

Surface Water Assessment

West Arthur Wind Farm

West Arthur Energy Pty Ltd

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CONTENTS

CONTENTS	2
1 INTRODUCTION	4
1.1 Overview	4
1.2 Methodology	6
1.3 Site	6
2 HYDROLOGIC MODELLING	8
2.1 Overview	8
2.2 Hillman River Catchment Hydrology	8
2.2.1 Methodology	8
2.2.2 Catchment Delineation	8
2.2.3 Model Parameters	10
2.2.4 Design Inputs	10
2.2.5 Critical Storm Events	10
2.2.6 Model Validation	11
2.3 Local Catchment Hydrology	11
3 HYDRAULIC MODELLING	12
3.1 Overview	12
3.2 Model Extent	12
3.3 Topography	12
3.4 Riverine Inundation	13
3.5 Local Catchment Inundation	13
3.6 Downstream Boundary	13
3.7 Land Use	13
4 RESULTS	15
4.1 Hydraulic Modelling – Existing Conditions	15
4.1.1 Flood Depth/Velocity	15
4.1.2 Flood Hazard	15
4.2 Hydraulic Modelling – Developed Conditions	20
4.2.1 Flow Crossing Locations	23
4.2.2 Surface Water Risk Assessment	33
4.2.3 Climate Change	34
5 RECOMMENDATIONS	35

LIST OF FIGURES

Figure 1-1	Site Locality	5
Figure 1-2	Site Topography	7
Figure 2-1	RORB Model Schematisation	9
Figure 3-1	TUFLOW Model Extent	12
Figure 3-2	TUFLOW Model Topography	13



Figure 3-3	TUFLOW Model Land Use	14
Figure 4-1	Flood Hazard Curves	16
Figure 4-2	1% AEP Flood Depth – Existing Conditions	17
Figure 4-3	1% AEP Flood Velocity – Existing Conditions	18
Figure 4-4	1% AEP Flood Hazard – Existing Conditions	19
Figure 4-5	Site Layout	21
Figure 4-6	Site Layout (Numbered Wind Turbines)	22
Figure 4-7	1% AEP Flood Afflux	24
Figure 4-8	1% AEP Flood Afflux (South-West)	25
Figure 4-9	1% AEP Flood Afflux (North-West)	26
Figure 4-10	1% AEP Flood Afflux (North-East)	27
Figure 4-11	1% AEP Flood Depth – Developed Conditions	28
Figure 4-12	1% AEP Flood Velocity – Developed Conditions	29
Figure 4-13	1% AEP Flood Hazard – Developed Conditions	30
Figure 4-14	Flow Crossing Locations	31

LIST OF TABLES

Table 2-1	RORB Model Parameters	10
Table 2-2	IFD Design Rainfall Depth	10
Table 2-3	1% AEP Critical Storm Event	11
Table 2-4	1% AEP Peak Flow Estimates	11
Table 3-1	Land Use Parameters	14
Table 4-1	Flow Crossing Design Values	32



1 INTRODUCTION

1.1 Overview

This report details the findings of the surface water impact assessment for a proposed wind farm development situated within the Shire of West Arthur in Western Australia. The site footprint is approximately 110 km² in size, and is located across the localities of Darkan and Duranillin approximately 100 km east of Bunbury.

The proposed wind farm development envelope is shown in Figure 1-1 and is described as the 'subject site' or 'site' in this report.

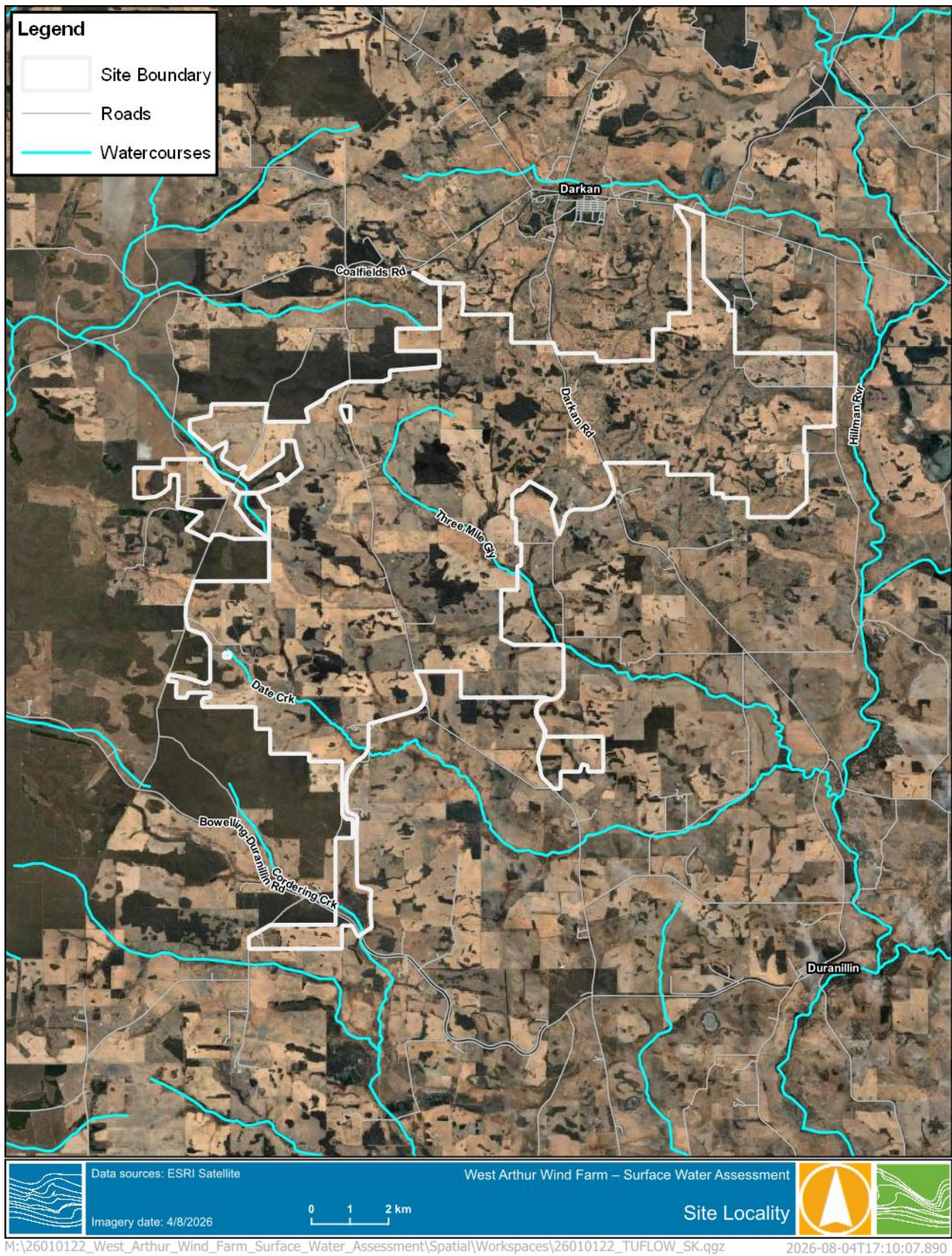


Figure 1-1 Site Locality



1.2 Methodology

The objective of this surface water impact assessment was to quantify the impact of the proposed wind farm development on several elements of the surface water environment. This includes assessment of the following:

- Inundation potential – the probability for the development to be inundated by riverine flooding and/or local stormwater runoff.
- Drainage alterations – the potential for the development to affect adjacent flood extents, levels, velocities and/or hazard classifications and flow rates and/or volumes.

The approach characterises the existing surface water environment, as well as the impact of the proposed wind farm development in relation to it. This includes:

- Establishing the existing surface water characteristics, including prevailing drainage functions/behaviour.
- Assessing changes to surface water behaviour resulting from the development of the proposed wind farm.
- Identifying design options and/or mitigation measures which serve to eliminate or minimise any potential negative effects of the wind farm construction and operation on the surface water environment.

The flood risk assessment for the subject site was based on hydrologic modelling of the Hillman River catchment upstream of the wind farm site footprint and hydraulic modelling of both riverine and direct rainfall / localised catchment inundation. Outputs from the hydraulic model were used to assess flood impacts and risk and inform decision-making in relation to the layout of the wind farm infrastructure.

1.3 Site

The site is located on rural land and is positioned directly west of the Hillman River at its north-eastern extent. The Hillman River has a catchment area of approximately 538 km² upstream of the subject site. Ridgelines run along the western and northern extents of the site, separating catchment areas feeding into tributaries that drain to the Arthur River (to the west of the site) and Hillman River (other perpendicular ridgelines further separate these areas into smaller sub-catchments). Given the size of the site, there is a wide variation in elevations, from 388 to 235 m AHD. The local topography is shown in Figure 1-2.

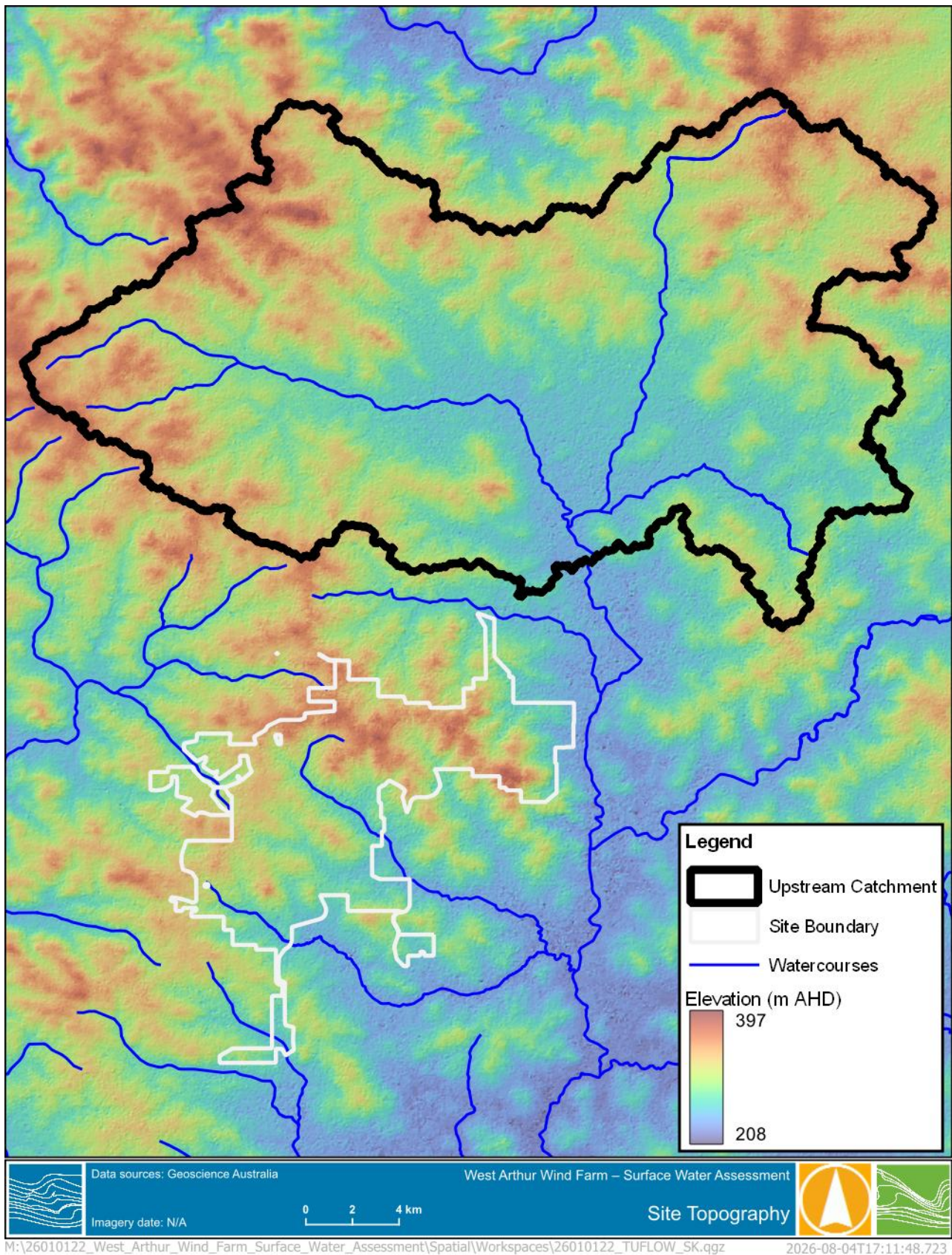


Figure 1-2 Site Topography



2 HYDROLOGIC MODELLING

2.1 Overview

Hydrological modelling of the subject site comprised of the following components:

- The hydrology of the Hillman River catchment was modelled using a RORB rainfall runoff model, which produced design hydrographs for the catchment in accordance with Australian Rainfall and Runoff 2019 V4.2 (ARR v4.2) guidelines. Inflow hydrographs from the Hillman River RORB model were incorporated into a TUFLOW hydraulic model, where the flows were routed through the surrounding site topography as part of determining the maximum flood depths, velocities and hazard classifications of the 1% annual exceedance probability (AEP) storm event.
- The local catchment hydrology was modelled using a rain-on-grid (RoG) approach, which introduces rainfall directly onto the TUFLOW hydraulic model.

2.2 Hillman River Catchment Hydrology

2.2.1 Methodology

Design hydrologic modelling was completed using an ensemble approach as recommended in ARR v4.2. The methodology for determining the 1% AEP design flow is outlined below:

- Delineation of the Hillman River catchment upstream of the subject site.
- Designation of design inputs (e.g. rainfall, temporal patterns).
- Determination of storage parameters and rainfall losses.
- Selection of critical storm event.
- Extraction of inflow hydrographs for hydraulic model.

Details of these steps are provided in the following sections.

2.2.2 Catchment Delineation

The Hillman River catchment upstream of the proposed wind farm was delineated into 15 individual sub-areas. The delineation was based on the 30 m SRTM digital elevation model (DEM) made available by Geoscience Australia. The resulting delineated sub-areas were then processed using geographic information system (GIS) mapping software to create a series of nodes and reaches, which represented the routing characteristics of the catchment, and were to be utilised in the RORB model. All reaches were defined as natural channels; this definition was assumed based on expected flow path characteristics owing to aerial photography, as well as prior hydrologic modelling experience. Sub-area fraction imperviousness was assumed as zero for all sub-areas based on the rural location of the catchment area.

The resulting RORB model encompassed a total catchment area of approximately 538 km², with the subject site located at the downstream end of the delineated catchment (as seen in Figure 2-1).

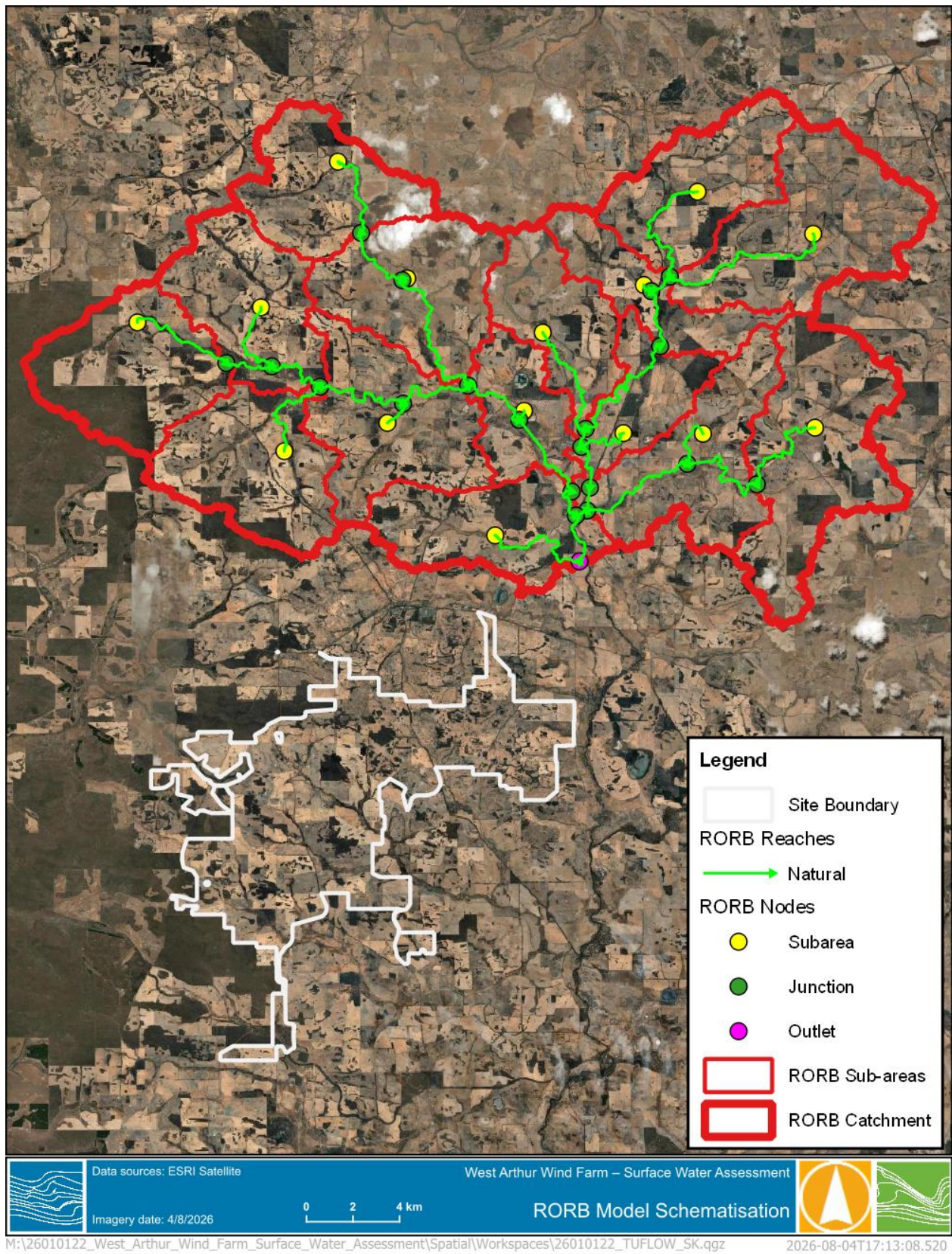


Figure 2-1 RORB Model Schematisation



2.2.3 Model Parameters

The storage and rainfall losses parameters adopted in the RORB model for the current study are listed in Table 2-1. The losses employed were based on the data obtained from the ARR Data Hub. The wind farm site is located within a region where sandy duplex, gravelly duplex and lateritic soil profiles are common, with these soil types possessing considerable infiltration capacities (particularly under dry antecedent conditions); hence, the relatively high initial and continuing loss values. The value of the storage coefficient k_c was determined using the default RORB manual equation, which resulted in the best fit of peak flow estimate to the flow quantiles produced by the ARR Regional Flood Frequency Estimation (RFFE) model (see Section 2.2.6).

Table 2-1 RORB Model Parameters

Parameter	Value
Initial Loss (IL)	33 mm
Continuing Loss (CL)	2.7 mm/h
k_c	51.03
m	0.80

2.2.4 Design Inputs

2.2.4.1 Intensity-Frequency-Duration (IFD) Design Rainfall

Rainfall depths for the 1% AEP event were estimated for the catchment centroid using the intensity-frequency-duration (IFD) information available from the Bureau of Meteorology (BoM) website. The design rainfall estimate for the study area is shown in Table 2-2 for the critical duration (also refer to Section 2.2.5).

Table 2-2 IFD Design Rainfall Depth

AEP	Rainfall Depth
1%	145 mm

2.2.4.2 Temporal Patterns

Design storm temporal patterns were downloaded from the ARR Data Hub and were used to simulate the distribution of rainfall depth bursts during each storm event modelled. Area-based temporal patterns were utilised given the large ($> 75 \text{ km}^2$) size of the catchment. Outputs owing to each of the ten temporal patterns for each event duration were compared, and the temporal pattern that resulted in the median peak flow was adopted for a particular event duration.

2.2.5 Critical Storm Events

An ensemble assessment was undertaken to determine the critical storm duration for the storm events affecting the subject site via riverine inundation. As mentioned previously, due to the large size of the upstream catchment, areal temporal patterns were used in the hydrologic analysis.

Table 2-3 details the 1% AEP peak flow at the Hillman River hydraulic model inflow location for the critical storm duration. The assessment indicated that a 24-hour storm duration generates the highest peak flow for the 1% AEP event in relation to the riverine system.



Table 2-3 1% AEP Critical Storm Event

AEP	Peak Flow	Critical Duration	Critical Temporal Pattern
1%	271 m ³ /s	24 hours	6

2.2.6 Model Validation

The 1% AEP event peak flow at the outlet of the RORB catchment model was compared to flow quantiles produced by the ARR RFFE model; the comparison of peak flow estimates is detailed in Table 2-4. The peak flow modelled in RORB as part of the current study is reasonably similar to the flow estimate produced by the RFFE model, and is comfortably within the 90% confidence limits.

Table 2-4 1% AEP Peak Flow Estimates

Source	Discharge (m ³ /s)
RORB Model	271
RFFE Model	355
RFFE Model 5% Confidence Limit	60.6
RFFE Model 95% Confidence Limit	2,090

2.3 Local Catchment Hydrology

As described in Section 1, a RoG modelling approach using TUFLOW was adopted for the simulation of local storm event inundation across the subject site. TUFLOW is an industry-standard one- and two-dimensional modelling package which has been used as part of numerous flood modelling projects across Australia.

The RoG approach involves applying rainfall directly onto a topographic grid of the area of interest; this serves to identify flow paths through the modelling of surface water runoff, and enables mapping of flood extents, depths, velocities and hazard classifications. RoG modelling is a robust method to determine runoff volumes, peak flow rates and areas of high flood risk within regions comprised of complex topography. RoG models enable the identification of major flow paths, depressions, and the interactions of overland flow.

The specific details of the RoG modelling undertaken in TUFLOW is discussed alongside the summary of the hydraulic modelling in Section 3.



3 HYDRAULIC MODELLING

3.1 Overview

The TUFLOW hydraulic model characterised both riverine and local catchment inundation, representing the two potential flooding mechanisms relevant to the site footprint. Riverine flooding was simulated using an inflow hydrograph located across the Hillman River, which was taken from the RORB hydrologic model and routed through the TUFLOW DEM, while localised catchment runoff was modelled using TUFLOW's RoG functionality.

3.2 Model Extent

The model extent is depicted in Figure 3-1, with flow boundaries also shown (it should be noted that for RoG modelling, rainfall was applied to the entirety of the model extent, and therefore no specific RoG boundary is depicted).

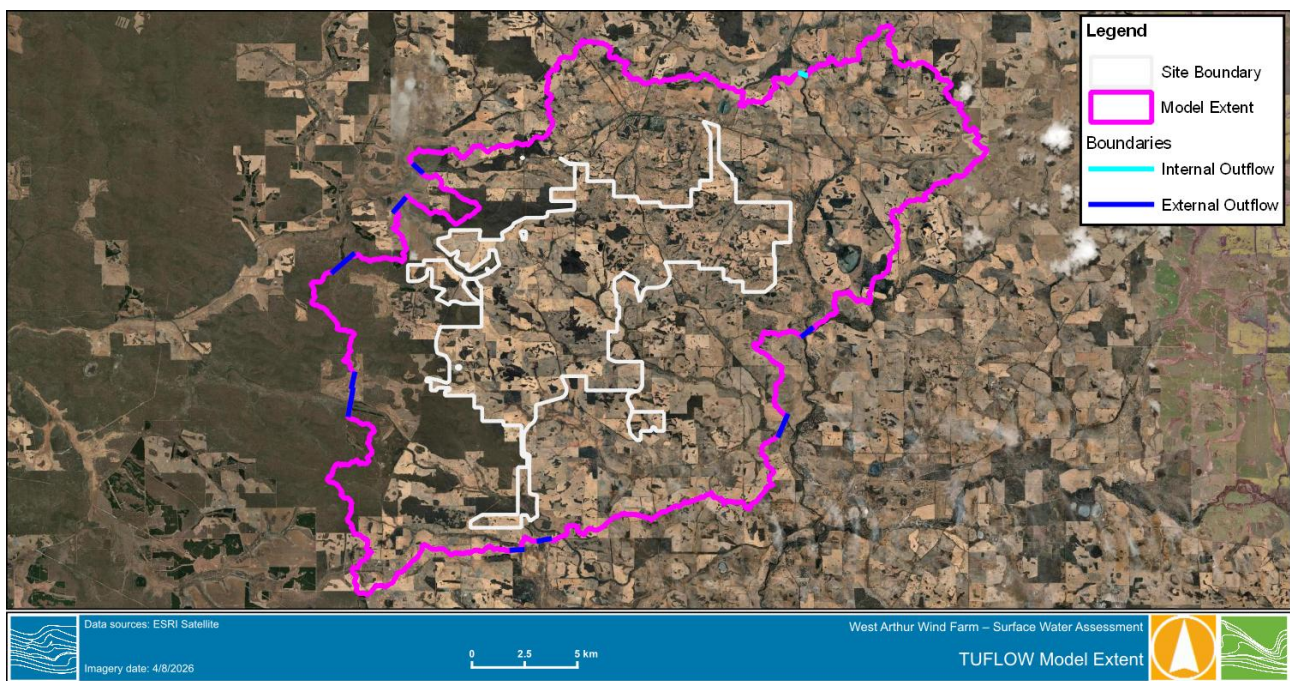


Figure 3-1 TUFLOW Model Extent

3.3 Topography

The TUFLOW DEM was generated based on 5 m LiDAR data specifically provided for the West Arthur Wind Farm (the TUFLOW DEM is seen in Figure 3-2). Road and railway alignments were reinforced in the DEM via the use of breaklines along their centrelines, with elevation spacing of 10 m (i.e. equal to the grid cell size). Terrain was cleared along major watercourse alignments where they intersected with roads or railways as a method of approximating the flow conveyance function of the hydraulic structures located at these points.

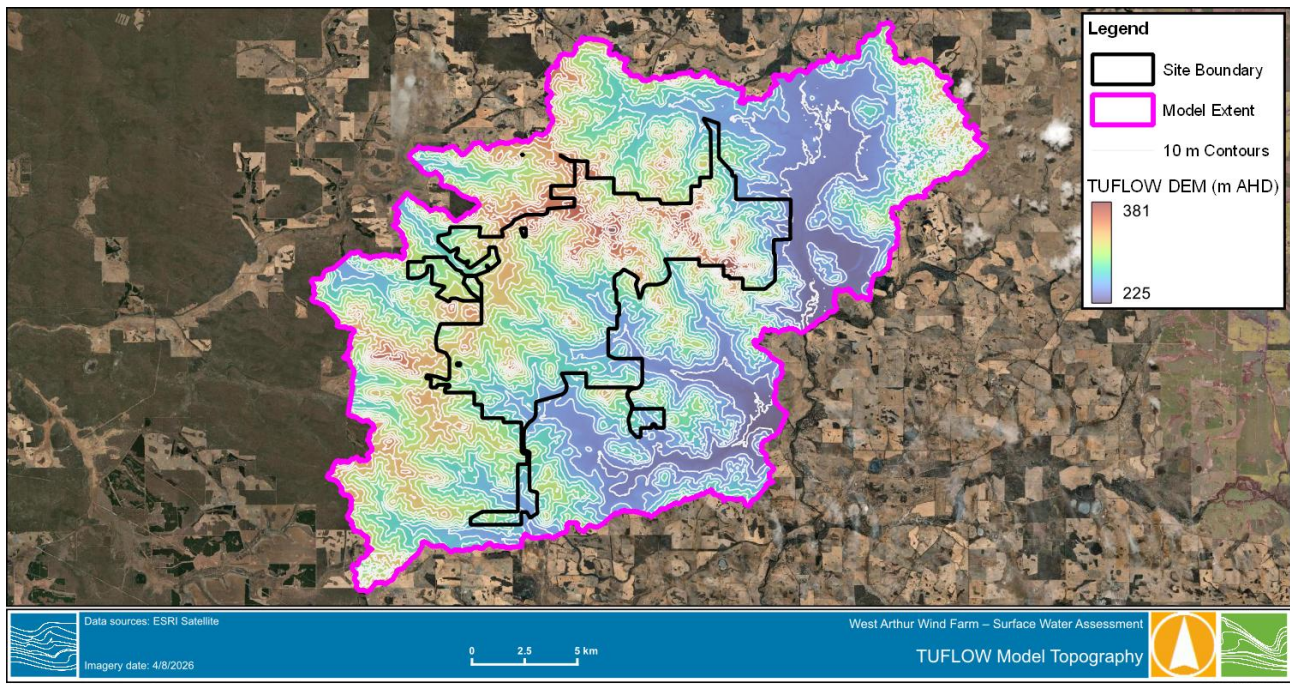


Figure 3-2 TUFLOW Model Topography

3.4 Riverine Inundation

The riverine inflow was located within the Hillman River channel, approximately 7 km north of the site footprint's most north-easterly extent. The inflow was modelled as an external discharge-time boundary referencing hydrographs derived from the Hillman River catchment RORB model.

3.5 Local Catchment Inundation

Localised catchment inundation was simulated by introducing rainfall directly onto the model extent. As mentioned previously, the model extent shown in Figure 3-1 was utilised as the area for the application of direct rainfall.

Rainfall inputs for the TUFLOW model were extracted using the ARR2019 feature in the QGIS TUFLOW plugin, which downloads the data required for RoG modelling from the ARR Data Hub and BoM websites. The 1% AEP rainfalls depths for storm events from 10 minutes to 72 hours in duration were incorporated into the hydraulic model as part of ensuring that the critical event durations could be ascertained. Based on the inundation depicted across the subject site in the modelling outputs, it was determined that the 4.5-hour, 9-hour and 30-hour events were those that were critical in relation to the hydraulic modelling completed.

3.6 Downstream Boundary

The downstream model outflow was represented using an external level-discharge boundary, with a slope corresponding to the local floodplain gradient; this allows flow to recede from the model without unduly influencing flood levels at the site.

3.7 Land Use

Land use layers were created based on aerial imagery and planning scheme zones. Hydraulic roughness coefficients (i.e. Manning's n) and rainfall loss values were assigned to each land use type. The values adopted were based on recommendations from ARR v4.2 and conservatively adjusted to account for the RoG modelling



approach. Table 3-1 summarises the adopted land use parameters, and Figure 3-3 presents the land use layers spatially.

Table 3-1 Land Use Parameters

Land Use	<i>n</i>
Road	0.025
Rural	0.04
Vegetation	0.09
Residential	0.05
Commercial	0.35
Railway	0.125
Residential Building	0.4
Watercourse	0.045
Dam	0.08

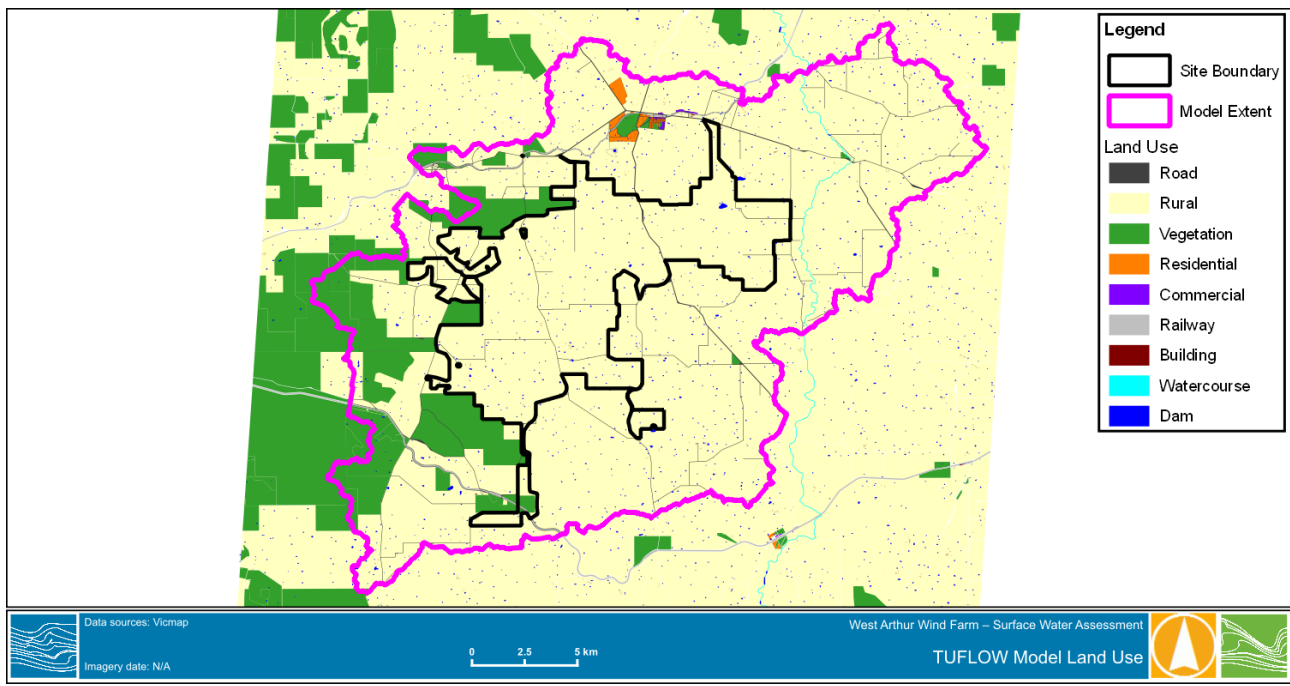


Figure 3-3 TUFLOW Model Land Use



4 RESULTS

4.1 Hydraulic Modelling – Existing Conditions

4.1.1 Flood Depth/Velocity

The 1% AEP event hydraulic modelling results under existing conditions are shown in Figure 4-2 to Figure 4-4 (mapping outputs were filtered to a depth of 0.05 m and puddle area of 0.01 ha). In general, flows adhere to within the anabranches of the defined watercourses that cross the site footprint, with no large, isolated bodies of ponded stormwater present. The deepest flow within a defined watercourse is observed in Three Mile Gully, with a depth of 1.8 m. Hillman River floodplain flows do not directly encroach upon the development area (this relates to the iteration of site extents based on preliminary modelling results; earlier versions of the subject site experienced floodplain inundation). There are a multitude of farm dams located within the site footprint; most of these waterbodies are inundated to a height of less than 1 m. The largest of these farm dams is situated adjacent to Beer Bottle Road at the inner north-east corner of the site footprint, with a maximum depth of 6.7 m observed at this feature.

As would be anticipated, the most noteworthy flood velocities are present in the defined watercourses aligned across the site footprint, with a maximum velocity of 2.5 m/s observed; however, most velocities within the watercourses are between 0.5 to 1.5 m/s.

4.1.2 Flood Hazard

Floods can be hazardous, producing harm to people, damage to infrastructure and, potentially, loss of life. In examining the potential hazard of flooding across the subject site, several factors were considered as outlined in ARR v4.2 (Book 6, Chapter 7). The assessment of flood hazard considered the following:

- Depth
- Velocity
- Depth-velocity product

The flood hazard of the site was assessed in accordance with ARR v4.2, which defines six hazard categories (the hazard categories are presented in Figure 4-1). Flood hazard is generally low across the site footprint, being at a H1 or H2 classification across most of the developable area. Hazard classifications reach a maximum of H5 within the local major watercourses; and within the large farm dam adjacent to Beer Bottle Road, a maximum hazard classification of H6 is observed.

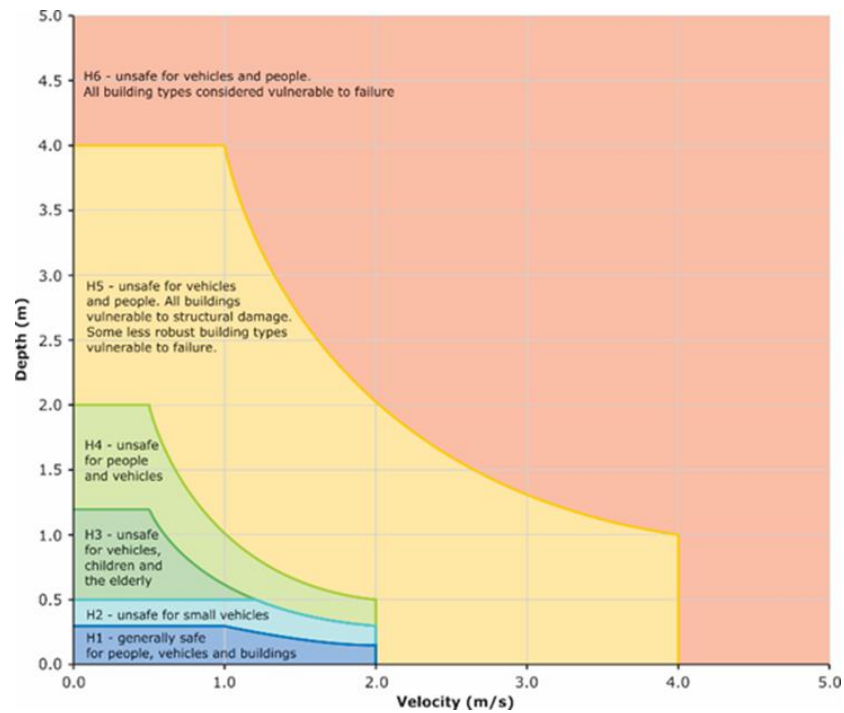


Figure 4-1 Flood Hazard Curves

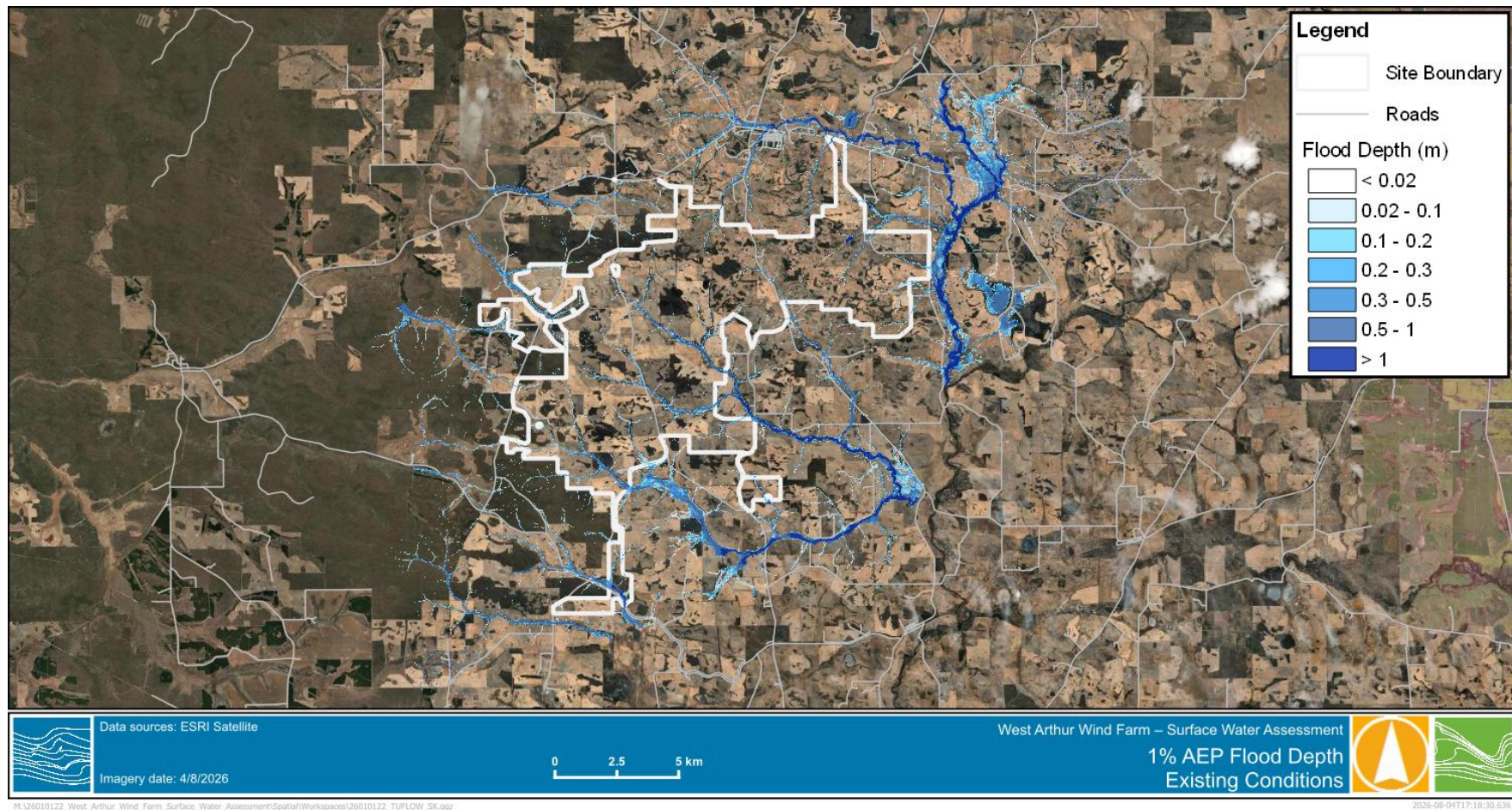


Figure 4-2 1% AEP Flood Depth – Existing Conditions

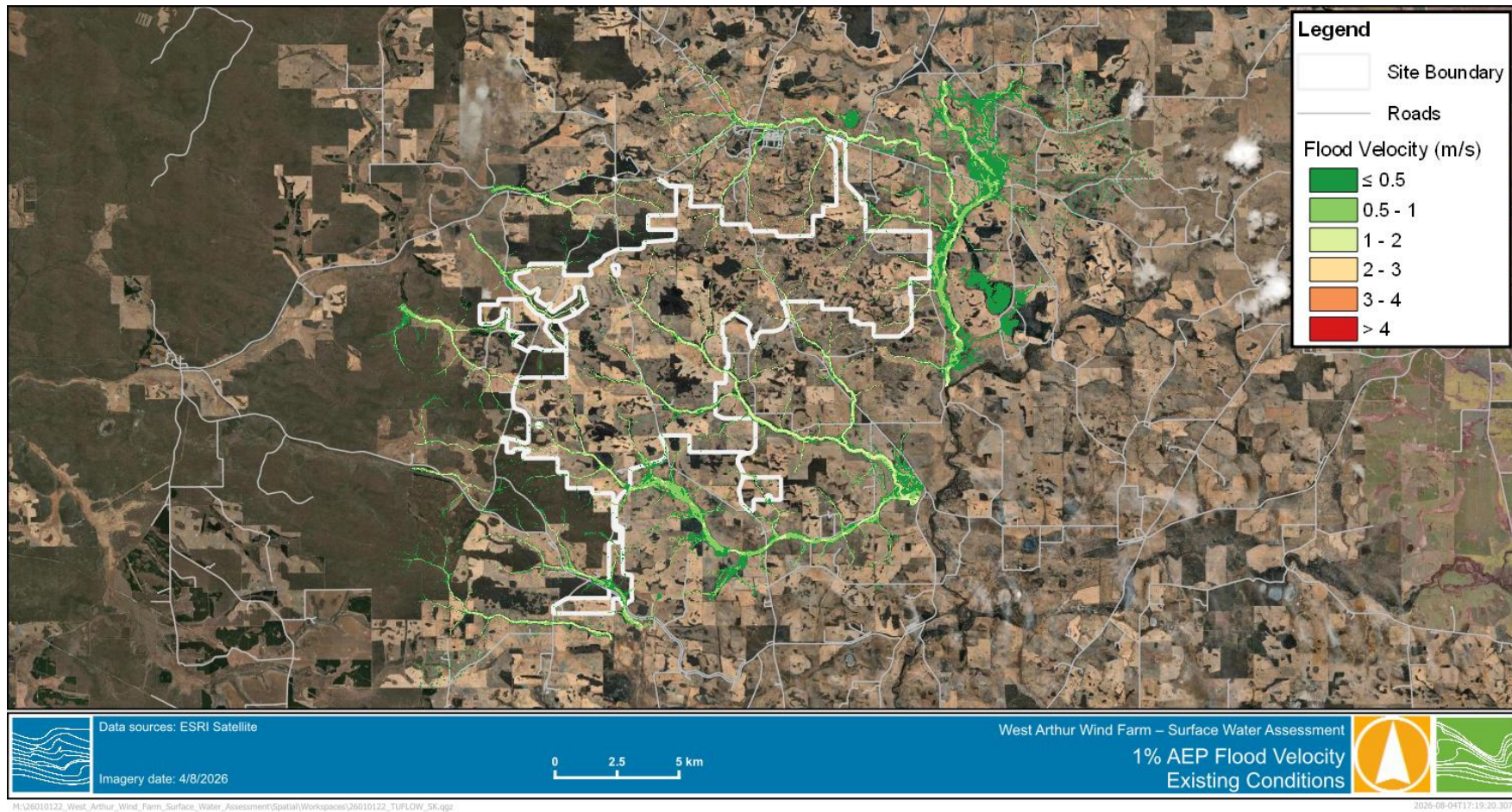


Figure 4-3 1% AEP Flood Velocity – Existing Conditions

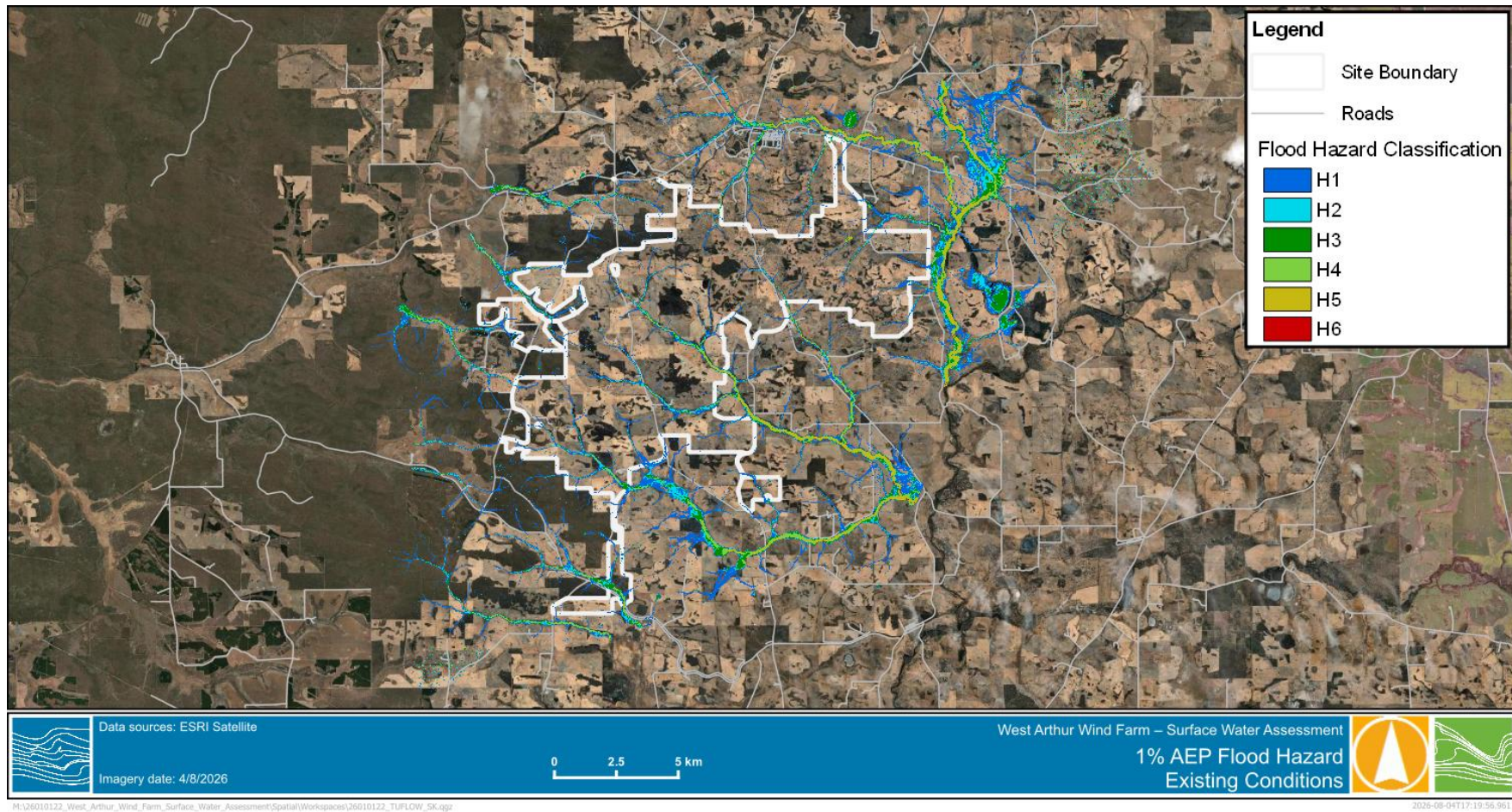


Figure 4-4 1% AEP Flood Hazard – Existing Conditions



4.2 Hydraulic Modelling – Developed Conditions

To characterise indicative worst-case topographic conditions for the proposed wind farm with respect to flooding, areas comprised of wind farm infrastructure (which includes access roads and turbine/facility hardstand regions) were raised globally by 300 mm within the TUFLOW model (this was done as part of a conservative approach to representing surface water conditions post-development). At the advice of the client, flows paths were not routed through access roads at locations where they intersected, as it is anticipated that runoff will be permitted to overtop the roads constructed as part of the wind farm (major flows upstream of the proposed access roads were still recorded; however, in the instance that hydraulic structures wish to be implemented at these intersection locations, and to aid in the detailed design of the access roads). The proposed wind farm layout is depicted in Figure 4-5 and Figure 4-6.

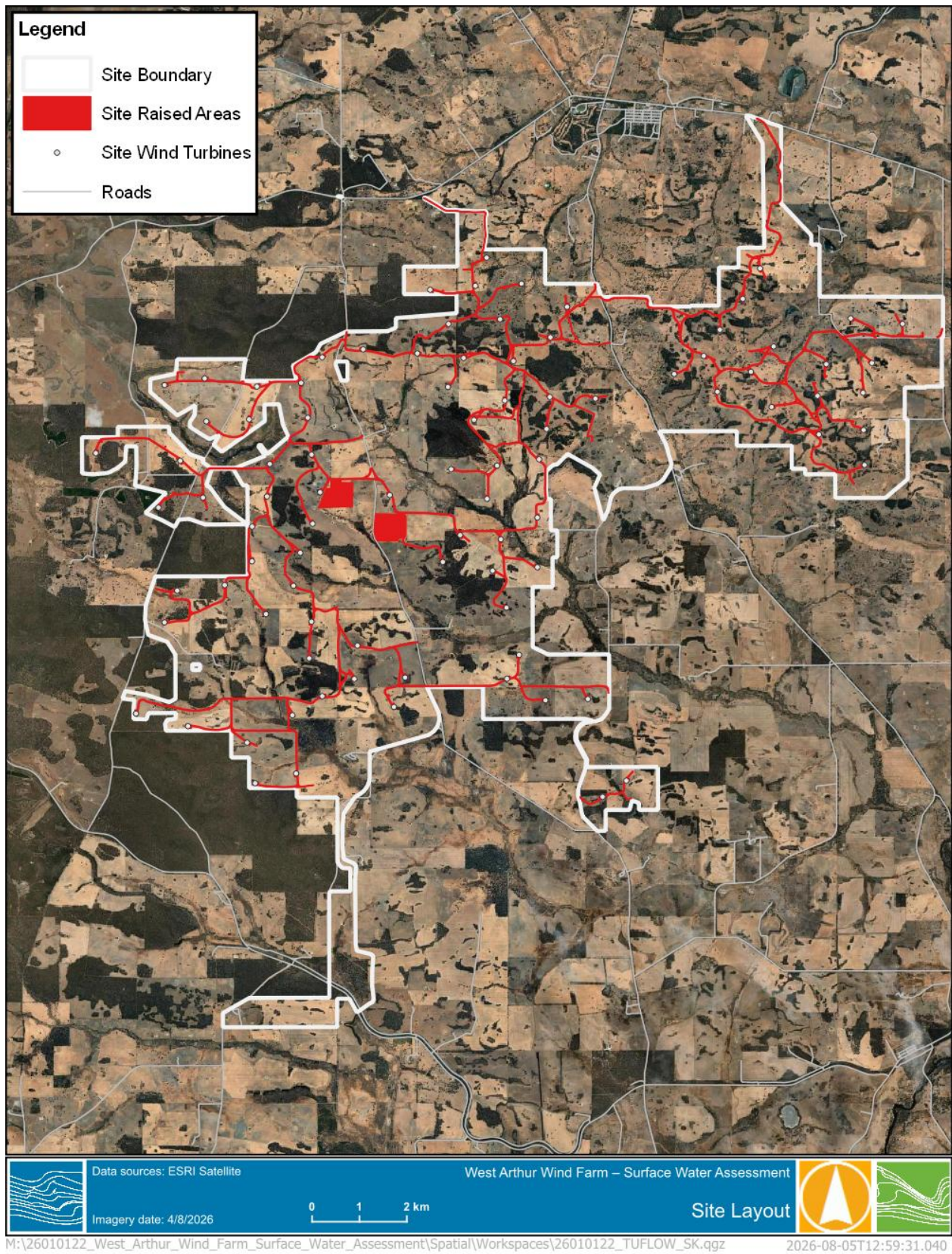


Figure 4-5 Site Layout

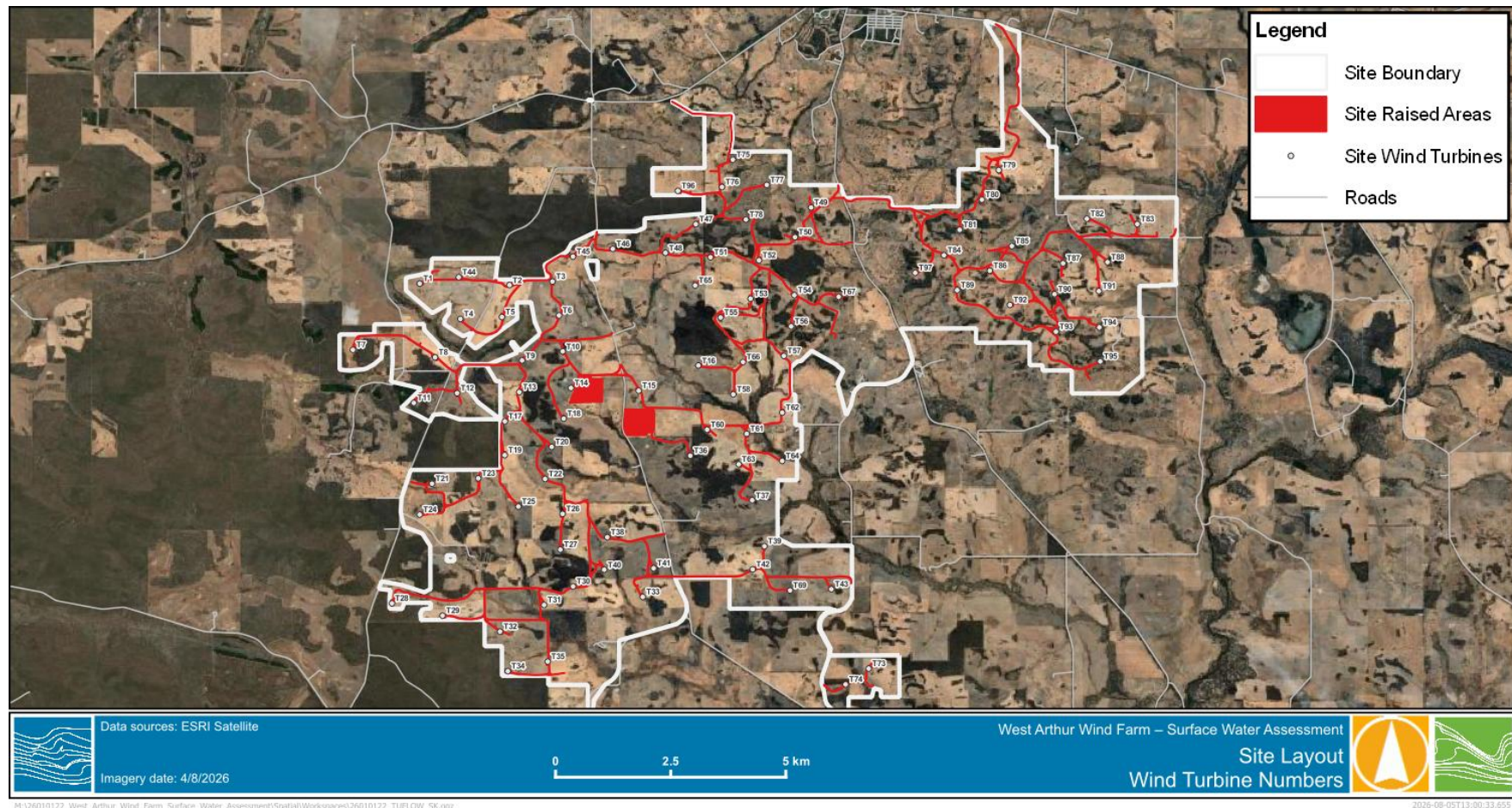


Figure 4-6 Site Layout (Numbered Wind Turbines)



An afflux grid quantifying the difference in 1% AEP flood levels between existing and developed conditions was generated and is depicted in Figure 4-7. Flood impacts can be seen at all of the flow path intersection points, with the associated maximum flood level increases ranging from 100 to 200 mm and peaking at approximately 250 mm. Positive afflux is also witnessed alongside the proposed access roads at other locations, at points where no major flow path is present; local runoff is being detained by the raised road alignment in these instances. The developed conditions scenario additionally engenders areas of negative afflux, with these typically being located on the downstream sides of proposed access roads. A planned access road intersects a significant watercourse in Three Mile Gully, resulting in a larger region of afflux on the upstream side of the carriageway. There is also considerable change to flood behaviour approximately 1.5 km south-west of the Capercup Road North and Coltart Road intersection, where different flow paths are simultaneously activated and deactivated between the two scenarios. Water level reductions of up to approximately 15 mm are seen along the drainage line adjacent to Cordering Road North, immediately south of the wind farm main facility area; these are likely due to the flow path being ringed by the proposed access roads, and having the facility area serve to detain the runoff directly upstream.

Figure 4-8 to Figure 4-10 detail the flood depth, velocity and hazard mapping results owing to the 1% AEP event under developed conditions.

4.2.1 Flow Crossing Locations

Locations where major flow paths intersect with proposed access roads have been identified. 1% AEP flow rates and water levels have been recorded at these points to inform (if so required) the detailed design of the access road and any associated hydraulic structures. The locations of the flow crossings are depicted in Figure 4-11; the corresponding flow and level values at these specified points are detailed in Table 4-1.

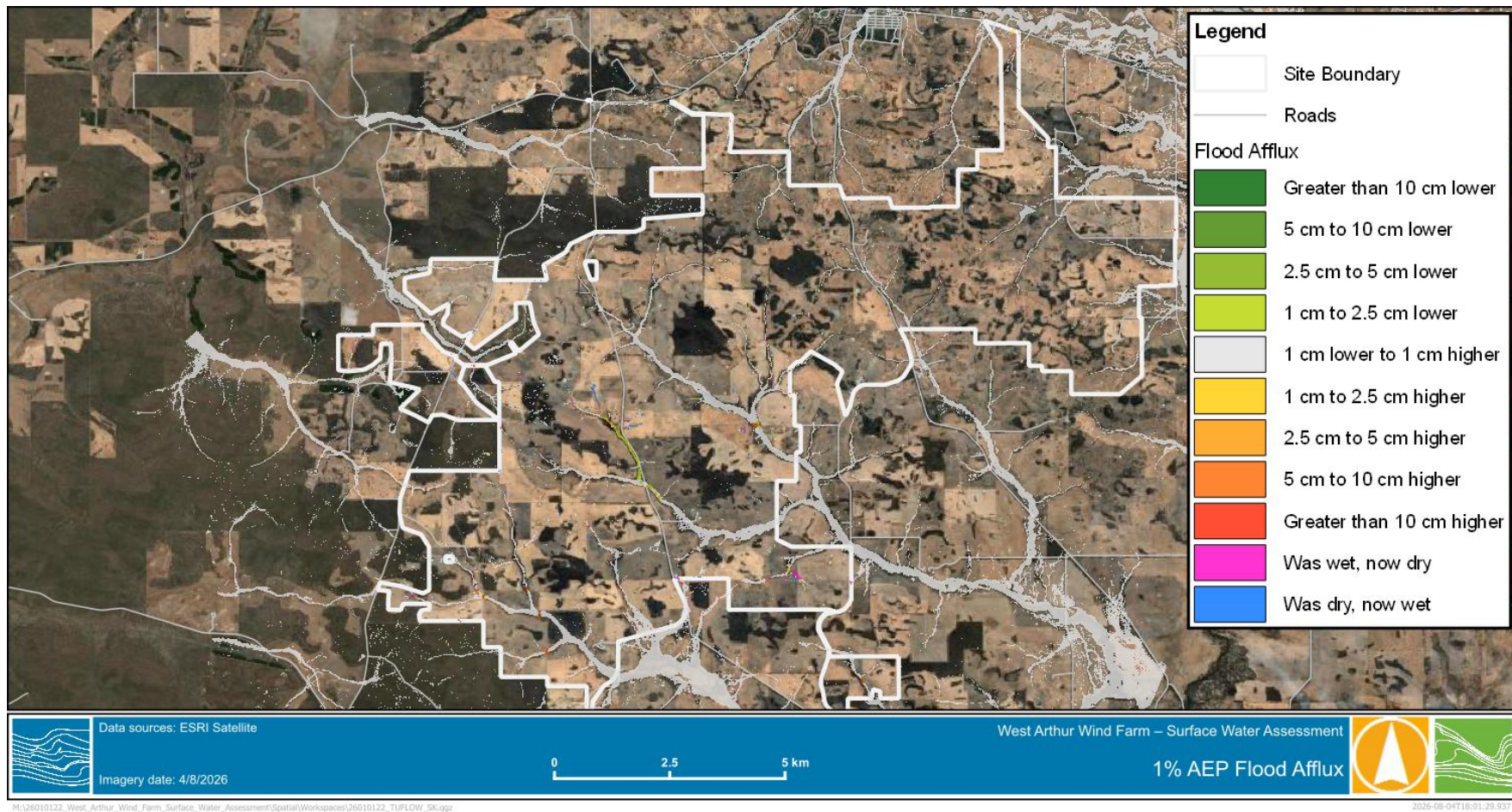


Figure 4-7 1% AEP Flood Afflux



Figure 4-8 1% AEP Flood Afflux (South-West)

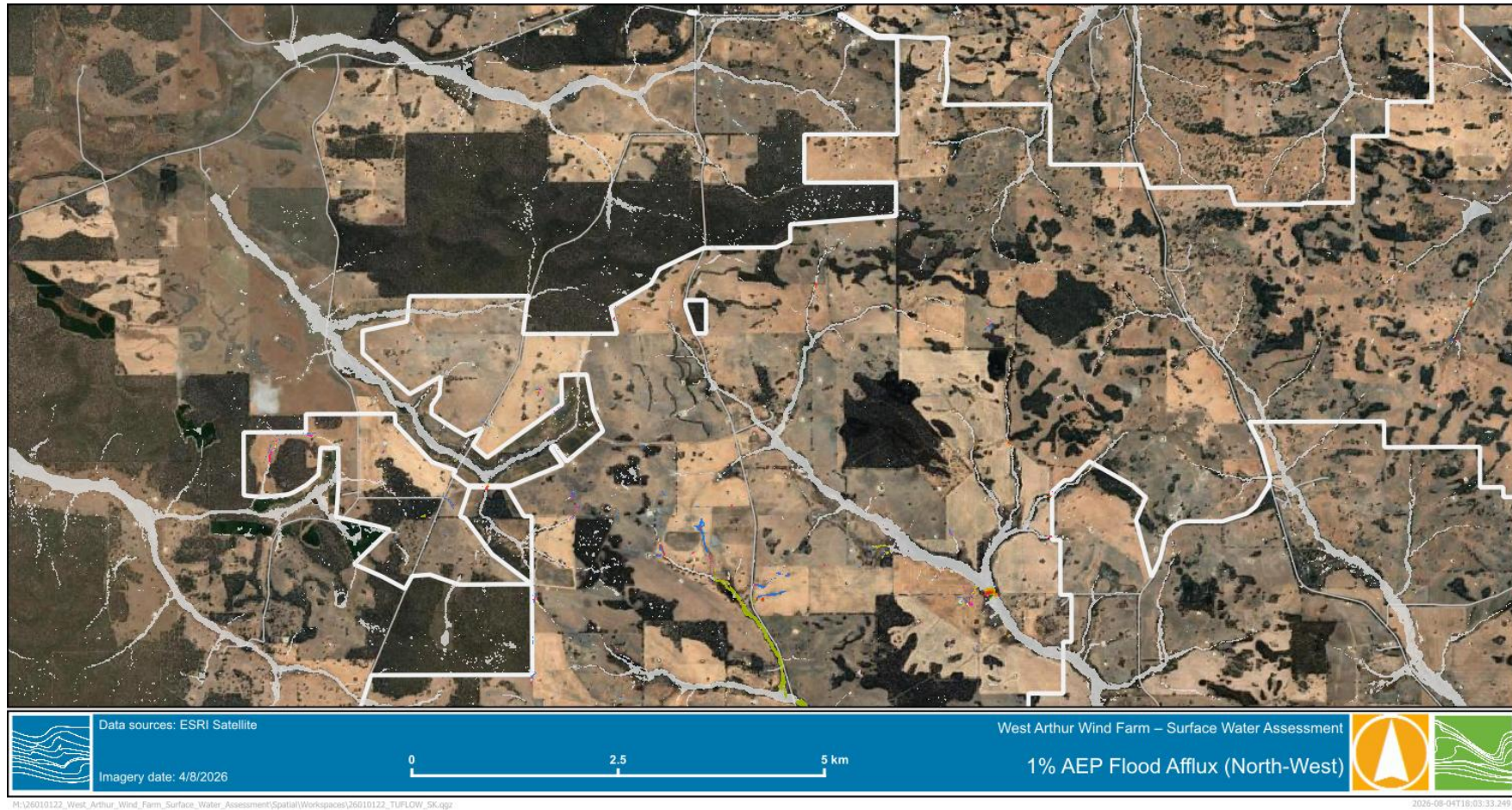


Figure 4-9 1% AEP Flood Afflux (North-West)

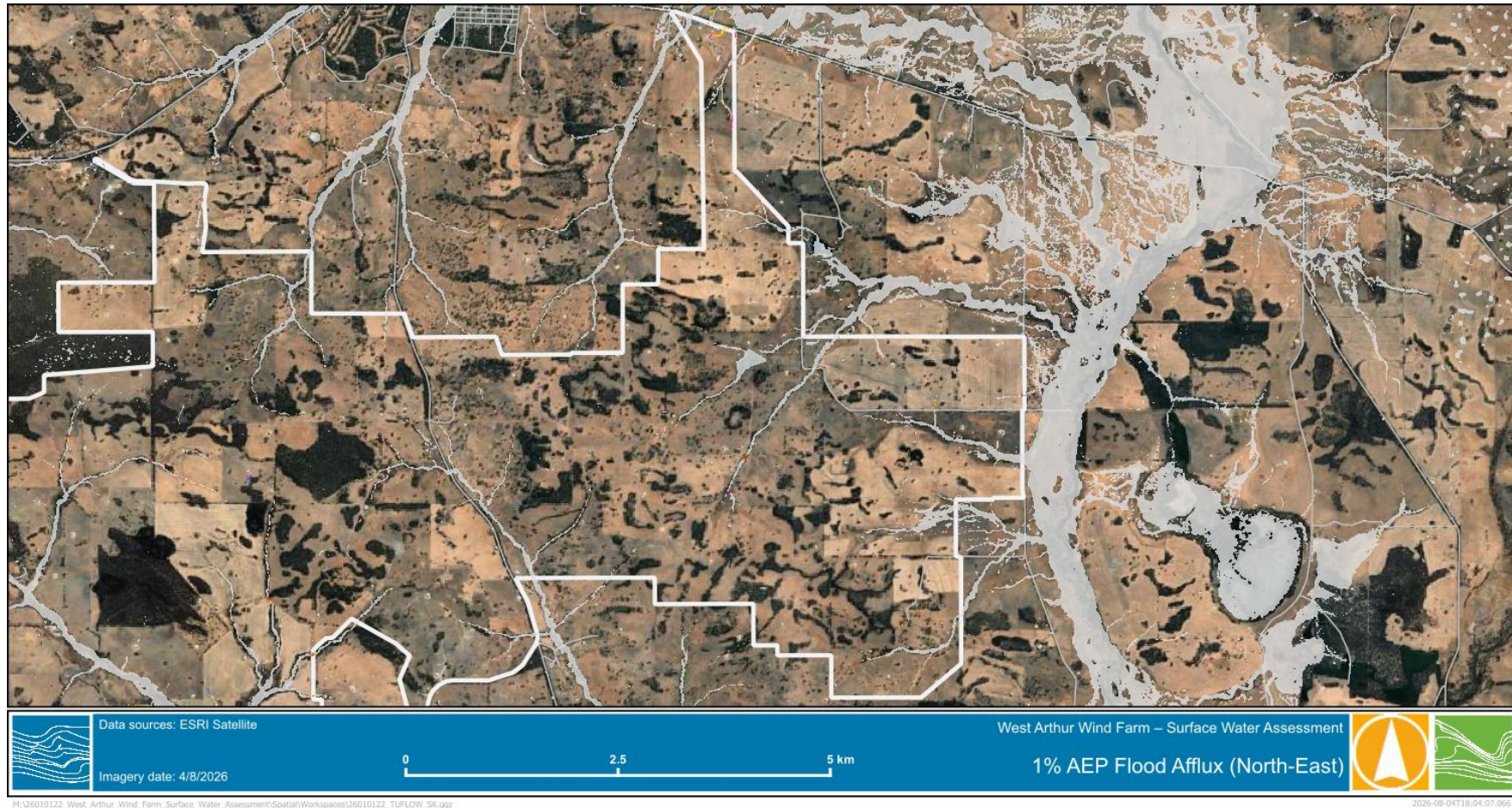


Figure 4-10 1% AEP Flood Afflux (North-East)



Figure 4-11 1% AEP Flood Depth – Developed Conditions

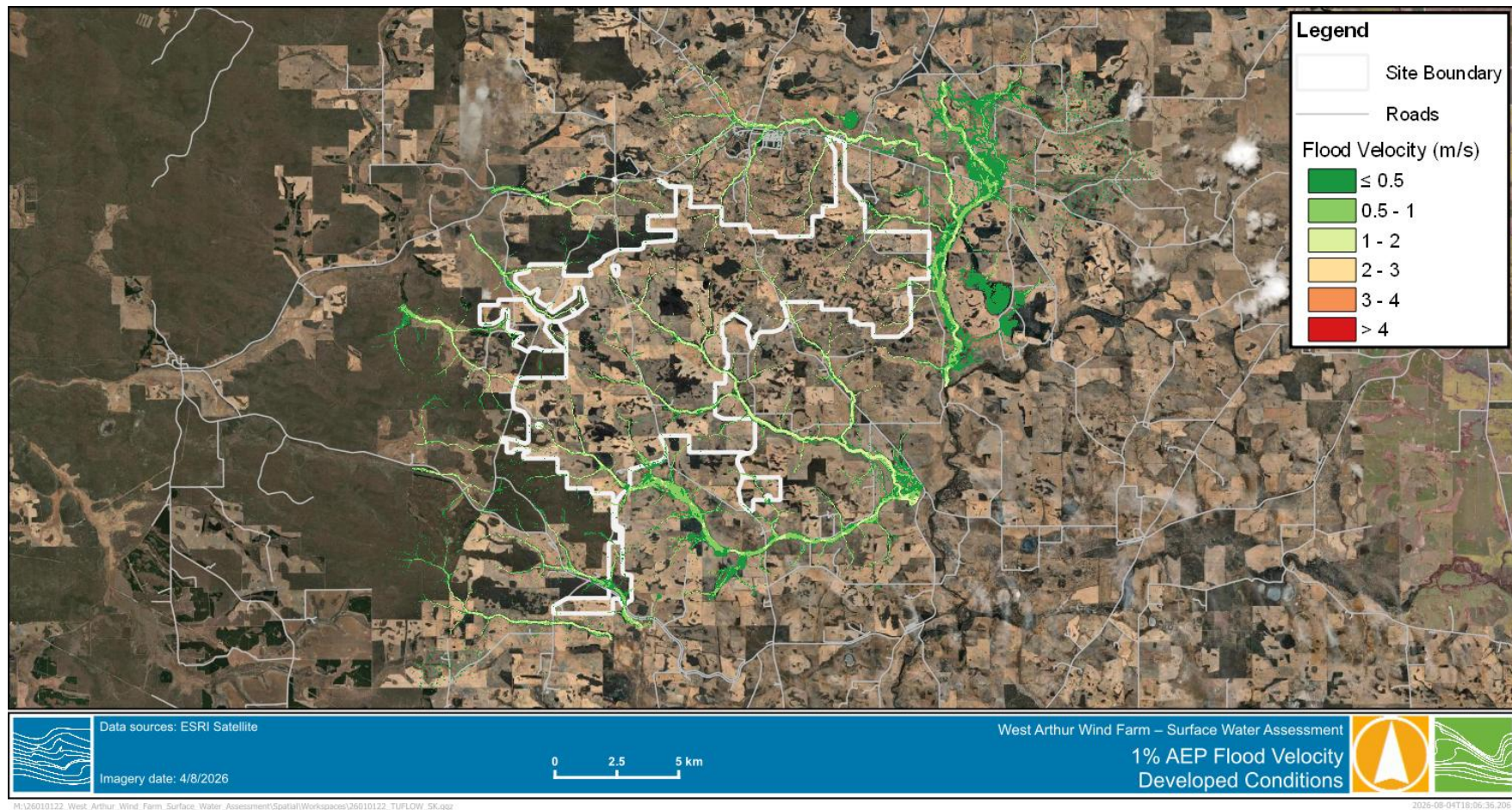


Figure 4-12 1% AEP Flood Velocity – Developed Conditions

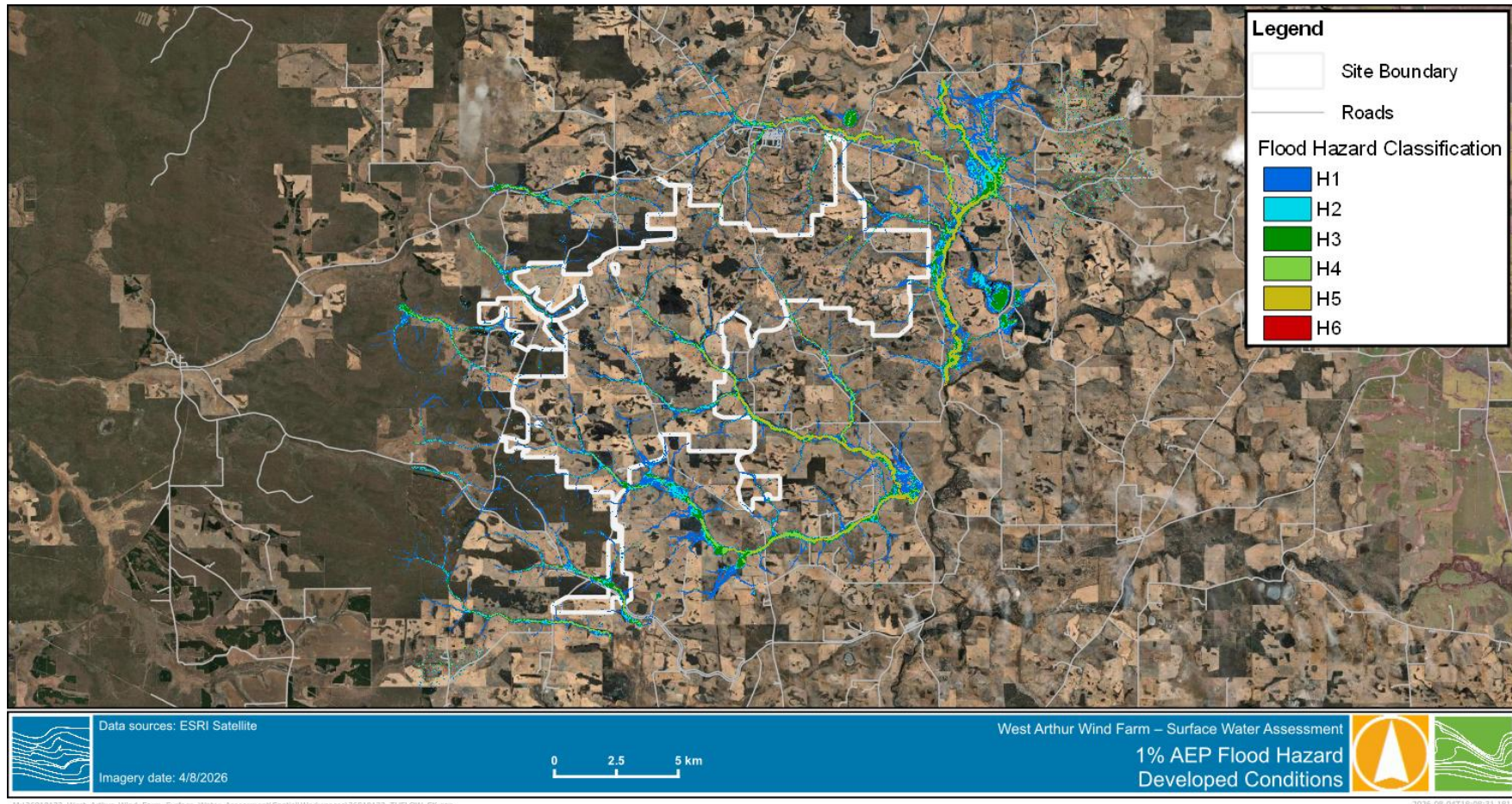


Figure 4-13 1% AEP Flood Hazard – Developed Conditions

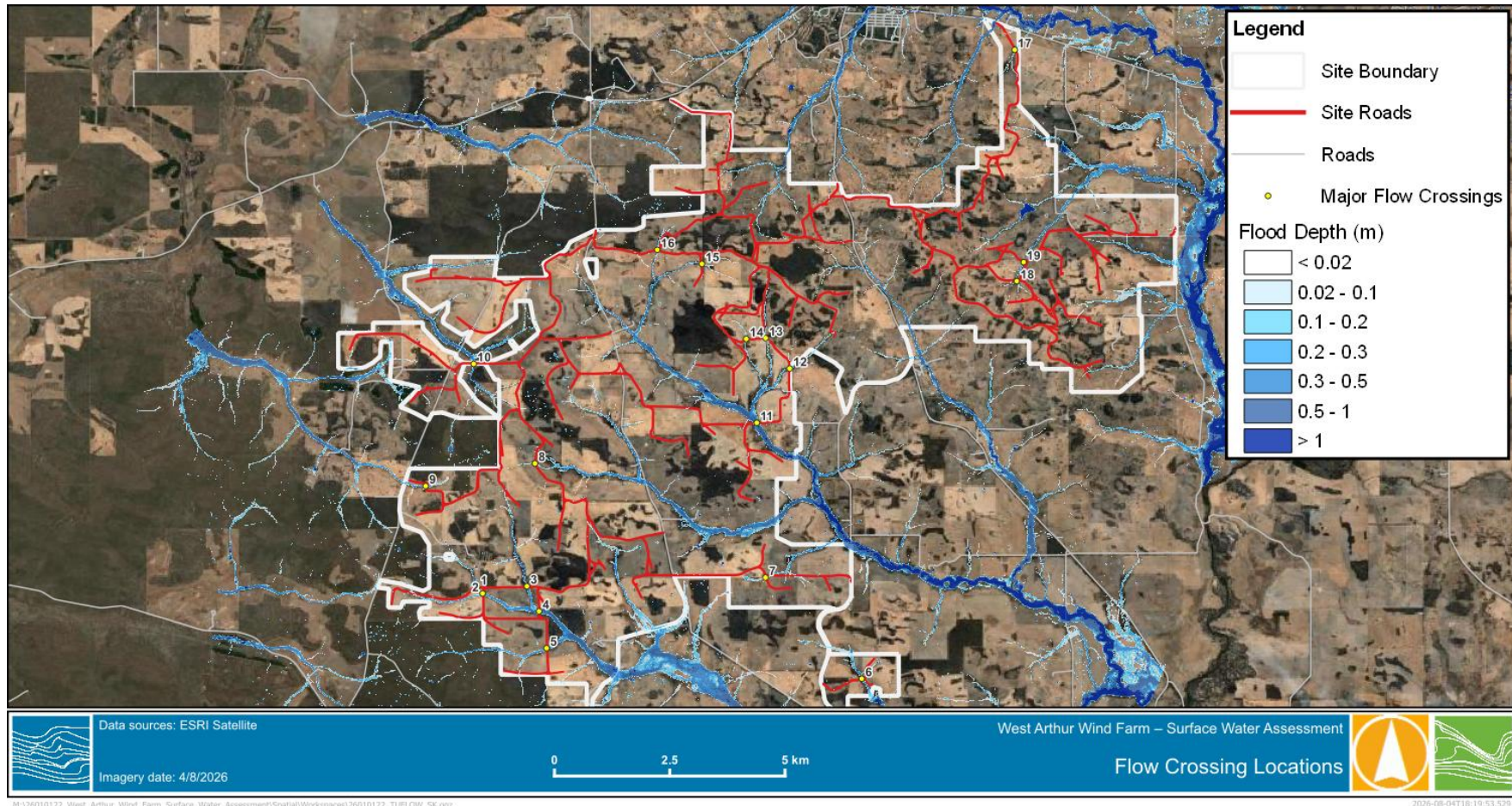


Figure 4-14 Flow Crossing Locations



Table 4-1 Flow Crossing Design Values

Crossing No.	Peak 1% AEP Flow (m3/s)	Peak 1% AEP Water Level (m AHD)
1	7.78	277.73
2	18.5	275.1
3	16.04	270.57
4	40.46	262.59
5	16.48	261.15
6	11.89	253.08
7	3.13	266.78
8	2.31	291.57
9	5.51	294.07
10	13.81	283.94
11	90.19	257.41
12	9.52	274.82
13	6.63	288.57
14	4.01	293.81
15	5.97	314
16	4.28	317.14
17	3.92	259.36
18	4.33	287.67
19	10.58	275.46



4.2.2 Surface Water Risk Assessment

Inundation across the site extent is generally less than 0.8 m deep in a 1% AEP event, with depths only exceeding 1 m along sections of Three Mile Gully and in some localised areas due to ponding. The wind turbine locations are spread across the subject site, and are positioned at both high points and low points of the topography. It is likely that the construction of the turbines will require minor earthworks to ensure a flat and stable base on which to construct the associated hardstand area; in some cases, this hardstand area is within the 1% AEP flood extent, with the platforms for Turbines 7, 47 and 97 inundated to depths of 50, 260 and 60 mm respectively (additionally, external ponding of runoff against these platforms is also present). The area of the wind farm's main facilities (substation, battery, etc.) is also subject to internal runoff along two different alignments, reaching a maximum depth of 210 mm to the east and 160 mm to the west; additionally, minor flow paths (no more than 170 mm in depth) and associated ponding are present across the site's accommodation area.

As the critical wind farm infrastructure is built, it will be important to ensure that flows do not enter excavations during construction, and that internal flows are retained on-site. Standard drainage measures will be required to reduce flood risk during the development and operation of the wind farm at the inundated locations; for example, the local internal inundation seen within the main facility areas will be alleviated via the construction of level benched areas, which will eliminate the channels and depressions where flows accumulate (an internal drainage network will then serve to further manage local stormwater runoff).

There is a degree of flood risk at numerous proposed access road alignments, relating to the intersections with major flow paths and the detention of local overland flows. The 1% AEP flood depths observed in the developed conditions modelling results exceed 300mm at 10 of the identified 19 flow path intersections. Some sections of the access roads would need to be further raised to facilitate safe access and egress during a major flood event. Thought to the likelihood of the described magnitude of inundation happening at a higher reoccurrence interval should be given (i.e. the 1% AEP event has been simulated, but roads may be overtopped at a lower depth more frequently), and culvert installation to prevent road closure during more frequent events should also be considered.

The modelling undertaken for this assessment can be used to guide the location and detailed design of the infrastructure proposed as part of the West Arthur Wind Farm development. It is anticipated that where hardstand areas are inundated, flood risk can be managed via local drainage and the elevation of the relevant hardstand region. The specifications of such mitigation options will be refined during the detailed design phase of the development, with the flood impacts established through the developed conditions modelling results informing this process.

Depending on the characteristics of the watercourse and how the road crossing is constructed, there may be temporary or permanent disruption to the localised surface water behaviour; partial or complete diversion of flows may be required if the watercourse is active at the time of construction. Construction of the impervious hardstand areas that accommodate the wind turbines also has the potential to modify flow paths; however, most of the wind turbines are located outside of the inundation extent. The afflux mapping presented above details ponding at a number of raised hardstand areas, as well as increased and decreased flood levels directly adjacent to proposed access roads. Mitigation of these flood impacts will require the implementation of standard drainage mitigation measures, which are likely to include (but not be limited to) swales, diversion drains, bunds, culverts and floodways, and will depend on the finalised site layout.

No downstream external impacts are anticipated; proportionally to the subject site area, the works associated with the wind farm are minor, indicating no meaningful increase in runoff leaving the development. Additionally, areas of afflux are limited and local to the proposed infrastructure, and the afflux mapping does not depict any increases in flood level outside of the development envelope downstream of the wind farm.



4.2.3 Climate Change

Climate change has the potential to alter the frequency and intensity of extreme rainfall events over time. Consistent with current ARR guidance and projections published by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and BoM, increases in extreme short-duration rainfall intensities may occur across parts of Western Australia under future climate scenarios. The magnitude and spatial distribution of these changes remains uncertain and is dependent on the emissions scenario, projection timeframe and storm duration considered. Nevertheless, future increases in rainfall intensity may result in corresponding increases in peak runoff and surface water inundation extents local to the study area.



5 RECOMMENDATIONS

Hydraulic modelling was completed for the West Arthur Wind Farm development under existing and developed conditions, with the outputs presented as part of this report. Elevating the site layout footprint has minor impacts on flood levels within the immediate surrounds of the wind farm infrastructure, which are proposed to be mitigated via the detailed design of the wind farm's facilities and access roads. Recommendations for the wind farm development in relation to surface water management and the mitigation of flood risk are as follows:

- The modelling described in this report to be used to inform the detailed design of the wind farm facilities and access roads, and to minimise construction in areas of flooding.
- The sizing of any potential culverts proposed as part of the design of the access roads to be informed by the modelling results summarised in this report.
- Inclusion of hydrological buffers around watercourses for wind farm infrastructure other than road crossings.
- Watercourse crossings at the proposed access roads to be appropriately designed to reduce flood risk and hazard and enable safe access to wind farm facilities, as well as to mitigate changes to flood extent/levels and behaviour.
- Crossing structures to conform to relevant local and/or state government authority guidelines.
- Construction in areas of flood risk where ponding is likely will require temporary local bunding, drainage channels and/or pumps to divert upstream runoff and prevent inundation of construction areas (this is to be detailed in the construction management plan).

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