant on catchment area. For small catchments up to 100km^2 such as the Broken Hill City environs the approximate probability of the PMF event is a 1-in-10,000,000 AEP.

7.2 Critical Duration and Temporal Pattern

The critical duration is the design storm duration which provides the highest peak water levels for a given design flood (for example 1% AEP) at a given location. The ARR2019 guidelines ensemble method to design flood hydrology involves the simulation of ten rainfall temporal patterns for each design event magnitude and duration, with the average peak flow condition of the ten being adopted for design purposes.

The TUFLOW model was simulated for storm durations ranging from ten minutes to 360 minutes. The design peak flows were extracted at multiple locations within the catchment along all key overland flow paths to establish a suite of critical durations and temporal patterns to adopt as representative design conditions.

The adopted representative design storms are summarised in Table 7-2

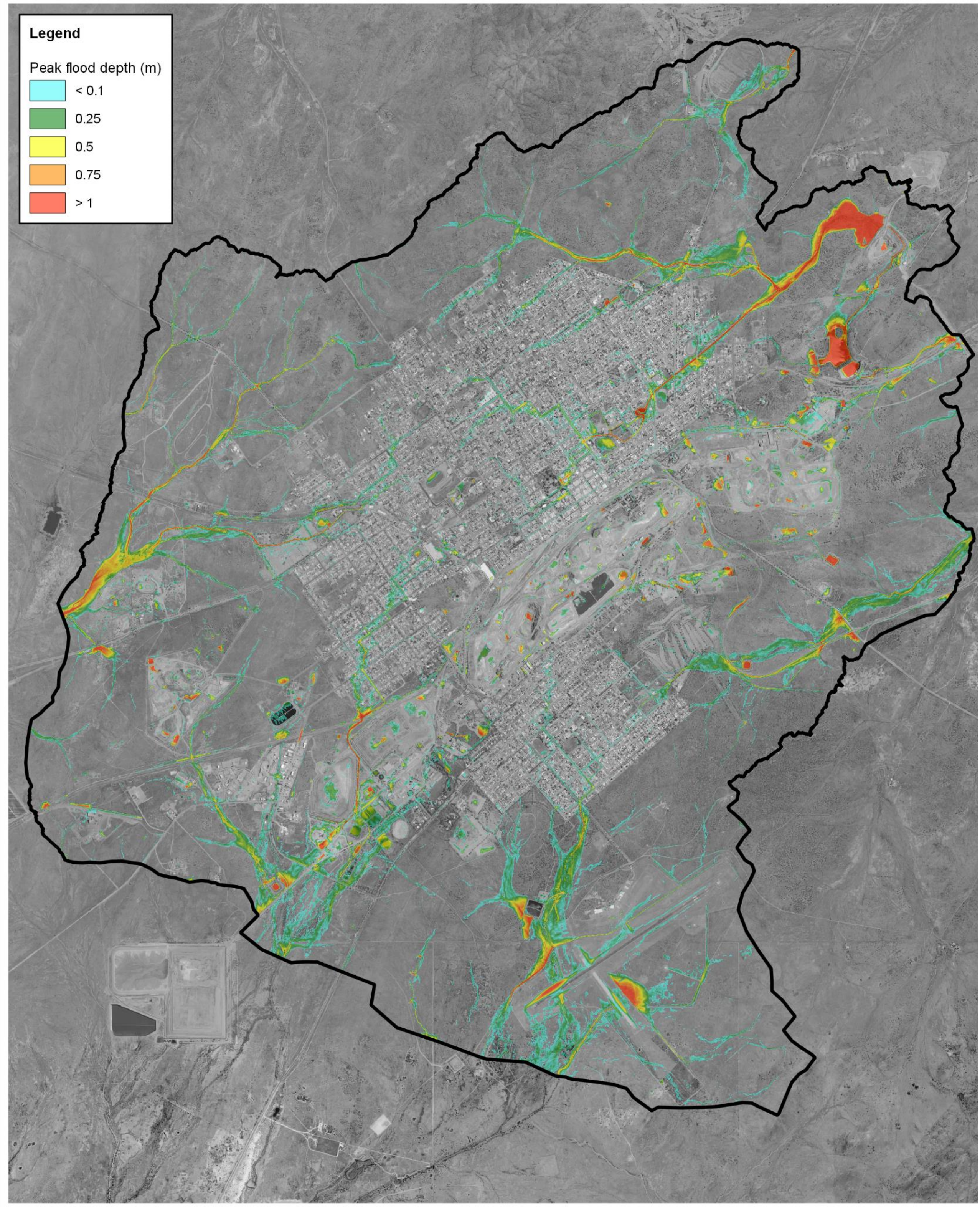
Table 7-2 Adopted Representative Design Storms

Event Temporal Pattern Bin	Events	Duration (mins)	Temporal Pattern ID
Frequent	50% AEP 20% AEP	25, 60	
Intermediate	10% AEP 5% AEP	25, 60	
Rare	2% AEP 1% AEP 0.5% AEP 0.2% AEP	25, 60	
n/a	PMP	15, 60	GSDM

7.3 Design Flood Results

7.3.1 Peak Flood Levels, Depths and Velocities

The flood depth, velocity, hazard, and flood function mapping for the 0.5% AEP and 0.2% AEP design events is included in Map Series A to D respectively. The changes in peak flood level from the baseline 1% AEP design flood condition is included in Map Series E.



Title:

Peak 1% AEP Flood Depths and Inundation Extent

Figure: 7-1

Revision: A

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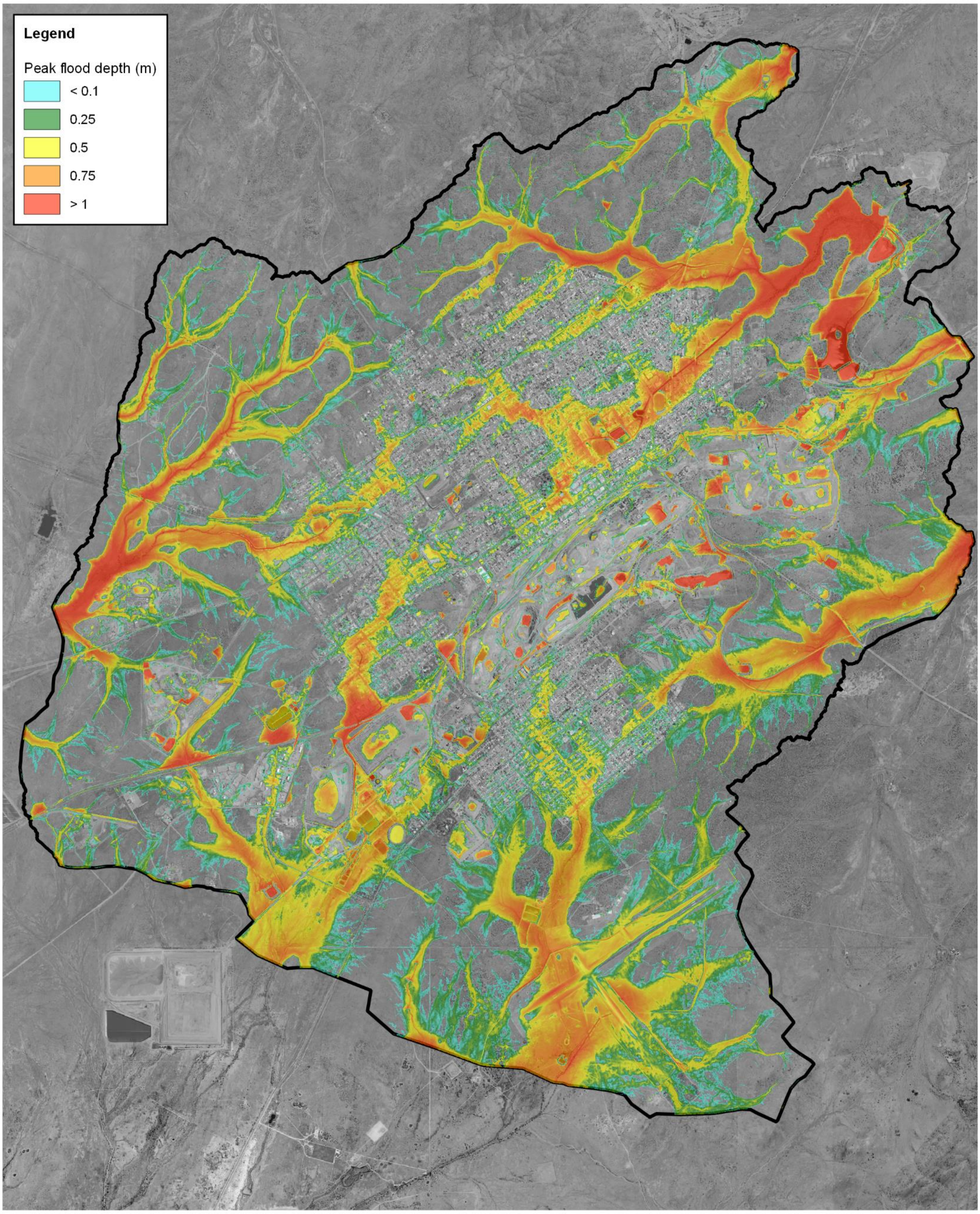

Title:

Peak PMF Flood Depths and Inundation Extent

0 1 2 km

approx. scale

Figure: **7-2**

Revision: **A**

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7.3.2 Flood Hazard

The flood hazards have been determined in accordance with Guideline 7-3 of the Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (AIDR, 2017). This produces a six-tier hazard classification, based on modelled flood depths, velocities, and velocity-depth product. The hazard classes relate directly to the potential risk posed to people, vehicles, and buildings, as presented in Table 7-3 and Figure 7-3.

Table 7-3 Combined hazard curves - vulnerability thresholds (AIDR, 2017)

Hazard	Criteria	Description
H1	Depth < 0.3 m and Velocity < 2.0 m/s and Velocity*Depth ≤ 0.3 m^2/s	Generally safe for vehicles, people and buildings
H2	Depth < 0.5 m and Velocity < 2.0 m/s and Velocity*Depth ≤ 0.6 m^2/s	Unsafe for small vehicles.
H3	Depth < 1.2 m and Velocity < 2.0 m/s and Velocity*Depth ≤ 0.6 m^2/s	Unsafe for small vehicles, children and the elderly.
H4	Depth < 2.0 m and Velocity < 2.0 m/s and Velocity*Depth ≤ 1.0 m^2/s	Unsafe for vehicles and people.
H5	Depth < 4.0 m and Velocity < 4.0 m/s and Velocity*Depth ≤ 4.0 m^2/s	Unsafe for vehicles and people. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure.
H6	Depth > 4.0 m OR Velocity > 4.0 m/s OR Velocity*Depth > 4.0 m^2	Unsafe for vehicles and people. All building types considered vulnerable to failure.

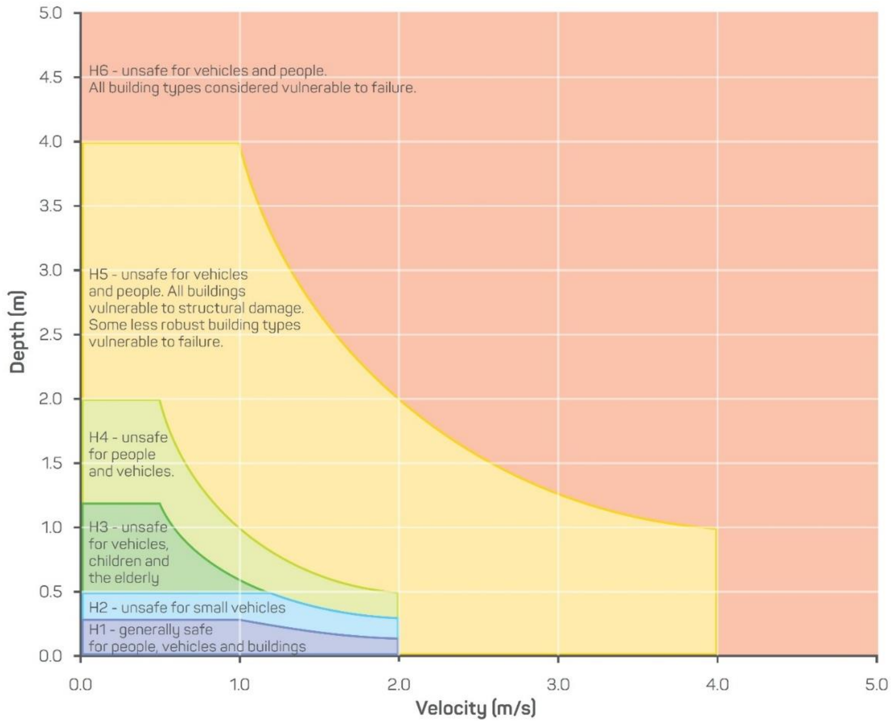


Figure 7-3 - General Flood Hazard Vulnerability Curves (AIDR, 2017)

The flood hazard mapping for the 5% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF design events is included in Map Series D. Figure 7-4 shows the peak flood hazard distribution across the study area for the PMF event.

7.3.3 Flood Function

The flood function categories of floodway areas, flood storage areas and flood fringe are defined in the Flood risk management manual: the policy and manual for the management of flood liable land (the manual; DPE 2023) as follows:

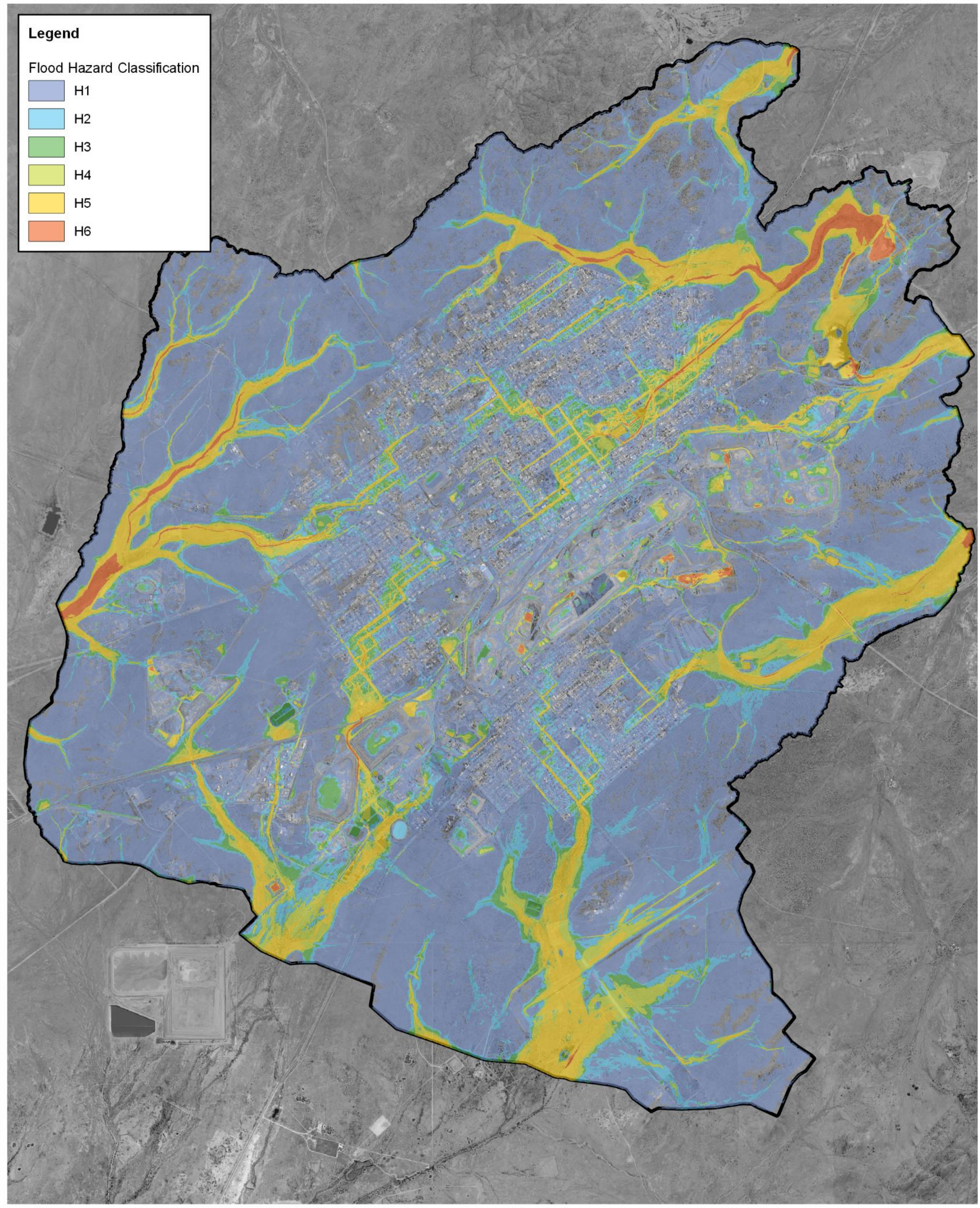
- **Floodway** - are generally areas which convey a significant portion of water during floods and are particularly sensitive to changes that impact flow conveyance. They often align with naturally defined channels.
- **Flood Storage** - are areas outside of floodways, are generally areas that store a significant proportion of the volume of water and where flood behaviour is sensitive to changes that impact on the storage of water during a flood.
- **Flood Fringe** - are areas within the extent of flooding for the event but which are outside floodways and flood storage areas. Flood fringe areas are not sensitive to changes in either flow conveyance or storage.

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the 'Floodplain Development Manual' (DPE, 2023) are essentially qualitative in nature and the definition of flood behaviour and associated impacts is likely to vary from one floodplain to another depending on the circumstances and nature of flooding within the catchment.

For this study, the multi-criterion approach considering peak flood depths, velocities and the velocity-depth product as described below

- Floodway is defined as areas where:
  - the peak value of velocity multiplied by depth (V*D) > 0.25 m^2/s AND peak velocity > 0.5 m/s AND depth > 0.1m, OR
  - peak velocity > 1.0 m/s AND depth > 0.1m
- Flood Storage comprises areas outside the Floodway where peak depth > 0.3 m; and
- Flood Fringe comprises areas outside the Floodway where peak depth < 0.3 m.

The flood function mapping for the 5% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF design events is included in Map Series E. Figure 7-5 shows the flood function categorisation for the 1% AEP event



Title:

Peak PMF Flood Hazard Classification

0 1 2 km

approx. scale

Figure: **7-3**

Revision: **A**

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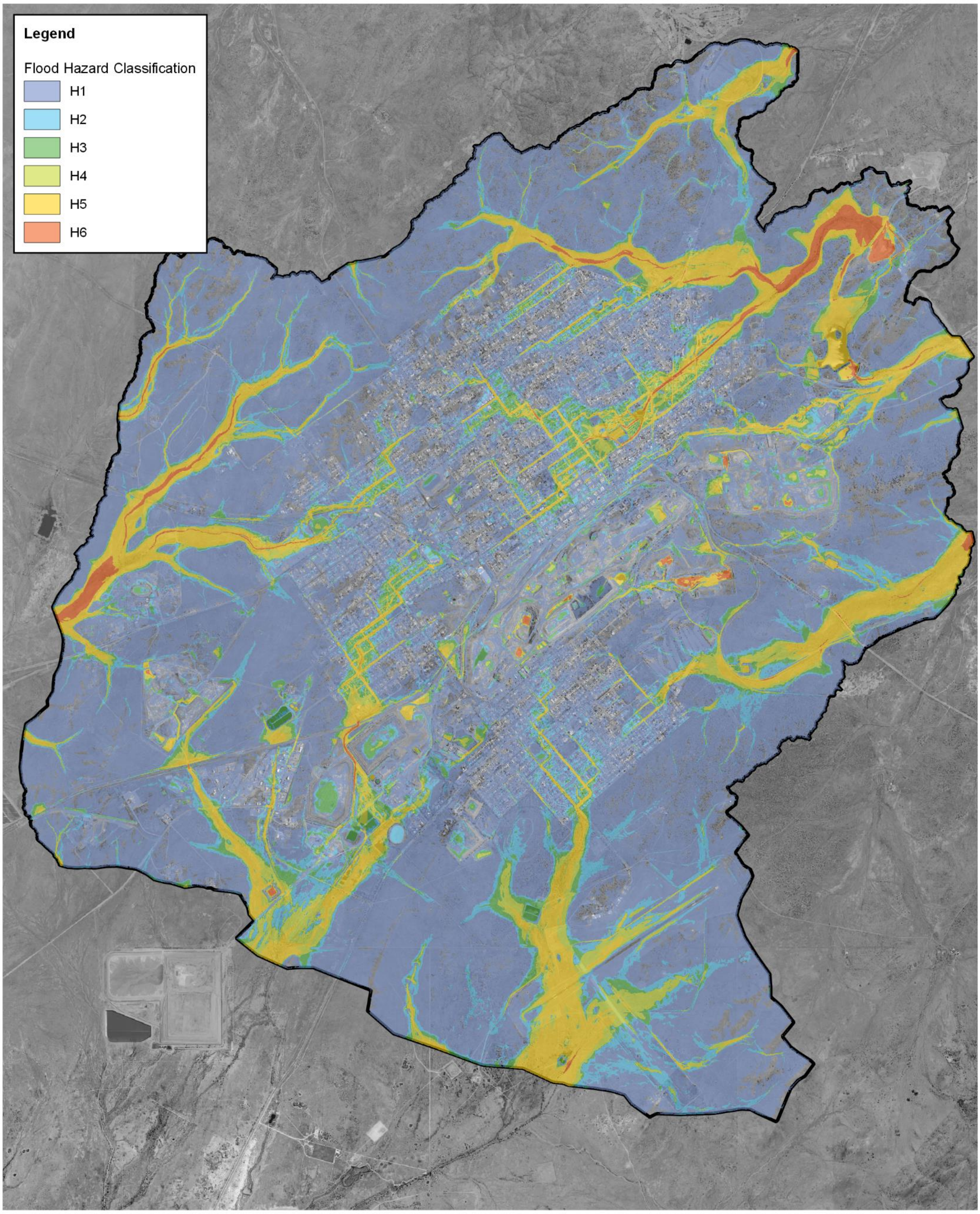

Title:

Peak PMF Flood Hazard Classification

0 1 2 km

approx. scale

Figure: 7-3

Revision: A

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7.4 Sensitivity Tests

Given the limited calibration data available and the inherent variability/uncertainty in defining modelling parameters, sensitivity assessment of key model parameters is undertaken to observe changes to simulated behaviour. The following sensitivity tests were undertaken:

- Climate Change – future increases in design rainfall intensity associated with future climate change impacts.
- Structure blockage – increase and decrease in adopted design blockage factors for selected structures.
- Hydraulic Roughness – increase and decrease in hydraulic roughness coefficient (Manning's 'n') assigned to various land use types.

Further detail of the sensitivity testing undertaken is provided in following report sections.

Other model parameters and configuration often considered for sensitivity testing were not assessed in this study as described below:

- Spatial and temporal rainfall variation – the key sub-catchments within the study area (refer to Figure 2-2) are relatively small and accordingly do not warrant consideration of design rainfall variability across the catchment.
- Design rainfall losses –the urban areas are the principal focus of the study in which there is a high proportion of impervious area (e.g. building roof area and roadway corridor) which dominate the runoff volumes generated.
- Downstream boundary conditions – the model boundaries are well beyond the City extents and have no influence on the design flood conditions in the modelled urban areas.
- Cumulative development – there is limited further development opportunity with the existing urban area that would impact on existing design flood conditions.

7.4.1 Climate Change

Updated ARR 2019 climate change guidance provides for adjustments to adopted design rainfall to account for potential increases in rainfall intensity. The rainfall adjustment is determined through a combination of an expected increase in global mean temperature and an associated percentage increase in design rainfall intensity per degree of warming.

For this assessment the Shared Socioeconomic Pathway SSP2 was adopted, which represents a continuation of historic global attitudes towards climate policy, i.e. a neutral rather than optimistic or pessimistic outlook. The SSP2-4.5 climate scenario has a best-estimate warming of around 2.4ºC by 2100. For the expected increase in design rainfall, the 7% per degree warming recommended in the NSW Flood Risk Management Manual (2023) was adopted. This gives a total increase in design rainfall intensity of 17.6% when using Equation 1.6.1 of ARR 2019.

The ARR 2019 climate change guidance includes a higher 15% increase in design rainfall per degree warming for small catchments with critical storm duration of an hour or less. This would provide an increase of 40.0% to the adopted IFD rainfall estimates to the year 2100 planning horizon.

The 0.5% AEP and 0.2% AEP events are often used as proxies for 1% climate change sensitivity tests. The increase in the short duration (1-hour or less) design 1% AEP IFD rainfall is approximately 18% and 40% for the 0.5% AEP and 0.2% AEP events. Conveniently, these two events are representative of either the 7% per degree or 15% per degree increase in rainfall intensity scenarios to 2100 as noted above.

Accordingly, the design 0.5% AEP and 0.2% AEP events are considered appropriate proxy events to represent potential climate change impacts. The flood depth, velocity, hazard, and flood function mapping for the 0.5% AEP and 0.2% AEP design events is included in Map Series B to E respectively.

The changes in peak flood level from the baseline 1% AEP design flood condition is included in Map Series F.

7.4.2 Structure Blockage

Design blockages factors for hydraulic structures (e.g. culverts, bridges) have been applied for the design event simulation as per Table 5-2. Sensitivity to blockage of hydraulic structures was assessed for both a low blockage and high blockage scenario.

Table 7-4 Blockage Sensitivity Assessment

Land Use	Design Blockage	Low Blockage	High Blockage
Small culverts (dia/width < 1.5m)	50%	0%	80%
Large culverts (dia/width ≥ 1.5)	20%	0%	50%
Bridge	5%	0%	10%
Drainage Pits	20%	0%	50%

The changes in peak flood level from the baseline design flood condition for 5% AEP and 1% AEP design events is included in Map Series F.

7.4.3 Hydraulic Roughness

The adopted hydraulic roughness values are within typical recommended ranges. However, given the limited detailed calibration data and the inherent variability/uncertainty in representing hydraulic roughness distribution across both catchment and lot scale, the sensitivity of the adopted parameters on design flood conditions is further considered. Sensitivity tests on the hydraulic roughness (Manning's 'n') were undertaken by applying a 20% increase and a 20% decrease in the adopted values for the baseline design conditions as summarised in Table 7-5. The nominal building footprint roughness of 2.0 was retained for both sensitivity scenarios. Applied material roughness values are summarised in Table 9-3.

Table 7-5 Mannings 'n' Values for Sensitivity Tests

Land Use	Baseline Manning's 'n'	20% decrease	20% increase
Cleared/maintained	0.04	0.032	0.048
Vegetated	0.06	0.048	0.072
Commercial/hardstand	0.02	0.016	0.024

Residential	0.04	0.032	0.048
Road reserve	0.02	0.016	0.024
Buildings	2.0	2.0	2.0

The changes in peak flood level from the baseline design flood condition for 5% AEP and 1% AEP design events is included in Map Series F.

7.5 Preliminary Flooding Hotspots

8 Information to Support Flood Planning

The Flood Study has been prepared to define the existing flood behaviour in the catchment and establish the basis for subsequent floodplain management activities. Land use planning and development controls are key mechanisms by which Council can manage flood-affected areas within the study area.

8.1 Flood Planning Area

Flood Planning Levels (FPLs) are used for planning purposes, and directly determine the extent of the Flood Planning Area (FPA), which is the area of land subject to flood-related development controls.

The 1% AEP flood is the typical Design Flood Event (DFE) used across NSW for flood planning and development control purposes. Freeboard is a factor of safety expressed as the height above the design flood level. The FPL is derived through a combination of the flood level for the DFE plus an adopted freeboard.

The NSW Government Department of Planning and Environment Guide 'Understanding and Managing Flood Risk: Flood Risk Management Guide' (2023) identifies that "*The typical freeboard used for flooding from waterways in New South Wales is 0.5 metres" and "A lower level of freeboard, 0.3 metres, is generally considered acceptable where there is very shallow water and where the influence of [uncertainties] is limited. This is generally limited to some areas affected by local overland flooding*."

It is understood that Council does not currently have formal flood related development controls incorporated in its Development Control Plan (DCP). It is expected that a full review of local flood planning and development controls will be undertaken in the next stage of the floodplain risk management process.

A lower freeboard value of 0.3 m can be considered in many parts of the city given the shallow depths of overland flow flooding across the study area. However, in more significant overland flow paths and open channel areas a 0.5 m freeboard value would be considered appropriate.

The suitability of the freeboard was also assessed relative to the results of the sensitivity assessment for the 1% AEP flood. It was determined that the impact of changes in modelling parameters and/or climate change lie within the 0.5 m freeboard tolerance, with predicted peak flood level impacts across local overland flooding areas typically less than 0.3 m. Accordingly, FPLs across the study area were derived from the 1% AEP flood level + 0.5 m freeboard.

Additional filtering of the results was undertaken to remove low risk areas not considered to require flood related development controls. This is required as a function of the high-resolution direct rainfall modelling approach in which some level of inundation is simulated across all cells within the model domain. Accordingly, the following results filtering was applied to derive the FPA:

- Removal of area with flood depths less than 0.1m
- Removal of isolated inundation area less than 100m^2
- Removal of areas with PMF hazard of H1

The resulting Flood Planning Area mapping is included in Map Series E.

8.2 Flood Emergency Response Classification

The NSW State Emergency Service (SES) has formal responsibility for emergency management operations in response to flooding in NSW. Flood Emergency Response Classification (FERC) provides an indication of the vulnerability of the community in flood emergencies and the potential impact of flooding. The primary purpose for doing this is to assist SES in the planning and implementation of response strategies. Flood impacts relate to where the normal functioning of services is altered due to a flood, either directly or indirectly, and relates specifically to the operational issues of evacuation, resupply and rescue.

Flood emergency response classifications are listed below as per the definitions from 'Flood Emergency Response Classification of the Floodplain' (AIDR, 2017).

- Flooded Isolated Elevated (FIE) – Areas flooded in the PMF and isolated from community evacuation facilities by floodwaters or impossible terrain where there is a substantial amount of land elevated above the PMF.
- Flooded Isolated Submerged (FIS) — Areas flooded in the PMF and isolated from community evacuation facilities by floodwaters or impossible terrain where all land will be fully submerged in the PMF after becoming isolated.
- Overland Escape Route (FEO) – Areas that are flooded in the PMF but not isolated from community evacuation facilities, where evacuation relies upon overland escape routes that rise out of the floodplain.
- Rising Road (FER) – Areas that are flooded in the PMF but not isolated from community evacuation facilities, where evacuation routes from the area follow roads that rise out of the floodplain.
- Indirect Consequence (NIC) – Areas outside the limit of flooding which are not inundated and do not lose road access but which may be indirectly affected as a result of flooding.

The FERC process follows the flow chart shown in Figure 8-1.

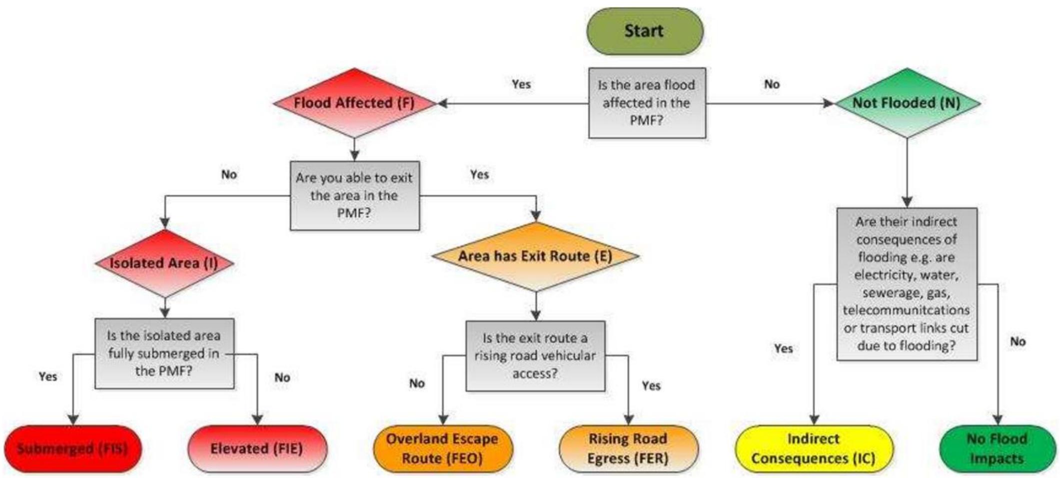

Figure 8-1 - Flow Chart for Determining Flood Emergency Response Classifications (AIDR, 2017)

The classification is typically undertaken on a precinct basis rather than lot-by-lot and is targeted at highlighting those areas which may require significant evacuation or assistance during a flood event.

Due to the nature of overland flow flooding within the study area, the majority of areas only impacted by overland flooding are generally classified as either Isolated Elevated, Overland Escape or Rising Road areas.

The FERC mapping is included in Map Series E.

8.3 Flood Damages

A flood damage assessment has been undertaken to identify flood affected property, to quantify the extent of damages in economic terms for existing flood conditions and to enable the assessment of the relative merit of potential flood mitigation options by means of benefit-cost analysis.

The general process for undertaking a flood damages assessment incorporates:

- Identifying properties subject to flooding;
- Determining depth of inundation above floor level for a range of design event magnitudes;
- Defining appropriate stage-damage relationships for various property types/uses;
- Estimating potential flood damage for each property; and
- Calculating the total flood damage for a range of design

Property locations have been derived from Council's cadastre information and associated detailed aerial photography of the catchment. A property database has been developed detailing individual properties within the floodplain area with potential for flood inundation identifying:

- Property type (e.g. residential, commercial)
- Ground and floor level
- Design flood levels

A site inspection was undertaken to guide floor level estimation in the areas with highest potential for flood inundation of property. It was noted that within the existing housing stock across the city, there is a high degree of variability of floor level heights above ground level. This variability presents limitations in adopting representative "height above ground" estimates for floor levels across the full study area. Given the limited extent of the visual floor level inspection, it is recommended that in future flood management studies a formal survey of floor levels is undertaken to better inform property flood risk exposure and potential damages.

Notwithstanding the above limitations, a preliminary flood damages assessment has been undertaken in accordance with NSW DPE guidance. A summary of the flood damages is provided in Table 8-1. The total number of properties affected at each design event magnitude is shown for reference. The number of lots affected indicates that the flood level was higher than the ground level near the building on the property and the number of lots affected above floor indicates that the flood level was higher than the floor level.

The Average Annual Damage (AAD) is the average damage in dollars per year that would occur in a designated area from flooding over a very long period of time. In many years there may be no flood damage, in some years there will be minor damage (caused by small, relatively frequent floods) and, in a few years, there will be major flood damage (caused by large, rare flood events). Estimation of the AAD provides a basis for comparing the effectiveness of different floodplain management measures (i.e. the reduction in the AAD).

The total estimated flood damage to occur in a 1% AEP catchment flood event is $XXM, increasing to an estimated $XX worth of damage for the PMF.

Table 8-1 Summary of Estimated Flood Damages

Flood Event	No. of Lots Affected	No. of Lots above Floor Level	Total Damages	% of AAD
50% AEP				
20% AEP				
10% AEP				
5% AEP				
2% AEP				
1% AEP				
0.5% AEP				
0.2% AEP				
PMF				

9 Conclusions

The Broken Hill Flood Study was undertaken to define the historical, existing and potential future climate overland flood conditions across the urban areas of the within City environs and surrounds.

Flood behaviour was predicted for a range of design floods based on a detailed TUFLOW hydraulic models developed for the study catchments. These models were verified qualitatively using anecdotal flood information for historical events that was provided by the community and Council.

The TUFLOW models were used to simulate a range of design events including the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP floods and PMF. The potential impacts of climate change incorporating increased rainfall intensity was also assessed for implications of managing the future floodplain environment. A suite of detailed design flood mapping has been prepared as a Mapping Compendium to this report.

Flood planning and emergency response information, including definition of the Flood Planning Area (FPA), Flood Control Lots, and Flood Emergency Response Classifications (FERCs), has also be developed based on the predicted flood characteristics.

The outputs of this flood study provide an improved understanding of overland flood behaviour that will aid in Council's management of flood risk and establish the basis for subsequent floodplain management activities.

10 References

Appendix A Community Consultation Information

BROKEN HILL
CITY COUNCIL

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Community feedback sought on floods

Published on 18 October 2023

Locals who are affected by flood events are invited to provide feedback as Council looks to find solutions to flooding in Broken Hill.

Council in partnership with flood modelling and risk management specialists Torrent Consulting are currently undertaking a Floodplain Management Study for the city.

A public information session and presentation will be held at 10am on October 25 at Council Chambers (240 Blende St) for those wishing to provide feedback or gain further information.

Those who would prefer to provide feedback online can do so via an online survey that can be found here.

Council's General Manager, Jay Nankivell, said community feedback would provide vital insight into ongoing efforts to try and safeguard our city against flooding and create potential flood mitigation strategies.

"We're somewhat lucky in that we don't receive as much flooding as other areas, but when a flood does occur we're affected quite heavily as our infrastructure historically hasn't been equipped to handle it very well," said Mr Nankivell.

"We're already aware of many areas that get particularly hard hit, but we're very keen to hear from locals regarding problem areas and come up with solutions to try and limit the impact when flooding does occur."

WHAT: Floodplain Management Study Community Session

WHEN: 10am, October 25

WHERE: Council Chamber, 240 Blende Street

Tagged as:

Media Releases

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Appendix B Design Flood Mapping

CONFIDENTIAL MATTERS

1. BROKEN HILL CITY COUNCIL REPORT NO. 147/25 - DATED AUGUST 08, 2025 - PROPOSED SALE OF 232 MORGAN STREET **- CONFIDENTIAL**

(**General Manager's Note**: This report considers Sale of Land and is deemed confidential under Section 10A(2) (c) of the Local Government Act, 1993 which provides for information that would, if disclosed, confer a commercial advantage on a person with whom the Council is conducting (or proposes to conduct) business).

BROKEN HILL

CITY COUNCIL

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