Normanton and Karumba Flood Study

Final Report



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1 Introduction

1.1 Background

The gulf region of northern Queensland experiences annual monsoons, with the wet season occurring between December and March. Rainfall depths over this period can be highly variable, and flooding is common from the major river systems as well as local creeks.

Carpentaria Shire Council have commissioned BMT to prepare the Normanton and Karumba Flood Study. The Norman River originates in the Gregory Range, approximately 200km southeast from Croydon. The river drains an area of 49,000 square kilometres, flowing in a northerly direction into the Gulf of Carpentaria. To the west is the larger Flinders River catchment and to the east is the Gilbert River. Major tributaries of the lower Norman River are Walker Creek and the Carron River. This region is illustrated in Figure 1.2.

Regional topography is relatively flat with expansive floodplains along the major rivers. During significant flood events, flows from the neighbouring Flinders and Gilbert Rivers interact with the Norman River. The absence of detailed topography across the wider area and sparce distribution of river gauges means that the flow interaction is not well understood.

In early 2019, prolonged rainfall was experienced, resulting in significant and widespread flooding. Figure 1.1 below illustrates the interaction, on this occasion, between the Norman and Flinders Rivers.

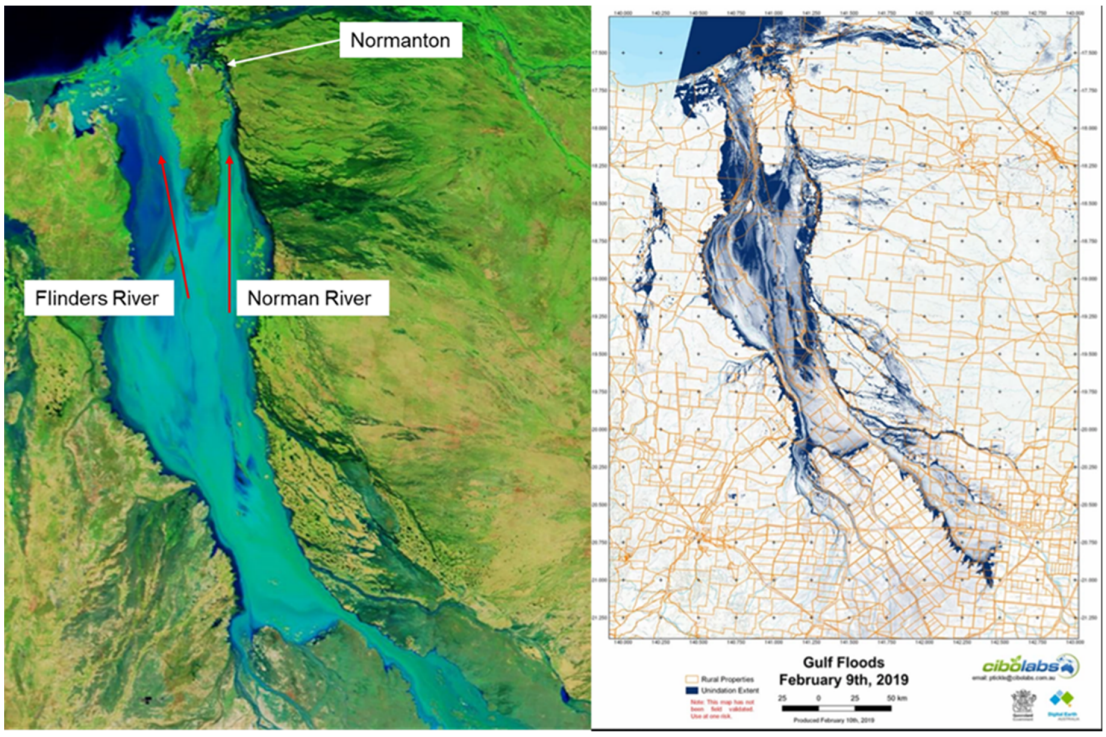


Figure 1.1 February 2019 flood extent in the Norman and Flinders Rivers

The overall objective of the flood study is to develop a hydraulic flood model that will produce spatial mapping for a range of design flood events and serve as a tool to assess flood behaviour under a range of 'what if' scenarios.

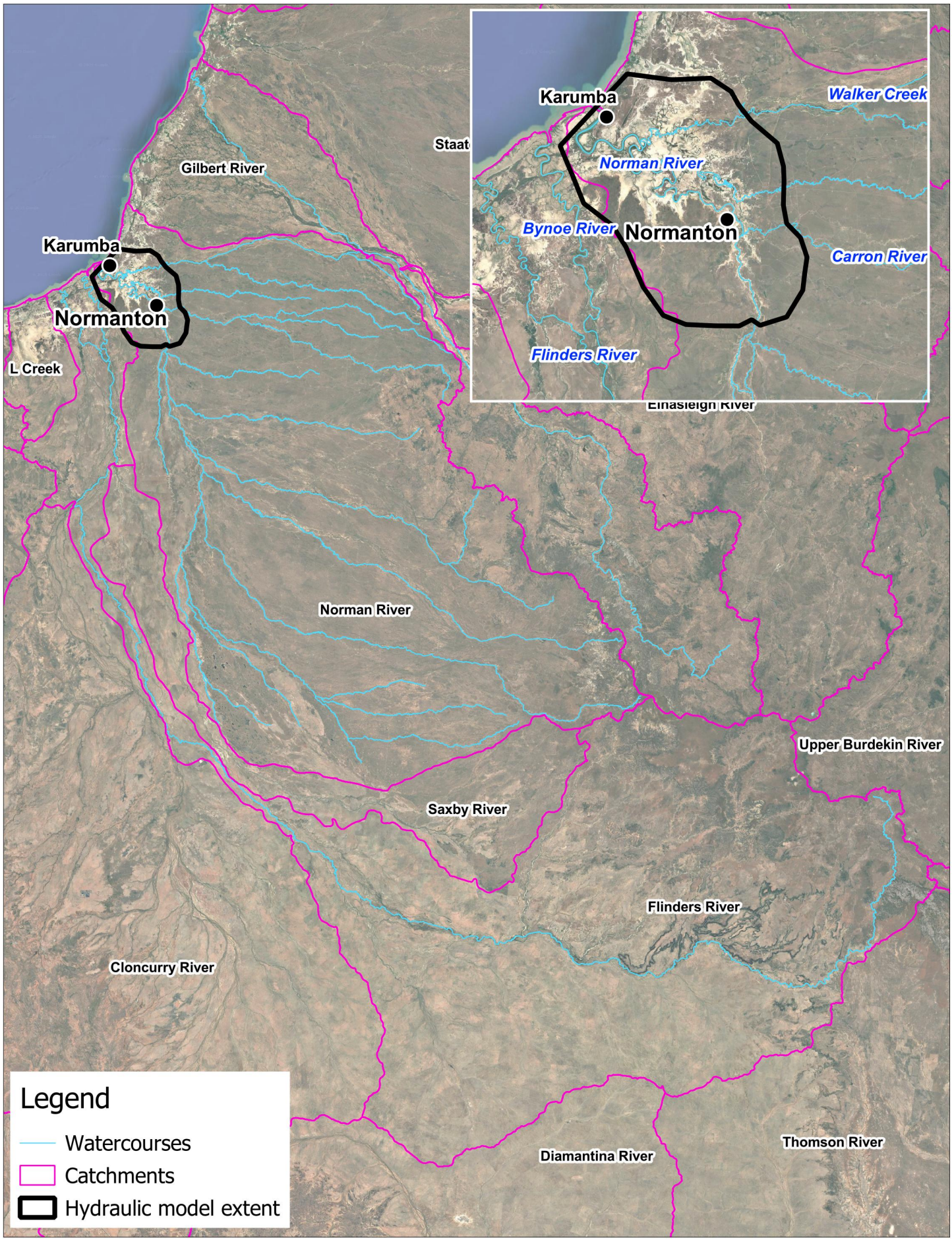
1.2 Summary of Model Development and Initial Calibration

This report follows an interim deliverable, referred to as the Calibration Report, (R.003338.001.00_Model_Development_and_Calibration.pdf, BMT, January 2025), the Calibration Report documented the development of the TUFLOW hydraulic model and representation of observed flood event. Following the accepted peer review of the Calibration Report, BMT proceeded to derive peak discharges at Glenore Weir for a range of design events.

During initial testing of the design event discharges, inconsistencies between modelled flood level at Normanton, and the magnitude of design event were identified. Specifically, modelled flood levels downstream of Glenore Weir were significantly lower than expected for the magnitude of design event. Extensive investigation of the inconsistencies resulted in a change in the methodology utilised to derive design event peak discharges, a summary of this investigation was documented in an update provided to Carpentaria Shire Council in August 2025 referred to as the Flood Study Update (L.003338.002.00_Update_Norman_River_Flood_Study.pdf, BMT, August 2025). Key contributing factors of this methodology change included:

- The discharge record for Glenore Weir which is a conversion of observed water level to flow did not consider the full cross-section
- Discharge estimates considering only a partial cross-section, in this case, only the flow within the Norman River channel, underestimated the total volume of flow during large flood events that inundated the floodplain
- Review of the existing rating curve for Glenore Weir confirmed this finding that, while in-bank flow was likely reasonably estimated, significant uncertainty would be associated with higher observed levels
- This misrepresentation led to lower-than-expected inflows in the hydraulic model, resulting in underestimation of flood levels at Normanton
- To resolve this challenge BMT proposed to develop a synthetic rating curve, based on steady-state hydraulic modelling, and derive an amended level and discharge relationship

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Locality Map

Figure: **1.2**

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2 Modelling Approach

The area of interest for this study are the towns of Normanton and Karumba. Due to the scale of the catchment and the uncertainty associated with flows entering the Norman River from the Flinders River, development of a hydrologic model of the catchment would have presented significant challenges. The presence of a fixed weir at Glenore on the Norman River upstream from Normanton, and a river gauge with an adequate duration of record presented an opportunity to quantify flows in the Norman River at the weir.

For the purposes of this assessment, discharge from the tributaries downstream of Glenore Weir, along with runoff from local rainfall, have been assumed to flow through Norman River prior to the arrival of flooding from upstream of Glenore Weir. This flood behaviour is typical of the scale, magnitude and duration of events recorded in the Norman River catchment and while there is a likelihood of coincident flood peaks occurring from regional and local sources at the same time, assessing coincident flooding was outside the scope of this assessment.

Flows from the gauge at Glenore Weir were included in a hydraulic model covering the lower Norman River from Glenore Weir to Gulf of Carpentaria at Karumba. Hydraulic modelling uses the TUFLOW software. Refer to Figure 1.2 above for the study hydraulic model area.

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3 Hydraulic Model Development

3.1 Modelling Objectives and Approach

3.1.1 Overall Approach

An important part of model development is assessing the performance of the model against historic events for which calibration data (river flows and levels) exist. Once calibrated and verified, the model will then be used to simulate design floods and ultimately be used to inform flood risk management decision making within the catchment.

3.1.2 Refinement of Model Extent

The study area is shown in Figure 1.2 and is defined as the reach of the Norman River from Glenore Weir to the Gulf of Carpentaria at Karumba. The extent of the hydraulic model area is shown in Figure 4.1.

3.1.3 Model Resolution vs Simulation Time

Model resolution refers to the level of detail within the model, primarily with regard to the representation of topography. The hydraulic model developed for the Normanton and Karumba Flood Study is a 2D model which uses a fixed model grid to represent the topography. In this model the resolution is determined by the cell size of the model. A high resolution model will have a smaller cell size and is therefore more able to represent smaller topographic features within the river channels and the floodplain, whereas a coarser model with a larger cell size will result in a greater degree of averaging of topographic features within each model cell.

The higher the model resolution (smaller the cell size), the greater the number of calculations the model needs to make and consequently, the slower the model simulation time. This is compounded by the need to utilise a smaller model timestep (simulation interval) for a smaller cell size. Halving the cell size typically increases the simulation time by a factor of eight.

A trade-off is therefore sought between model resolution and simulation time. As the model is to be used as a functional tool for input to a floodplain management study in which a number of ‘what-if’ scenarios are to be considered, it is important to maintain a manageable simulation time. On a high performance modelling machine, it is preferable that the model simulation time be less than 24 hours, and ideally 12 hours or less.

The final model configuration adopted is a 100 metre cell size 2D resolution over the majority of the model area, with the remainder of the model, including the Normanton township and Norman River watercourse, represented at a 50 and 25 metre cell size respectively. Karumba was maintained at a 100 metre cell size for calibration as the town was not inundated. For the calibration events considered in this study simulation times are typically in excess of 24 hours. In keeping with the target simulation times, design event simulations are expected to be less than 24 hours.

Irrespective of whether a 100 metres or finer grid resolution is used, either resolution could be used for flood mapping based on a finer resolution ground DEM to enhance the mapping resolution around the flood inundation extent and improve the depiction of fine scale topographic features. It is common practice to project the peak flood level surface from a 2D hydraulic model on to a finer resolution surface of the ground terrain and bathymetry to produce higher resolution flood extent and depth mapping. Therefore, the 100 metre resolution of the model could be projected on to finer resolution ground DEMs of 5m or less to produce higher resolution depth and extent mapping outputs should this be required.

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3.2 Model Construction

The modelling software used is TUFLOW, an industry standard modelling software package which solves the full 2D hydrodynamic shallow water equations using TUFLOW's GPU based explicit solver.

3.3 Model Topography

3.3.1 Introduction

Given the desired outcomes of flood modelling being accurate and reliable, defining an appropriate topographic surface is of significant importance to ensure the best representation of real world characteristics. Digital elevation models are a representation of the real world characteristics derived from various datasets read into the model in a series of layers. Topography is represented by a fixed grid of cells, where each grid cell results in a degree of averaging of elevations within that cell.

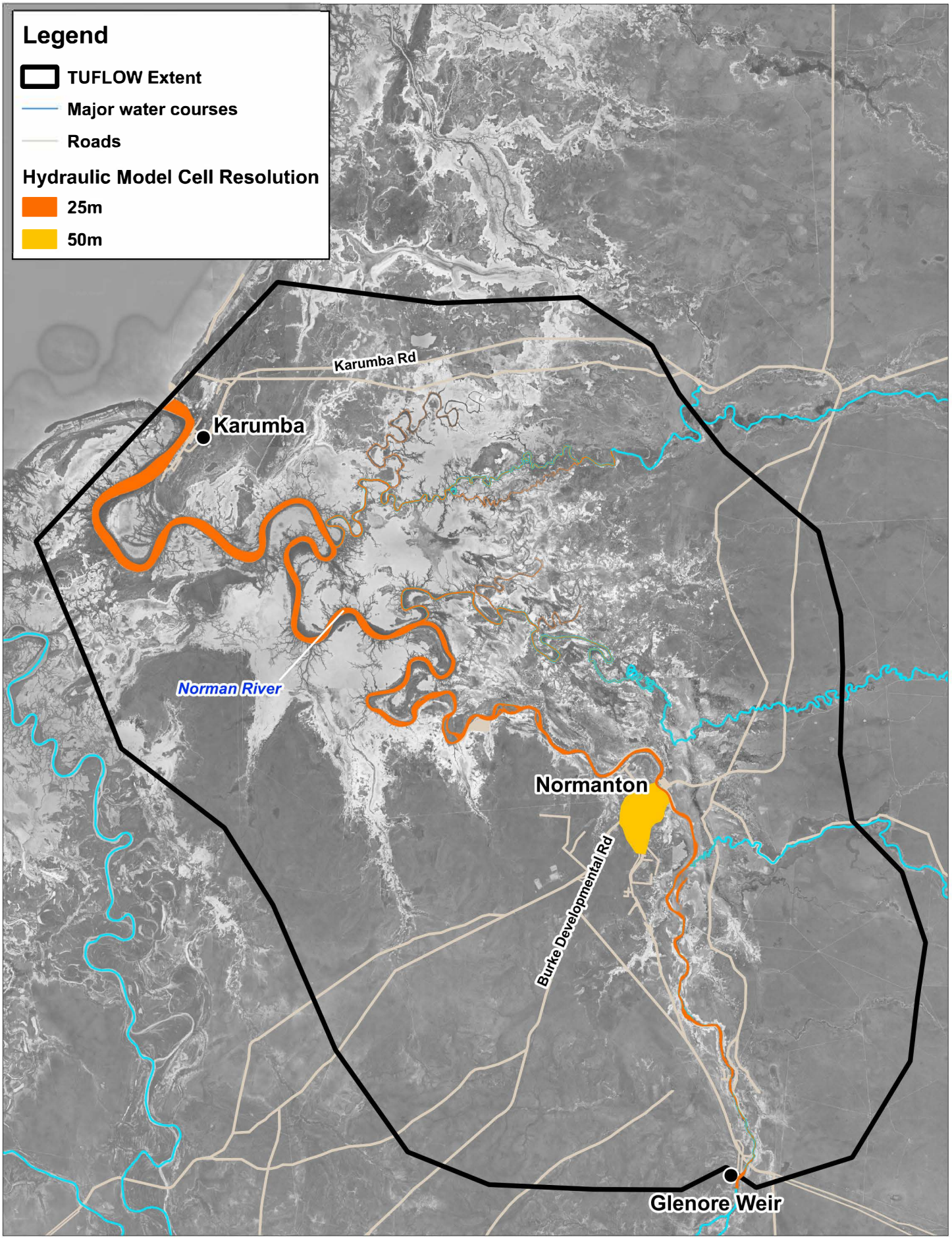
LiDAR aerial survey data is used to represent the Norman River floodplains. The LiDAR was captured in 2010 and compiled into a grid with a 5m cell size and is named '5m_DEM_0_0.asc' and '5m_DEM_0_0_south.asc'. An additional LiDAR dataset provided to BMT was collected in October and November 2023 and has been included at a resolution of 1m cell size named 'DEM_1m_Combined.asc'. Figure 3.3 shows the spatial coverage of the LiDAR datasets used in the model and brief descriptions are provided below along with details on how they have been applied in the model.

For areas outside of the coverage of LiDAR datasets 1 second (30 metre) Shuttle Radar Topography Mission (SRTM) has been applied. While SRTM is considered unreliable for defining topography, due to the absence of LiDAR coverage the SRTM has been included. To improve the interface between the SRTM and the LiDAR datasets the SRTM elevations were reduced by 1 metre, this resulted in a broadly consistent topographic surface and an improved representation.

3.3.2 Model Resolution

For locations outside of Normanton and the Norman River, TUFLOW samples ground elevations from the LiDAR grids at 50m intervals (at 2D cell centres, mid-sides and corners) resulting in a 100m grid. Within Normanton and the Norman River TUFLOW's quadtree feature has been included which reduces the grid cell size from 100m to 25m for the river and 100m to 50m for Normanton. The application of this feature (illustrated in Figure 3.1 below) significantly improves the resolution and subsequent hydraulic representation of the Norman River and Normanton township.

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Title:

Hydraulic Model Cell Resolution

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3.3.3 Ridge Breaklines

Where it was important to represent linear features that are narrow in relation to the cell size (typically this is the case for road centrelines and embankments), and may therefore not have the controlling elevation represented, topographic alterations referred to as ‘breaklines’ have been incorporated into the model.

Breaklines representing key linear ridge type features that have the potential to affect flow within the floodplain, were included in the model. Typically, these breaklines represent road and rail embankments but, any other notable embankments were included if they were likely to affect the flood behaviour.

3.3.4 Bathymetry

The LiDAR survey of the floodplain does not include river bathymetry (shape of the river below the water line) as conventional LiDAR survey cannot penetrate water. A reliance on LiDAR alone to represent the bathymetry led to insufficient flow area in the Norman River, and overestimation of water levels. This was identified by comparing the initial 200 hours of simulation time to the observed data when there is no influence from flood flows (i.e. solely the tidal signal). The comparison found that tidal fluctuations during this period were not accounted for in the model results.

To improve the calibration, an additional dataset was developed to represent the bathymetry of the Norman River. Figure 3.2 below illustrates the configuration of the 2D breakline applied in the TUFLOW model to represent the Norman River. Sensitivity testing of the shape of the breakline was conducted to optimise the modelled flow area of Norman River and resultant modelled water levels compared to the observed water levels at the Normanton river level gauge.

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Legend

TUFLOW Extent

Watercourses

Bathymetry (m AHD)

-3.5

-3.0

-2.5

Karumba Rd

Karumba

Norman River

Walker Creek

Bynoe River

Burke Developmental Rd

Carron River

Glenore Weir

Flinders River

Title:

Representation of Model Bathymetry

Figure: 3.2

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3.3.5 Final Model Topography

The model topography is read into the model in layers. The various digital elevation layers are applied first, forming the base floodplain topography, followed by breaklines representing road and river features. The final topography, resulting from all of the layers applied in order, is output as a grid file which can be checked for consistency with the original datasets. Refer to Figure 3.3 for model topography.

3.3.6 Topographic Limitations

Inspection of the final topography identified significant step changes at the interface of the LiDAR and SRTM with the SRTM generally higher at the interface. With the SRTM being generally higher than the LiDAR, an artificial wall along the interface between SRTM and LiDAR, within the floodplain, is present.

While the artificial constriction is not providing an accurate representation of existing elevation profiles, without an alternative higher resolution topographic dataset along the eastern boundary of the hydraulic model the final topography is considered adequate for this assessment. However, an update to LiDAR, covering this eastern extent, should be prioritised in future updates of the flood study.

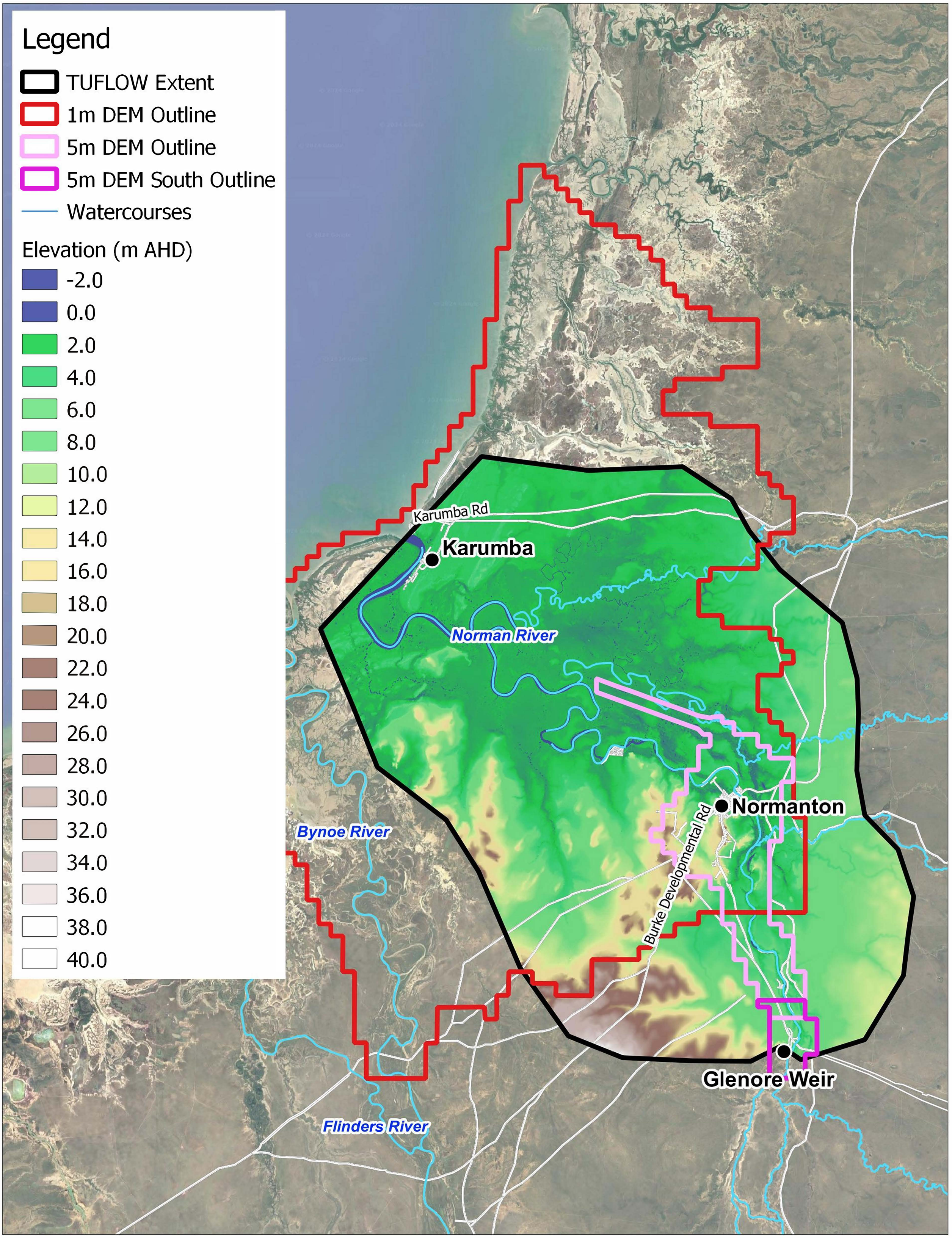
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Legend

- TUFLOW Extent
- 1m DEM Outline
- 5m DEM Outline
- 5m DEM South Outline
- Watercourses

Elevation (m AHD)

- -2.0
- 0.0
- 2.0
- 4.0
- 6.0
- 8.0
- 10.0
- 12.0
- 14.0
- 16.0
- 18.0
- 20.0
- 22.0
- 24.0
- 26.0
- 28.0
- 30.0
- 32.0
- 34.0
- 36.0
- 38.0
- 40.0



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Final Model Topograpghy

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3.4 Land Use

Similarly to topography, the delineation of land use is important to define as the characteristics of water flow is dependent on the surface. Land use across the modelled extent was digitised as it forms the basis to spatially allocate hydraulic roughness values (Manning's n values) during the process of model calibration. Land use was predominantly digitised from aerial imagery. It was also supplemented with cadastre information on watercourse, road networks and buildings. Greater focus was provided when digitising land use within areas of higher flow conveyance such as areas within the riparian corridor as these areas would have a greater effect on flood levels. Outside of these areas the land use mapping was more generalised as it would only play a role in extreme flood events.

Vegetation has been broadly considered as vegetated and unvegetated due to the clear boundaries between the two categories and uniform coverage derived from the satellite imagery. Unvegetated areas have been defined spatially across the region, predominantly between Normanton and Karumba, and vegetated has been represented as the underlying roughness for the remaining model area. Refer to Figure 3.4 for land use across the model domain.

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Legend

- TUFLOW Extent
- Watercourses
- Watercourse
- Buildings
- Roads
- Unvegetated

Karumba Rd
Karumba
Norman River
Walker Creek
Normanton
Burke Developmental Rd
Bynoe River
Carron River
Glenore Weir
Flinders River

Title:

Land use

Figure: 3.4

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3.5 Model Boundaries

The extent of the hydraulic model is shown in Figure 3.5. Inflow boundaries are applied to the model at the following locations:

- Normanton River at Glenore Weir

A single downstream boundary is applied in the model at Karumba (shown in Figure 3.5). This is a time varying water level boundary. Initial water levels in the model at the start of each simulation are set to match the starting water elevation in this downstream boundary.

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Legend

- TUFLOW Extent
- Downstream (HT)
- Downstream (HQ)
- Upstream (QT)
- Major water courses
- Roads

Karumba Rd
Karumba
Walker Creek
Norman River
Normanton
Bynoe River
Burke Developmental Rd
Carron River
Glenore Weir
National HWY
Flinders River

Title:

Model Boundaries

Figure: 3.5

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4 Development of the Glenore Weir Rating Curve

4.1 Introduction

As outlined in Section 1.2 the available discharge data for Glenore Weir could not be utilised due to several factors including consideration of the full floodplain cross-section as well as the existing rating curve used to derive the discharge data. To remedy this significant source of uncertainty an updated relationship between observed water level and discharge at Glenore Weir was developed with a hydraulic model.

4.2 Development of a Steady State Hydraulic Model

The development of a rating curve is generally completed using physical measurements of observed level and observed discharge (using specialised equipment), then extrapolated to estimate the discharge for larger events. The extrapolation occurs as it is often too dangerous to physically measure discharge during large flood events. An alternative method to extrapolating discharge at higher observed water levels is developing a relationship between discharge and water level using a hydraulic model.

To develop this relationship, a hydraulic model is simulated with various magnitudes of discharge as a steady state inflow. For each of the simulations, the resultant modelled water level at the gauge location is extracted for each discharge, producing a series of modelled water levels and discharges. The resulting plot of these data points produces the modelled rating curve.

For the purposes of this assessment the extent of the hydraulic model was reduced to an area surrounding Glenore Weir, inclusive of the full floodplain cross-section, this model is referred to as the steady state model. The reduced model size provided an opportunity to simulate the steady state inflows at a reduced cell size providing an improved resolution for the model results.

4.3 Development of Water Level vs Discharge Relationship

The steady state hydraulic model was simulated for a series of discharges from 200 to 50,000 cubic metres per second overtopping Glenore Weir. Following the simulation of each discharge the associated modelled water level was extracted. Figure 4.1 below illustrates the relationship between the modelled water level and discharge at Glenore Weir.

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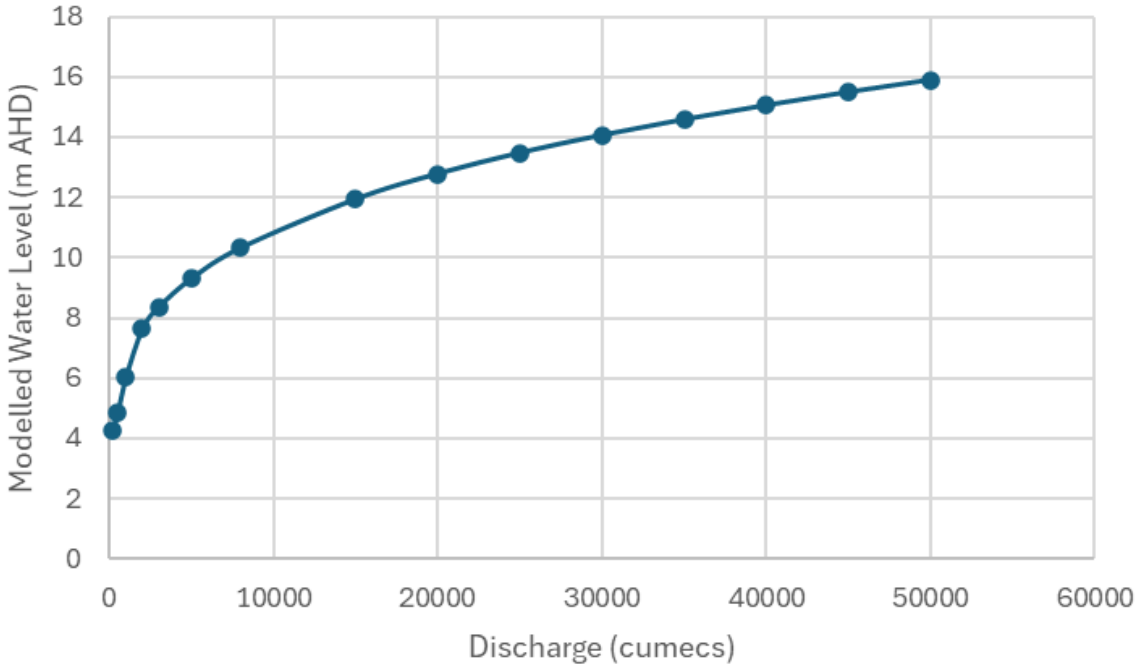


Figure 4.1 Modelled relationship between Water Level and Discharge at Glenore Weir

4.4 Conversion of Observed Water Level Record

For the final stage in updating the previous estimate of discharge at Glenore Weir, the rating curve is utilised to convert the observed record of water level data to a calculated discharge. Where the previous rating curve (shown in Figure 4.2Where the previous rating curve (shown in Figure 4.2 below) was significantly underestimating resulting discharge the updated methodology, informed by steady state hydraulic modelling, significantly increases the confidence in derived discharge estimates.

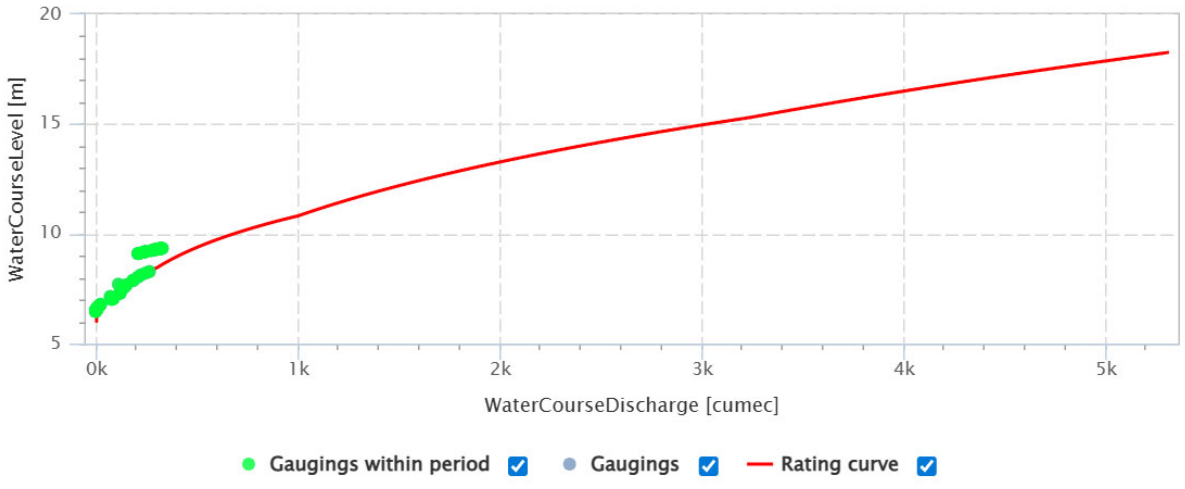


Figure 4.2 Rating curve for Glenore Weir

Following development of the rating curve a line of best fit and associated equation was produced to describe the relationship between modelled water level and discharge. Figure 4.3 below shows the equation that was utilised to convert observed water level (x) to derived discharge (y).

$$y = 0.5691x^{4.1045}$$

Figure 4.3 Equation which describes the relationship between modelled water level and discharge

Figure 4.4 below illustrates the application of the above equation on the record of observed water level at Glenore Weir. The record has been truncated from an initial start year of 1974 to 1997 due to inconsistencies with the datum shift and conversion from gauge level to Australian Height Datum (AHD). While this significantly reduces the length of record at Glenore Weir the reliability of the consequent assessment of design events is improved.

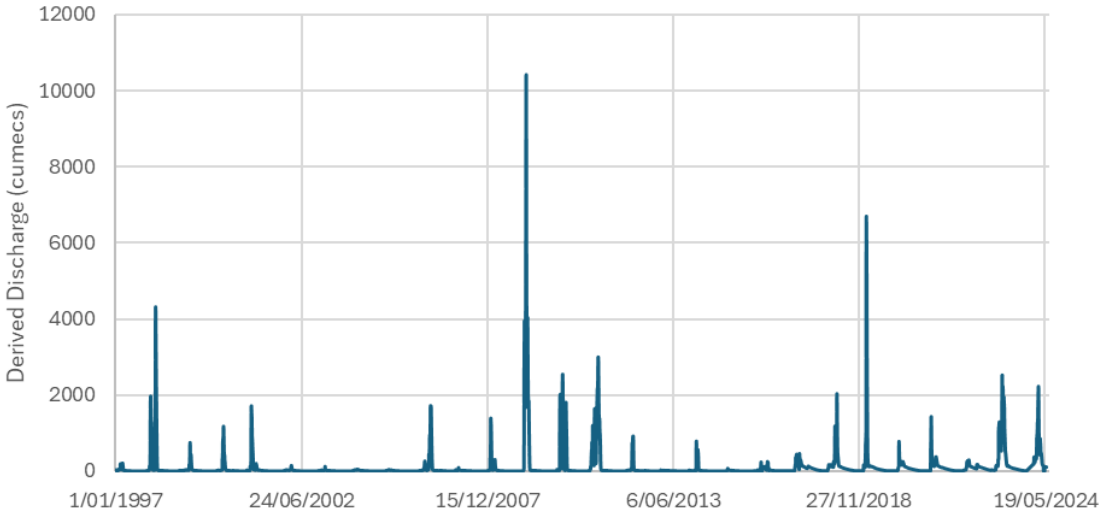


Figure 4.4 Derived discharge at Glenore Weir between 1997 and 2024

5 Calibration Events and Available Data

5.1 Introduction

Model calibration is the process by which model parameters are adjusted until the model is deemed to adequately represent real world behaviour. Historical flood events are used as the basis for achieving this with the goal of having modelled flood results matching closely with recorded flood data.

Calibration events (historical flood events) are typically selected as being events of significant magnitude (i.e. significant enough to cause flooding) and that have good availability of calibration data.

Calibration data is the data available on historical flood events that can be used to compare against model results. Two historic events have been used for model calibration/verification purposes. These are 2023 and 2024. This section expands on the events selected for model calibration and specific data available for these nominated calibration events.

5.2 Calibration Approach

The hydraulic model was calibrated utilising two boundaries:

- Norman River flows at Glenore Weir;
- Tidal boundary at Karumba; and

5.3 Calibration Events

A single event was chosen for calibrating the hydraulic model to define hydraulic parameters that were validated with a second flood event. These events exhibit differing flood characteristics and have a sufficient amount of available data to enable calibration to be undertaken. Furthermore, given the recency of the events, they are considered most representative of current catchment conditions. These events are summarised briefly below.

5.3.1 2023 Event

The Bureau of Meteorology made the following comments on rainfall and storm activity associated with the 2023 flood event:

- *January 2023: Several days of locally heavy falls of rain and thunderstorms affected many areas of Queensland at the start of January, including the Gulf Country, Peninsula, northern interior, and the tropical east coast, with daily rainfall totals generally in the range of 20 to 70 mm, and isolated falls of more than 100 mm over the southern Cape York Peninsula. Major flooding resulted along the Georgina River between Roxborough Downs and Glenormiston. The Leichhardt River was also flowing, with flooding along the road from Normanton to Doomadgee/Burketown. Burketown, Doomadgee, and Gregory remained isolated into mid-January due to the high levels of the Nicholson/Gregory and Leichhardt river systems.*[1]
- *February 2023: Storms and heavy rain occurred across the northern tropics during the last week of February, with weekly totals of 150 to 300 mm from the eastern Kimberley (Western Australia), through the Northern Territory Top End and the Cape York Peninsula (Queensland). Minor to Moderate flooding resulted in some areas, leading to the closure of the Victoria Highway in the Katherine region. A few stations in the Kimberley and the west of the Northern Territory had their*

[1] http://www.bom.gov.au/clim_data/IDCKGC1AR0/202301.summary.shtml

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wettest February day on record at the end of the month, but mostly at locations with less than 30 years of observations.[2]

5.3.2 2024 Event

The Bureau of Meteorology made the following comments on rainfall and storm activity associated with the 2024 flood event:

- *February 2024: A tropical low (07U) embedded into the monsoon trough started to develop over the Top End on 13 February. It moved eastwards across the Top End, along the monsoon trough and on the 14th was just off-shore in the south-west Gulf of Carpentaria, strengthening over the warm gulf waters. Showers and thunderstorms impacted parts of the Top End, much of the Gulf coast and parts of northern Queensland. Some stations had their highest daily rainfall record for February. Groote Eylandt Airport (Northern Territory) had 119.0 mm in the 24 hours to 9 am on the 15th, while Sweers Island and Burketown Airport (both in Queensland) had 227.0 mm and 154.6 mm respectively to 9 am 16 February. Tropical low 07U developed into Tropical Cyclone Lincoln on the morning of 16 February. It crossed the southern Gulf of Carpentaria coast as a Category 1 system in the evening on the 16th just to the west of the border between Northern Territory and Queensland. Heavy rainfall resulted in renewed flooding across parts of north-western Queensland and north-eastern Northern Territory, as rain fell on already saturated rivers and creeks. Numerous Flood Warnings were issued with Major Flood Warnings for the Nicholson, Gregory and Flinders rivers (Queensland). Burketown and Doomadgee (Queensland) were recently flooded and isolated for weeks due to flooded roads, and the return of widespread flooding resulted in an extended isolation.*[3]
- *March 2024: A monsoon trough that redeveloped across the Top End (Northern Territory) and the far north Queensland on the 11th resulted in areas with rain, widespread showers and thunderstorms over parts of northern Australia. Heavy rainfall impacted especially Queensland's North Tropical Coast where many stations recording daily rainfall totals above 100.0 mm on multiple days. Daily rainfall totals of 100 mm to 150 mm were reported near the Top End coast during the passage of tropical low 09U before it developed into Tropical Cyclone Megan. Heavy rainfall resulted in flash and riverine flooding and road closures across parts of northern Queensland, the Northern Territory and northern Western Australia. A strong monsoonal flow persisted until about 20 March.*[4]

5.3.3 Summary of Calibration Events at Normanton

Figure 5 1 shows the flood hydrographs for the two historical events at the Normanton gauge. For each event the time has been adjusted from conventional date and time to hours. The assessed floods cover a range of durations and shapes, while having a similar magnitude.

[2] http://www.bom.gov.au/clim_data/IDCKGC1AR0/202302.summary.shtml
[3] http://www.bom.gov.au/clim_data/IDCKGC1AR0/202402.summary.shtml
[4] http://www.bom.gov.au/clim_data/IDCKGC1AR0/202403.summary.shtml

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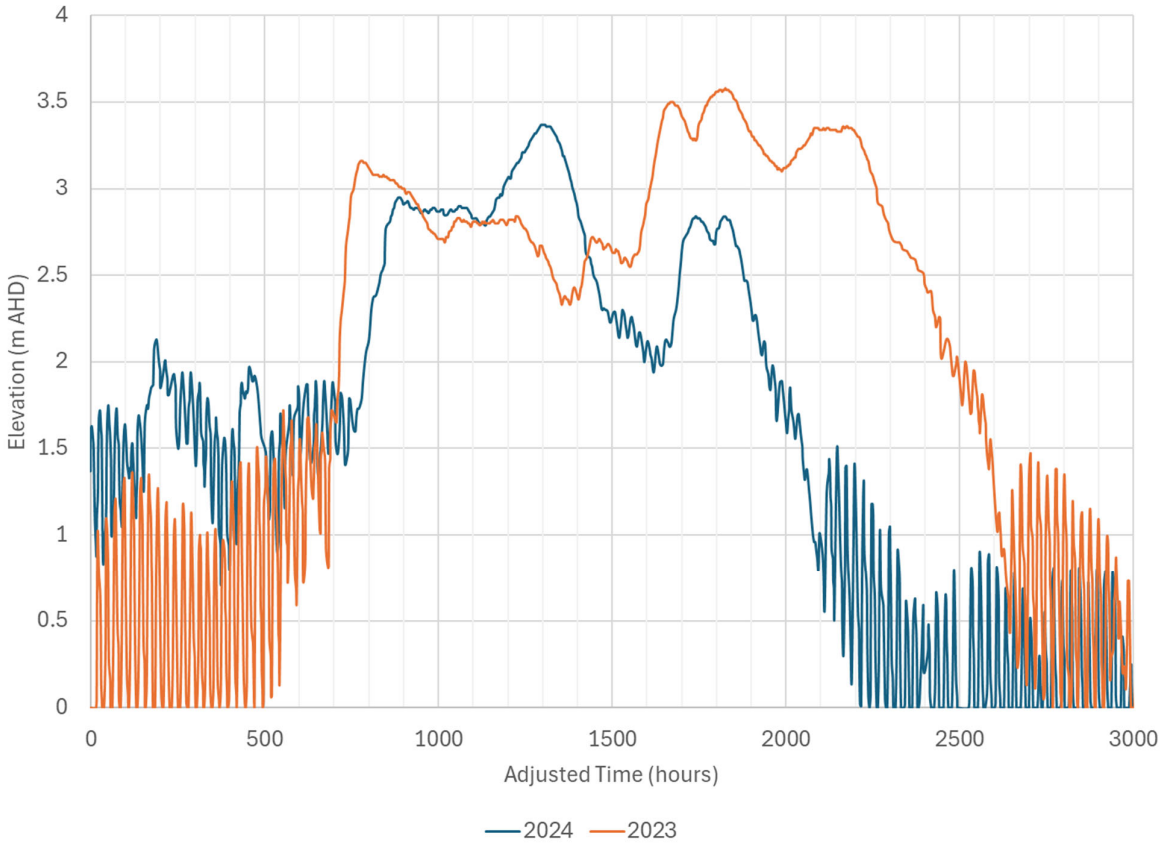


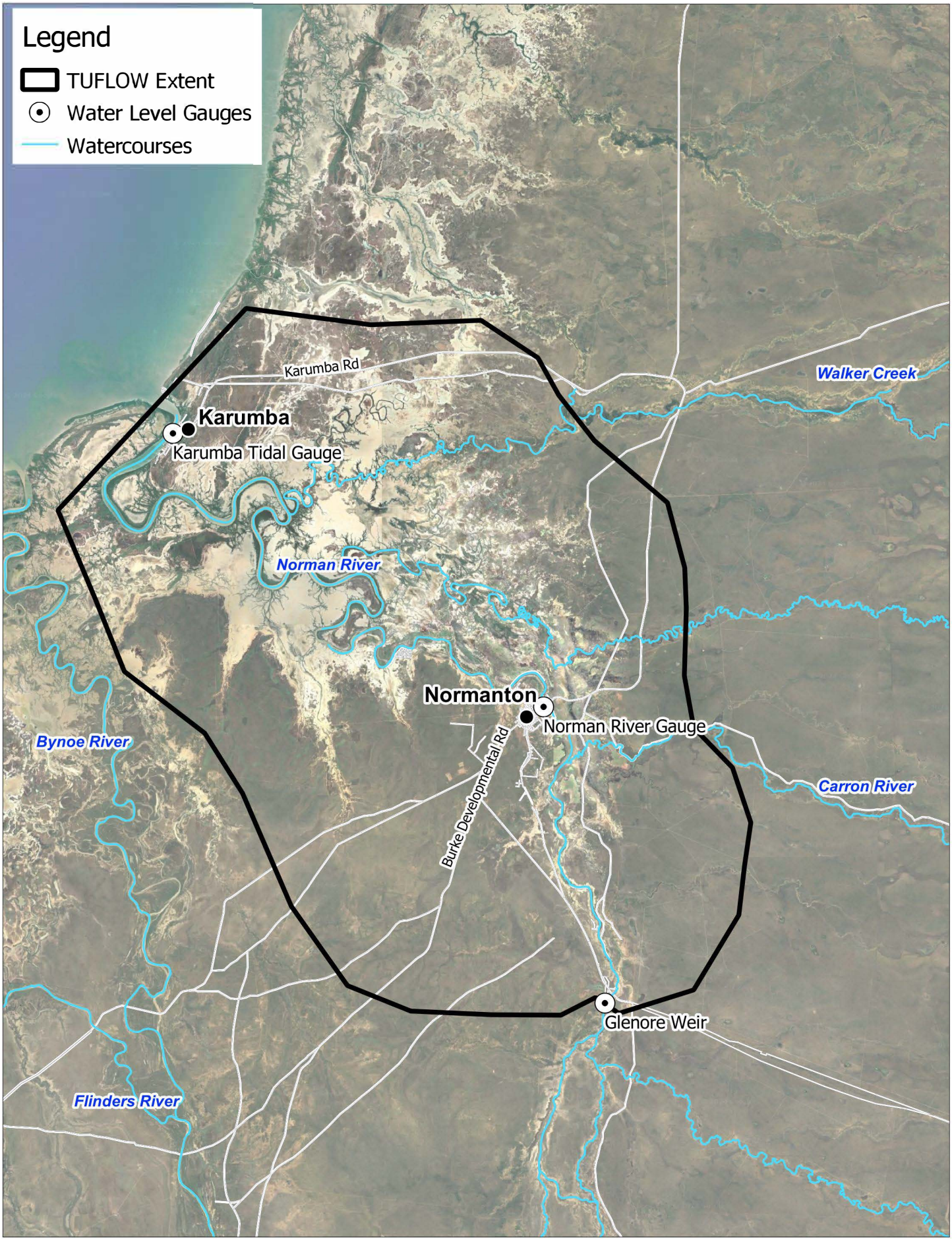
Figure 5.1 Comparison of recorded water level at Normanton

5.4 Available Calibration Data

5.4.1 River Level Gauges

A single gauge was available at Normanton for the purpose of calibration and verification of the Norman River model. An additional gauge located at Karumba recorded tidal fluctuations throughout the two events, this record of water levels at Karumba was used as the downstream boundary. The location of the gauge location is shown in Figure 5.2 below.

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Title:

Available water level gauge

Figure: **5.2**

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6 Hydraulic Model Calibration

6.1 Calibration Approach

This section discusses the performance of the hydraulic model results compared to stream gauge records from these historic events.

This was a hydraulic calibration and verification exercise with derived discharge applied at Glenore Weir. The calibration event (2024) was used to optimise model parameters and the verification event (2023) were used to check the performance of the adopted parameters.

The calibration of the hydraulic model has been assessed against model performance indicators. These performance indicators (discussed in Section 5.2) include comparisons of modelled results against recorded peak levels, timings of the flood peak and shape of the hydrograph.

The overall aim of the calibration was to derive a single set of hydraulic model parameters, principally Manning's n bed resistance values, and hydrologic model parameters (alpha and beta values) that can be applied across a range of events and which can be used in subsequent design event modelling.

6.2 Performance Indicators

6.2.1 Overview

Numerous performance indicators have been adopted to assess the performance of the hydraulic model for calibration events. Primarily these are focussed on the peak of the flood (magnitude and timing).

Information obtained from stream gauges to judge model performance is:

- The peak water level for the specific event;
- The time when the peak water level occurred; and
- The shape of the rising and falling limbs of the hydrograph.

Further explanation on how this data has been used is provided below.

Specific performance indicators are discussed in the following sections.

6.2.2 Peak Water Level

The recorded peak water level at the Normanton water level gauge was compared to the modelled peak water level.

The aim was to achieve a desired tolerance for differences in peak flood level of ±0.3m.

6.2.3 Time of the Peak Water Level

The time at which the peak water level was recorded was compared against modelled time. This performance indicator demonstrates how fast the modelled flood wave is travelling with respect to actual travel times. The comparison between the recorded and modelled peak level times was considered as a comparison of the peak water level.

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6.2.4 Shape of the Hydrograph

The shape of hydrograph was considered a primary indicator of model performance. This allows the models performance to be indicated in regard to the rising and falling hydrograph limbs. This can be assessed subjectively by visual inspection of results or objectively using a mathematical estimate of the error between the simulated and observed levels. For the purposes of this study a visual inspection was considered the most appropriate method of assessment. The performance was judged based on the closeness of fit.

6.3 Calibration Results

6.3.1 Introduction

The following sections summarise the hydraulic model calibration for each of the historical events considered in the assessment. The commentary should be read in conjunction with the supporting tables, drawings and plots of results provided in a separate Results Addendum. This addendum contains the following:

- Tabulated peak flood heights and time of peaks for both modelled and recorded output. Differences between modelled and recorded are shown (modelled minus recorded).
- Peak flood surface maps showing modelled flood elevations for each event considered. The catchment area is split across five separate maps and a key sheet is provided on individual maps. Where surveyed flood debris marks were available, these have been included on the peak flood surface maps with a colouring and symbology that matches project tolerances.
- Plots of Normanton river level gauge. These plots include the following datasets (where available):
  - Observed levels (i.e. levels recorded at the gauge)
  - Modelled levels (based on outputs from the model developed for this study)

6.3.2 2023 Flood Event Calibration

The 2023 event was a significant, long duration, multi-peaked flood event across the Norman River catchment. The river level gauge at Normanton operated throughout the event, collecting suitable level data and could be used in the calibration. The results shown in Figure 6.1 illustrates the following:

- The overall shape of modelled hydrograph compares well against the recorded hydrograph. While there are some inconsistencies between levels the model generally performs well for the main peak of the event. The results show some attenuation in the modelled results compared with the observed levels particularly in the initial rising limb and between 3 January and 10 January where the increase in level is slower than observed.
- The modelled peak water level in the event compares very well to recorded peak level. At approximately 0.14 metres difference the modelled peak level is well within the 0.3 metre tolerance.
- Modelled flood peak travel times within the catchment compare very well with recorded travel times for this event. At the Normanton gauge, the modelled time of peak is 1,834 hours with the observed peak occurring at 1,827 hours for a difference of 7 hours between observed and modelled.

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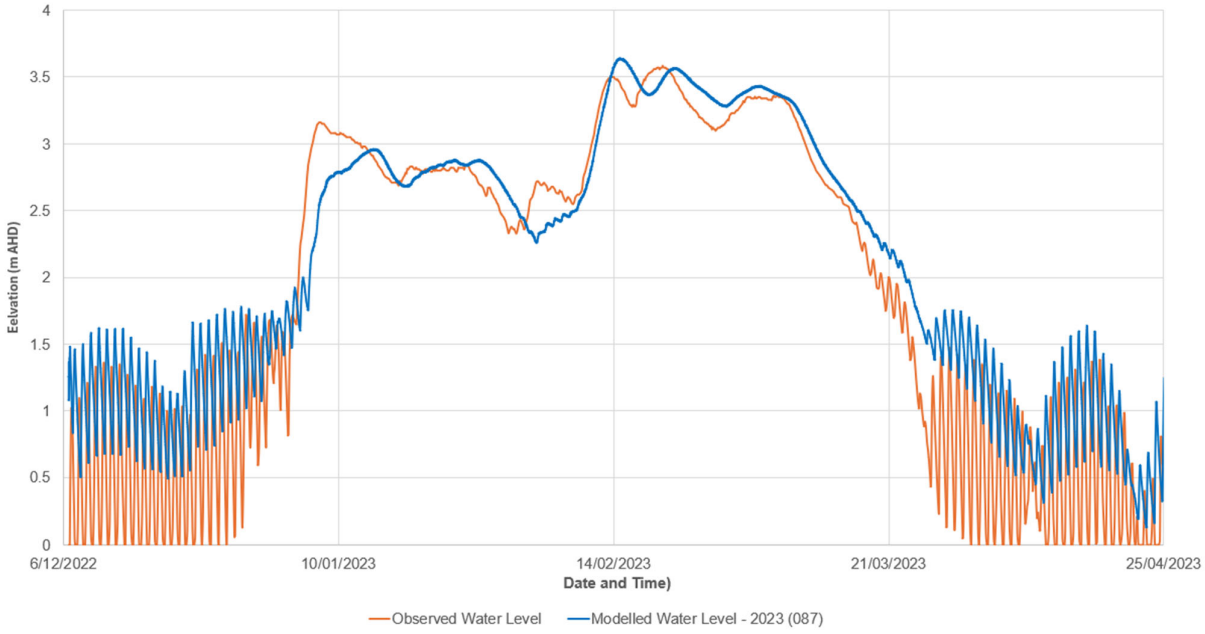
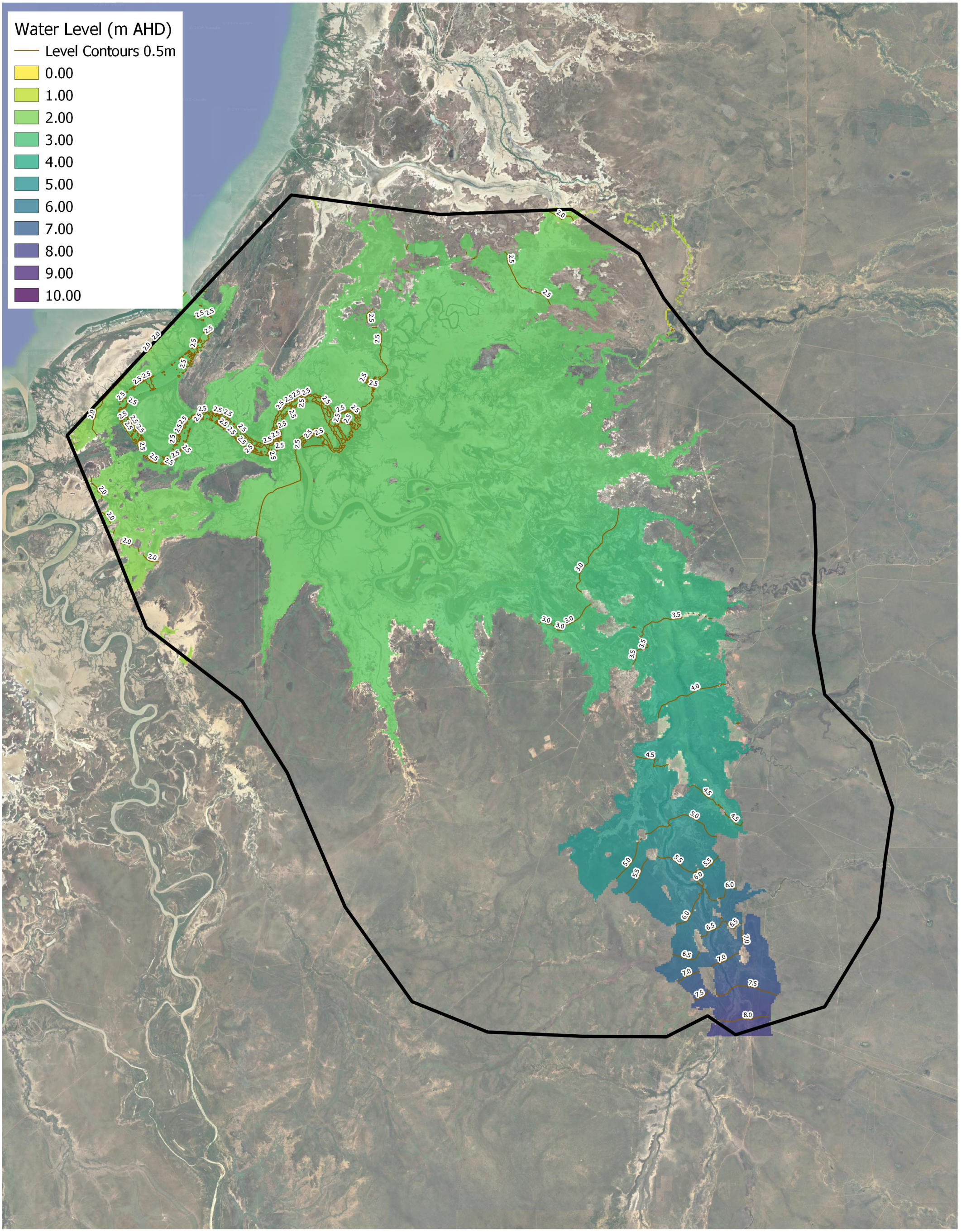


Figure 6.1 Comparison of observed and modelled water level hydrographs at Normanton

Overall, the modelling of the 2023 event is considered to result in a good calibration, this is recognised through a suitable timing and magnitude of the modelled peak compared to existing, as well as a consistent hydrograph shape.

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TUFLOW Extent

Title:

Modelled Water Level 2023 Flood Event Calibration

Drawing: 6.2

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6.3.3 2024 Flood Event Calibration

Similarly to the 2023 event, the 2024 flood event was a significant, long duration, multi-peaked flood event across the Norman River catchment. The river level gauge at Normanton operated throughout the event, collecting suitable level data and could be used in the calibration. The results shown in Figure 6.3 below illustrate the following:

- The overall shape of modelled hydrograph compares well against the recorded hydrograph. While there are some inconsistencies between levels, the model generally performs well for the main peak of the event. The results show a greater volume of water in the modelled results compared with the observed levels leading to higher water levels in the modelled results, particularly between hours 180 and 800.
- The modelled peak water level in the event compares very well to recorded peak level. At approximately 0.03 metres difference the modelled peak level is well within the 0.3 metre tolerance.
- Modelled flood peak travel times within the catchment compare very well with recorded travel times for this event. At the Normanton gauge, the modelled time of peak is approximately 1,282 hours with the observed peak occurring at 1,296 hours for a difference of 15 hours between observed and modelled.

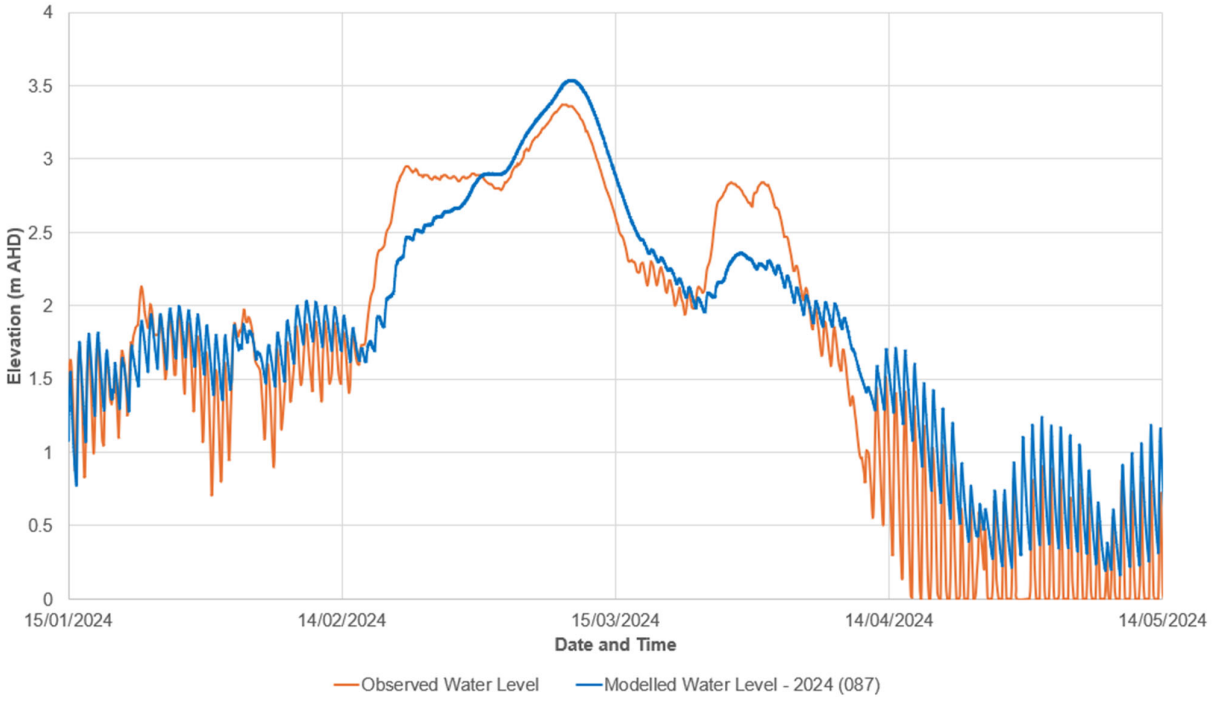
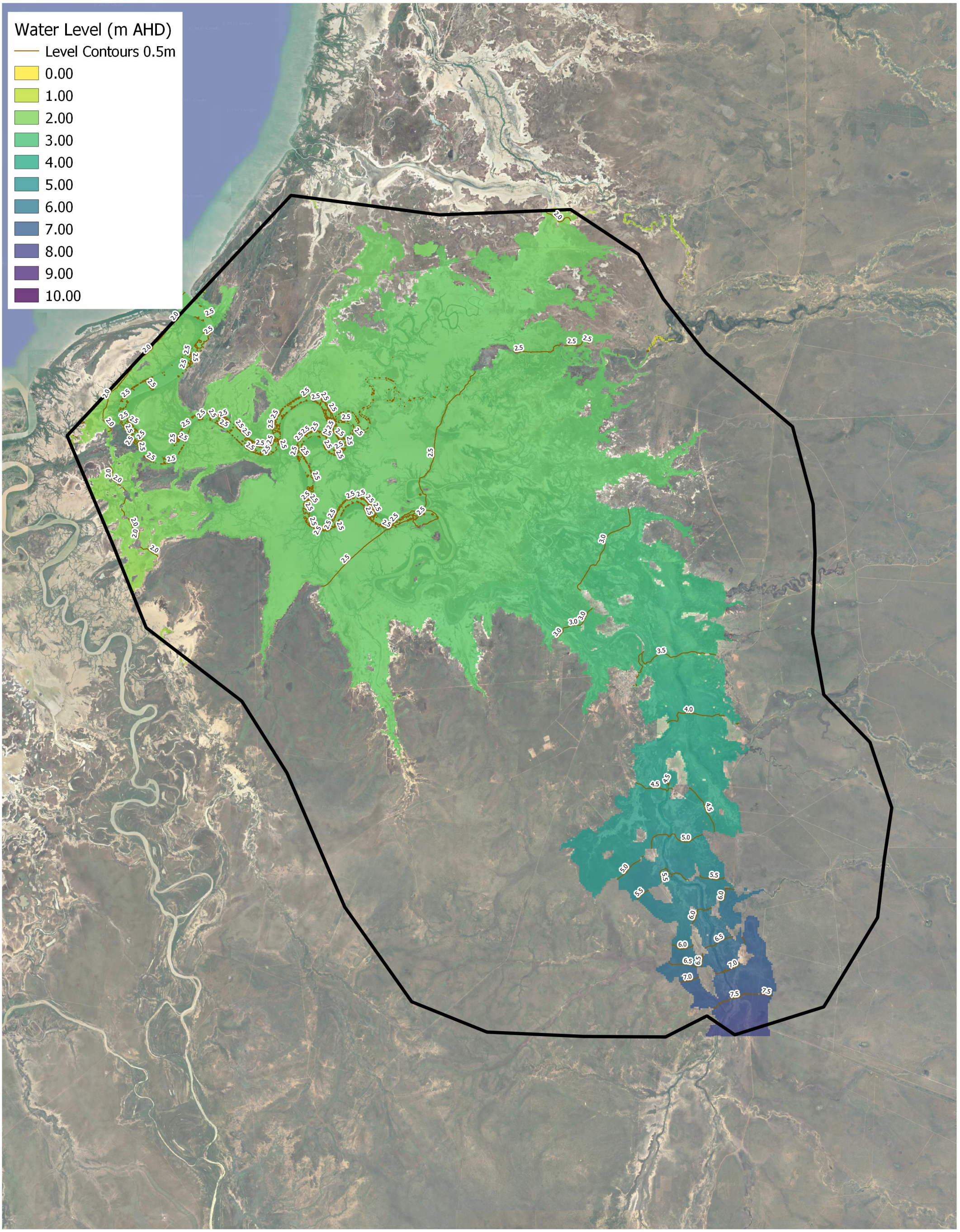


Figure 6.3 Comparison of observed and modelled water level hydrographs at Normanton

Overall, the modelling of the 2024 event is considered to result in a good calibration, this is recognised through a suitable timing and magnitude of the modelled peak compared to existing, as well as a consistent hydrograph shape in comparison. This gives confidence that the model is able to satisfactorily replicate flood events in the Norman River.

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TUFLOW Extent

Title:

Modelled Water Level 2024 Flood Event Calibration

Drawing: 6.4

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6.4 Recommended Hydraulic Parameters for Design

Overall, it has been demonstrated that the model performs well across multiple long duration flood events of different characteristics, a reasonable match of flood peaks has been achieved. The calibration has been accomplished using a single set of Manning's n roughness values, recognising that the calibration performance could potentially be improved for any particular event using a customised set of Manning's n values.

Use of a single set of parameters demonstrates that these values can be applied in a design case and be representative of a range of floods. The final set of calibrated and adopted Manning's n values are listed in Table 6.1.

Table 6.1 Applied roughness parameters

Landuse	Manning's 'n'
Water	0.010
Unvegetated Areas	0.030
Vegetated Areas	0.100
Roads	0.020
Urban Precinct	0.100
Buildings	0.333

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7 Design Event Modelling

7.1 Estimation of Peak Discharge using Flood Frequency Analysis

As previously discussed, due to the scale of the Norman River catchment and the uncertainty associated with flows entering the Norman River from the Flinders River, development of a hydrologic model of the catchment would have presented significant challenges. The presence of Glenore Weir on the Norman River presented an opportunity to quantify flows in the Norman River.

This study identified the potential to improve the estimation of discharge as a factor of observed water level at Glenore Weir. The modelled rating curve, discussed in Section 4, enabled this improvement to occur. Following the conversion of the Glenore Weir record, a review of the resulting discharge identified a significant disparity in calculated flows between the time periods from 1974 to 1996 and 1996 to present day as shown in Figure 7.1 below.

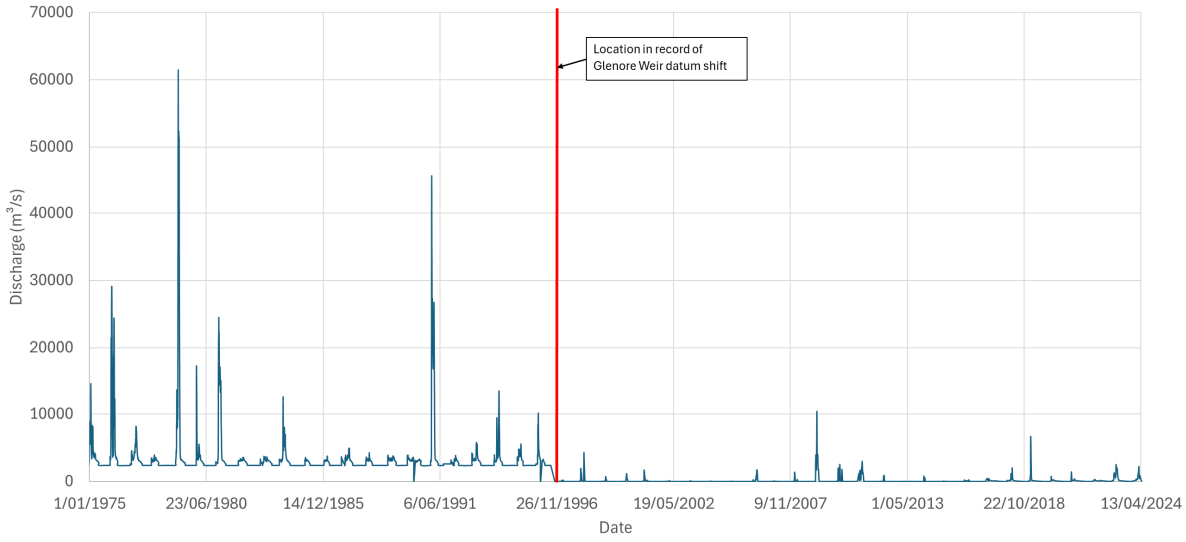


Figure 7.1 Derived Flow Record at Glenore Weir from 1974

Further investigation of the gauge record and history of Glenore Weir identified a shift in the Glenore Weir gauge datum occurring in 1996, resulting in a significant difference in observed gauge levels. Table 7.1 below identifies the shift in datum conversion factor.

Table 7.1 Datum Correction of Glenore Weir

Time period	Gauge Correction (m) relative to Datum (m AHD)[5]
10/01/1974 to 24/10/1996	1.64
24/10/1996 to present day	- 4.32

Without further information and justification for the shift in gauge datum available, the record was divided into pre- and post-1996 with the post-1996 data utilised for the Flood Frequency Analysis (FFA).

[5] https://www.bom.gov.au/qld/flood/networks/section6.shtml

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Considering the adopted process for an FFA, reducing the length of record by approximately 20 years results in an increased uncertainty related to the estimation of peak discharges. While reducing the full length of record excludes significant flow events in 1974, 1976, 1979, 1981 and 1993, considering the disparity between pre- and post-1996 derived discharges and uncertainty regarding the location of the gauge prior to 1996, more data is not necessarily reflective of an improved estimate. Inclusion of pre-1996 events would ultimately result in greater uncertainty if the study was continued with the full length of record.

Future updates of this assessment may consider revisiting historic events pre-1996, however this would be dependent on the availability of gauge location and datum correction methodology for the pre-1996 configuration.

Table 7.2 Record of Largest 10 Annual Maxima Discharge

Rank	Event Year	Peak Discharge @ Glenore Weir (m^3/s)
1	2009	10,422
2	2019	6,698
3	1998	4,315
4	2011	2,999
5	2010	2,544
6	2023	2,525
7	2024	2,226
8	2018	2,034
9	2006	1,720
10	2001	1,716

The FFA was undertaken on an annual maxima series of peak discharge presented in Table 7.2. The analysis of the data was completed using TUFLOW-FLIKE software which is consistent with ARR2019 methodologies. A Bayesian approach was applied within the software with results fitted to a Log Pearson (LP3) distribution. Table 7.3 below shows the results of the FFA.

Table 7.3 FFA Derived Peak Discharge Estimate

AEP (%)	Peak FFA Discharge Glenore Weir (m^3/s)
20	2,710
10	5,074
5	8,220
2	13,628
1	18,688
0.5	24,589
0.2	33,672
0.05	50,118

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7.2 Glenore Weir Design Event Hydrograph

Application of the peak discharge values as determined from the FFA in the TUFLOW hydraulic model require fitting to a flood event hydrograph. Typically the design event hydrographs will be an output of a hydrology model, in this case, given the determination of peak discharge through FFA, the flood hydrographs for each design event have been applied to the 2023 flood event hydrograph and scaled to match the design peak discharge. Figure 7.2 below illustrates the dimensionless flood hydrograph that each of the design events have been based on.

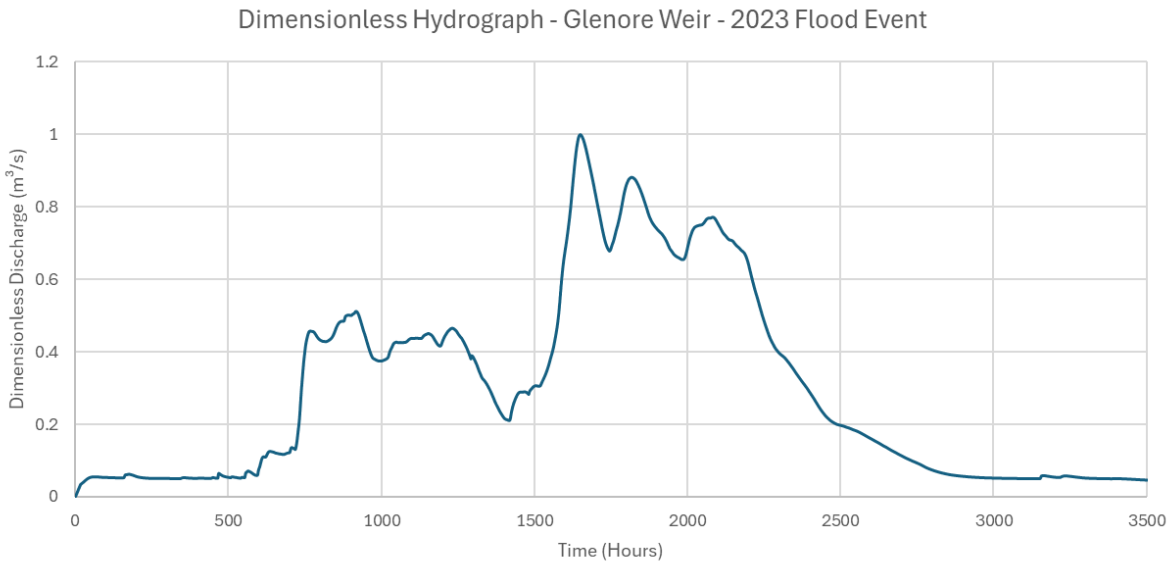


Figure 7.2 Dimensionless Hydrograph of 2023 Flood Event

Figure 7.3 below presents the flood hydrograph associated with each design event at Glenore Weir.

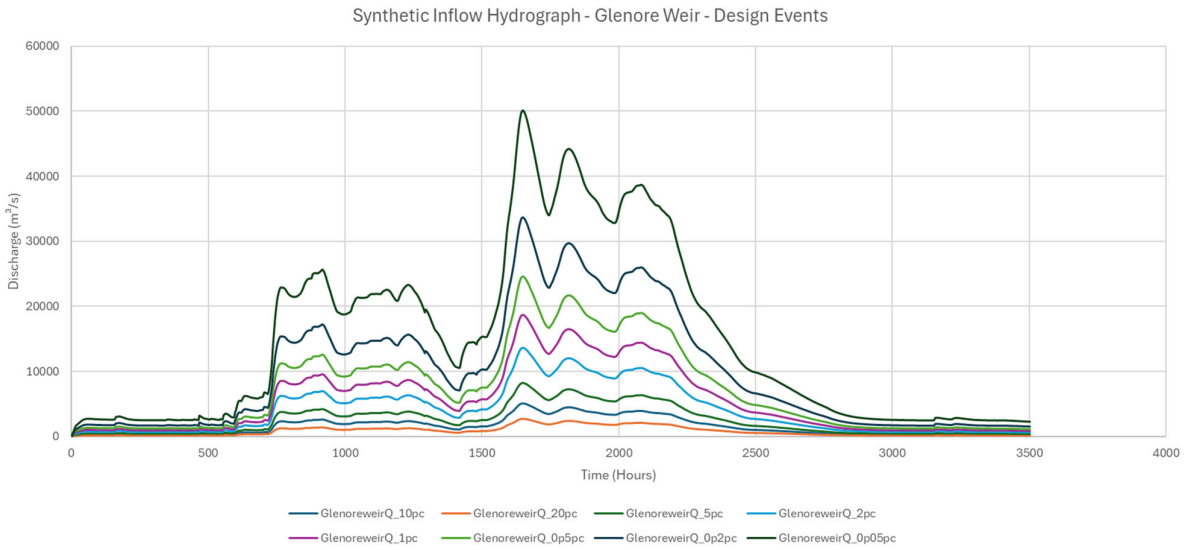


Figure 7.3 Synthetic Hydrograph Scaled for Design Events

7.3 Sensitivity Testing of the 1% AEP Design Event

Four additional scenarios have been simulated for the 1% AEP design event to assess the impact of influencing factors including coincident inundation, flooding independent of storm tide, storm tide independent of flooding and climate change. These four sensitivities have been included in line with ARR2019 methodology.

7.3.1 Storm Tide Coincident Inundation

When investigating the risk of combined inundation from storm tide and flooding a worst-case scenario considers the timing of each inundation peak occurring simultaneously. In this sensitivity test the 1% AEP design flood event was simulated with the 1% AEP storm tide (replacing the previously simulated 10% AEP storm tide) with the flood and storm tide peak (3.4m AHD[6]) coinciding at the peak of the flood event.

7.3.2 Storm Tide Independent Event

While the worst-case scenario for inundation during a 1% AEP design event will consider coinciding inundation, flooding and storm tide can occur independent of each other. For this sensitivity test the 1% AEP storm tide timeseries was utilised as the downstream boundary of the model with the exclusion of any Norman River flow, resulting in an assessment of storm tide alone.

7.3.3 Flooding Independent Event

Similarly to a storm tide independent event, flooding can occur during the influence of a full tidal range. This sensitivity test on the 1% AEP design flood event considered an inflow at Glenore Weir alone, with no tidal timeseries. Instead, the downstream boundary was defined as a fixed relationship between water level and discharge applied as a water level slope of 0.1%.

[6] 'Gulf of Carpentaria Storm Tide and Inundation Study, GHD, 2013'

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7.3.4 Observations from Sensitivity Analysis simulations

The four sensitivity tests were simulated using the TUFLOW hydraulic model with the results reviewed with respect to resultant flood extent and level. The simulations resulted in a similar flood extent for the 1% AEP coincident inundation, 1% AEP flooding independent event and 1% AEP with climate change, a significantly smaller extent of inundation resulted from the 1% AEP storm tide independent event. The results of the sensitivity testing were compared to the 1% AEP design event which incorporated a 10% AEP storm tide downstream boundary.

The results show that the sensitivity options with a flooding component result in higher water levels than the design event in all scenarios besides flooding independent and storm tide independent. The results suggest that the selected design event (including a 10% AEP storm tide downstream boundary) results in higher flood levels, compared to implementing a static downstream boundary, without introducing excessive conservativeness to the study results.

7.4 Downstream Boundary

A peak 10% AEP storm tide level of 2.9m AHD has been applied in this assessment. This peak storm tide level was identified from an assessment of storm tide and inundation within the Gulf of Carpentaria (GHD, 2013)[7]. The downstream boundary was modelled as a dynamic tidal boundary requiring the consideration of timing of the tidal peak relative to the Norman River flood event. The adopted approach for this study considers the tidal peak occurring earlier than and independent of the peak of the flood event (non-coincident inundation). A sensitivity test of the 1% AEP flood event investigated the resultant inundation of a 1% AEP flood event and storm tide occurring at the same time.

[7] 'Gulf of Carpentaria Storm Tide and Inundation Study, GHD, 2013'

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8 Climate Change Assessment

8.1.1 Considering Climate Change and Riverine Inundation

Consideration of future climate on flood behaviour is important to understand future flood risk. ARR2019 prescribes a comprehensive methodology for the assessment of influencing factors related to climate change when considering increases in rainfall and discharge. The assessment involves selecting a climate change scenario or Shared Socio-economic Pathway (SSP) which includes SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5 with SSP5 being the most conservative pathway.

For this assessment SSP5 has been selected to define the upper bounds of climate change sensitivity. Secondly a time horizon and storm duration is considered, in this case the 2100 time horizon with a 24-hour storm duration resulting in an increase of 41% has been applied for this sensitivity test. While this assessment is not considering a design storm, the 24-hour duration is consistent with a catchment the size of Norman River.

Table 8.1 SSP5-8.5 Climate Change Factors for Normanton from ARR Datahub[8]

Year	<1 hour	1.5 Hours	2 Hours	3 Hours	4.5 Hours	6 Hours	9 Hours	12 Hours	18 Hours	>24 Hours
2100	86%	77%	71%	64%	58%	54%	50%	47%	43%	41%

8.1.2 Considering Climate Change and Sea Level Rise

Coinciding with riverine inundation the consideration of future climate on sea level rise is equally important. A thorough literature review was undertaken to understand the influence of climate change on sea level rise in the study area. Carpentaria Shire Councils Coastal Hazard Adaptation Strategy (CHAS) completed in 2020 was developed with funding awarded through QCoast 2100, a Queensland Government and Local Government Association of Queensland (LGAQ) initiative to help councils plan for present and future management of coastal hazard impacts. Section 3.4 of the CHAS outlines tidal inundation due to sea level rise. The study states that the Queensland State Government is currently planning for a 2100 sea level rise of 0.8 metres.

Additional resources, including Gulf of Carpentaria Storm Tide and Inundation Study (GHD, 2013)[9], were reviewed to confirm that a 0.8 metre increase was appropriate for application in climate change hydraulic modelling.

[8] https://data.arr-software.org/
[9] 'Gulf of Carpentaria Storm Tide and Inundation Study, GHD, 2013'

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9 Results

Results for the design flood events are presented as mapping of peak flood, depth and velocity for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% and 0.05% AEP design events. The map outputs for design event modelling and sensitivity testing are included in Annex A and Annex B respectively.

9.1 Limitations of Assessment

The approaches used for this assessment have been implemented using the best available data. Sources of uncertainty with these approaches and data are summarised as follows:

- Data
  - Short gauge record length (29 years) relative to the magnitude (infrequency) of events relevant to this assessment.
  - Incomplete gauge records, specifically the previously discussed shift in gauge datum at Glenore Weir. A detailed review of data quality and suitability has not been undertaken.
  - Quality of rating curve used to convert levels to flows. Rating curves are typically most effective when based on field measurements. The discussed update to the rating curve in this study was completed using hydraulic modelling only and, while this is considered an improvement on the existing rating curve, can be improved further using accurate physical measurements.
  - Quality of topography data, for example the assessment has been completed with portions of the hydraulic model implementing SRTM as this is the best available data. SRTM is generally considered unreliable for representing topography when used in digital elevations models (DEM).
- Approach
  - Flood Frequency Analysis (FFA) employs a statistics driven process to estimate design event peak discharge for a range of flood events. The accuracy or confidence in the FFA process improves with larger datasets, typically greater than 50 years. For this assessment, due to technical constraints, only 29 years of observed water level data at Glenore Weir is available which increases the uncertainty in design event discharges.
  - Limited consideration of statistical behaviour has been implemented in this assessment. Design event modelling has been completed on a single synthetic hydrograph representative of the 2023 flood event. This approach is a result of constraints in project resources, scope and data availability.
- Freeboard
  - Freeboard is a necessary safety factor added to a derived flood level in order to reduce the risk to proposed development. Freeboard can be influenced by a number of factors and accounts for uncertainty in the estimates of flood levels, the Carpentaria Shire Council Planning Scheme 2024 recommends a 0.5m freeboard on the defined flood level. A freeboard of 0.5m is appropriate considering limitations of the assessment outlined above.

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10 Conclusions

A hydraulic model of the Norman River between Glenore Weir and Karumba have been developed for the purposes of the Normanton and Karumba Flood Study. Joint calibration and validation has been undertaken to two historical events; 2023 and 2024. While of similar flood magnitude, durations and floods characteristics differ between the two events.

The hydraulic model is a 2D variable sized grid model utilising the TUFLOW HPC solver, SGS and QPC which has allowed for the large study area of around 2,000 square kilometres to be modelled at a high resolution 25m cell size for the Norman River, 50m cell size for Normanton township and 100m cell size for the remainder of the model.

The assessment identified significant discrepancies between observed water level and calculated discharge at Glenore Weir. To improve the representation of flood behaviour at Glenore Weir, additional investigation resulted in the development of a modelled rating curve based on a steady state cut down hydraulic model at Glenore Weir. The derived rating curve was applied to the observed water level record to produce a calculated discharge record. This output was utilised for calibration and design event modelling.

The model calibration has been undertaken with model boundaries consisting of a dynamic tidal boundary at Karumba and a discharge hydrograph at Glenore Weir. Overall, there is good consistency in the modelled flow hydrographs at the Normanton gauge, recognising that limitations of the model are present including the eastern extent of topography as well as the Norman River bathymetry.

Overall the hydraulic model has undergone a robust and comprehensive calibration exercise. The hydraulic model is calibrated to peak flood levels with additional significant emphasis placed on replicating the flood hydrograph timing for the 2023 and 2024 flood events.

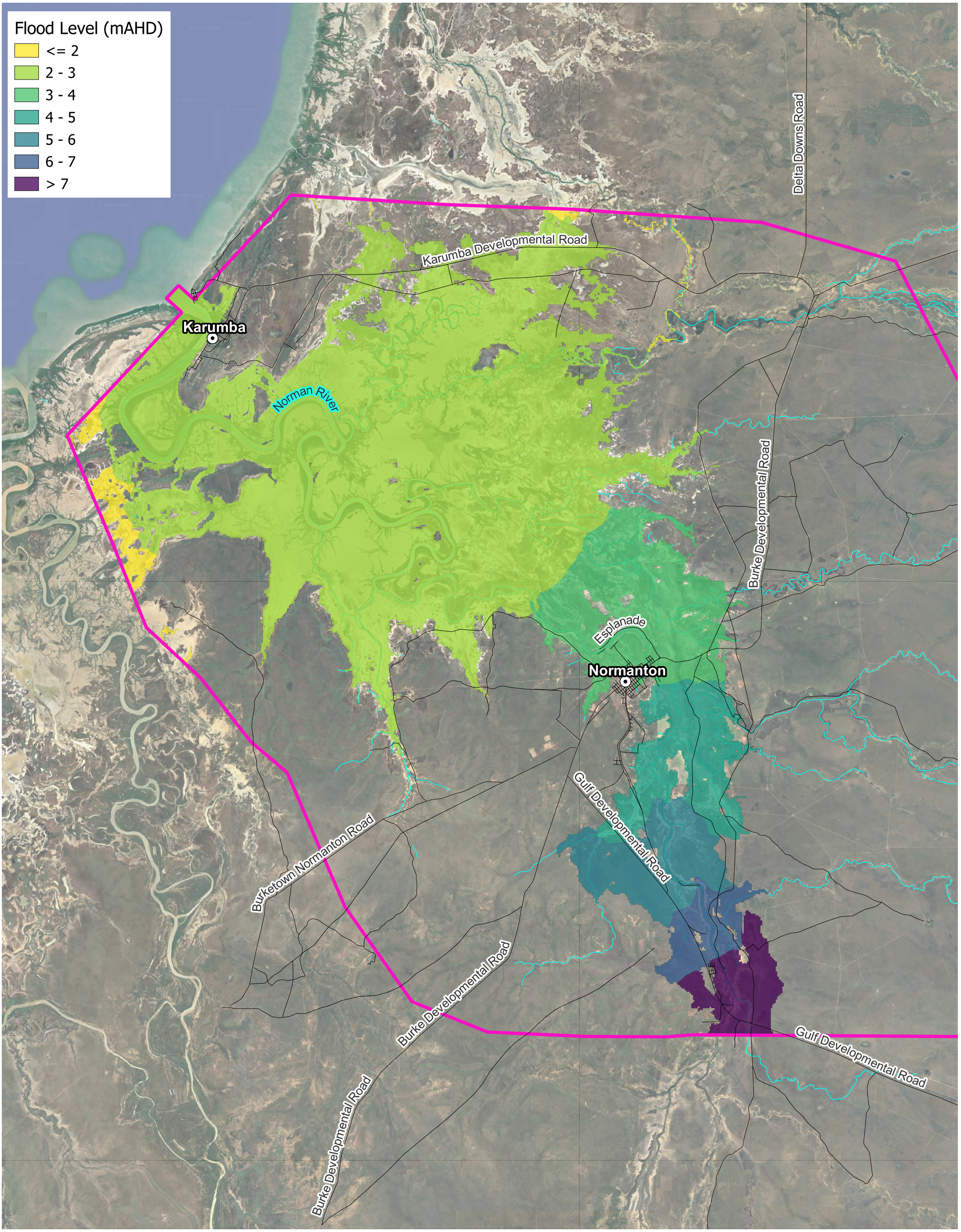
Design event peak flood discharges has been derived through an FFA process. The peak discharges have been applied to a dimensionless hydrograph based on the 2023 flood event utilised for hydraulic model calibration. The dimensionless hydrograph has been scaled based on the outputs of the FFA process and simulated in the hydraulic model for events ranging from 20% to 0.05% AEP design events.

An additional analysis was conducted on the 1% AEP design event to investigate the variations to flood behaviour, this included coincident inundation, storm tide independent of a Norman River flood event and climate change.

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Annex A Design Event Mapping

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- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

20% AEP Peak Flood Level

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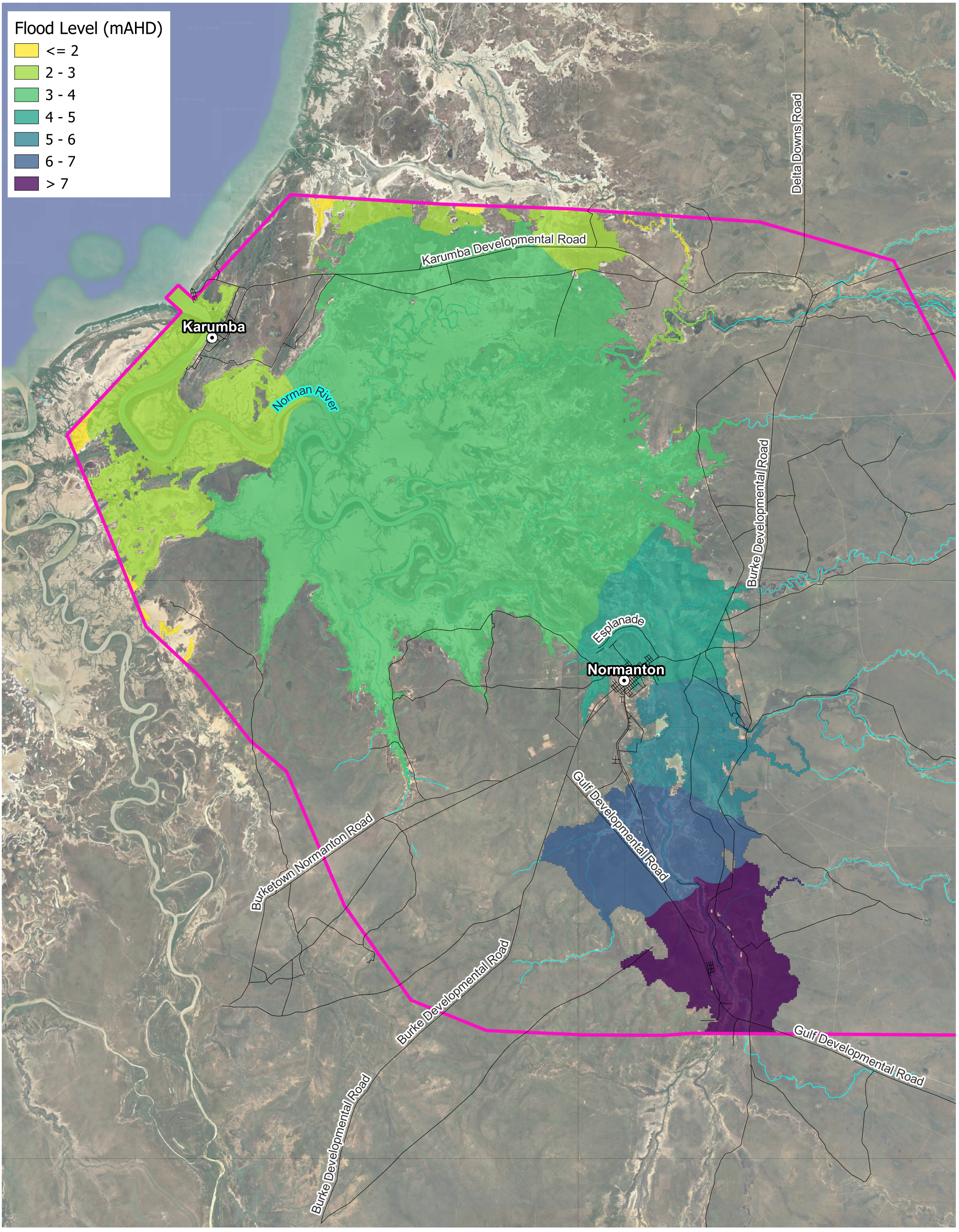
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

10% AEP Peak Flood Level

Drawing: A.2

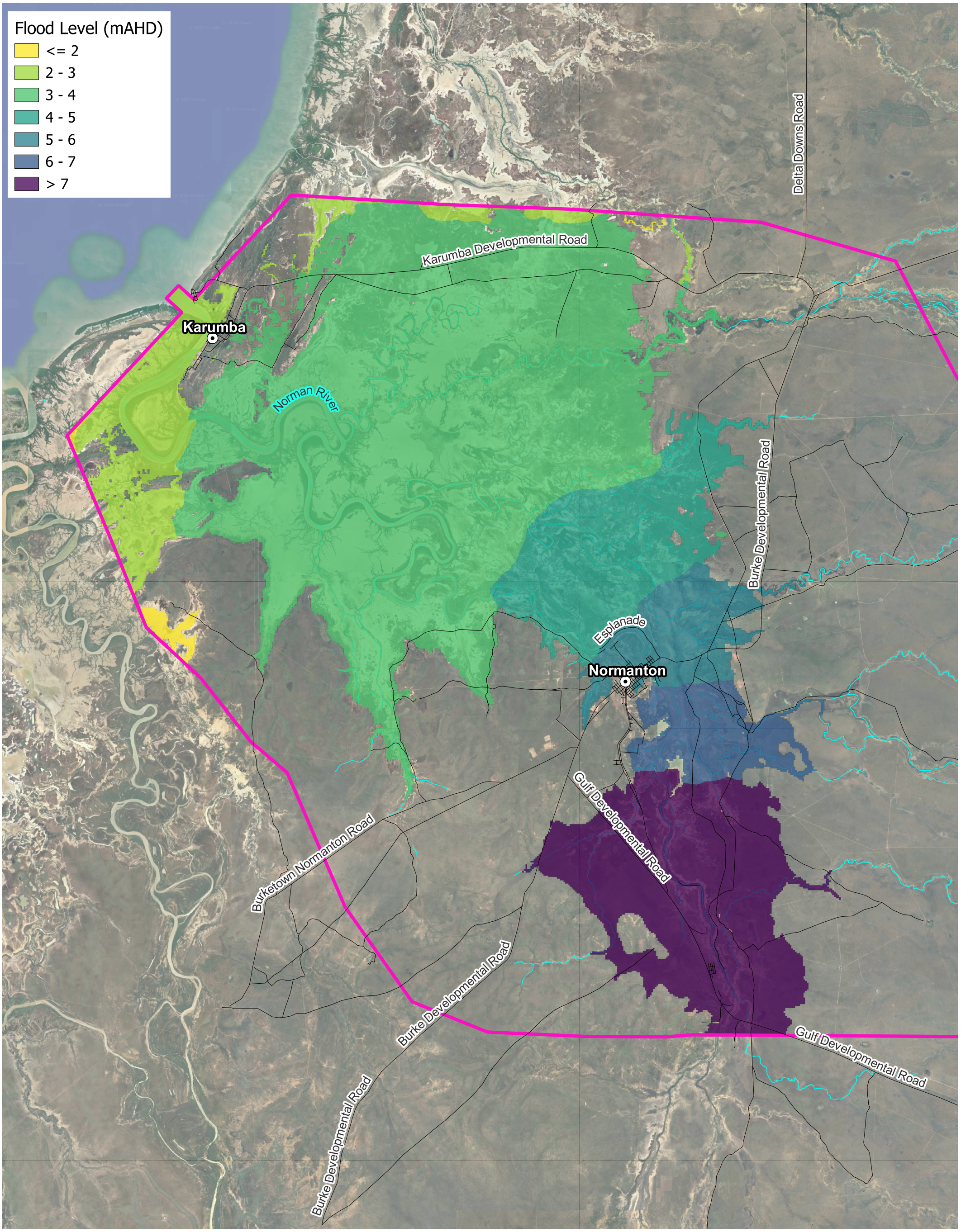
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

5% AEP Peak Flood Level

Drawing: A.3

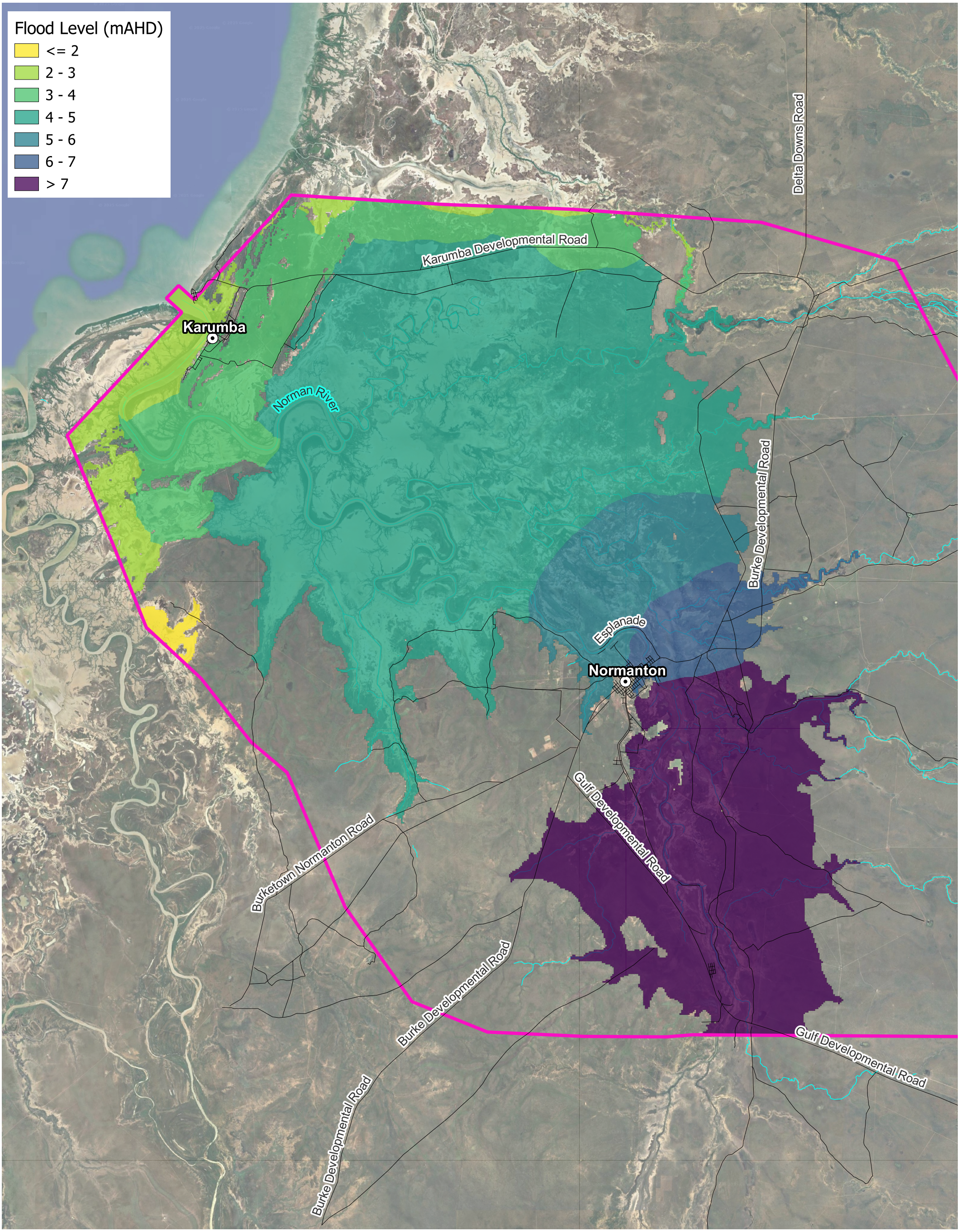
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

2% AEP Peak Flood Level

Drawing: A.4

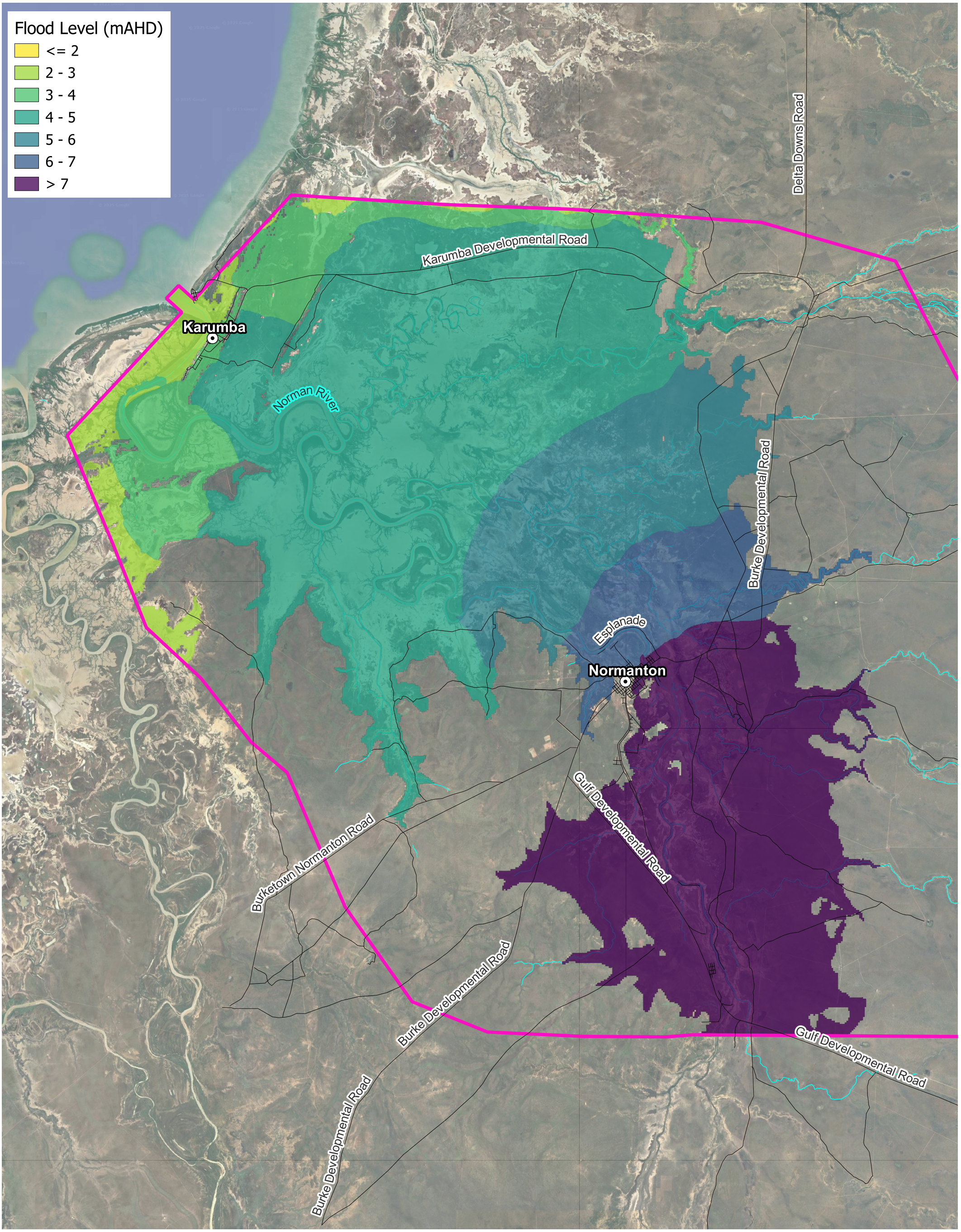
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP Peak Flood Level

Drawing: A.5

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Flood Level (mAHD)
<= 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
> 7

Karumba
Normanton
Karumba Developmental Road
Delta Downs Road
Norman River
Burke Developmental Road
Esplanade
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

0.5% AEP Peak Flood Level

Drawing: A.6

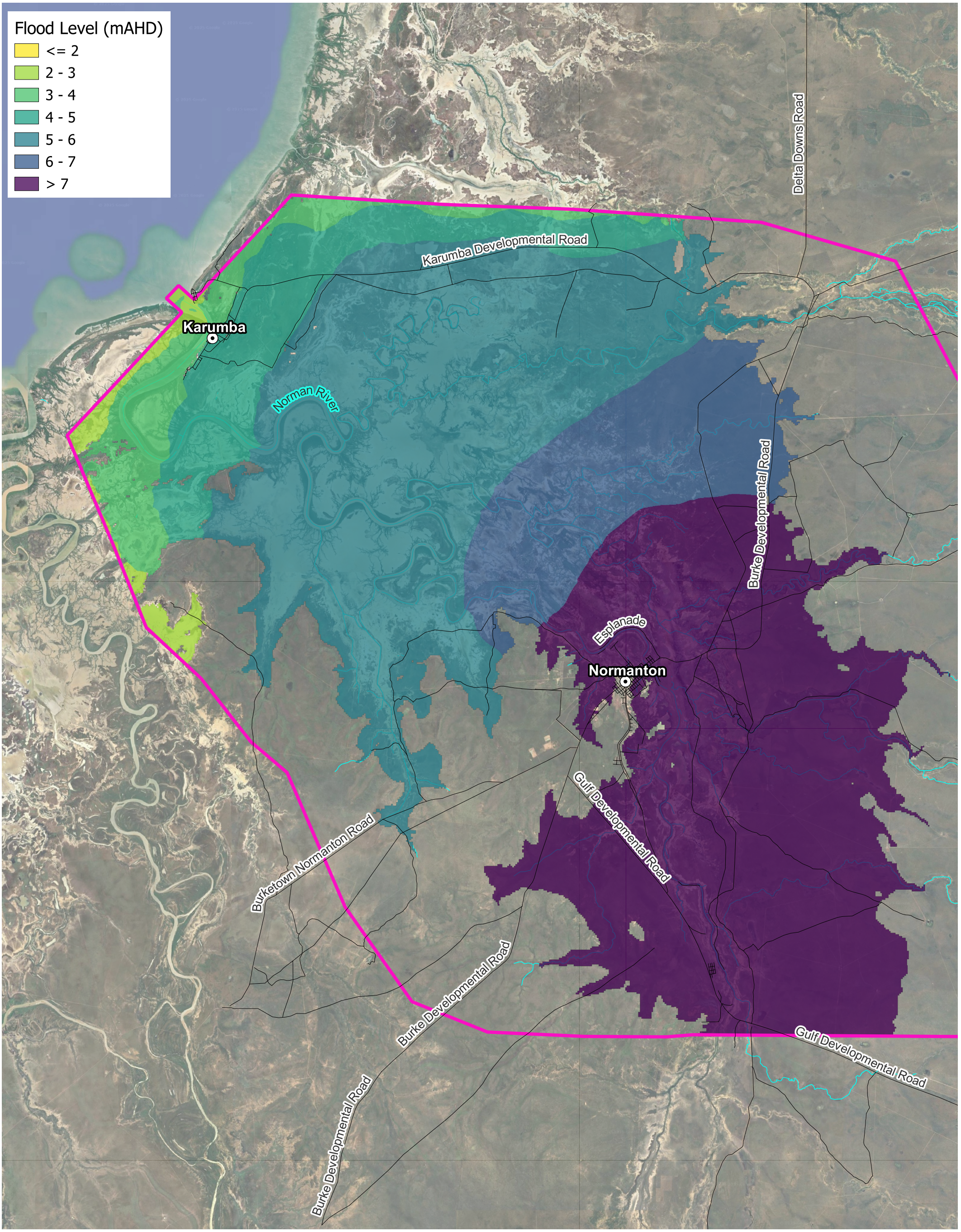
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

0.2% AEP Peak Flood Level

Drawing: A.7

Rev: A

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Flood Level (mAHD)
<= 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
> 7

Karumba
Normanton
Karumba Developmental Road
Delta Downs Road
Norman River
Burke Developmental Road
Esplanade
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

0.05% AEP Peak Flood Level

Drawing: A.8

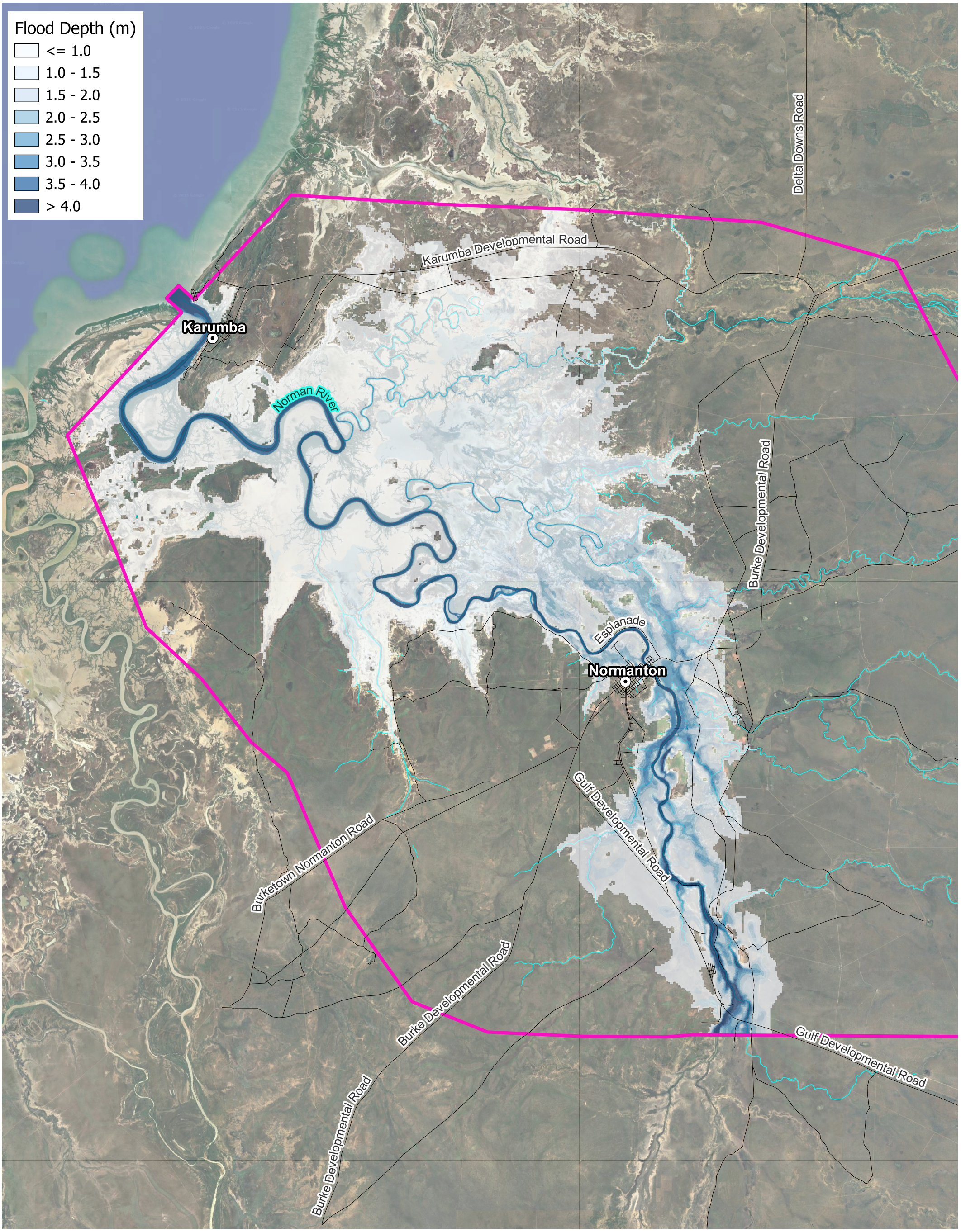
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

20% AEP Peak Flood Depth

Drawing: A.9

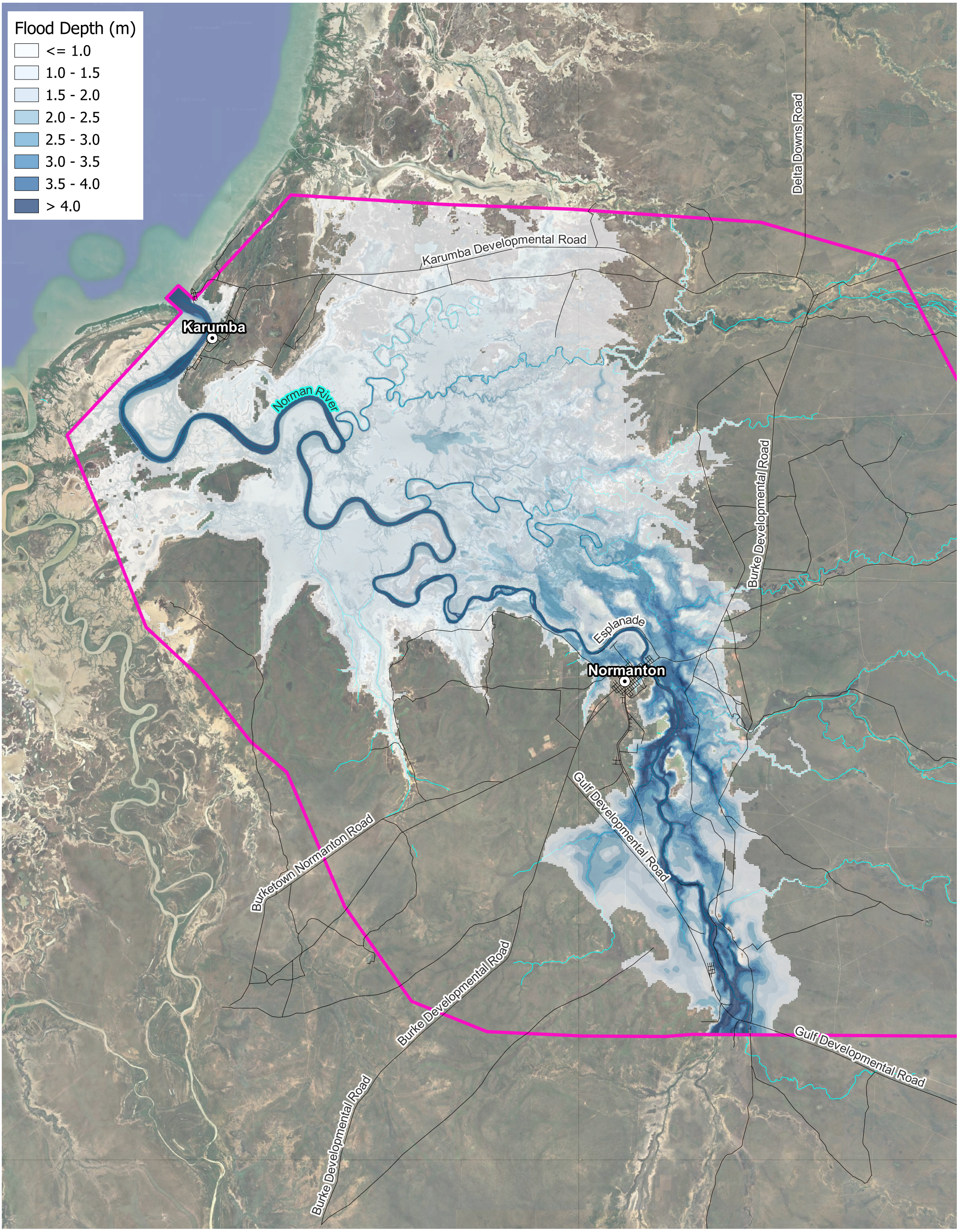
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

10% AEP Peak Flood Depth

Drawing: A.10

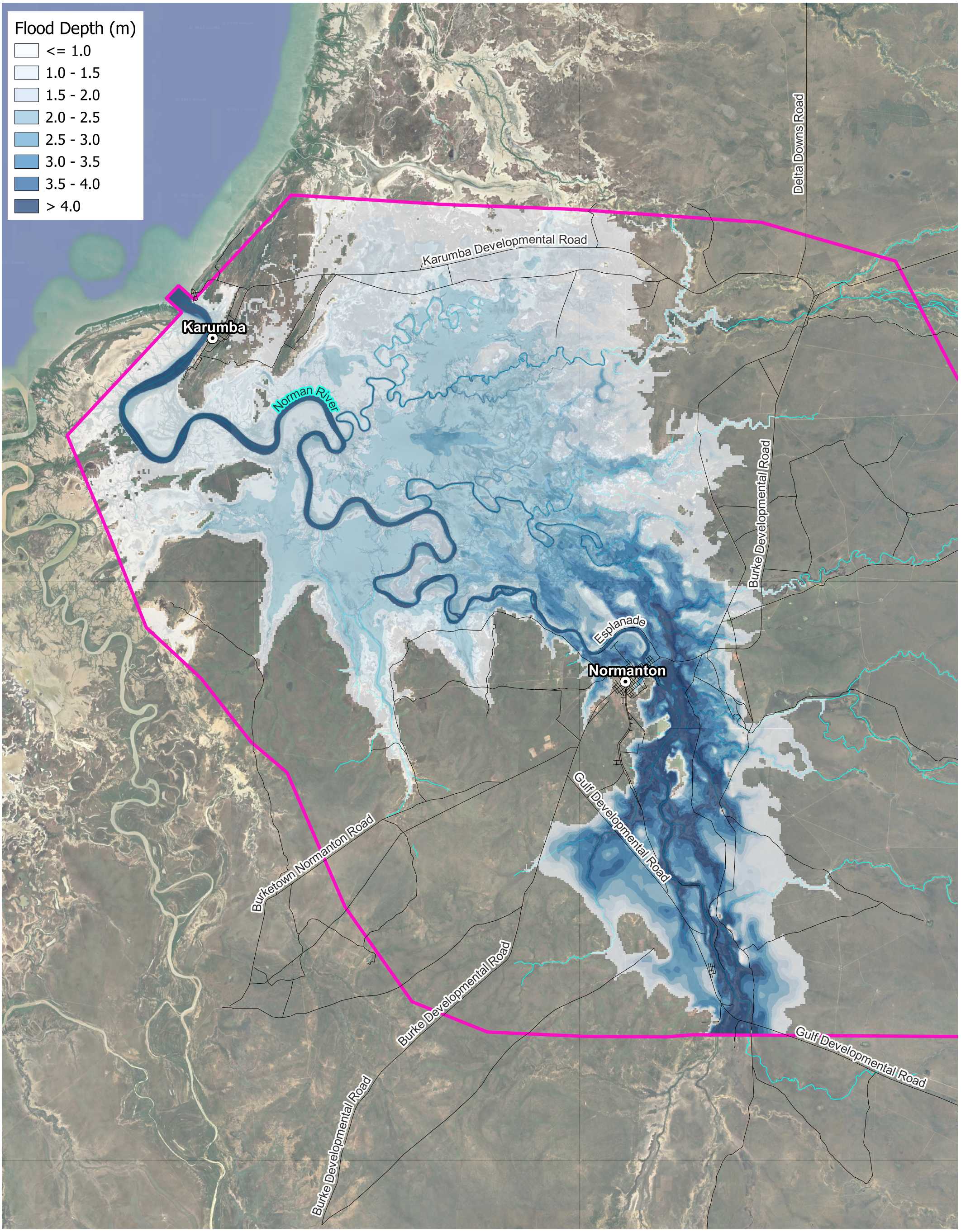
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

5% AEP Peak Flood Depth

Drawing: A.11

Rev: A

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Flood Depth (m)
<= 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
3.5 - 4.0
> 4.0

Karumba
Karumba Developmental Road
Delta Downs Road
Norman River
Burke Developmental Road
Esplanade
Normanton
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend
Towns
Roads
Waterways
TUFLOW Extent

Title:
2% AEP Peak Flood Depth

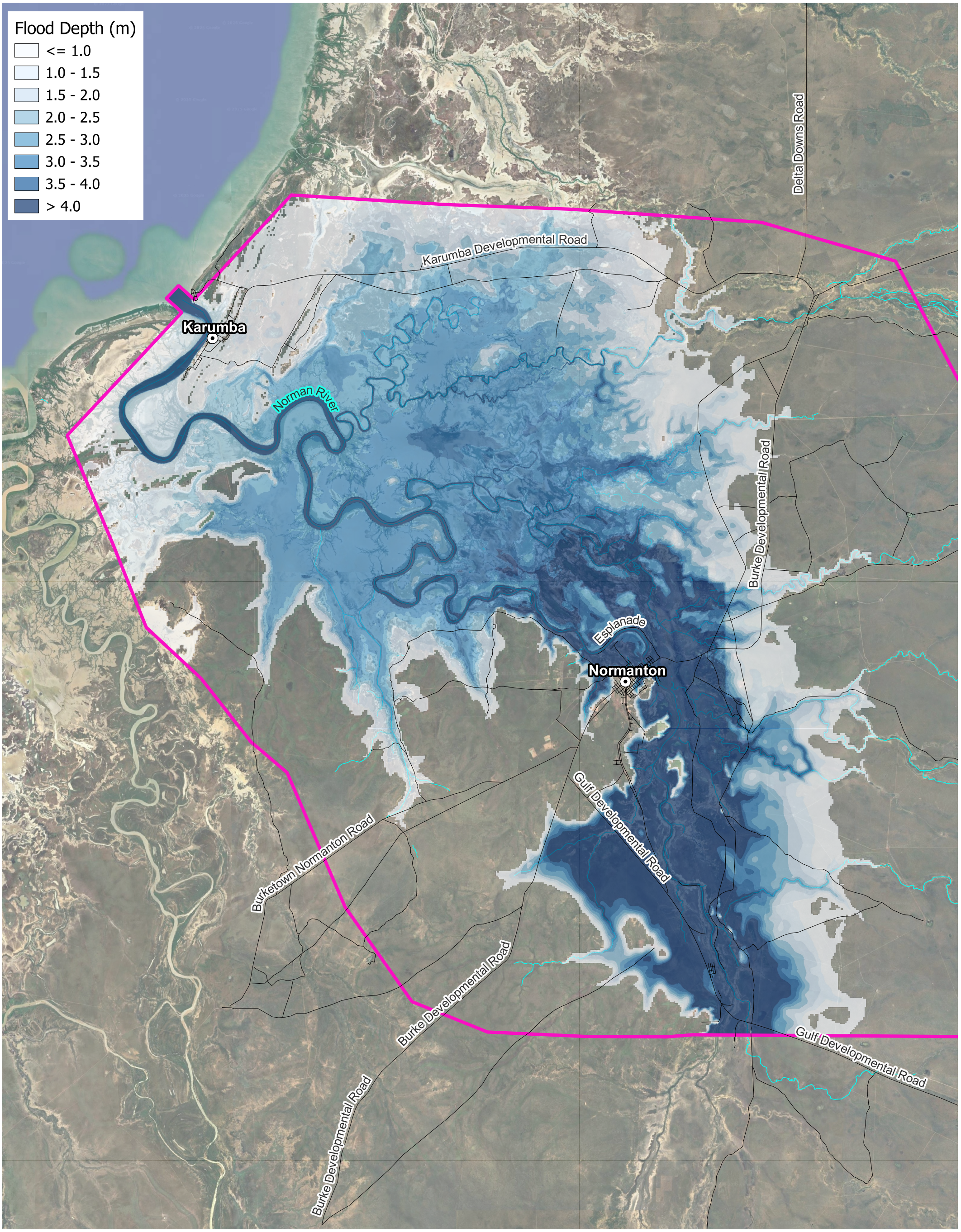
Drawing: **A.12**
Rev: **A**

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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP Peak Flood Depth

Drawing: A.13

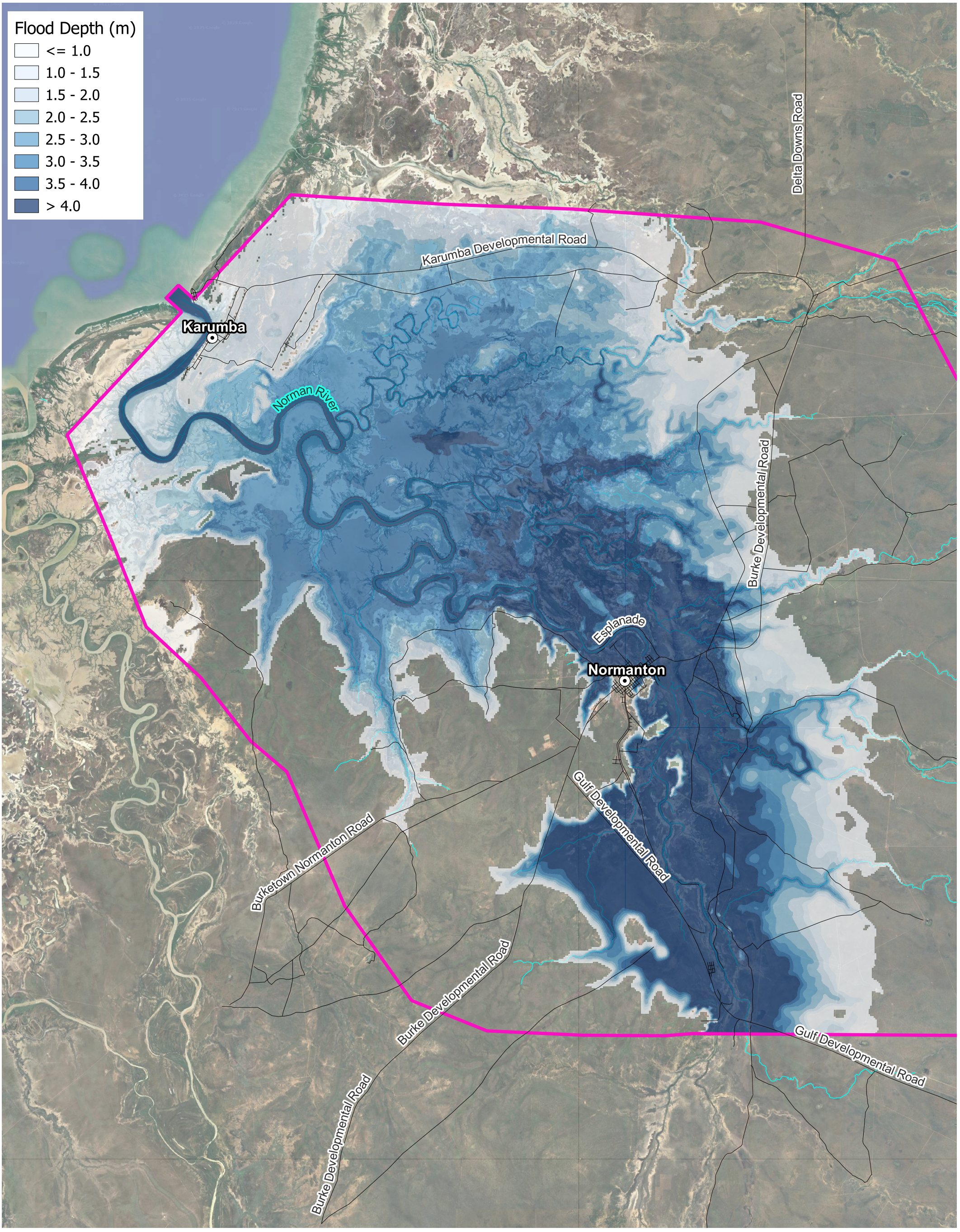
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

0.5% AEP Peak Flood Depth

Drawing: A.14

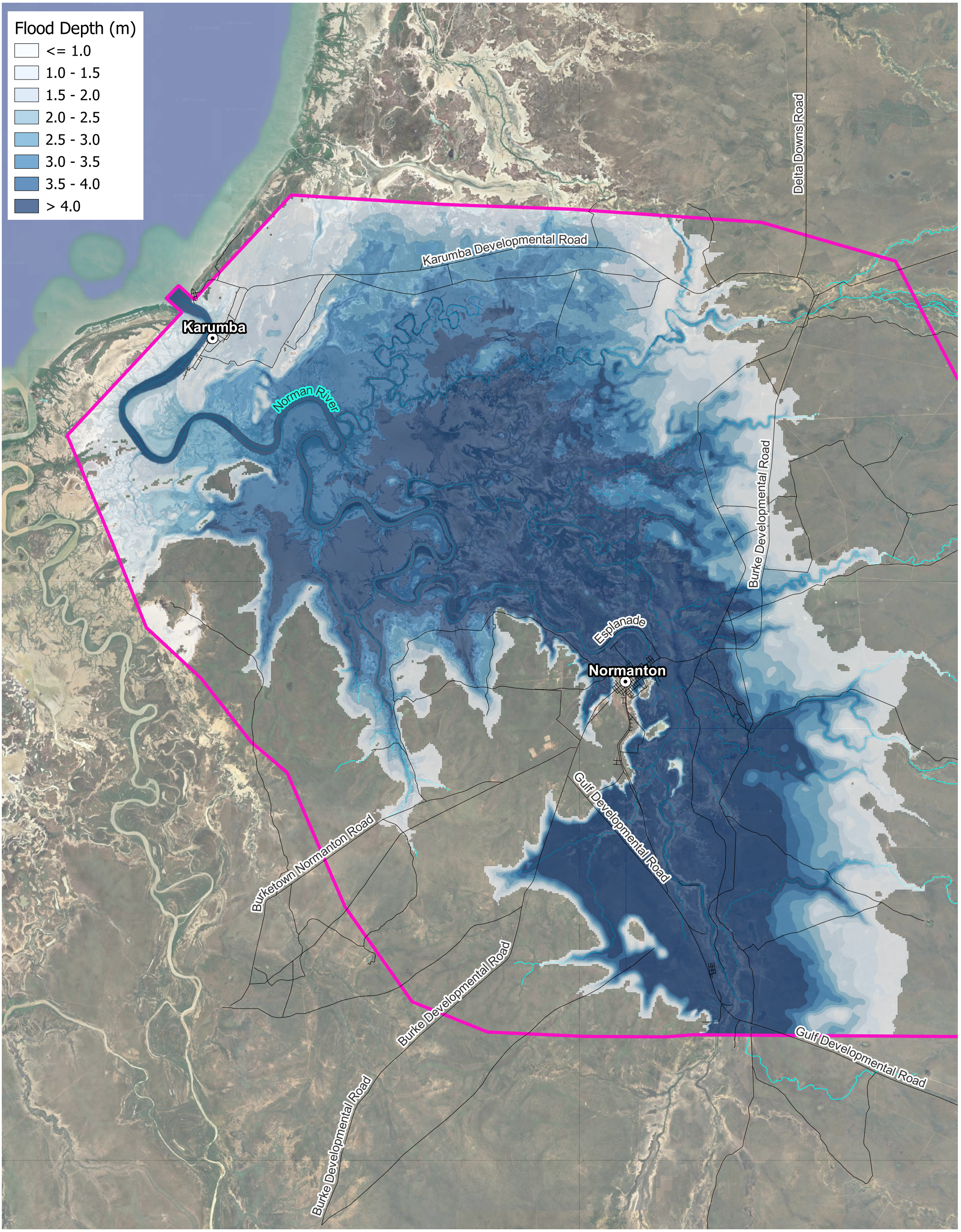
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

0.2% AEP Peak Flood Depth

Drawing: A.15

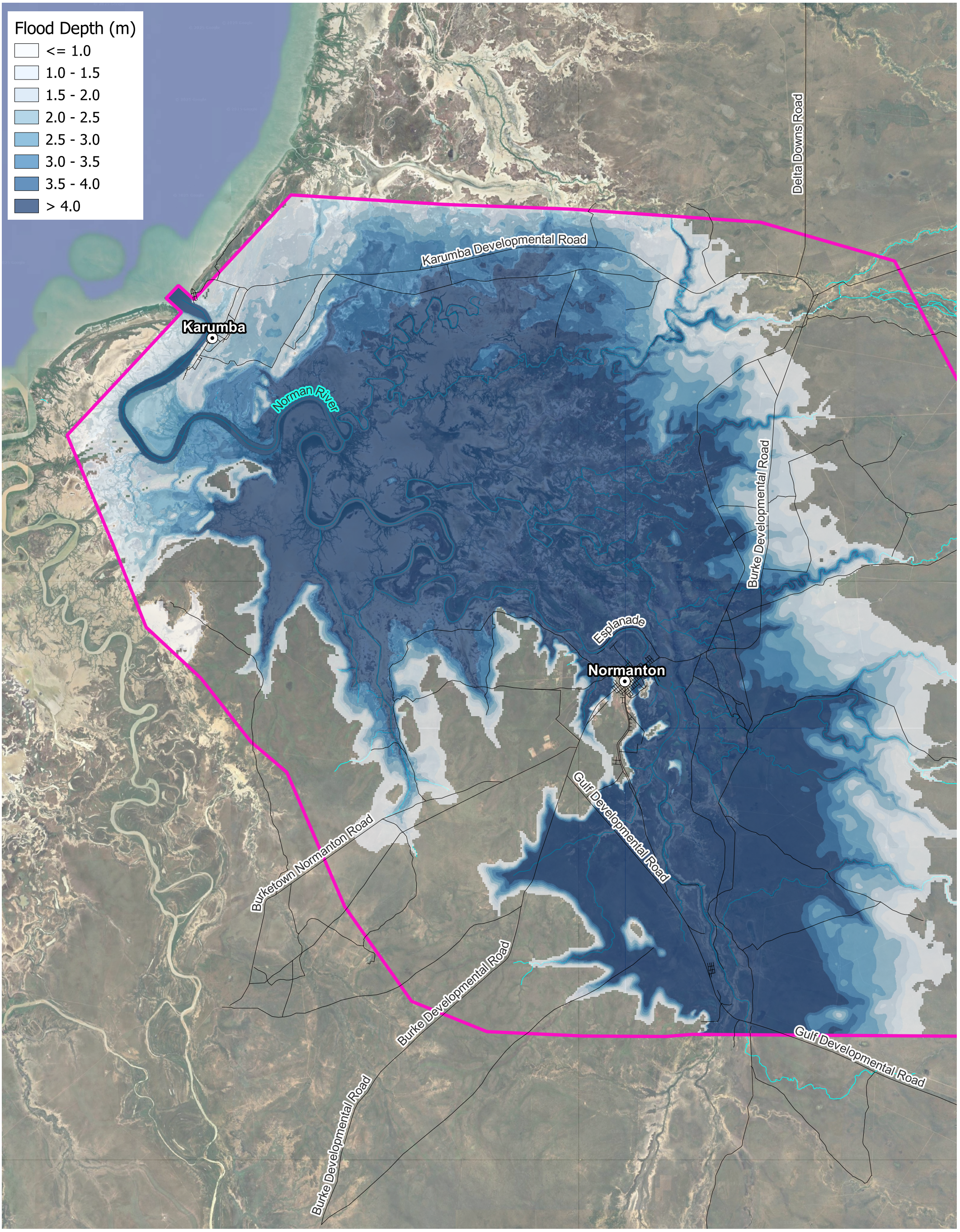
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

0.05% AEP Peak Flood Depth

Drawing: A.16

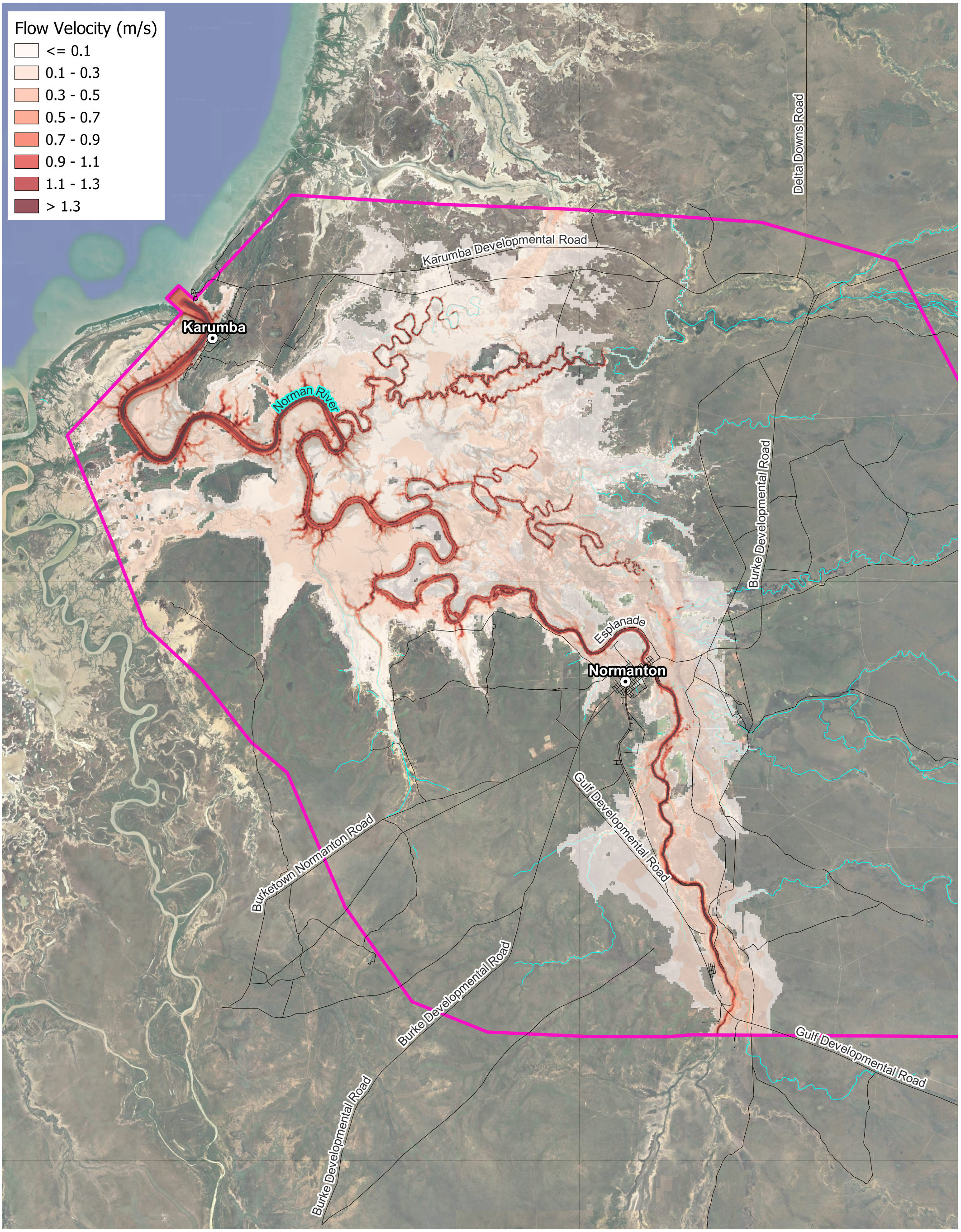
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

20% AEP Peak Flow Velocity

Drawing: A.17

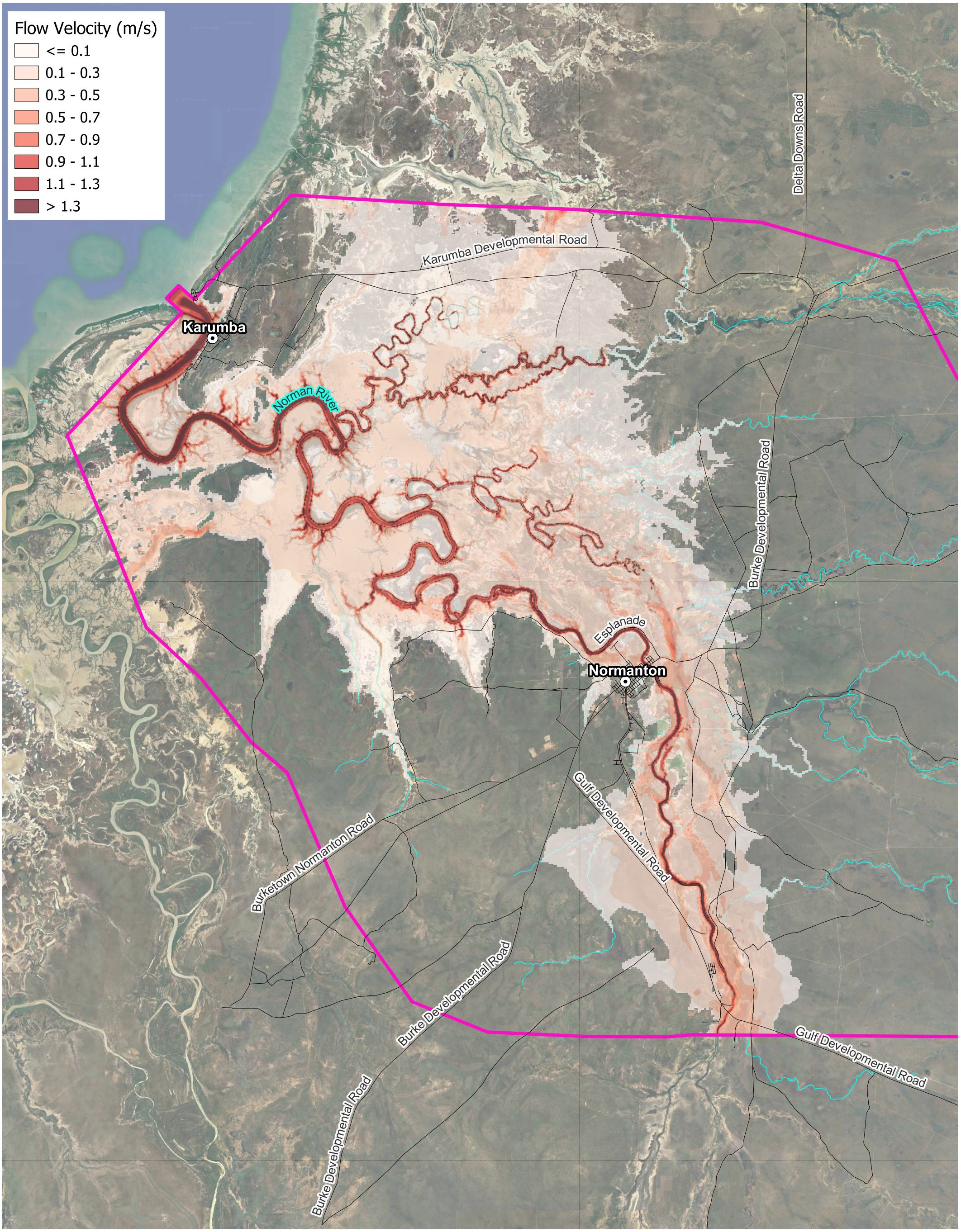
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

10% AEP Peak Flow Velocity

Drawing: A.18

Rev: A

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0 5,000 10,000 m

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Flow Velocity (m/s)
- <= 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- 0.7 - 0.9
- 0.9 - 1.1
- 1.1 - 1.3
- > 1.3

Karumba
Normanton
Karumba Developmental Road
Delta Downs Road
Norman River
Burke Developmental Road
Esplanade
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

5% AEP Peak Flow Velocity

Drawing: A.19

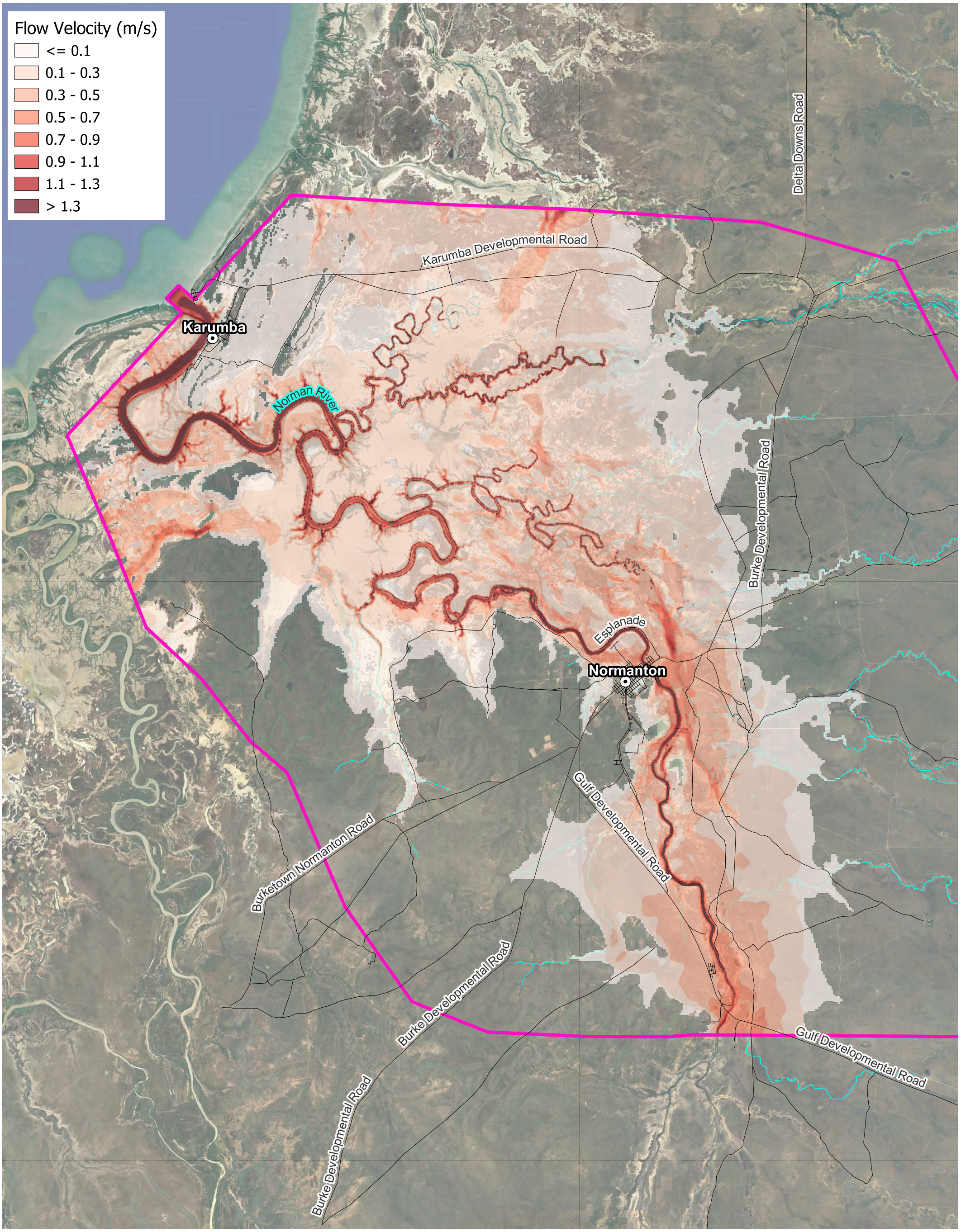
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

2% AEP Peak Flow Velocity

Drawing: A.20

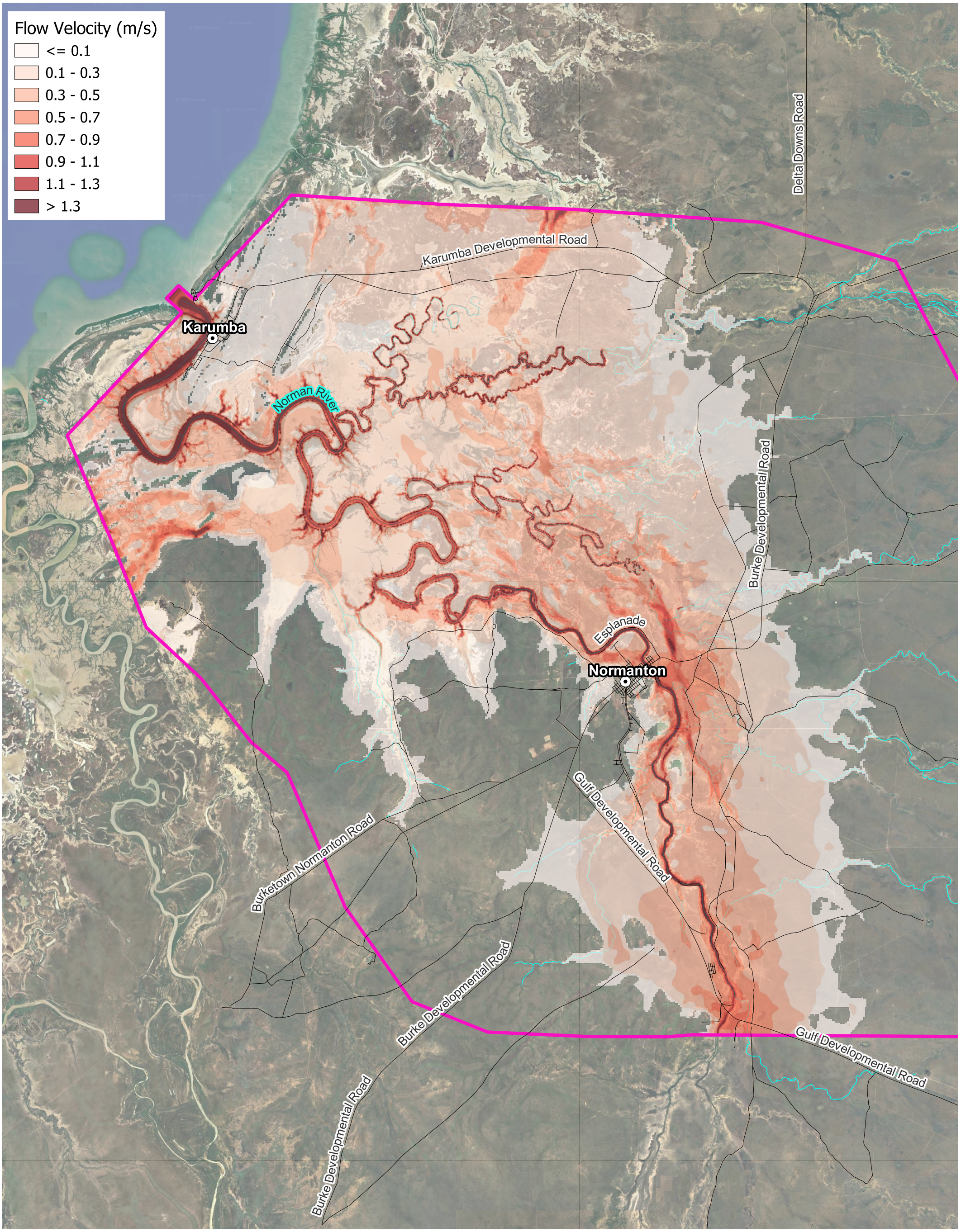
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP Peak Flow Velocity

Drawing: **A.21**

Rev: **A**

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Flow Velocity (m/s)
- <= 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- 0.7 - 0.9
- 0.9 - 1.1
- 1.1 - 1.3
- > 1.3

Karumba
Normanton
Norman River
Karumba Developmental Road
Delta Downs Road
Burke Developmental Road
Esplanade
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

0.5% AEP Peak Flow Velocity

Drawing: A.22

Rev: A

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Flow Velocity (m/s)
- <= 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- 0.7 - 0.9
- 0.9 - 1.1
- 1.1 - 1.3
- > 1.3

Karumba
Normanton
Norman River
Karumba Developmental Road
Delta Downs Road
Burke Developmental Road
Esplanade
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

0.2% AEP Peak Flow Velocity

Drawing: A.23

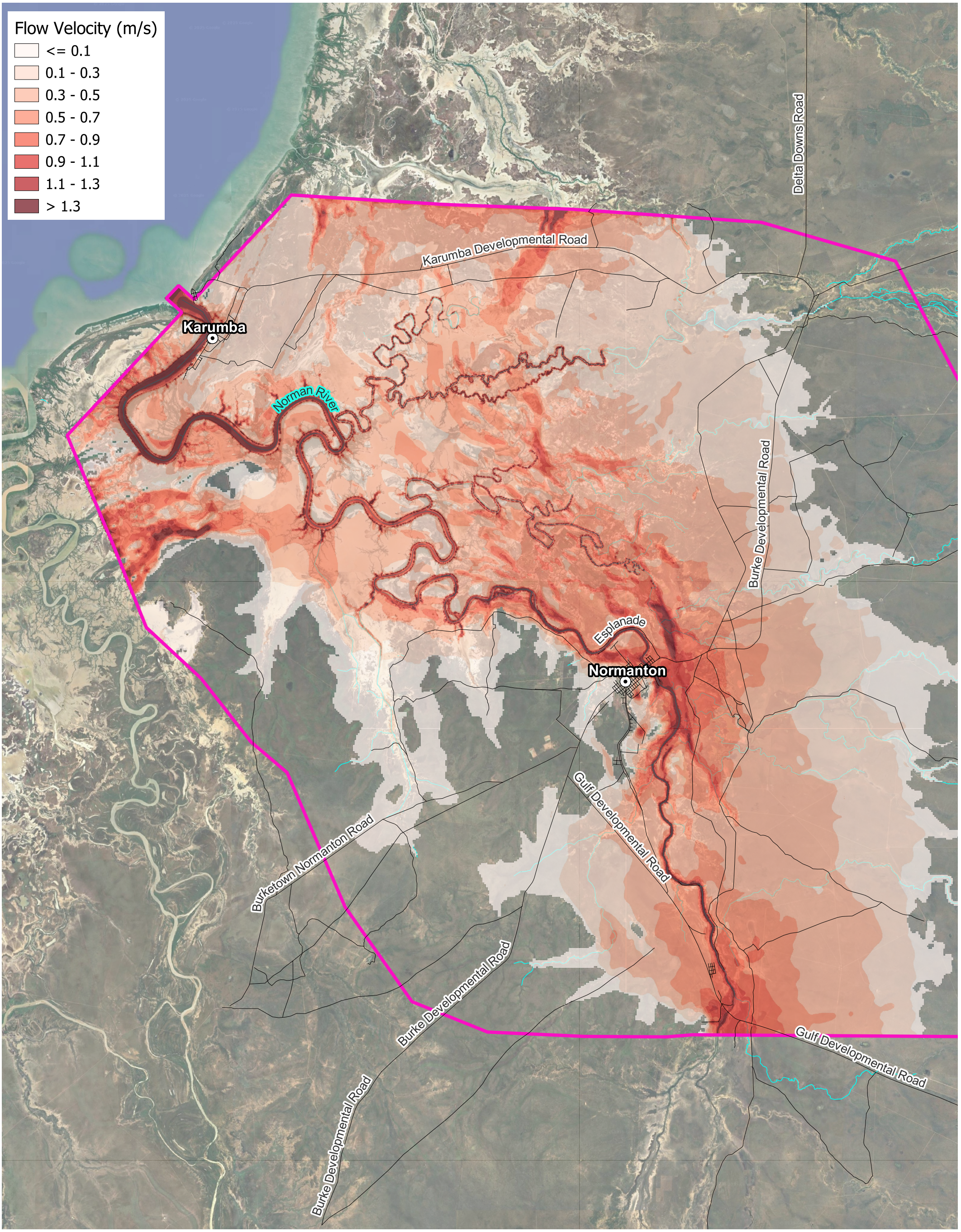
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

0.05% AEP Peak Flow Velocity

Drawing: A.24

Rev: A

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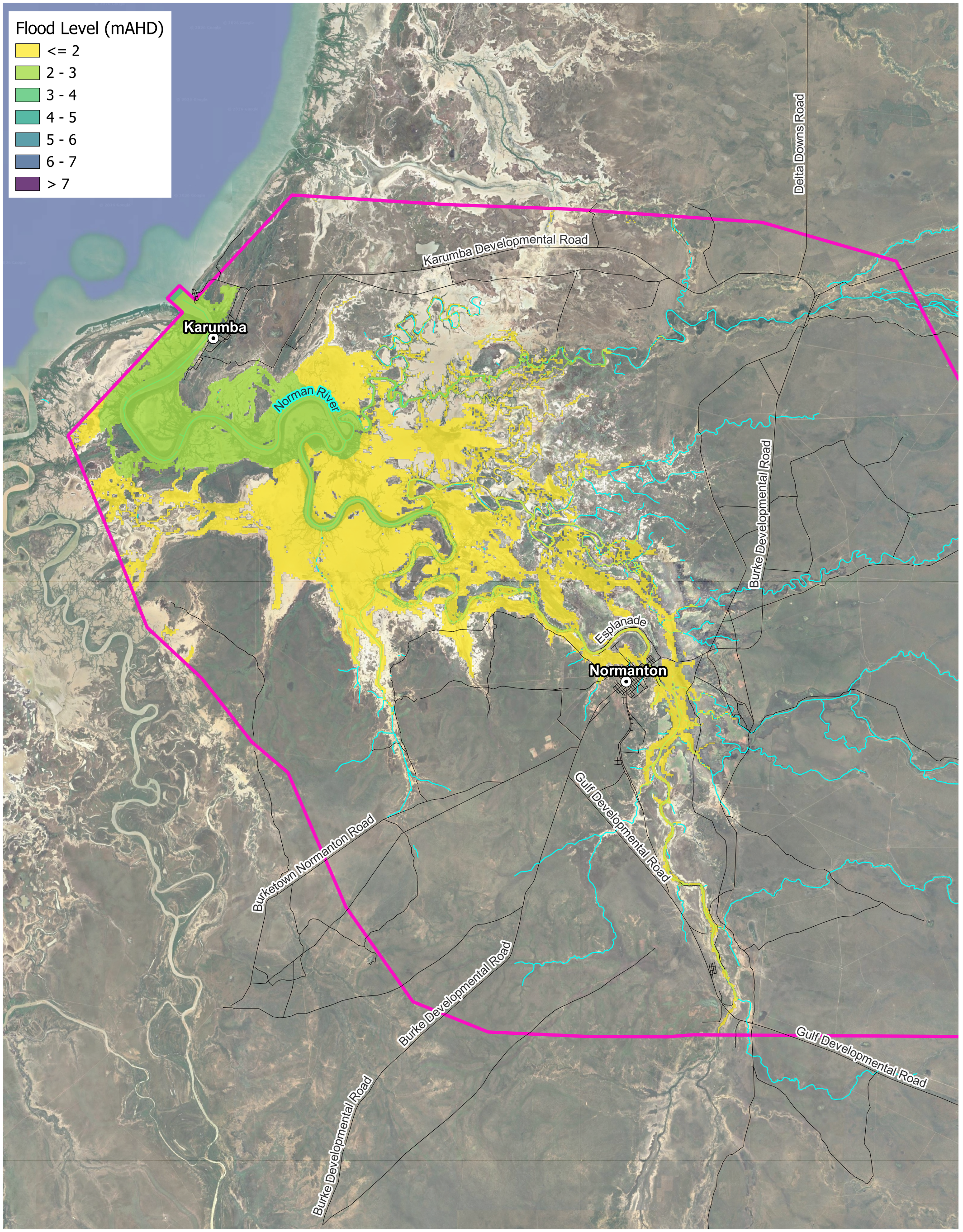
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Annex B Design Event Mapping Sensitivity Testing

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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP Storm Surge with No Norman River Flood | Flood Level

Drawing: B.1

Rev: A

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Filepath: I:\003338\QGIS\Report_Maps\Maps_sensitivity_20260514\Maps_sens.qgz

Flood Level (mAHD)
<= 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
> 7

Karumba
Normanton
Karumba Developmental Road
Delta Downs Road
Norman River
Burke Developmental Road
Esplanade
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP Storm Surge and 1% Norman River Flood – Joint Probability Assessment | Flood Level

Drawing: B.2

Rev: A

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Flood Level (mAHD)
<= 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
> 7

Karumba
Normanton
Karumba Developmental Road
Delta Downs Road
Norman River
Burke Developmental Road
Esplanade
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP Design Flood Event with Norman River inflow and Static Downstream Boundary | Flood Level

Drawing: B.3

Rev: A

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Flood Depth (m)
<= 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
3.5 - 4.0
> 4.0

Karumba
Karumba Developmental Road
Delta Downs Road
Norman River
Burke Developmental Road
Esplanade
Normanton
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend
Towns
Roads
Waterways
TUFLOW Extent

Title:
1% AEP Storm Surge with No Norman River Flood | Flood Depth

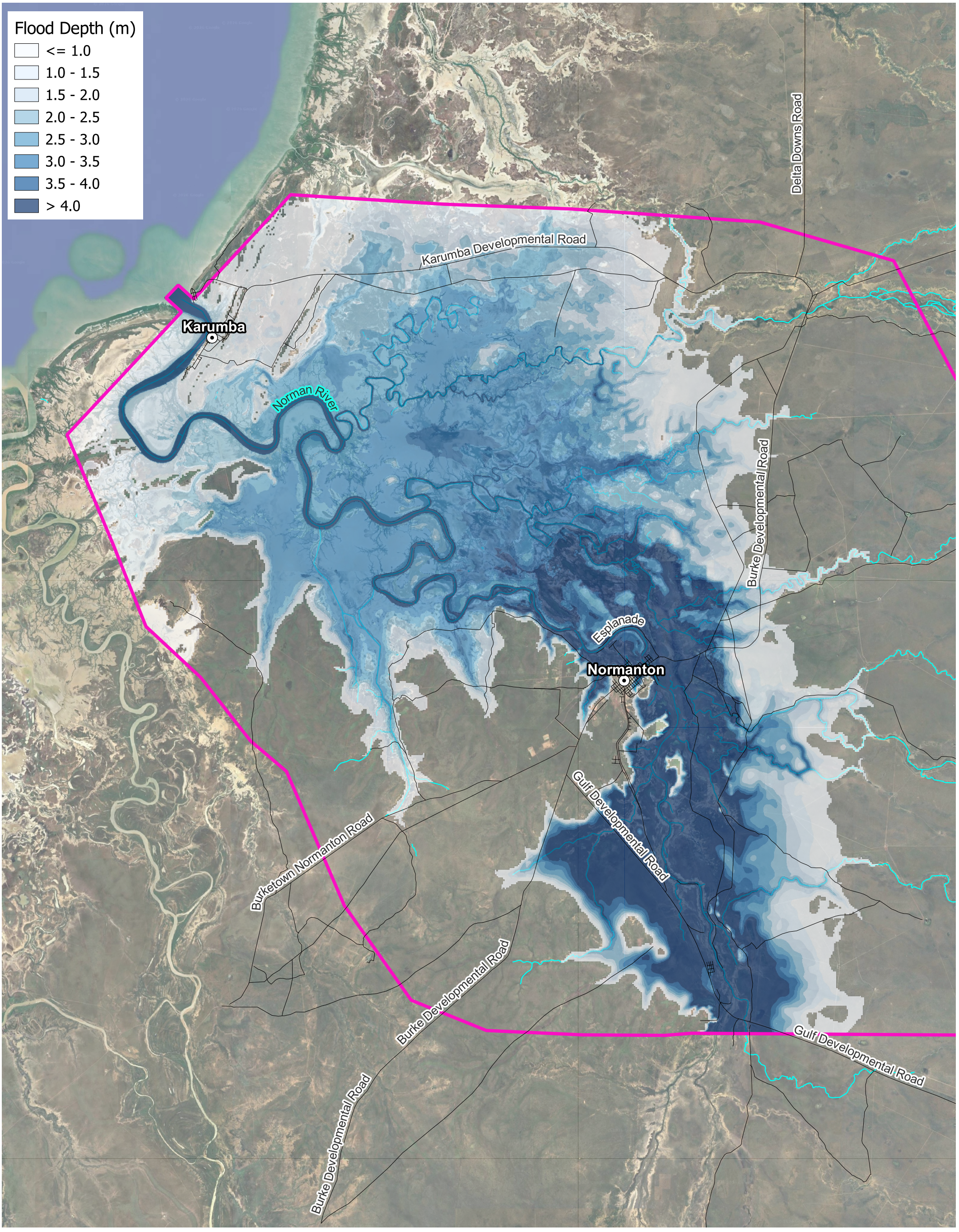
Drawing: **B.4**
Rev: **A**

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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP Storm Surge and 1% Norman River Flood – Joint Probability Assessment | Flood Depth

Drawing: B.5

Rev: A

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Flood Depth (m)
- <= 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- > 4.0

Karumba
Normanton
Karumba Developmental Road
Delta Downs Road
Norman River
Burke Developmental Road
Esplanade
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP Design Flood Event with Norman River inflow and Static Downstream Boundary | Flood Depth

Drawing: B.6

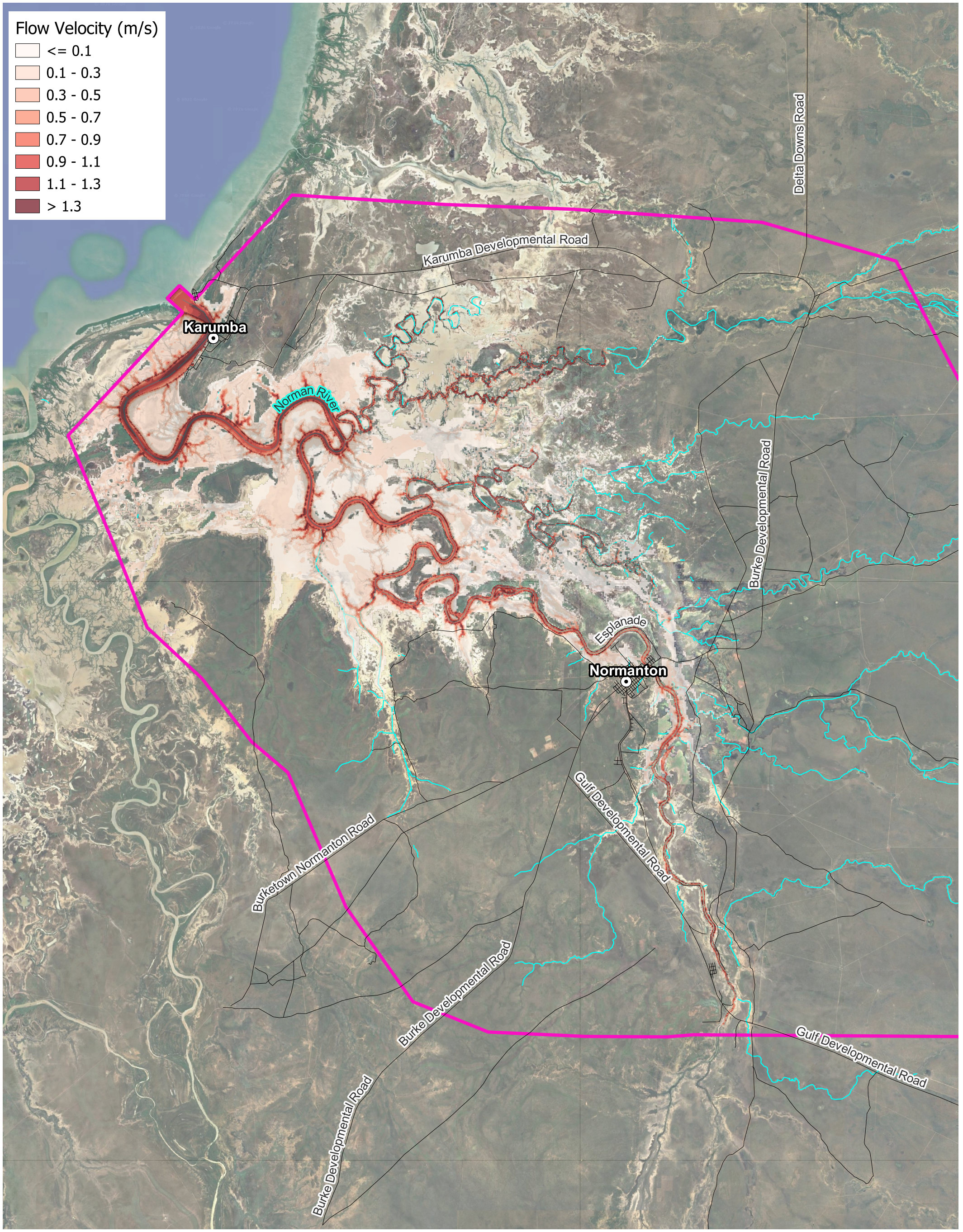
Rev: A

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0 5,000 10,000 m

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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP Storm Surge with No Norman River Flood | Flow Velocity

Drawing: **B.7**

Rev: **A**

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Flow Velocity (m/s)
<= 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 0.7
0.7 - 0.9
0.9 - 1.1
1.1 - 1.3
> 1.3

Karumba
Karumba Developmental Road
Delta Downs Road
Norman River
Burke Developmental Road
Esplanade
Normanton
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP Storm Surge and 1% Norman River Flood – Joint Probability Assessment | Flow Velocity

Drawing: B.8

Rev: A

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Flow Velocity (m/s)
- <= 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- 0.7 - 0.9
- 0.9 - 1.1
- 1.1 - 1.3
- > 1.3

Karumba
Karumba Developmental Road
Delta Downs Road
Norman River
Burke Developmental Road
Esplanade
Normanton
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend
- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP Design Flood Event with Norman River inflow and Static Downstream Boundary | Flow Velocity

Drawing: B.9

Rev: A

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Annex C Climate Change Mapping

Flood Level (mAHD)
<= 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
> 7

Karumba
Normanton
Karumba Developmental Road
Delta Downs Road
Norman River
Burke Developmental Road
Esplanade
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP 2100 Climate Change RCP 8.5 + 0.8m Sea Level Rise | Flood Level

Drawing: C.1

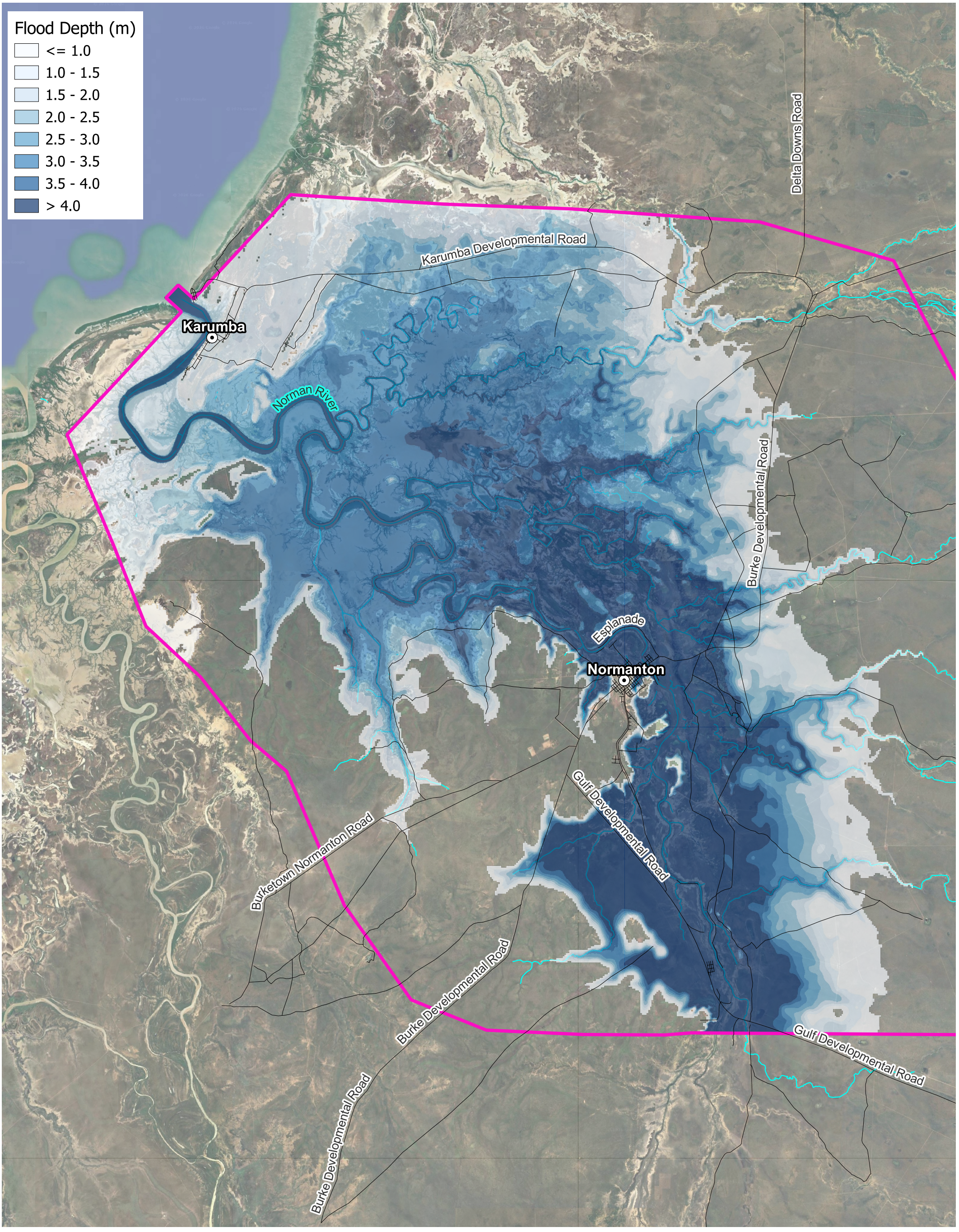
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Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP 2100 Climate Change RCP 8.5 + 0.8m Sea Level Rise | Flood Depth

Drawing: C.2

Rev: A

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Flow Velocity (m/s)
- <= 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.7
- 0.7 - 0.9
- 0.9 - 1.1
- 1.1 - 1.3
- > 1.3

Karumba
Normanton
Norman River
Karumba Developmental Road
Delta Downs Road
Burke Developmental Road
Esplanade
Gulf Developmental Road
Burketown Normanton Road
Burke Developmental Road
Burke Developmental Road
Gulf Developmental Road

Legend

- Towns
- Roads
- Waterways
- TUFLOW Extent

Title:

1% AEP 2100 Climate Change RCP 8.5 + 0.8m Sea Level Rise | Flow Velocity

Drawing: C.3

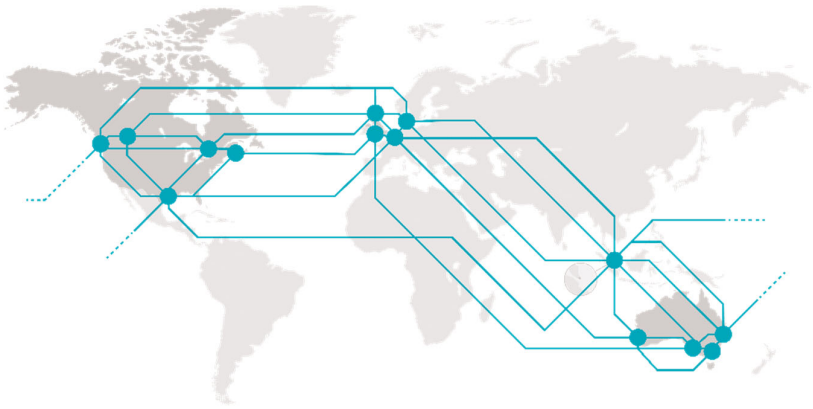
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