Fortescue

Report

Baseline Surface Water Assessment

North Star Junction West Solar Farm

22 May 2024

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Rev: 0

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DOCUMENT CONTROL

Baseline Surface Water Assessment		
Status	IFU - Issued for Use	24-May-24
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1 INTRODUCTION

The North Star Junction West Solar Farm (the Project) 30 km west of Fortescue's existing Iron Bridge operations is in early planning stages. As part of Fortescue's decarbonisation pathway, the Project will generate approximately 600MW of renewable energy to support Fortescue's operations in Pilbara Region.

The proposed development envelope and study areas include both the North Star Junction West area (NSJW area) and the Wodgina area which are located within miscellaneous tenements L45/692, L45/693 and L45/694 as shown in Figure 1. The overall project encompasses solar panels, storage and transmission facilities, access roads, and construction facilities (such as water supply bores, concrete plant, office, workshop, laydowns, borrow pits, etc.).

A pre-development flood assessment has been undertaken to characterise the current hydrological regime for the Project to support approvals. The study incorporates hydrological and hydraulic modelling of the 1% Annual Exceedance Probability (AEP) event for both the Turner River West and Turner River catchments and the local catchments contributing to flooding in the Project area, to enable assessment to ensure the footprints of key infrastructure are located outside of the floodplain and minimise potential project impacts.

This report outlines a summary of the assumptions, methodology, and the results of this assessment.

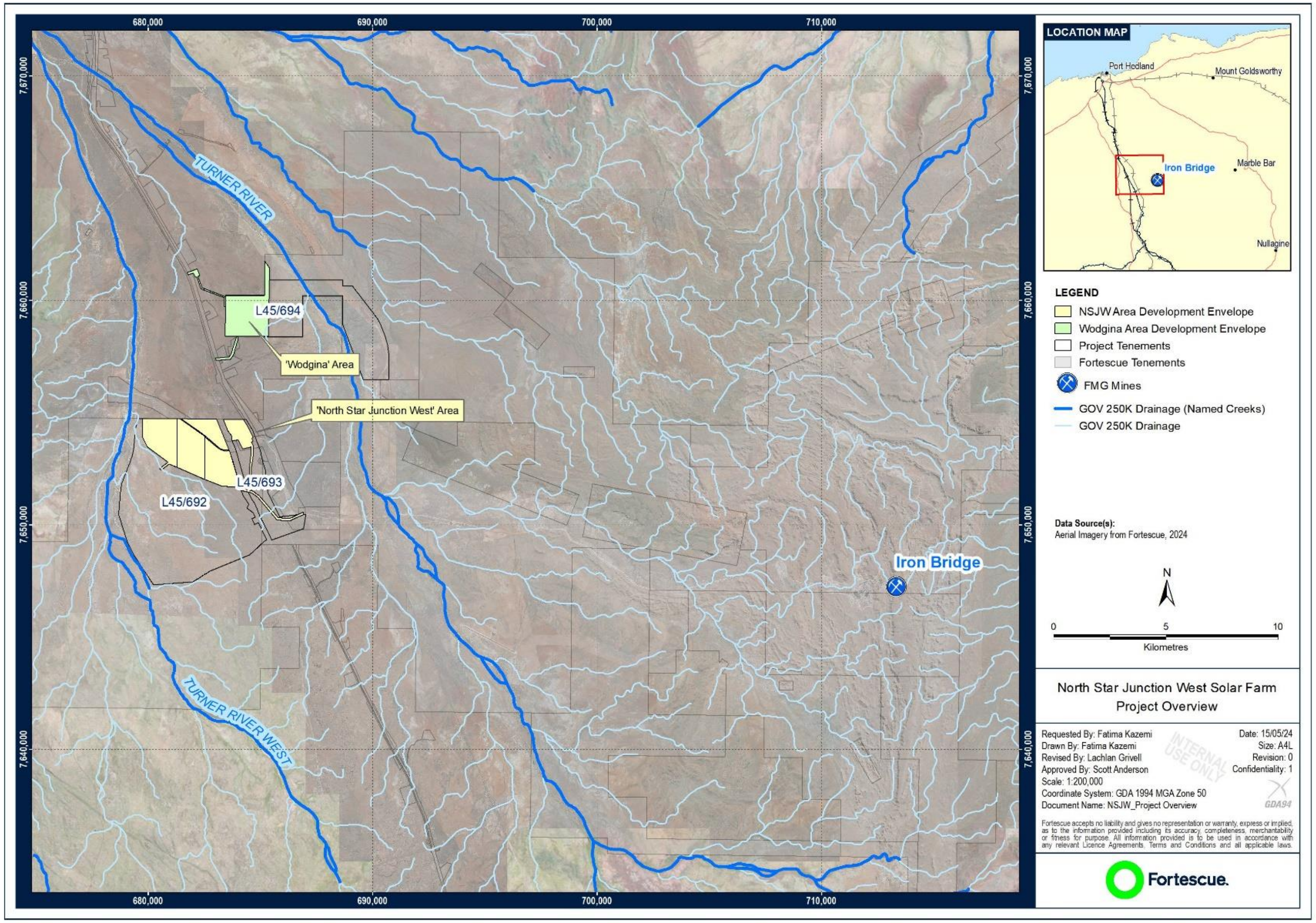

Figure 1 Project Overview

2 STUDY AREA

2.1 Climate

Climate conditions within the study area are typical of the Pilbara, and the project tenements straddle the border between the 'Hot, Persistently Dry (Desert)' and 'Hot, Persistently Dry (Grassland)' Köppen climate classifications (Bureau of Meteorology, 2023).

Interpolated point climate observation data was extracted from the Scientific Information for Land Owners (SILO) database for grid point (-21.20, 118.75), the nearest available point dataset to the project location (Queensland Government, 2023). This dataset showed a mean annual evaporation of 3,260 mm, more than ten times the mean annual rainfall of 316 mm, typical of the water limited environment of the Pilbara. A plot of total rainfall by year and the mean annual rainfall is provided in Figure 2.

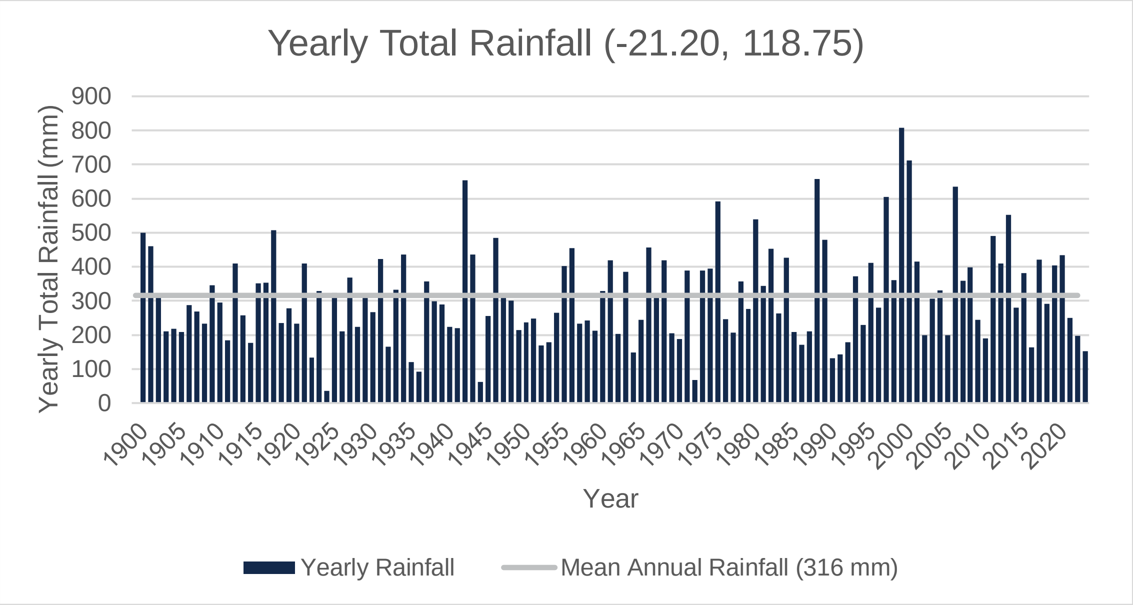

Figure 2 Yearly total rainfall (-21.20, 118.75)

Also typical of the Pilbara, temperatures in the project area are warm to hot throughout most of the year, with average daily maxima over 30°C for 8 months of the year and not below 26°C for any month. The hottest month of the year in the project area is December, with an average daily maximum of 39.7°C. Monthly temperature statistics are provided in Figure 3.

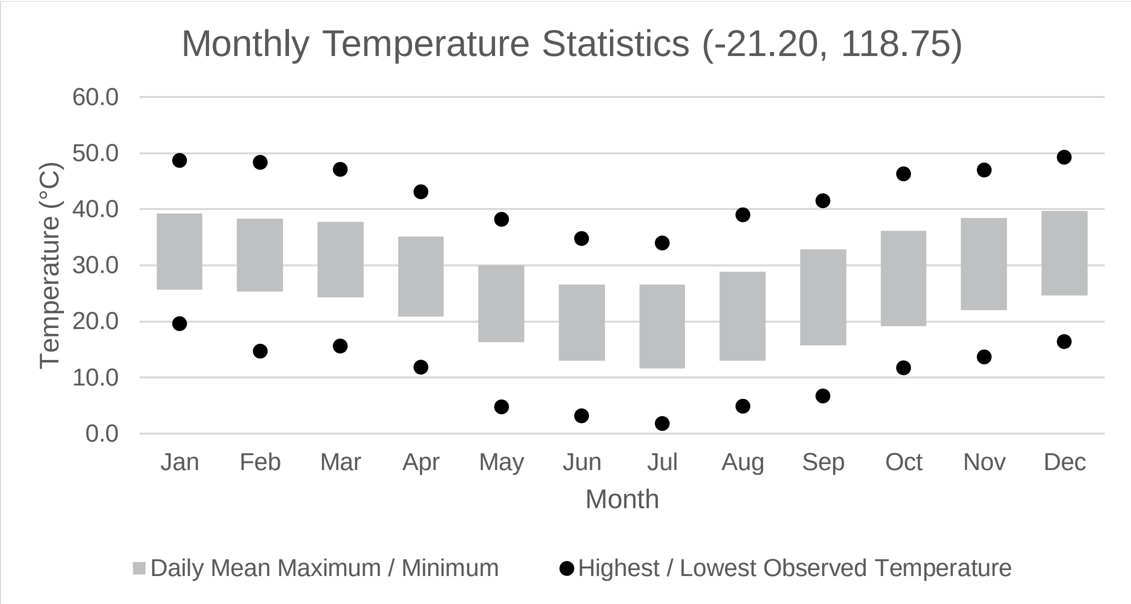

Figure 3 Monthly temperature statistics (-21.20, 118.75)

Like other regions within the Pilbara, there is also a distinct wet season, with rainfall occurring mainly in the summer months due to tropical cyclones and/or convective storms. Low-pressure trough systems can result in rainfall from late-autumn into winter, resulting a bimodal monthly rainfall distribution (Figure 4).

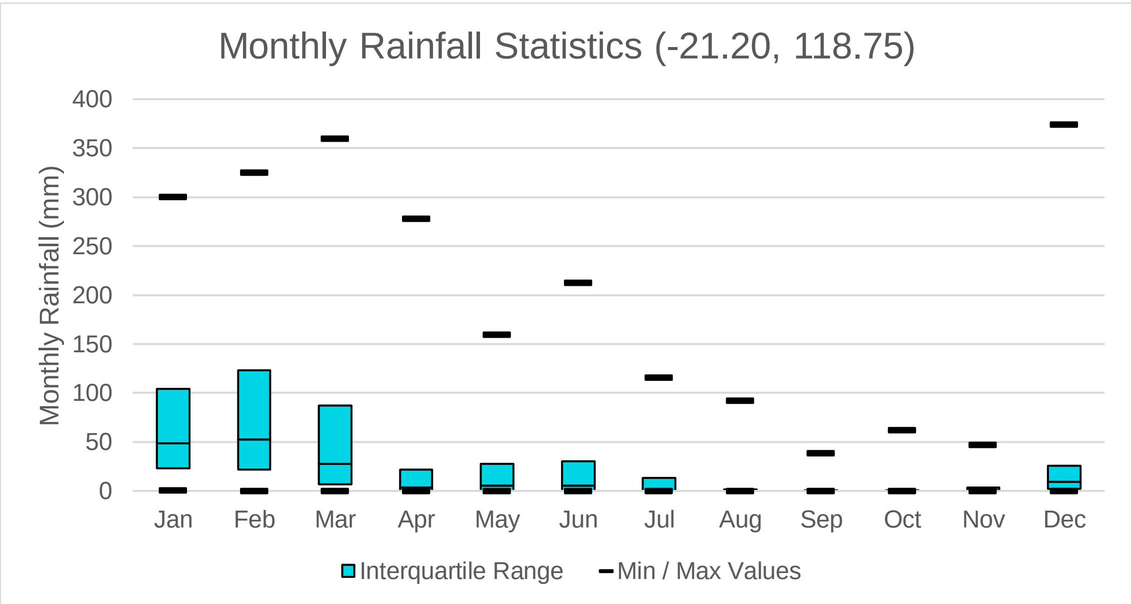

Figure 4 Monthly rainfall statistics (-21.20, 118.75)

2.2 Catchment Description

The proposed development of the NSJW area is bounded by the Fortescue and Roy Hill Iron Ore railways in the east and is largely located within the Turner River West catchment, with a small part of the area within the Turner River catchment. Turner River West flows along the eastern boundary of tenement L45/692 with some minor drainage paths within the development footprint of the NSJW area. To the east of Turner River West is the Turner River, on which the Pincunah streamflow gauge (709010) is installed.

The proposed development in the Wodgina area is bounded by the Roy Hill Iron Ore railway in the west and Turner River in the east and is located both within the Turner River West and Turner River catchments. Like the NSJW area, some minor drainage paths flow within the development footprint of the area. The Wodgina area is also approximately 1.5 km downstream of the Pincunah streamflow gauge.

The Turner River West catchment is generally hydrologically analogous to Turner River catchment upstream of the Pincunah gauge. Both catchments are relatively flat with mainstream equal area slopes are 2.1 and 1.6 m/km, respectively, soils are similar with both catchments dominated by Monzogranite groups with some colluvial/alluvial deposits in watercourses, their adjacency results in largely identical climatic conditions, and their sizes are in the same order of magnitude.

The study extent for the Project contains both Turner River West and the Turner River. The Project in the context of the study catchment and the Turner River catchment upstream of the Pincunah streamflow gauge (709010) is shown in Figure 5.

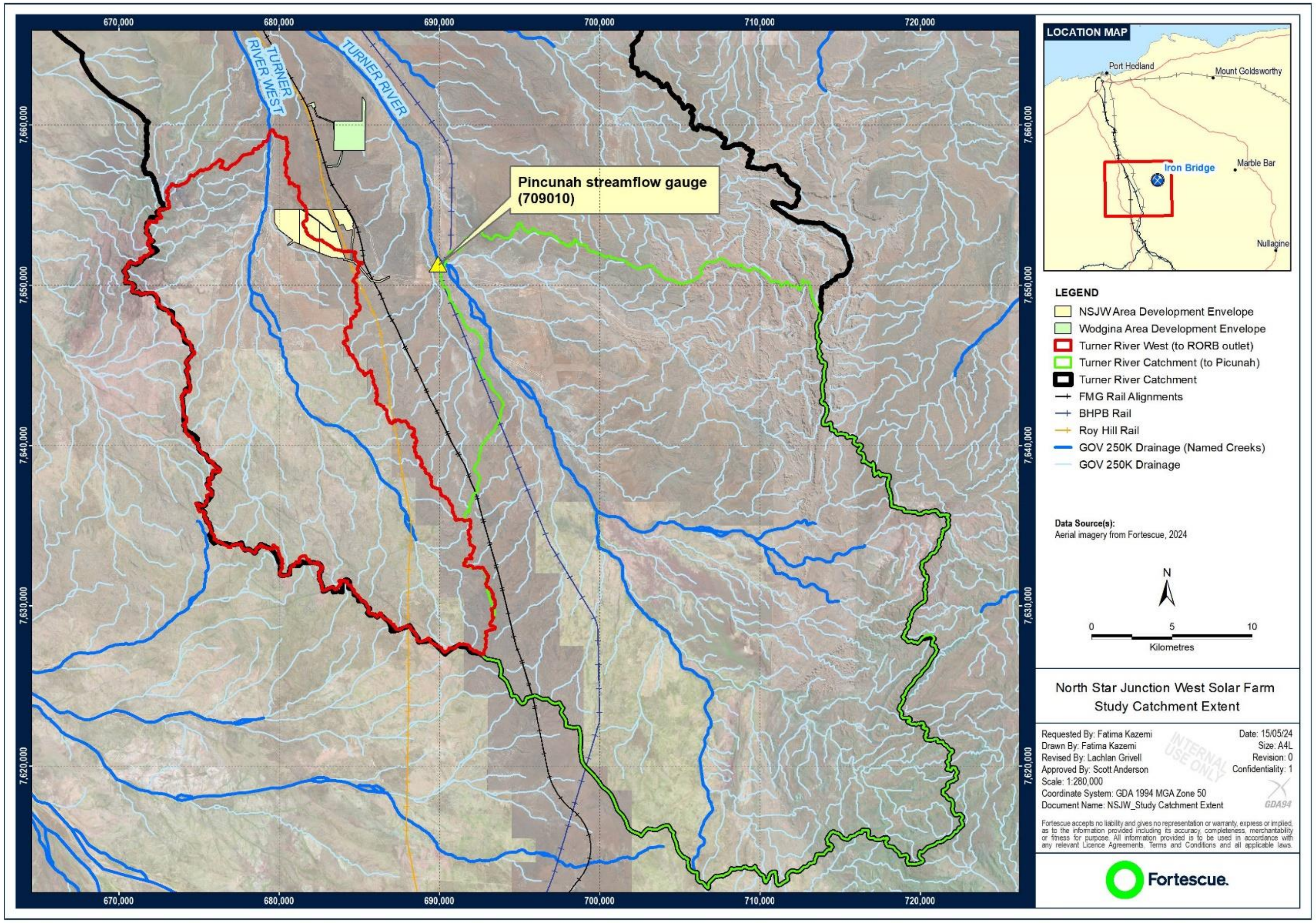

Figure 5 Study Catchment Extent

3 HYDROLOGY

3.1 Turner River West

3.1.1 Hydrological Modelling Parameters

In the absence of a gauge on Turner River West, the adjacent Turner River catchment was investigated for hydrological modelling parameters. Flows from the Turner River catchment in this area are actively monitored by DWER with a telemetered streamflow gauge. This gauge is the Pincunah gauge (709010) and was established in January 1985. This gauge records flows from the 885 km^2 catchment upstream.

Fortescue has previously undertaken a study characterising flows in the Turner River at Pincunah. Using the 36-year streamflow record of the Pincunah gauge, a censored flood frequency analysis (FFA) was developed, and a hydrological model of the Turner River catchment to this point was developed and calibrated to match this FFA to design flood estimates (DFEs) from a RORB Monte Carlo approach. This process was documented in the Iron Bridge Slurry Corridor Design Flood Estimation memorandum (Fortescue Metals Group, 2021).

The rating curve of the Pincunah gauge was updated in August 2021 by DWER, providing a better estimate of the stage-flow relationship at the gauge. Subsequently, the FFA of the gauge was updated using the new rating curve. This updated FFA showed good agreement with the RORB DFEs developed as part of the Iron Bridge Slurry Corridor Design Flood Estimation memorandum (Fortescue Metals Group, 2021). Hence, the parameters used in RORB as part of that study were adopted for the Turner River West model. These parameters were appropriate as they resolved a very good match between the RORB results and FFA for the Turner River catchment, and the environments upstream of both the Pincunah gauge and in the Turner River West catchment are hydrologically similar, as discussed in Section 2.2.

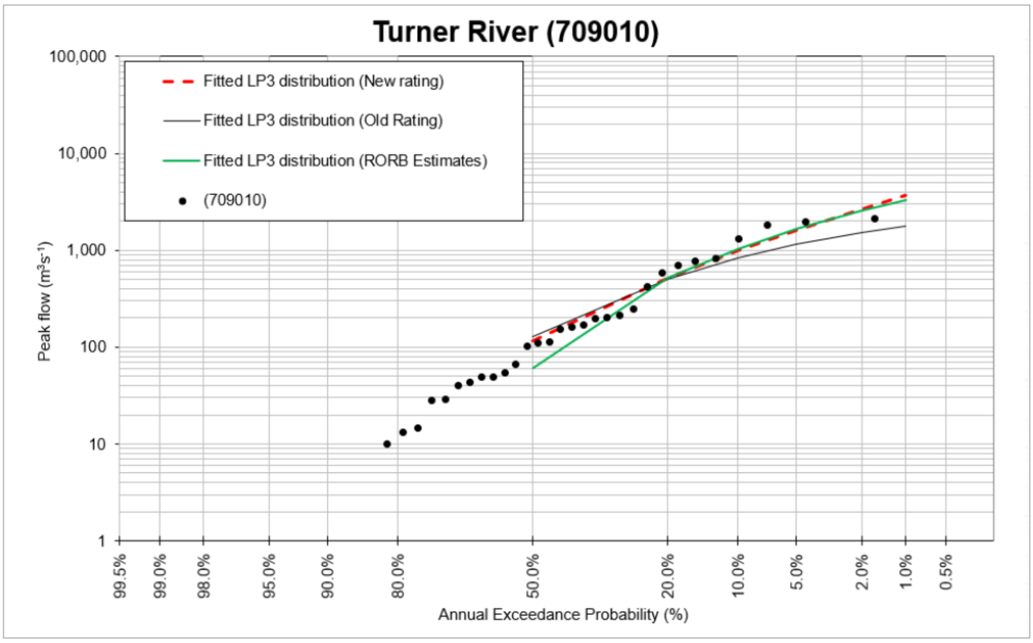

Figure 6 FFA and RORB Monte Carlo Design Flood Estimates for Pincunah (709010)

3.1.2 Hydrological Model

A hydrological model using the RORB Runoff Routing Program (v6.45) was developed to select representative design storms and to obtain flood hydrographs associated with the Turner River West catchment. Subsequently, these hydrographs were applied at the upstream end of the development envelope as inflow boundary conditions into the hydraulic model.

The spatial layout of the RORB model outlining the subareas, stream paths and nodes is illustrated in Figure 7. The model boundary has an area of 342 km^2, which partially encompasses the development envelope, and is extended to approximately 5 km downstream of the Project. The model comprises of 17 subareas, ranging from 11-42 km^2, and has an average flow distance (d_{av}) of 19.08 km from the subarea centroids to the model outlet.

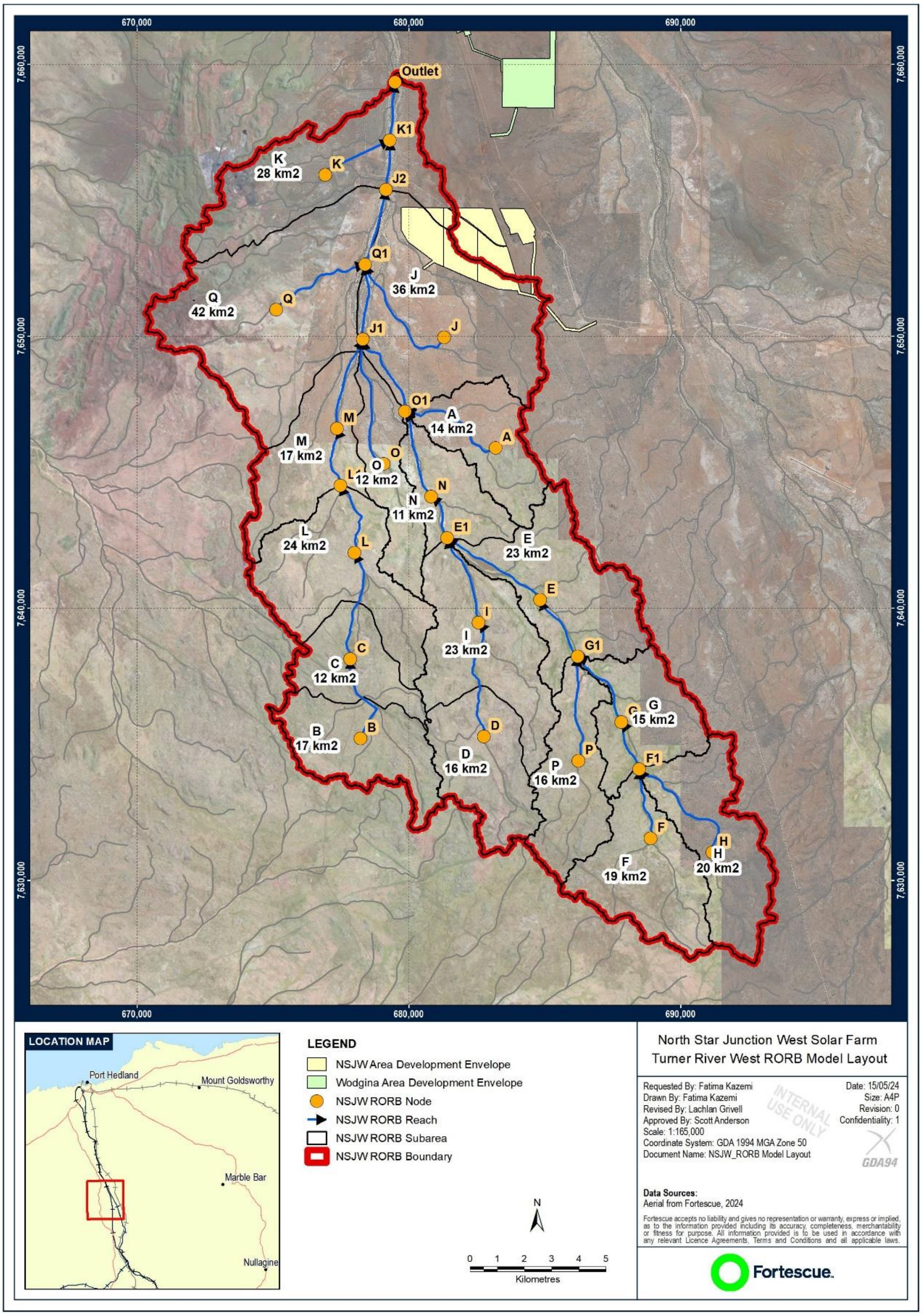

Figure 7 Turner River West RORB Model Layout

3.1.3 Routing Parameter

A RORB model requires several input parameters, including rainfall depth (both pre-burst and burst), areal reduction factor, temporal and spatial patterns of rainfall, and rainfall losses. Parameters specific to RORB include the catchment non-linearity parameter (m) and routing parameter (k_c) which relates reach storage to flowrate. The k_c parameter can be calculated using an equation developed by McMahon & Muller (1983) assuming that k_c is directly proportional to the average flow distance for a given value of the non-linearity parameter (typically 0.8).

$$k_c = C_{0.8} * 0.8\, d_{av}$$

Where $C_{0.8}$ defines the catchment characteristics (assuming non-linearity exponent of 0.8) and d_{av} is the average flow distance from the centroid of subareas to the catchment outlet.

In gauged catchments, the k_c parameter is typically derived through calibration to recorded flood discharges. A $C_{0.8}$ value of 0.8 was adopted, which was informed by a direct rainfall hydraulic model. This aligned well with the calibrated value presented by Pearcey et al., (2014) for the Turner River catchment. This value of $C_{0.8}$ yields a K_c value of 15.26 for the Turner River West model.

3.1.4 Rainfall Depth

Point design rainfall depths for the main burst were obtained for the centroid of the model (Latitude: -21.3012, Longitude: 118.7490) using the Design Rainfall Data System available from the BOM website. Additionally, pre-burst rainfall depths and temporal pattern increments for the Rangeland West Region were obtained from Australian Rainfall & Runoff (ARR) Datahub (Babister, et al., 2016).

The areal reduction factor (ARF) serves to convert point rainfall to areal depth estimates and account for the variation of rainfall intensities over a large catchment (as opposed to a point rainfall estimate). In accordance with recommendations of the ARR2019 guidelines, point temporal patterns for catchments smaller than 75 km^2 and areal temporal patterns for catchments greater than 75 km^2 were adopted in the hydrological model.

At a minimum, ARR2019 guidelines recommend applying a single non-uniform spatial pattern to catchments with an area greater than 20 km^2. The design rainfall depth grids provided by BOM for the 1% AEP, 12-hour duration storm were used to compute average rainfall depth for each catchment subarea, as preliminary model runs indicated that the critical duration was likely to be the 12-hour storm. The spatial pattern was then calculated using the ratio of these subarea rainfall estimates to the overall average catchment rainfall depth and this spatial pattern of rainfall was used for all modelled durations.

3.1.5 Loss Parameters

Loss parameters were based on those adopted in the Turner River study (Fortescue Metals Group, 2021), which refined losses to ensure consistency with flood frequency analysis at the Pincunah gauge (709010). Initial loss was estimated at 20 mm with a continuing loss of 6.2 mm/hr (Fortescue Metals Group, 2021).

These loss parameters are considered suitable for use in Turner River West RORB model and hydraulic modelling of the Project due to the adjacency of these catchments and their similarity in other hydrological factors, including topography and loss potential resulting from geology.

3.1.6 Design Temporal Pattern

Using a Monte Carlo approach, a range of storm durations and temporal patterns were simulated for each duration, with simulations modelling variability in initial losses (effectively variability in antecedent moisture conditions) and variability in design rainfall. 1% AEP design flood estimates for each duration were then determined by flood frequency analysis of these Monte Carlo Runs, and the critical (highest flow) duration determined as the design flood estimate for the overall 1% AEP event.

The 1% AEP critical duration peak flow estimate was then compared to an ensemble of 1% AEP design rainfall simulations for the same duration using median losses to select a temporal pattern which produced values closest to the expected peak discharge. This temporal pattern was adopted as the representative design storm for the 1% AEP design flood.

A 1% AEP 12-hour duration with temporal pattern 2 was selected for Turner River West, and hydrographs produced at two RORB model nodes (E1 and L1) upstream of the development envelope shown below in Figure 8 These were applied as inflow boundary conditions for the hydraulic model (*"East_Inflow"* and *"West_Inflow"*).

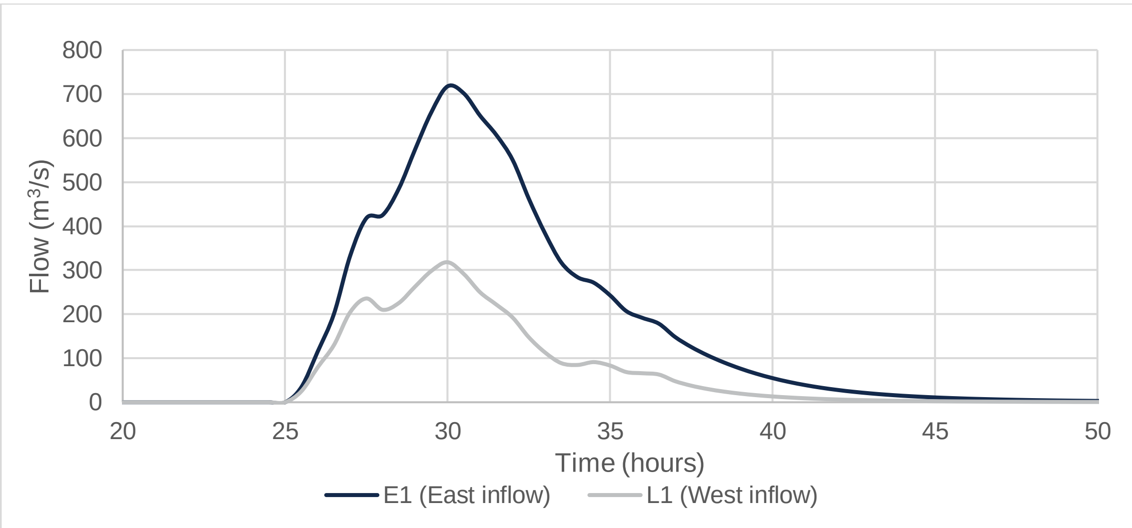

Figure 8 Turner River West RORB outflow hydrographs

3.2 Turner River

Hydrological modelling of the Turner River was based on an updated model using previous work undertaken by Fortescue (Fortescue Metals Group, 2021). This report should be referenced for details regarding the development of this hydrological model. Updates to this hydrological model included the addition of the spatial variation of rainfall and minor changes to areal reduction factors (ARF) to account for the increase in catchment area to Turner River adjacent the Wodgina area, a change in area from 884 km^2 to approximately 1030 km^2.

The output location of the model remained as the Turner River at Pincunah Gauge (709010), as the outputs of this model were to be used as inflows in a TUFLOW model used for assessment of the floodplain adjacent the Wodgina area, with the upstream boundary of the TUFLOW model approximately at the location of the gauge.

Using the updated RORB model a set of RORB Monte-Carlo runs were performed to calculate the design flood estimate to the Pincunah gauge (the inflow boundary of the TUFLOW model) using the ARF of Turner River at Wodgina (the location of interest). Using these Monte Carlo runs, it was found that the critical duration remained the same, and the design flood estimate for the Pincunah gauge using the updated ARF was 3299 m^3/s.

A representative design storm was then selected based on the storm within the 1% AEP, 12-hour duration ensemble which had the closest flowrate to the Monte-Carlo design flood estimate. This storm was TP08 of the Rangelands West, 1000 km^2 areal temporal patterns. This storm had a peak flowrate of 3318 m^3/s. This storm was not only the closest storm to the RORB Monte-Carlo runs, but it was also the upper-median and the second closest storm to the mean of the ensemble.

The hydrograph of this representative design storm at the Pincunah gauge (shown in Figure 9) was then used as an inflow boundary condition and the rainfall generated by RORB as a rainfall boundary condition for the TUFLOW model described in Section 4.2.

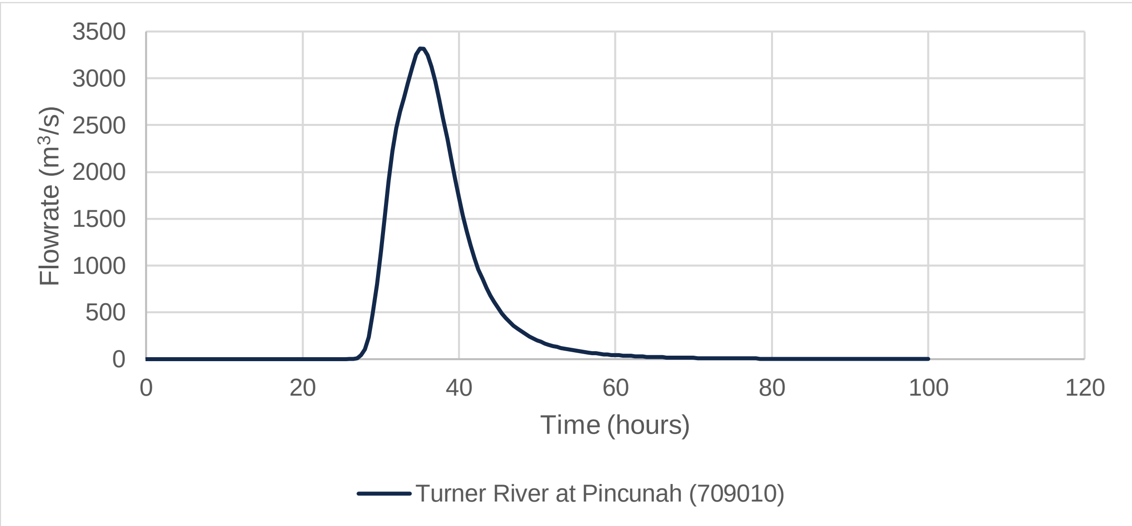

Figure 9 Turner River at Pincunah RORB outflow hydrograph

4 HYDRAULIC MODELLING

4.1 Turner River West

To estimate flood depths and velocities in the Turner River West catchment, a two-dimensional (2D) hydraulic model was developed using TUFLOW HPC version 2023-03-AB-iSP.

To assess the 1% AEP event within the area of interest, the representative design storm developed for the 1% AEP event as described in Section 3.1 was implemented as a scenario (the 'RORB' scenario), routing through the appropriate hydrographs and applying the corresponding rainfall. To estimate flooding associated with runoff from smaller local tributaries, a direct-rainfall ensemble approach was implemented as a separate scenario (the 'Local' scenario).

The model domain along with inflow boundary conditions from the hydrological model outputs (previously discussed in Section 3.1.6) is illustrated in Figure 10. A summary of the model inputs and assumptions is presented in Table 1.

Table 1 Turner River West TUFLOW Model Setup

Item	Description	Comments
Topographic data	3 m Landgate DEM* and 1 m LiDAR DEM*, with breaklines applied at significant hydraulic controls (e.g. rail lines, significant roads within area of interest)	FMG DEMs from GIS Data warehouse: IRON_BRIDGE_1m_DEM_MAR2020 IRON_BRIDGE_DECARB_1M_DEM_MAR2023
Grid resolution	12m cell size Sub-Grid Sampling at 3 m or 1 m depending on the DEM resolution	Sub-Grid Sampling enhances topographic representation
Roughness (Manning's n)	0.05	Based on 2D model roughness recommended by ARR2019 guidelines
Rainfall	Applied rainfall dependent on scenario: • 'Local' scenario utilises point temporal patterns and no ARF • 'RORB' scenario utilises RORB generated rainfall hyetographs	'Local' scenario rainfall generated using QGIS TUFLOW plugin ARR 2019 rainfall generation functionality.
Inflows	Inflows applied dependent on scenario: • 'Local' scenario has no inflows • 'RORB' scenario uses hydrographs calculated from RORB model	'RORB' scenario inflows converted using TUFLOW 'asc_to_asc' utility.
Losses	20 mm initial loss 6.2 mm/h continuing loss	Calibrated loss parameters for the Turner River catchment as per Fortescue Metals Group (2021)
Culverts	Multiple culvert locations under the existing access roads and railway lines	Culvert sizes as measured from FMG aerial maps, including size and count. Culverts connected to 2D model domain using 'SXZ' connection type

* Digital elevation model

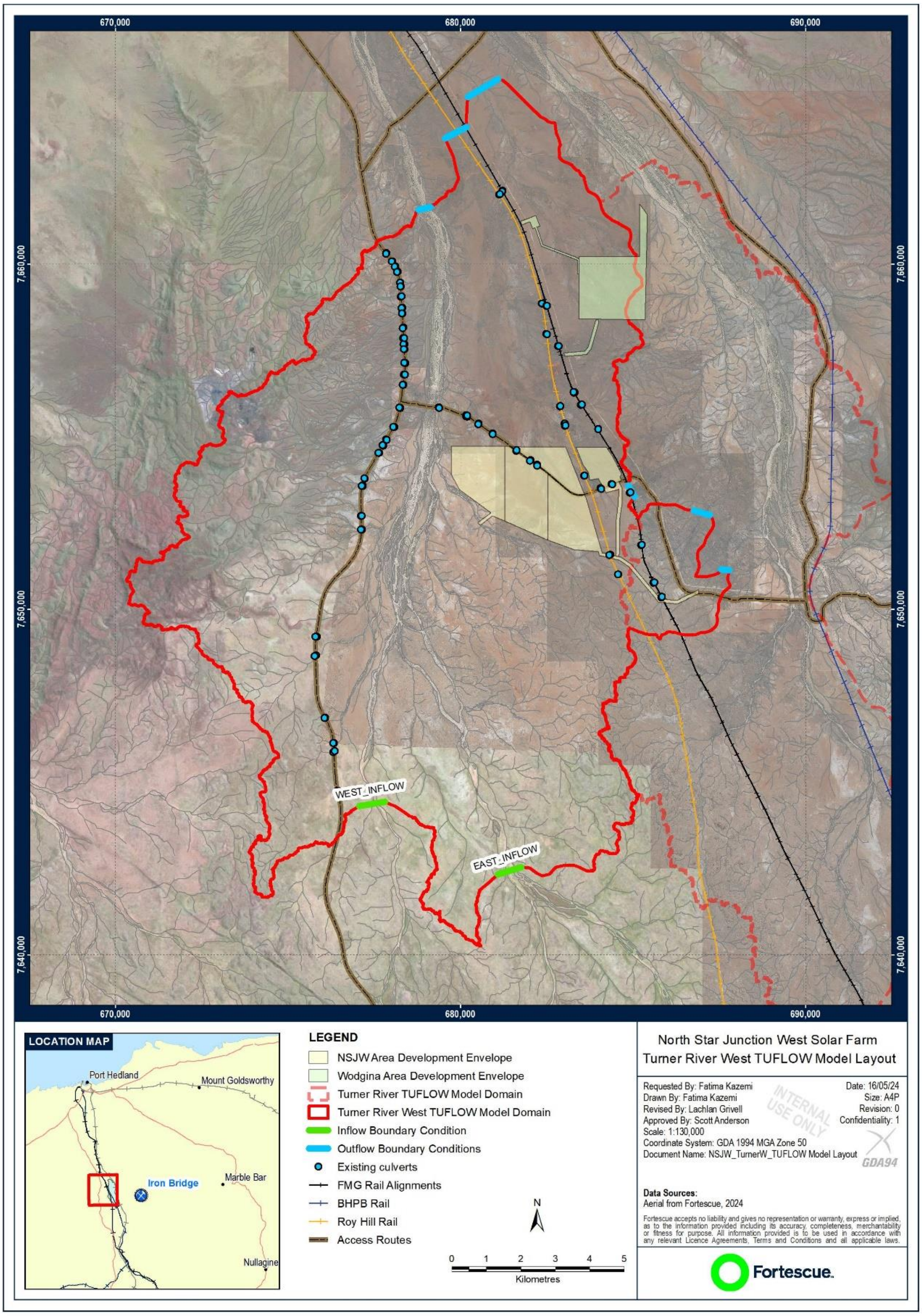

Figure 10 Turner River West TUFLOW Model Layout

4.2 Turner River

To estimate flood depths and velocities in the Turner River catchment, a two-dimensional (2D) hydraulic model was developed using TUFLOW HPC version 2023-03-AB-iSP.

To assess the 1% AEP event within the area of interest, the representative design storm developed for the 1% AEP event as described in Section 3.2 was implemented as a scenario (the 'TR' scenario), routing through the appropriate hydrograph and applying the corresponding rainfall. To estimate flooding associated with runoff from smaller local tributaries, a direct-rainfall ensemble approach was implemented as a separate scenario (the 'Local' scenario).

The model domain along with inflow boundary conditions from the hydrological model outputs (discussed in Section 3.2) is illustrated in Figure 11. A summary of the model inputs and assumptions is presented in Table 2.

Table 2 Turner River TUFLOW Model Setup

Item	Description	Comments
Topographic data	3 m Landgate DEM* and 1 m LiDAR DEM*, with breaklines applied at significant hydraulic controls (e.g. rail lines, significant roads within area of interest)	FMG DEMs from GIS Data warehouse: IRON_BRIDGE_1m_DEM_MAR2020 IRON_BRIDGE_DECARB_1M_DEM_MAR2023
Grid resolution	12m cell size Sub-Grid Sampling at 3 m or 1 m depending on the DEM resolution	Sub-Grid Sampling enhances topographic representation
Roughness (Manning's n)	0.05	Based on 2D model roughness recommended by ARR2019 guidelines
Rainfall	Applied rainfall dependent on scenario: • 'Local' scenario utilises point temporal patterns and no ARF • 'TR scenario utilises RORB generated rainfall hyetographs	'Local' scenario rainfall generated using QGIS TUFLOW plugin ARR 2019 rainfall generation functionality.
Inflows	Inflows applied dependent on scenario: • 'Local' scenario has no inflows • 'TR scenario uses hydrographs calculated from RORB model	'TR' scenario inflows converted using TUFLOW 'asc_to_asc' utility.
Losses	20 mm initial loss 6.2 mm/h continuing loss	Calibrated loss parameters for the Turner River catchment as per Fortescue Metals Group (2021)
Culverts	Multiple culvert locations under the existing access roads and railway lines	Culvert sizes as measured from FMG aerial maps, including size and count. Culverts connected to 2D model domain using 'SXZ' connection type

* Digital elevation model

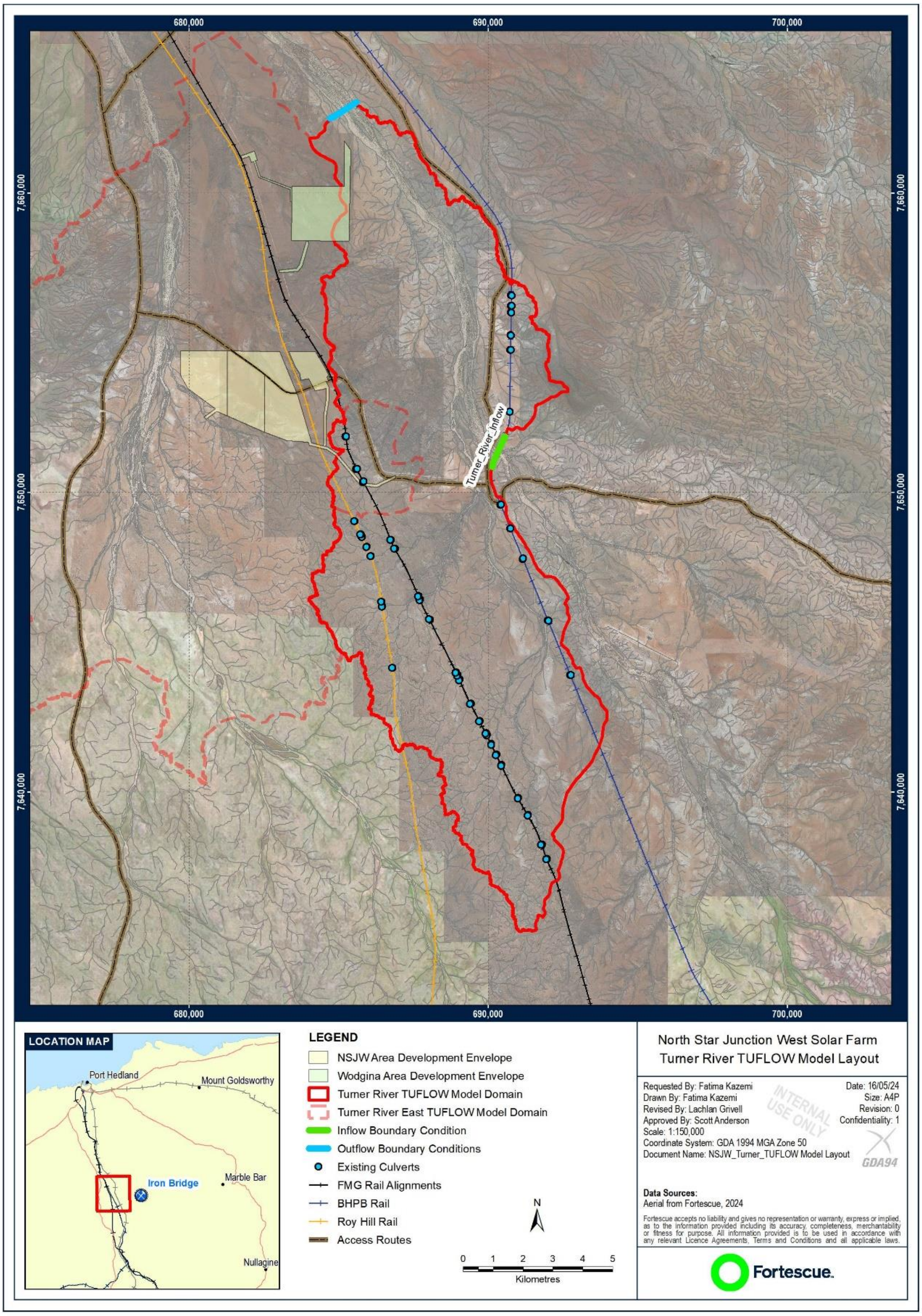

Figure 11 Turner River TUFLOW Model Layout

5 RESULTS

Following the model runs of the 'Local' and 'RORB' scenarios (for the Turner River West catchment) and the 'Local' and 'TR' scenarios (for the Turner River catchment), the results were collated as follows using the TUFLOW "ASC to ASC" utility as follows:

1. The results for each temporal pattern were averaged on a per-duration basis to obtain the mean set of results for each duration for the 1% AEP event over the 'Local' scenario domains;

2. The per-duration results for the 'Local' scenario were enveloped in each model domain to obtain a single set of results for the 1% AEP result for each domain for the 'Local' scenario;

3. The enveloped 1% 'Local' model results for Turner River West and Turner River were enveloped with the results for the 12-hour, 1% AEP representative design storm run as part of the 'RORB' (for Turner River West) and 'TR' (for Turner River) scenarios to obtain a single set of results for each of Turner River West and Turner River, including minor local tributaries.

4. The Turner River West and Turner River results were enveloped to obtain a single set of flood maps for the locations of interest across both the Turner River West and Turner River domains.

5. The final collated 1% AEP results grids were filtered based on a minimum depth of 0.05 m to exclude areas dominated by minor sheet flows from mapping.

Maximum 1% AEP depths and 1% AEP velocity maps are provided in Figure 12 and Figure 13 respectively. Figure 14 shows the critical duration for flood depth across the study area.

The floodplain of Turner River West is significantly braided, with flooding resulting from Turner River West as wide as 1,700 m adjacent to some areas of the proposed development in the north. Depths in this area are typically shallow, mostly less than 1.5 m and almost all less than 2.0 m. Velocities in this area are similarly limited because of the flat channel geometry, with only very isolated pockets of faster velocities which approach 1.5 m/s. Conversely, some areas are deeper due to more confined channel geometry, and higher velocities (> 2.5 m/s) result. From a water management perspective, these results confirm that in the 1% AEP event flooding driven by Turner River West has no interaction with the proposed North Star West Junction area.

Outside of the main floodplain of Turner River West, there is a larger tributary which runs along the southern edge of the proposed development envelope. This tributary has relatively shallow depths, at most 1.5 m, and slow velocities, typically less than 1.5 m/s. Only minor interaction between this tributary and the proposed development envelope is noted, at the very periphery of the proposed North Star West Junction area.

In comparison to Turner River West, while similarly braided low flow channels are evident in Turner River, flows are sufficient that continuous relatively deep flows are observed across the full width of the floodplain, consistent with the higher flowrates resulting from the larger upstream catchment. These depths can be as much as 5 m in the thalweg of Turner River, with velocities as high as 3.5+ m/s in isolated pockets, and typically not less than 2.5 m/s in the thalweg. However, these results confirm the 1% AEP event flooding driven by Turner River has no interaction with the proposed Wodgina area.

Within the Turner River catchment, but outside of the floodplain of Turner River proper, minor catchments contribute to small tributaries and sheet flow within the Wodgina development area, but flows are shallow (typically < 0.5 m deep) and slow (< 1 m/s). Little meaningful interaction between concentrated flows and the Wodgina area is observed.

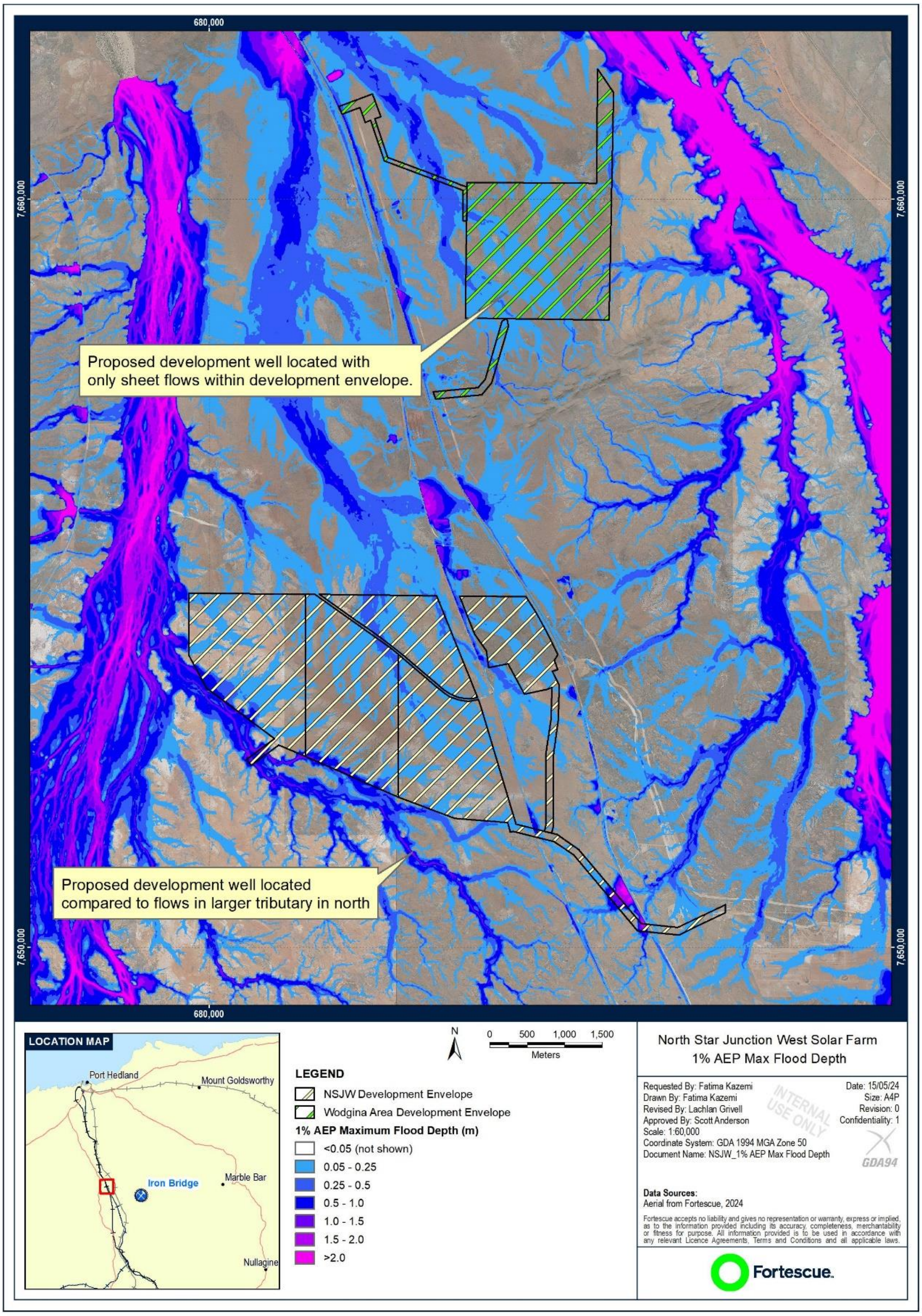

Figure 12 1% AEP Maximum Flood Depth

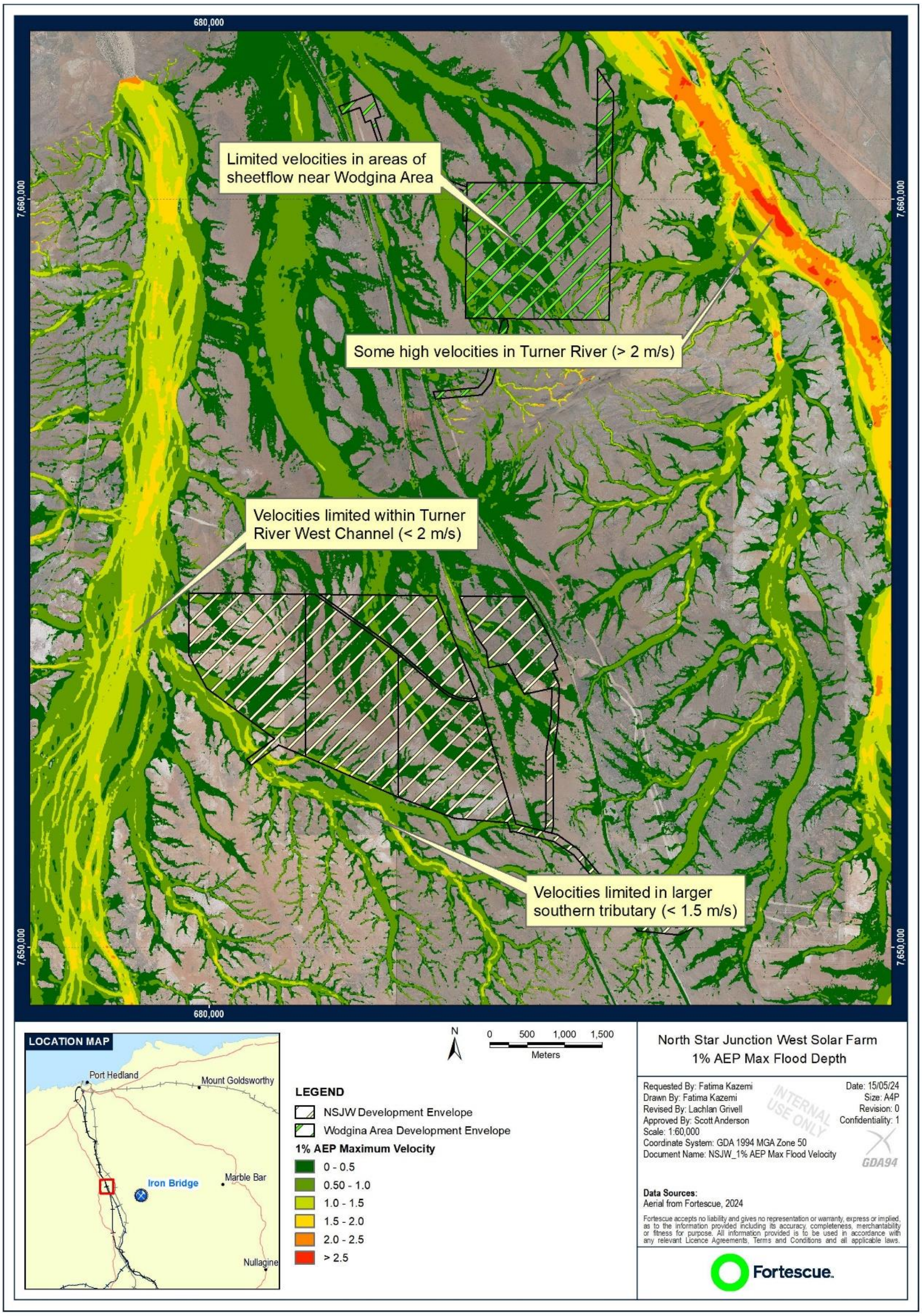

Figure 13 1% AEP Maximum Velocity

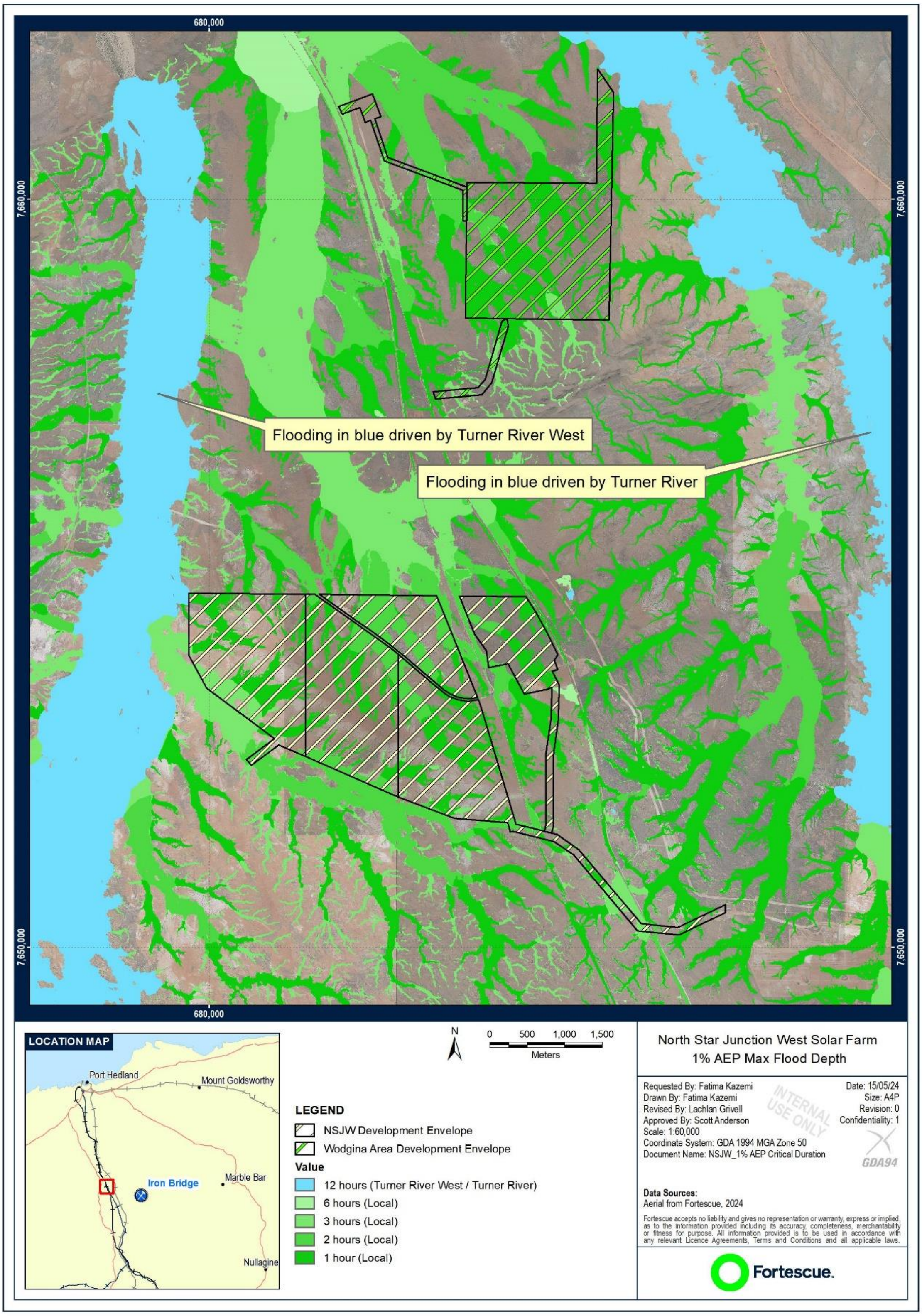

Figure 14 1% AEP Critical Duration

6 CONCLUSION

The North Star Junction West area envelope is located outside of the Turner River West floodplain and provides corridors for flow along the main tributaries to Turner River West. Flow velocities are typically low throughout this area and scour and channel movement are unlikely to be an issue.

Significant flood protection from Turner River West and the tributaries running through the area will not be required, and water and drainage management for the proposed North Star Junction West development area should consist of management of local flows within the development envelope. Any road access across tributaries will also need to incorporate appropriately sized culverts or floodways to limit any impact to flows resulting from the development.

Similarly, the Wodgina Area development envelope is located outside of Turner River, and there is limited interaction between the area and significant tributaries. Like the North Star Junction West Area, water and drainage management for the proposed Wodgina area should consist of management of local flows within the development envelope. As for the North Star Junction West area, any road access across tributaries will also need to incorporate appropriately sized culverts of floodways to limit any impact to flows resulting from the development.

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