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Flood Assessment Report

Chalumbin Wind Farm

iCubed

26 May 2021

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26 May 2021

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Dear Josh

Chalumbin Wind Farm

The following report documents findings of the Chalumbin Wind Farm Flood Assessment. Flood risk on site was determined via hydraulic modelling of the critical duration for the 0.5%, 1%, 2%, 50% and 63.5% rainfall events. Maximum surface water depths and velocities were mapped based on results from a rain-on-grid model for pre-development conditions.

Yours sincerely

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Project Manager

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1 INTRODUCTION

1.1 Background

Water Technology was engaged by i³ Consulting to assess flood risk across the Chalumbin Wind Farm site under existing conditions (pre-development of the wind farm). The objective of this report was to provide i³ Consulting with a comprehensive assessment of the existing site flood risk. The flood risk across the wind farm area was assessed via a rain-on-grid hydraulic model.

1.2 Site Description

The proposed Chalumbin Wind Farm is located within Tablelands Council district in far north Queensland. The study area, which lies west of Tully Gorge National Park, is largely undeveloped, consisting of state forest reserves and farmland. An overview of the study area is shown in Figure 1 below.

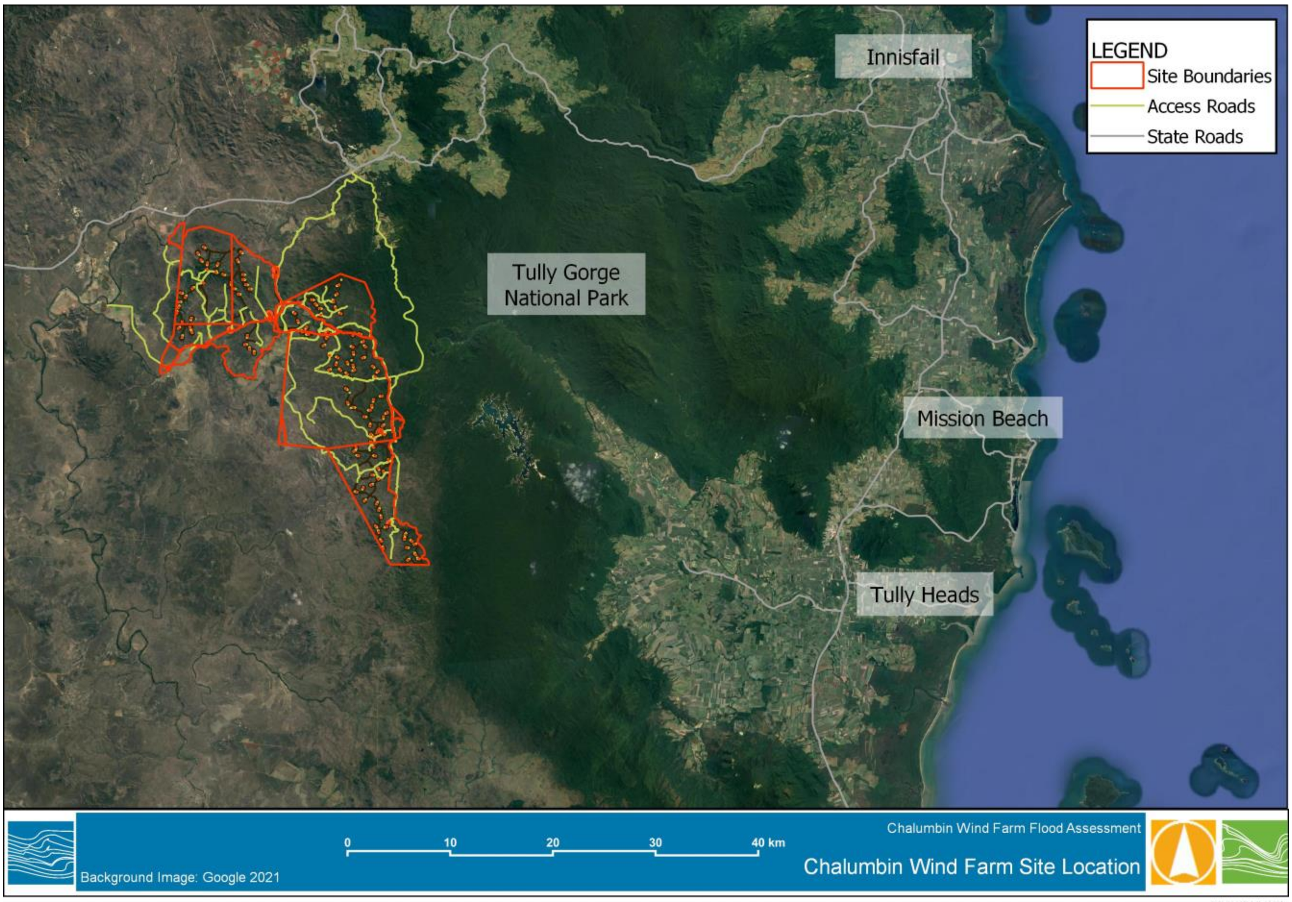


FIGURE 1 SITE LOCATION

1.3 Study Objectives

A detailed hydraulic assessment has been undertaken based on existing site conditions. The objectives of the flood study as documented in this report are summarised as follows:

- Development of a discrete, standalone hydraulic model to assess and analyse overland flooding in the region of the Chalumbin Wind Farm. The model was developed using the TUFLOW HPC software package and will utilise the rain-on-grid modelling approach.

- The overland flow model was prepared according to the Australian Rainfall and Runoff (ARR) 2019 guidance (ARR2019).
- The surface water assessment was undertaken to determine the potential site flood risk and flood levels, depths and velocities at the wind turbine locations and access roads. Digital flood results have been provided separately to this report to inform future planning and detailed design of the wind farm.

The following sections of this report provide technical details of the modelling undertaken for this study to fully address the study objectives stated above.

2 METHODOLOGY

2.1 Overview

A TUFLOW hydraulic model of the entire site was prepared which employed the current HPC (Highly Parallelised Computations) solution scheme software (build 2020-10-AA). TUFLOW is a 1D-2D linked hydraulic model that solves the depth-averaged shallow water equations.

A detailed direct rainfall (rain-on-grid) hydraulic modelling approach has been adopted for this assessment. Due to the scale, complexity and the numerous waterways that transect the site (shown in Figure 2), the direct rainfall model is advantageous as it allows all waterways to be assessed and mapped without the need for hydrological modelling. In this approach, rainfall is applied directly to each grid cell within the model. Overland flows move across the grid based on the site topography and catchment characteristics.

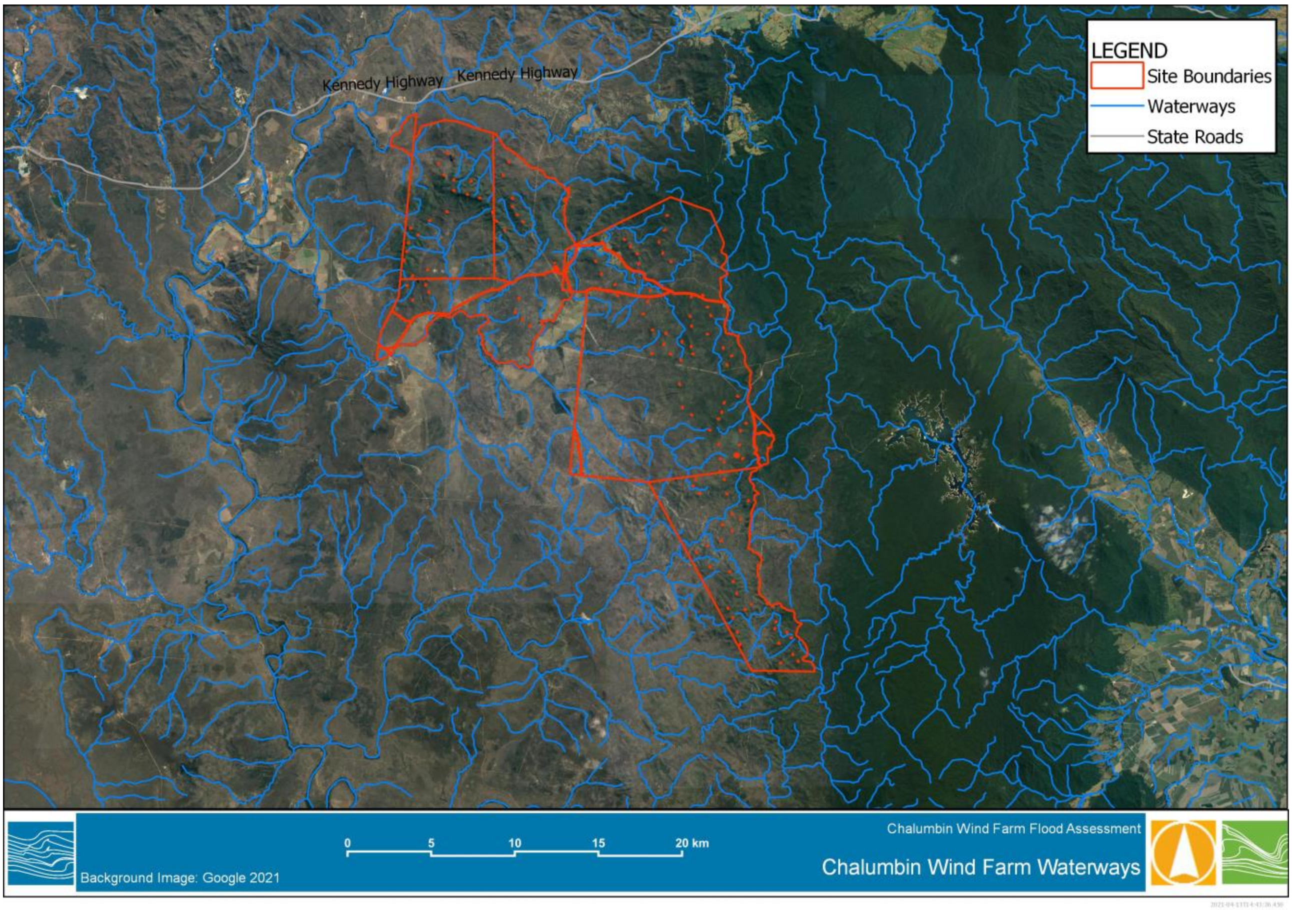


FIGURE 2 AERIAL IMAGE SHOWING WATERWAYS TRAVERSING THE PROJECT SITE

2.2 Model Development

2.2.1 Topography

The topography incorporated into the model is presented in Figure 3. The topography was informed almost entirely by 1m LiDAR recorded specifically for the project (2021). Where the overall catchment and model boundary was not covered by the 1m LiDAR, Shuttle Radar Topography Mission (SRTM) data was used to supplement the LiDAR (resolution of approximately 30m or 1-second of arc).

In the south west of the model extent SRTM data was significantly higher than the 1m LiDAR which caused water to pond upstream of the interface. The model topography was locally manipulated to tie in with the 1m LiDAR and allow flows to pass over the area in a more realistic manner. The accuracy of model results in this region may be affected by the mismatch in elevation data, however, this area of the model is not close to any important wind farm infrastructure or access roads and does not significantly affect areas downstream.

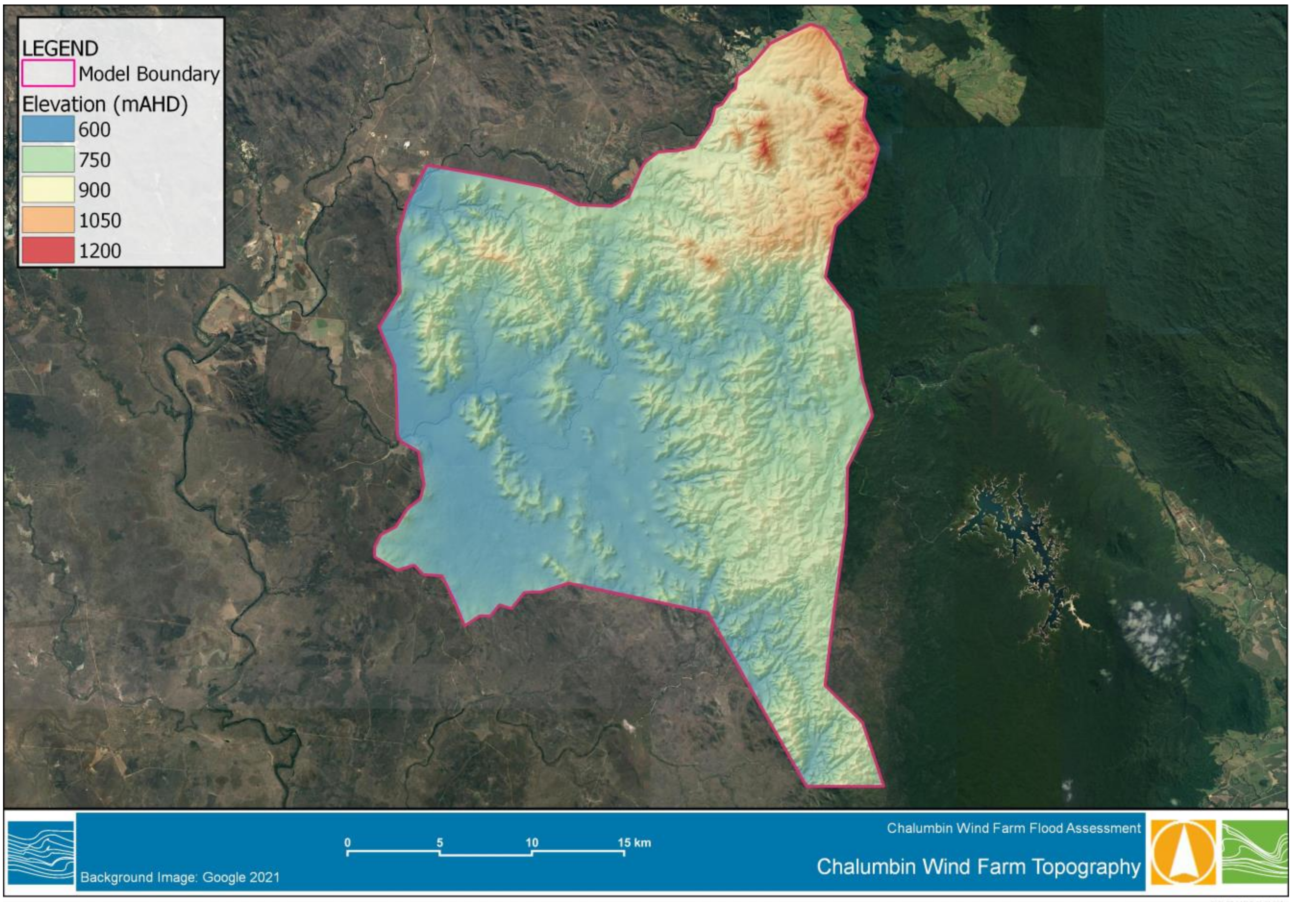


FIGURE 3 TUFLOW MODEL TOPOGRAPHY

2.2.2 Model Grid Size

The TUFLOW model adopted a grid size of 20 m with the inclusion of sub-grid sampling (SGS) down to a grid size of 2 m. SGS stores and uses curves representing the sub-2D-cell terrain data of the DEM used to construct the model instead of each 2D cell having one elevation. SGS allows catchment scale models, such as this one, to flow more effectively with water not being "trapped" by a coarse cell resolution.

The TUFLOW Quadtree module was also utilised in this model. Quadtree allows for a more detailed analysis, within a given area of the model, by nesting smaller cells in the model grid. In this assessment, the area surrounding the construction compound, batch plant and site access from Ravenshoe were designated as quadtree areas with a grid size of 10 m (Figure 4). This approach allowed for a detailed analysis of flooding around key infrastructure.

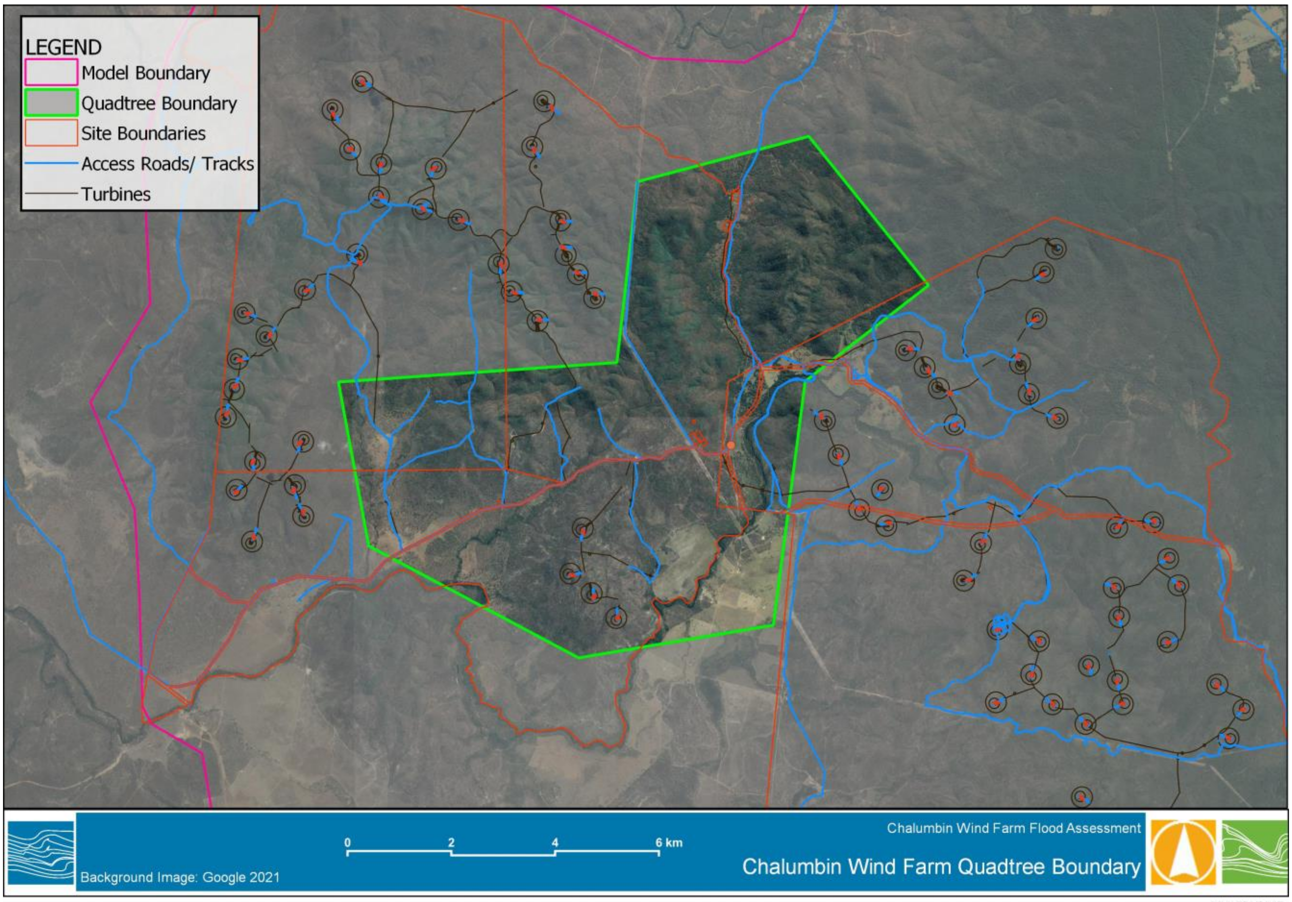


FIGURE 4 TUFLOW QUADTREE BOUNDARY

2.2.3 Design Event Rainfall

Design rainfall temporal patterns and intensities were determined using the standard procedure in Australian Rainfall and Runoff (ARR2019) (IEAust, 2019). Rainfall temporal patterns and depths based on Intensity, Duration, Frequency (IFD) information were sourced from the TUFLOW ARR2019 plugin. Due to the large extent of the study area (~650km^2) multiple IFDs were adopted. The study area was divided into 16 sub sections of approximately 40km^2 and IFDs determined according to the centroid of each.

Areal reduction factors (ARF) have been applied in accordance with the ARR Datahub guidance.

2.2.4 Rainfall Losses

The rainfall losses were incorporated into the model as rainfall excesses in a TUFLOW materials file. The losses adopted for this assessment were extracted from the ARR2019 Datahub and reflect a conservative approach with regards to infiltration in predominantly rural areas. The application of these losses is spatially represented in Figure 5 which shows the configuration of the TUFLOW materials file. The adopted initial and continuing losses are outlined respectively in Table 1.

2.2.5 Floodplain Roughness

Floodplain roughness was represented in the model as shapefile polygons assigned a Manning's 'n' roughness value. The surface materials were determined from satellite imagery and the spatial location of these polygons is presented in Figure 5. The adopted Manning's 'n' values are outlined in Table 1.

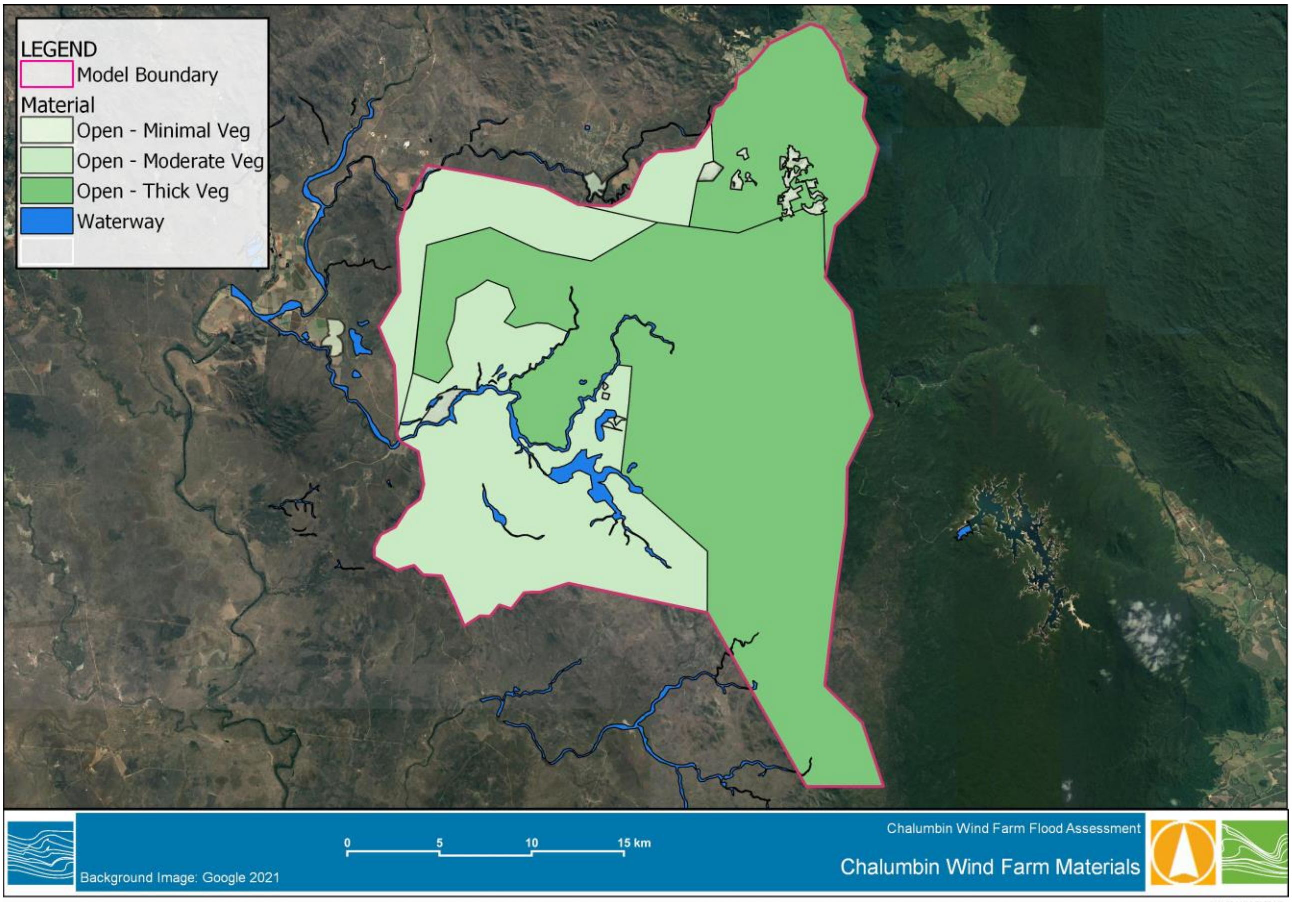


FIGURE 5 TUFLOW MATERIALS FILE

TABLE 1 ADOPTED LOSSES AND ROUGHNESS VALUES

Material	Initial Loss (mm)	Continuing Loss (mm/hr)	Manning's 'n'
Open Pervious Area – Minimal Vegetation	37	3.4	0.04
Open Pervious Area – Moderate Vegetation	37	3.4	0.07
Open Pervious Area – Thick Vegetation	37	3.4	0.15
Waterway	37	3.4	0.035

2.2.6 Model Boundaries

A HQ (water level-flow) boundary was applied around the entire edge of the model to prevent unrealistic ponding against the model extent. The boundary was digitised approximately perpendicular to the flow direction at the downstream end of any major flow paths. This boundary was located a sufficient distance from any proposed windfarm infrastructure such that it did not influence flood behaviour on site.

2.3 Model Validation

Given the lack of gauges within the study area, there is no site-based or historical data to validate the TUFLOW hydraulic model results against. As such, the model has been validated using a combination of the Rational Method (RM) and Regional Flood Frequency Estimation (RFFE). Validation was completed at the outlet of three local catchments that exists within the site as shown in Figure 6. The smaller catchments 2 and 3 do not exceed 25 km^2 and were used for the RM validation in accordance with QUDM. The parameters used for estimating peak discharge using the Rational Method are summarised in Table 2. A comparison of discharges from the RM, RFFE and the TUFLOW model are shown in Table 3. The RFFE tended to overestimate peak discharge values for the larger catchment, and underestimate values for the smaller two catchments. Critically though, all TUFLOW model peak flows were within the 95% confidence limits for the RFFE predicted peak flows and deemed to be reasonable.

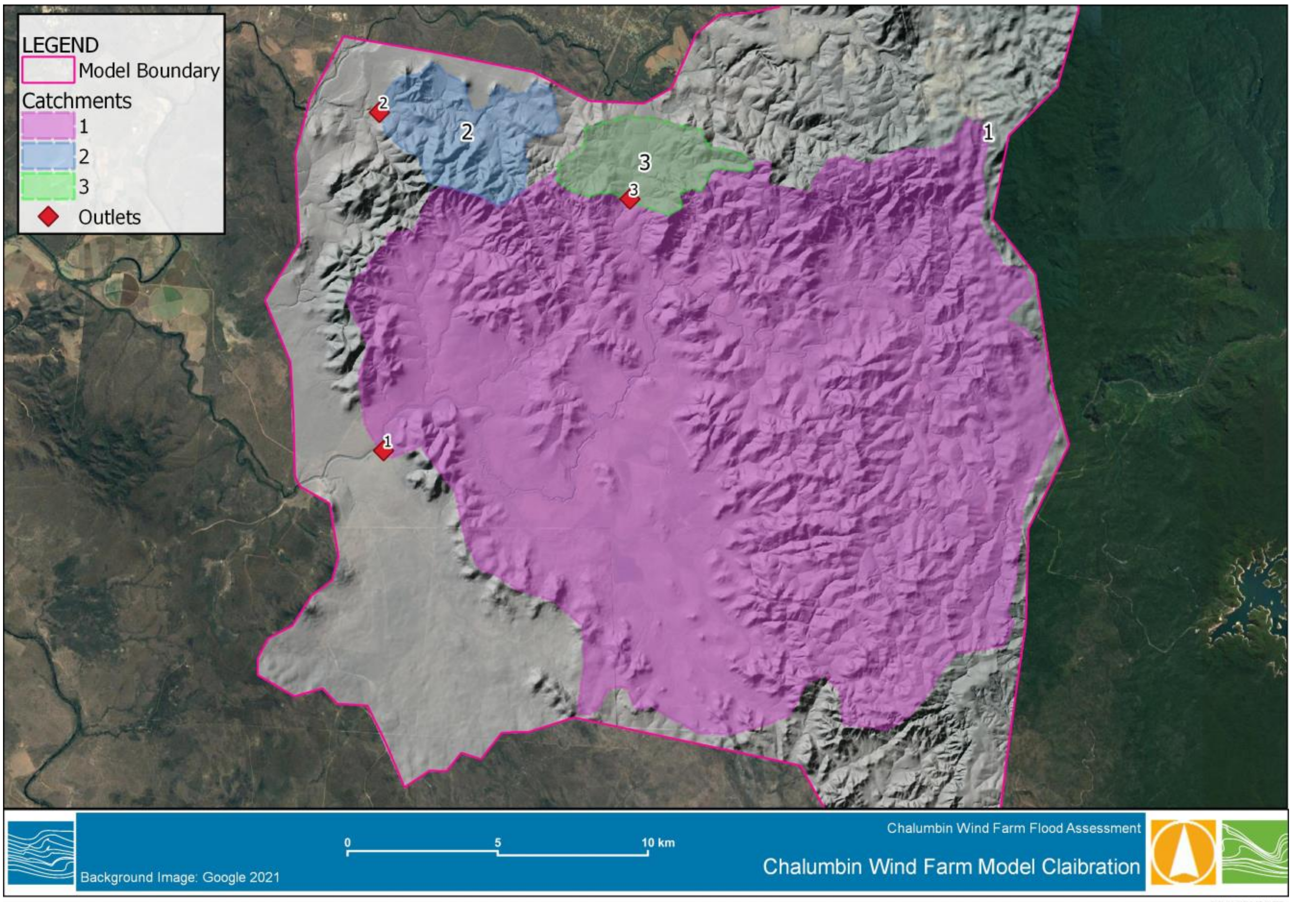


FIGURE 6 DELINEATION OF CATCHEMNTS USED FOR MODEL VALIDAITON

TABLE 2 VALIDATION CATCHMENT PARAMETERS

Catchment	Area (km^2)	Catchment C_{10}	T_C (minutes)
1	350	N/A	N/A
2	16.7	0.598	90
3	12.4	0.598	75

TABLE 3 VALIDATION RESULTS SUMMARY

Catchment	Design Event (AEP)	RM Discharge (m^3/s)	RFFE Discharge (m^3/s)	TUFLOW Peak Discharge (m^3/s)
1	1%	N/A	2090	1667
	50%	N/A	356	110
2	1%	232	212	255
	50%	84	38	44
3	1%	192	161	215
	50%	70	27	39

2.4 Post-Processing

The hydraulic model results have been subject to post-processing to quantify water depths, levels, and velocities. In order to achieve the overall envelope of flood results, multiple storm durations (from 60 to 1440 minutes) and ensemble temporal patterns (i.e. 10 patterns per duration) were considered for each of the design events. The TUFLOW "asc_to_asc" utility was employed for the grid enveloping of the model result files, in two steps as summarised below:

1. The TUFLOW asc_to_asc utility was used to extract the respective water depths, levels and velocities based on the median (6^{th} ranked) grid value. The process was applied across all ten (10) ensemble events per storm duration and design AEP to provide a single envelope grid per storm duration and AEP event.
2. The TUFLOW asc_to_asc utility was then used to prepare the maximum envelope grid across the multiple storm duration ensemble temporal pattern envelope grids output in Step 1.

The process enables critical duration flood envelope grids to be prepared per design AEP for each of the respective water depths, levels, and velocities.

3 RESULTS

3.1 Depth and Velocity Maps

Maximum flood depth and velocity maps for the 0.5%, 2%, 50% and 63.2% AEP events are contained in Appendix A and Appendix B. Figure 7 and Figure 8 show the maximum depths and velocities across the site for the 1% AEP event. As shown in the mapped results, the steep terrain causes high velocities and generally well-defined drainage paths. Preliminary turbine locations are located outside any ponding areas and main flow paths. However, access tracks intersect drainage paths in several locations. Due to the steep terrain, peak velocities are relatively high which creates risk of erosion, particularly at track crossings.

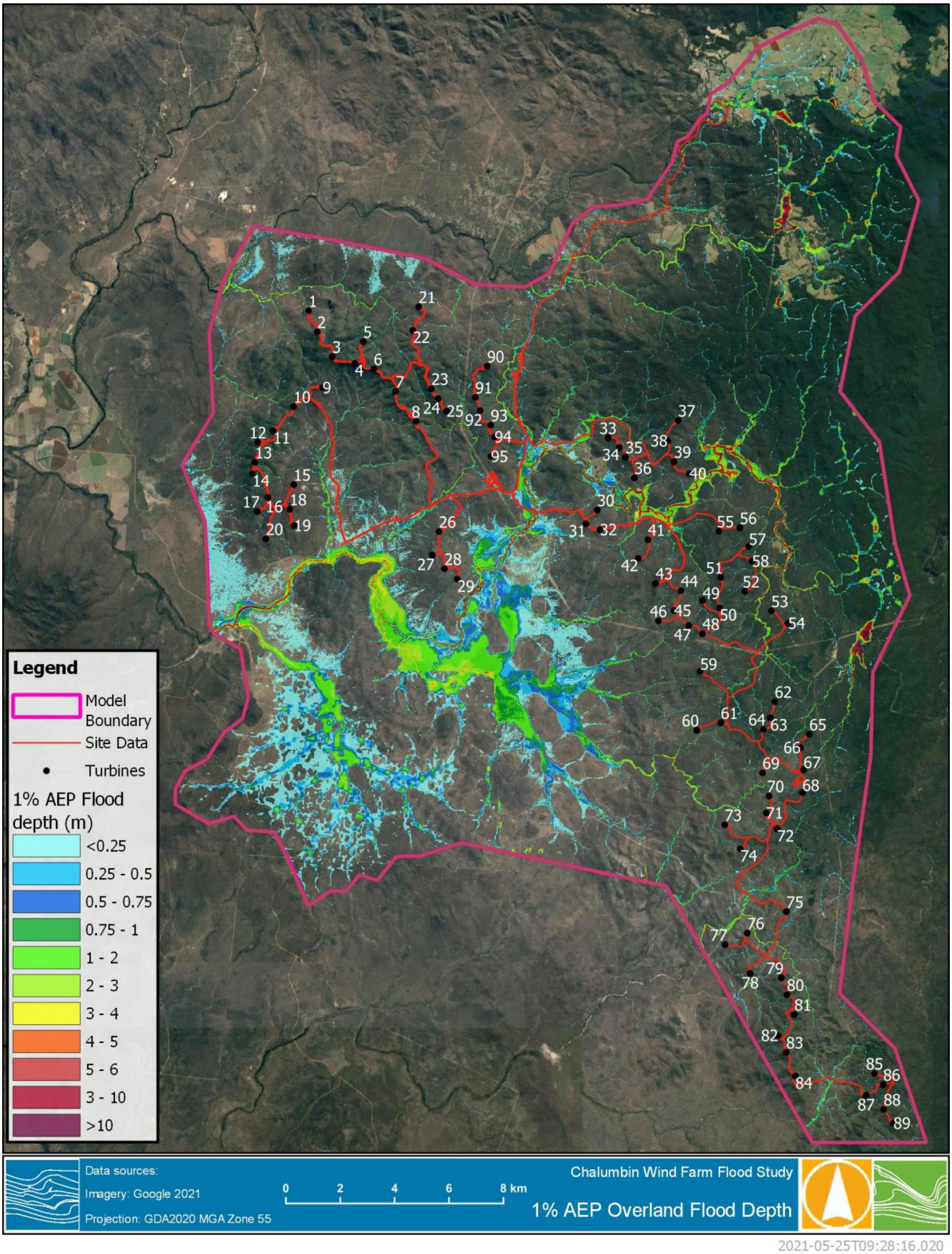


FIGURE 7 OVERLAND FLOOD DEPTHS FOR THE 1% AEP EVENT (WHOLE SITE)

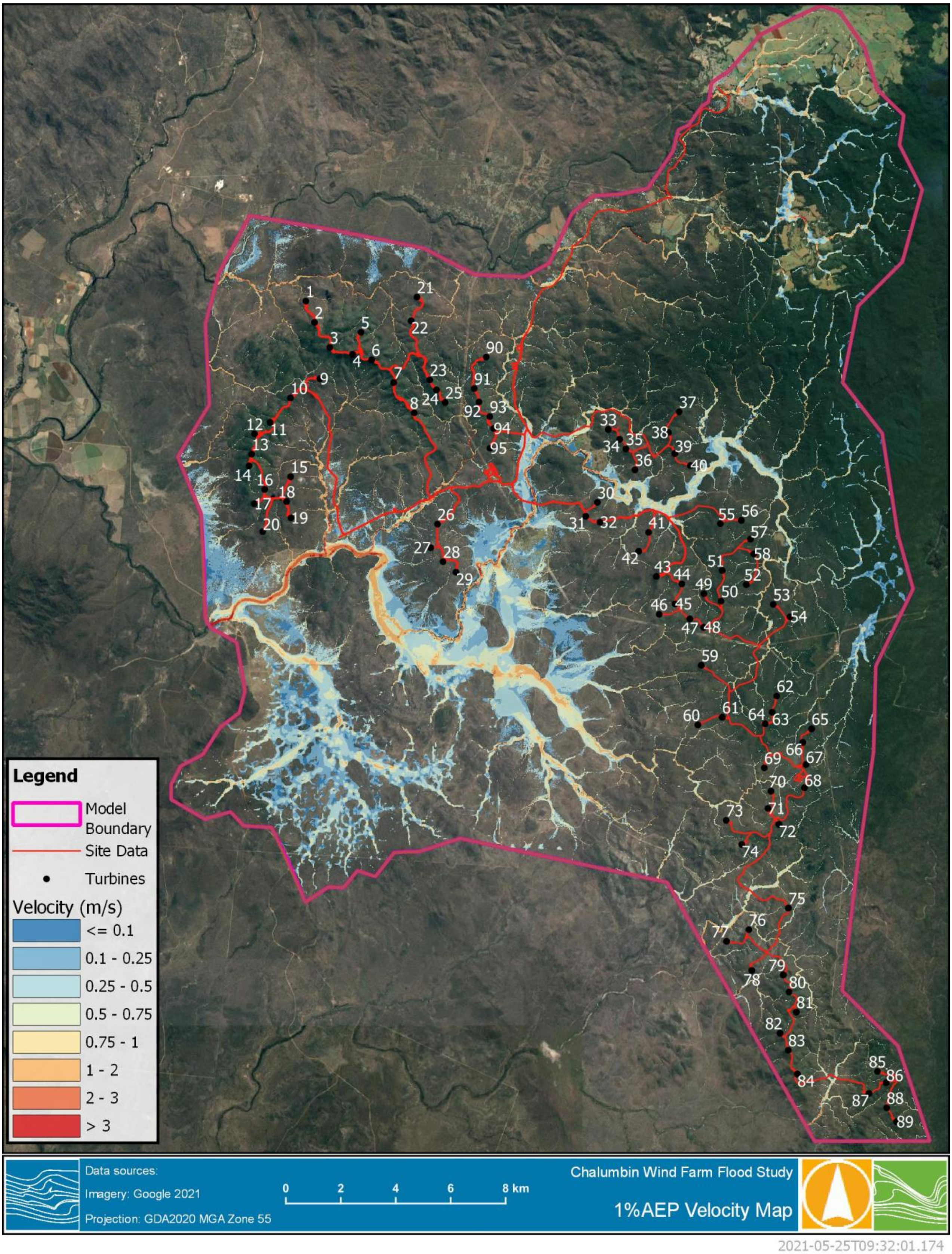


FIGURE 8 FLOOD VELOCITIES FOR THE 1% AEP EVENT

3.2 Flows at Waterway Crossings

Flows have been analysed at 42 nominated waterway crossings within the site. The location of the crossings is shown in Figure 9. More detailed images labelled with the crossing IDs are shown in Appendix C. The peak-flow associated with the median temporal pattern and critical duration for the 1% AEP event at each crossing is given in Table 4. Peak flows for all storms analysed are given in Appendix C.

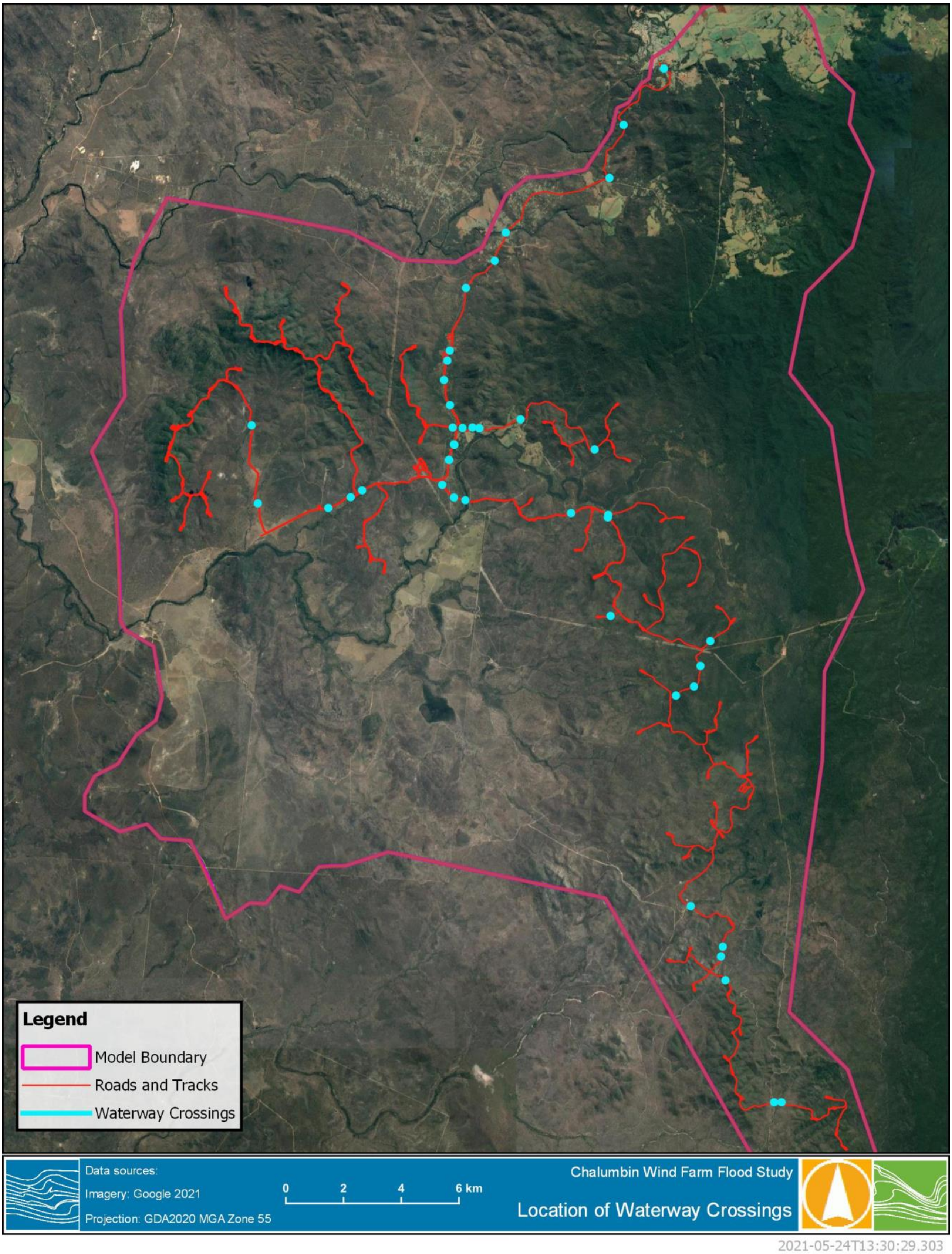


FIGURE 9 LOCATION OF WATERWAY CROSSINGS WITHIN THE CHALUMBIN WINDFARM

TABLE 4 1%AEP CRITICAL DURATIONS AND PEAK FLOWS (MEDIAN PATTERN) AT WATERWAY CROSSINGS

Crossing ID	Critical Duration (Mins)	Peak Flow (m^3/s)	Crossing ID	Critical Duration (Mins)	Peak Flow (m^3/s)
65	90	121.10	6B	180	117.23
66	90	76.92	6A	90	66.40
78	90	25.38	63	360	24.89
69	90	19.49	61	60	19.53
64	180	142.40	60	1080	9.36
55	60	19.17	5F	1080	681.04
56	60	0.86	76	90	2.48
57	60	7.84	6C	180	141.26
58	180	185.04	6D	180	79.46
5B	180	67.58	6F	90	18.18
5D	180	3.73	6E	90	29.57
5A	180	31.51	70	180	107.57
79	90	15.88	72	90	17.30
7A	180	146.72	71	180	87.12
7B	1080	151.07	73	60	0.03
7C	180	80.25	74	90	45.00
7D	90	62.97	75	180	55.59
7E	1080	99.63	62	360	44.26
5C	180	128.23	67	60	0.52
5E	90	11.31	59	180	133.08
77	90	33.61			

3.2.1 Major Catchment Boundaries

Catchment data has been calculated for major catchments contributing flows to waterway crossings. The catchment delineation is shown in Figure 10. The area of each along with the critical duration and peak flow associated with the 1% AEP event are given in Table 5.

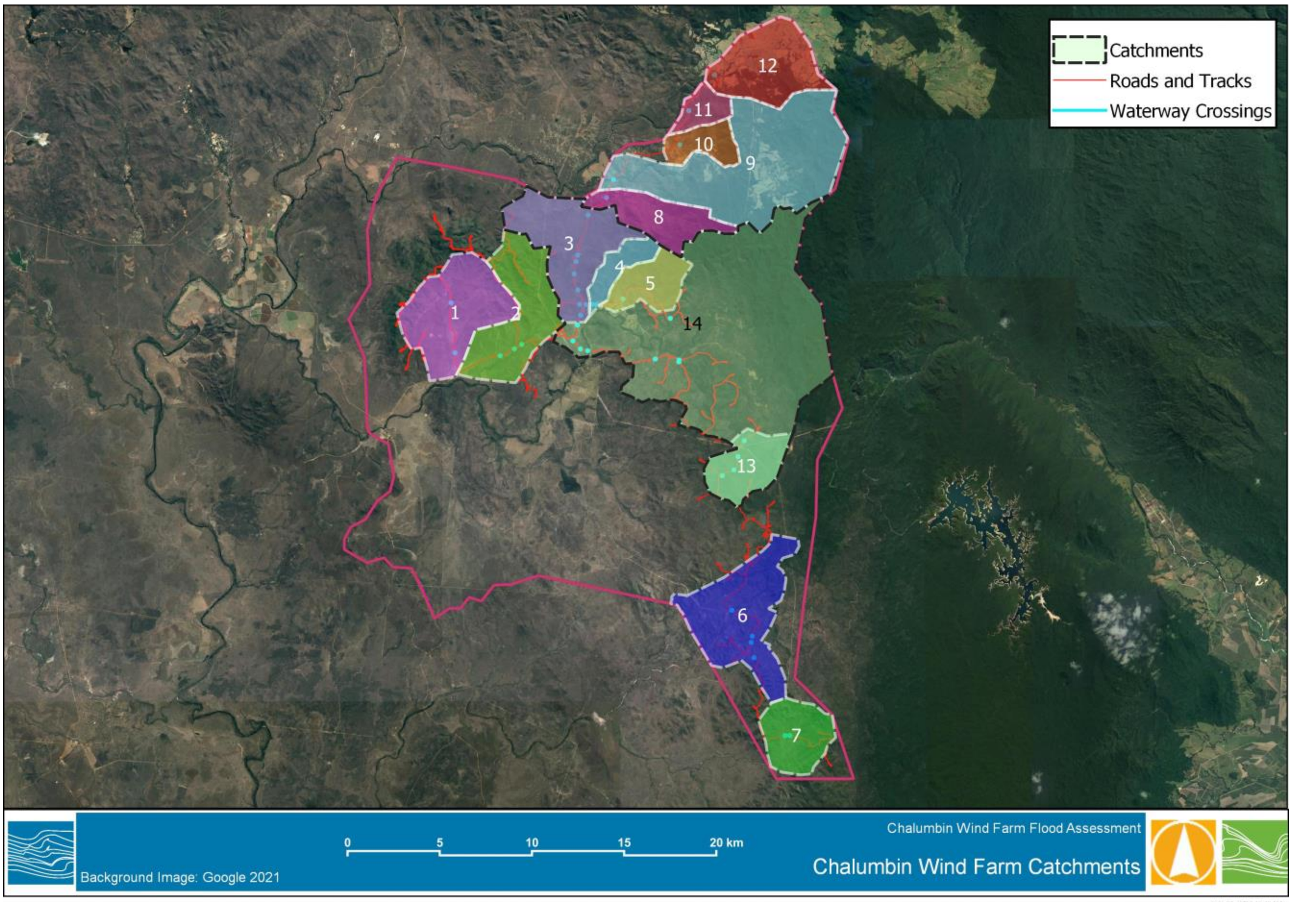


FIGURE 10 CATCHEMNT DELINEATION

TABLE 5 CATCHEMNT DATA

Catchment ID	Area (km^2)	1% AEP Critical Duration (Minutes)	1% AEP Peak flow at outlet (m^3/s)
1	25.41	90	311.03
2	23.52	180	230.53
3	25.18	180	144.02
4	6.03	180	67.36
5	10.01	180	122.82
6	28.01	360	225.21
7	12.58	180	151.88
8	13.09	180	165.93
9	51.77	360	152.96
10	6.89	180	101.52
11	5.01	90	74.11

Catchment ID	Area (km^2)	1% AEP Critical Duration (Minutes)	1% AEP Peak flow at outlet (m^3/s)
12	20.08	90	102.97
13	12.2	180	153.13
14	156.44	1080	698.41

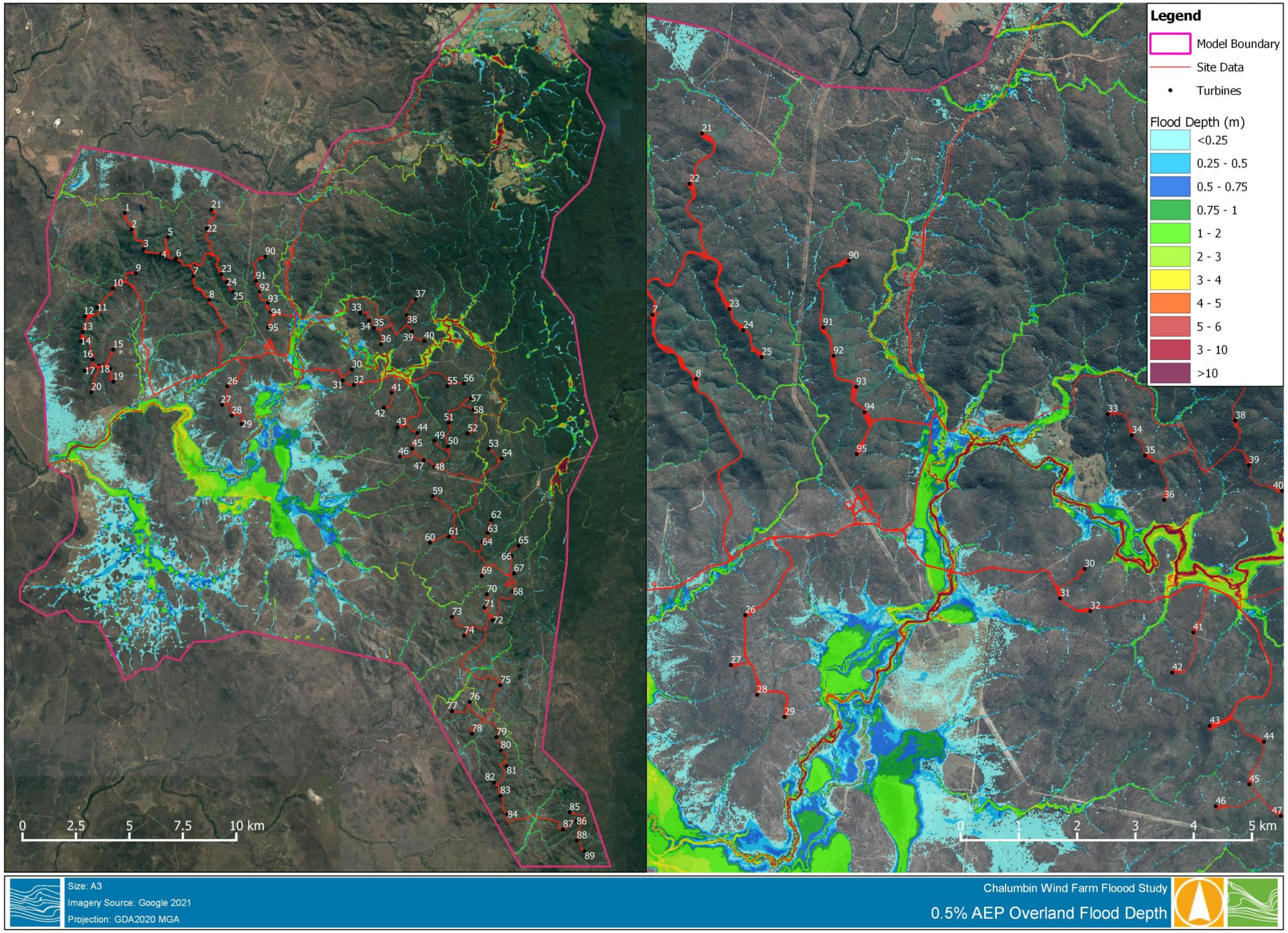
4 CONCLUSION

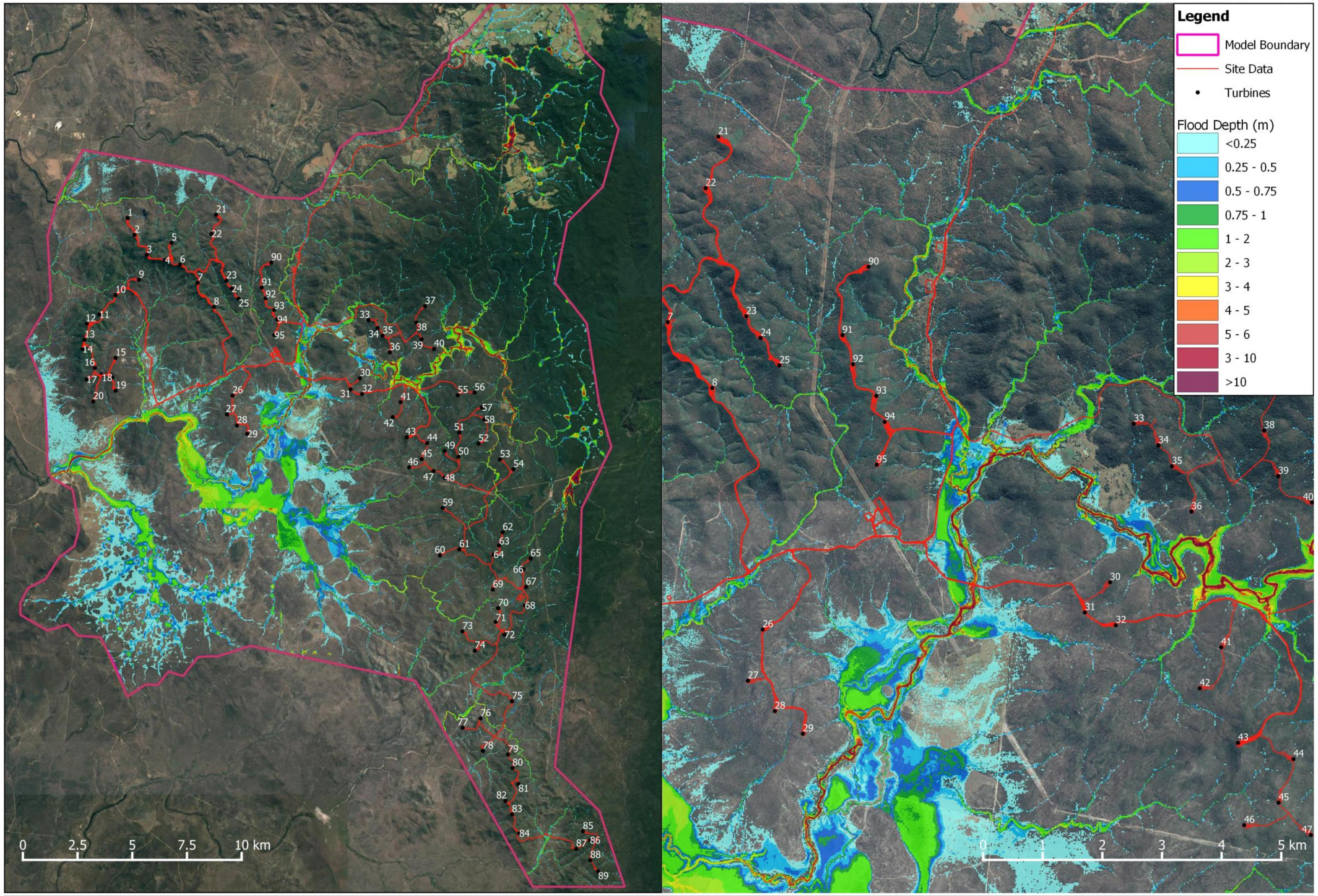
Water Technology was engaged by i^3 Consulting to undertake a detailed flood assessment for the proposed Chalumbin Wind Farm site under existing conditions (pre-development of the wind farm).

To understand site drainage behaviour on the windfarm site, a detailed rain-on-grid flood model was developed using detailed LiDAR and satellite data topography data. Several roads and proposed access tracks intersect overland flow paths, due to the steepness of the terrain velocities are commonly in the range of 2 to 3 m/s across the site. This can pose a risk of scour or damage to infrastructure. The erosion risk at these locations should be considered further in design, with these locations monitored after storm events to check for damage to structures.

To inform future planning and subsequent design stages, all results from the pre-development modelling will be provided in GIS format separately to this report (maximum depth, water level and velocity for 0.5%, 1%, 2%, 50% and 63% AEP storm events).

APPENDIX A
PEAK FLOOD DEPTH MAPS


Legend
Model Boundary
Site Data
Turbines
Flood Depth (m)
<0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
3 - 10
>10
0 2.5 5 7.5 10 km
0 1 2 3 4 5 km
Size: A3
Imagery Source: Google 2021
Projection: GDA2020 MGA
Chalumbin Wind Farm Floood Study
0.5% AEP Overland Flood Depth



Size: A3
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Projection: GDA2020 MGA

Chalumbin Wind Farm Floood Study
1% AEP Overland Flood Depth

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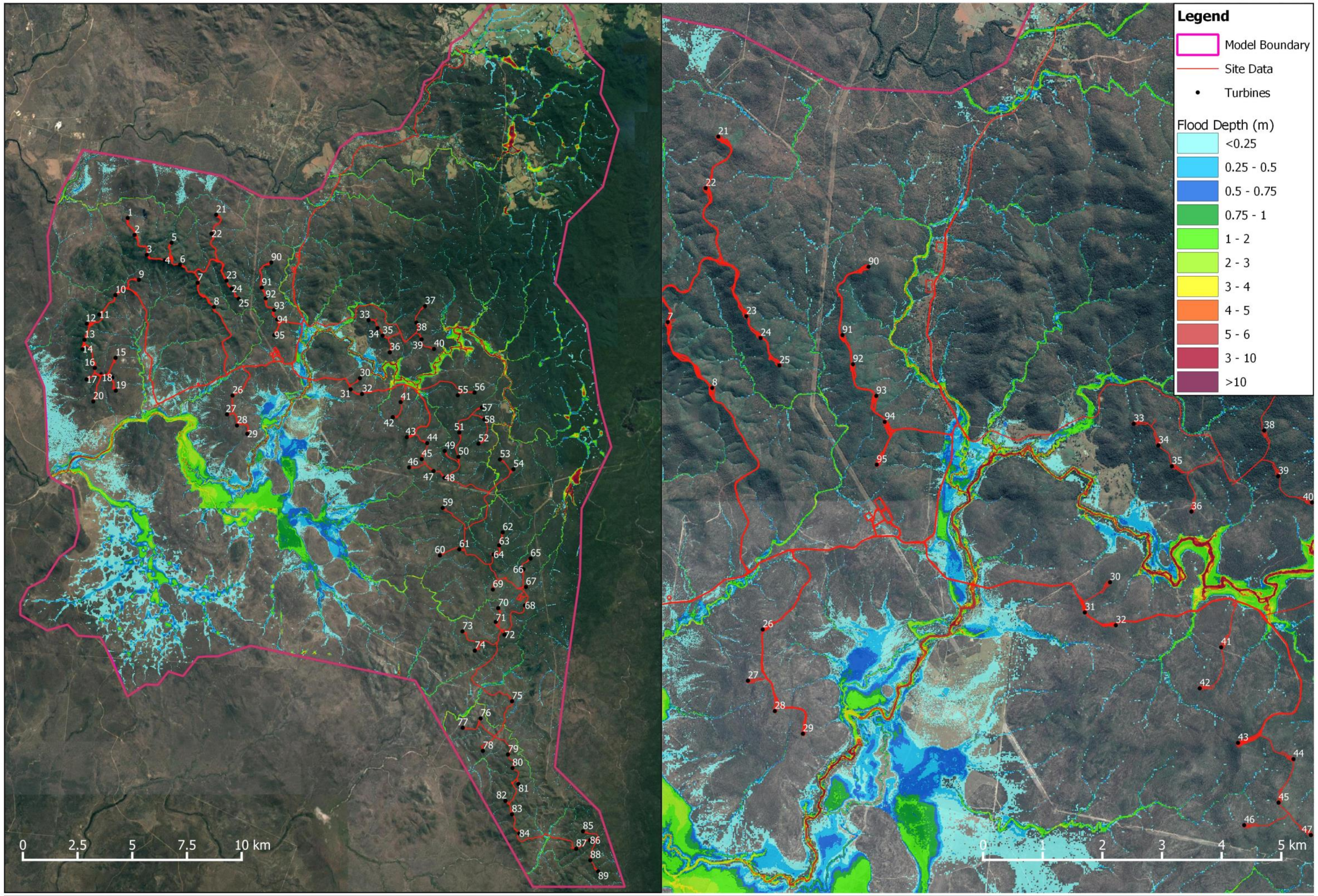

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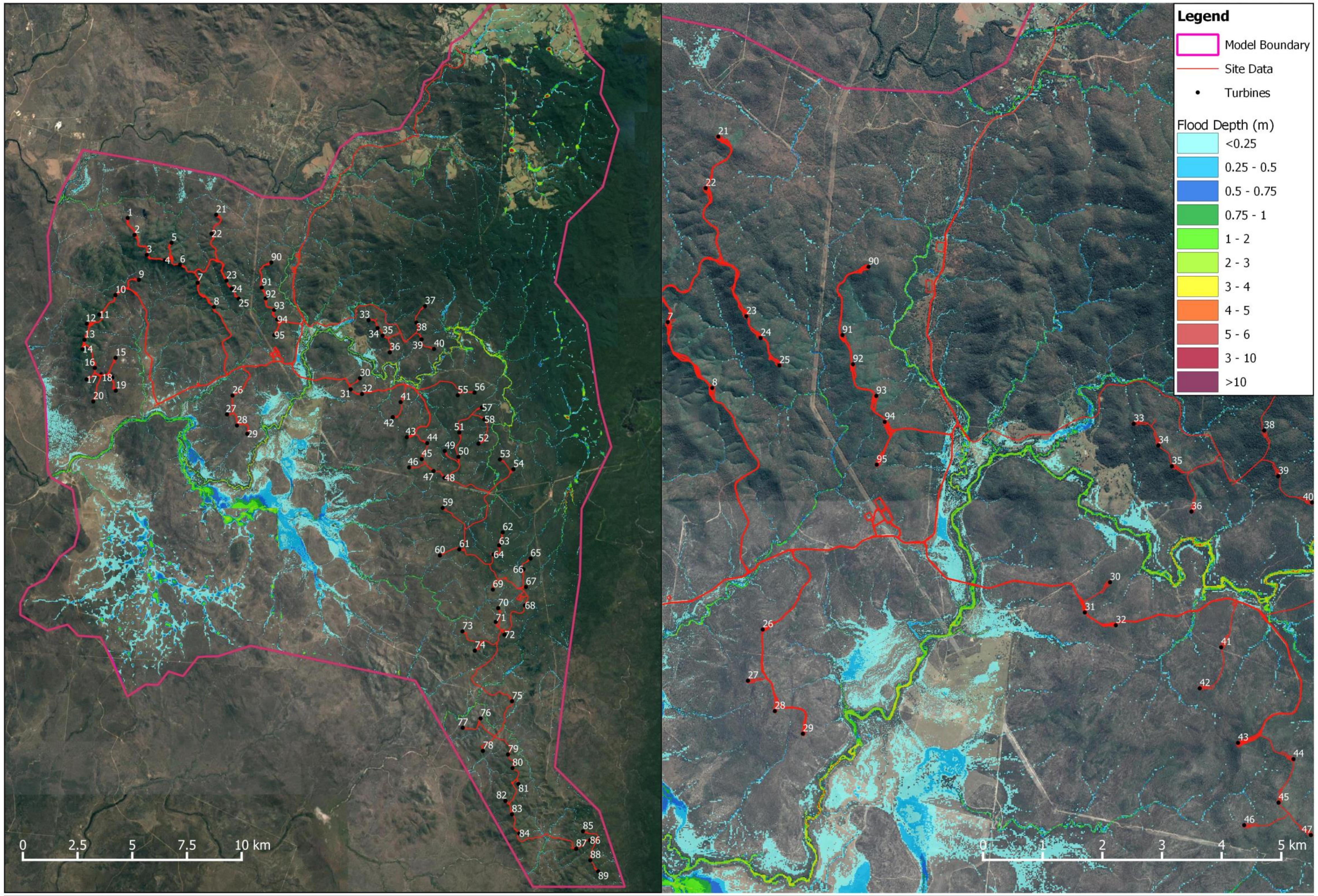
Projection: GDA2020 MGA

Chalumbin Wind Farm Floood Study

2% AEP Overland Flood Depth

021-05-25T09:35:50.974



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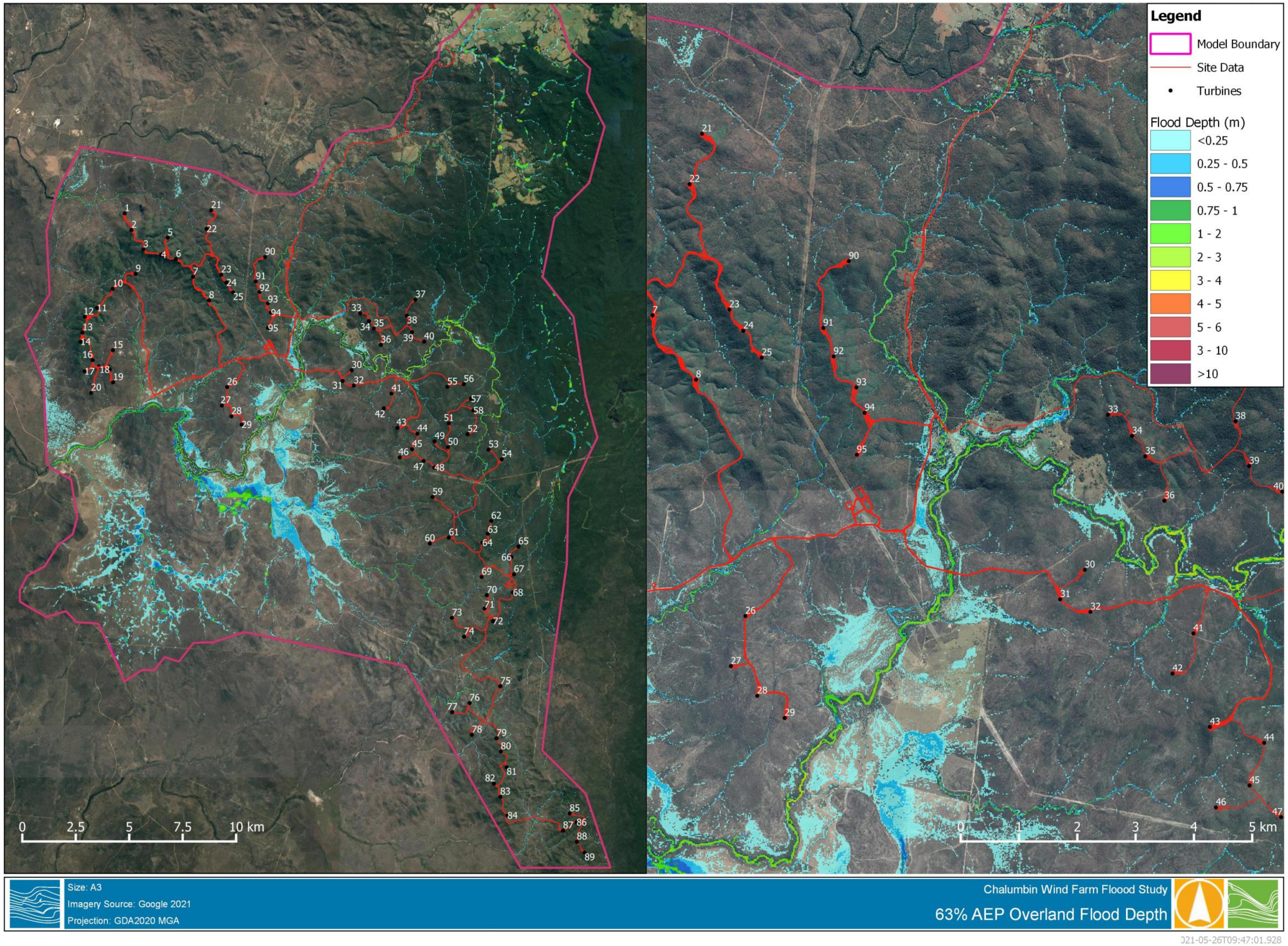
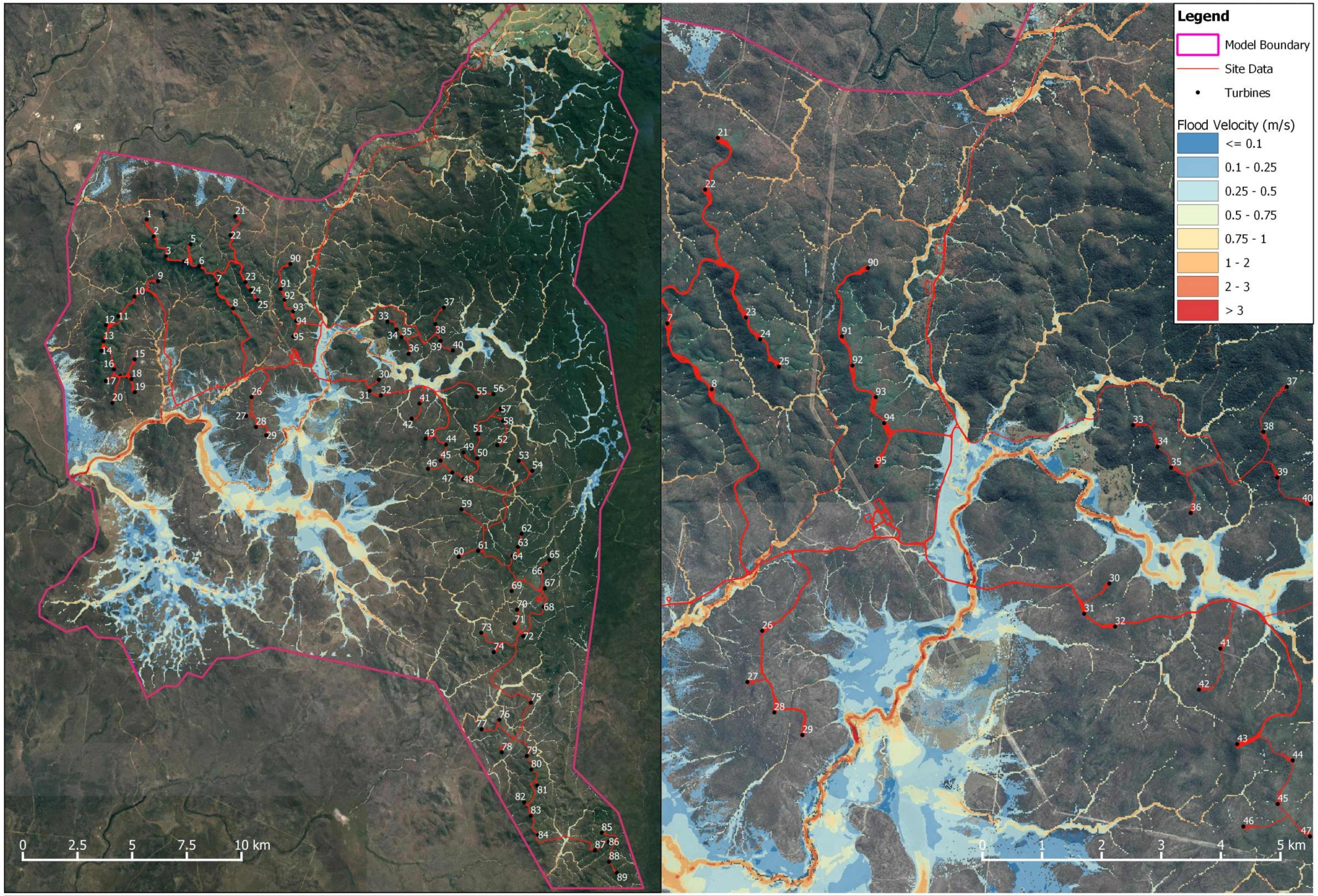
Chalumbin Wind Farm Floood Study
50% AEP Overland Flood Depth


Legend
Model Boundary
Site Data
Turbines
Flood Depth (m)
<0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
3 - 10
>10
0 2.5 5 7.5 10 km
0 1 2 3 4 5 km
Size: A3
Imagery Source: Google 2021
Projection: GDA2020 MGA
Chalumbin Wind Farm Floood Study
63% AEP Overland Flood Depth
321-05-26T09:47:01.928

APPENDIX B
PEAK FLOOD VELOCITY MAPS



Size: A3
Imagery Source: Google 2021
Projection: GDA2020 MGA

Chalumbin Wind Farm Floood Study
0.5% AEP Flood Velocity

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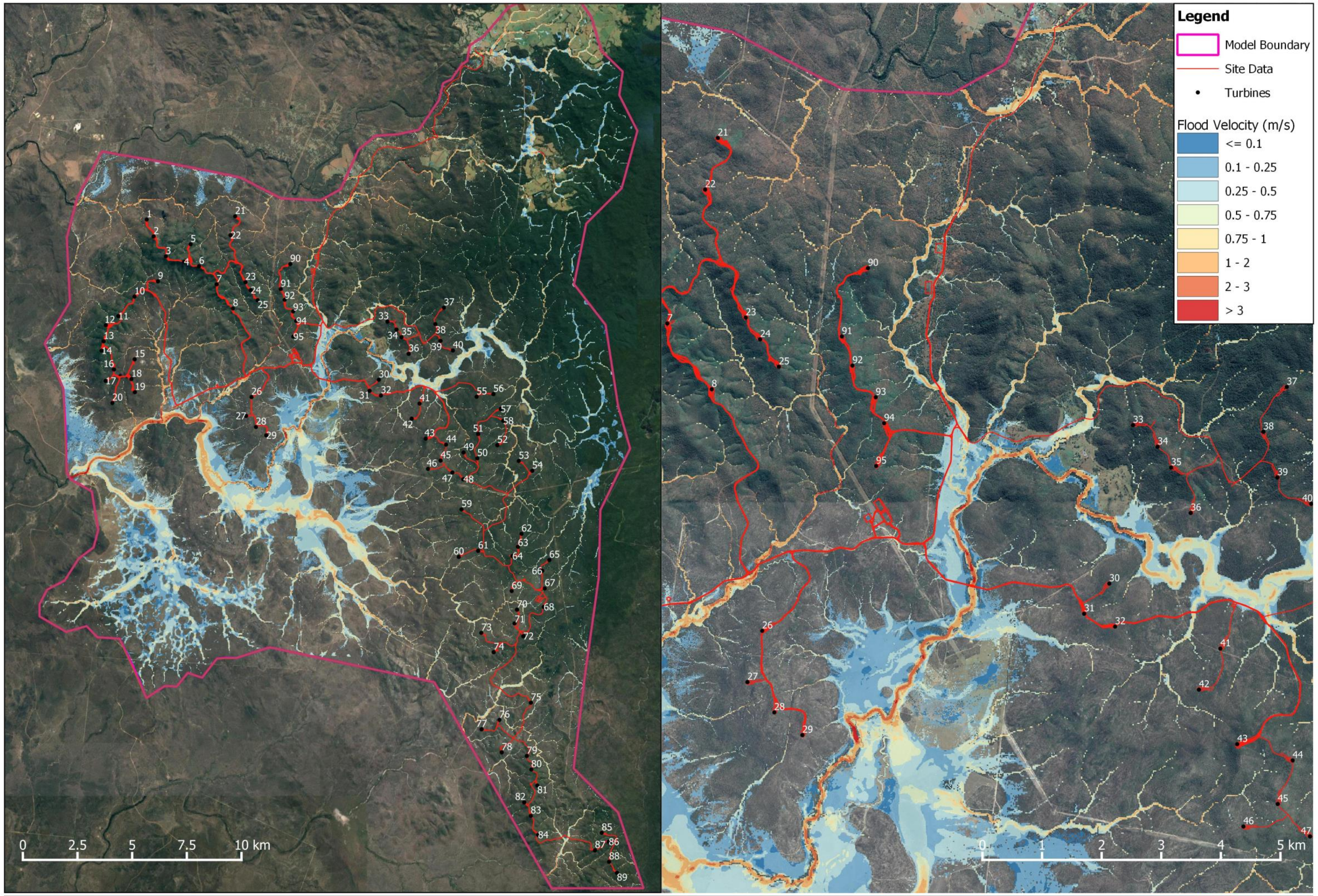

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Imagery Source: Google 2021
Projection: GDA2020 MGA

Chalumbin Wind Farm Floood Study

1% AEP Flood Velocity

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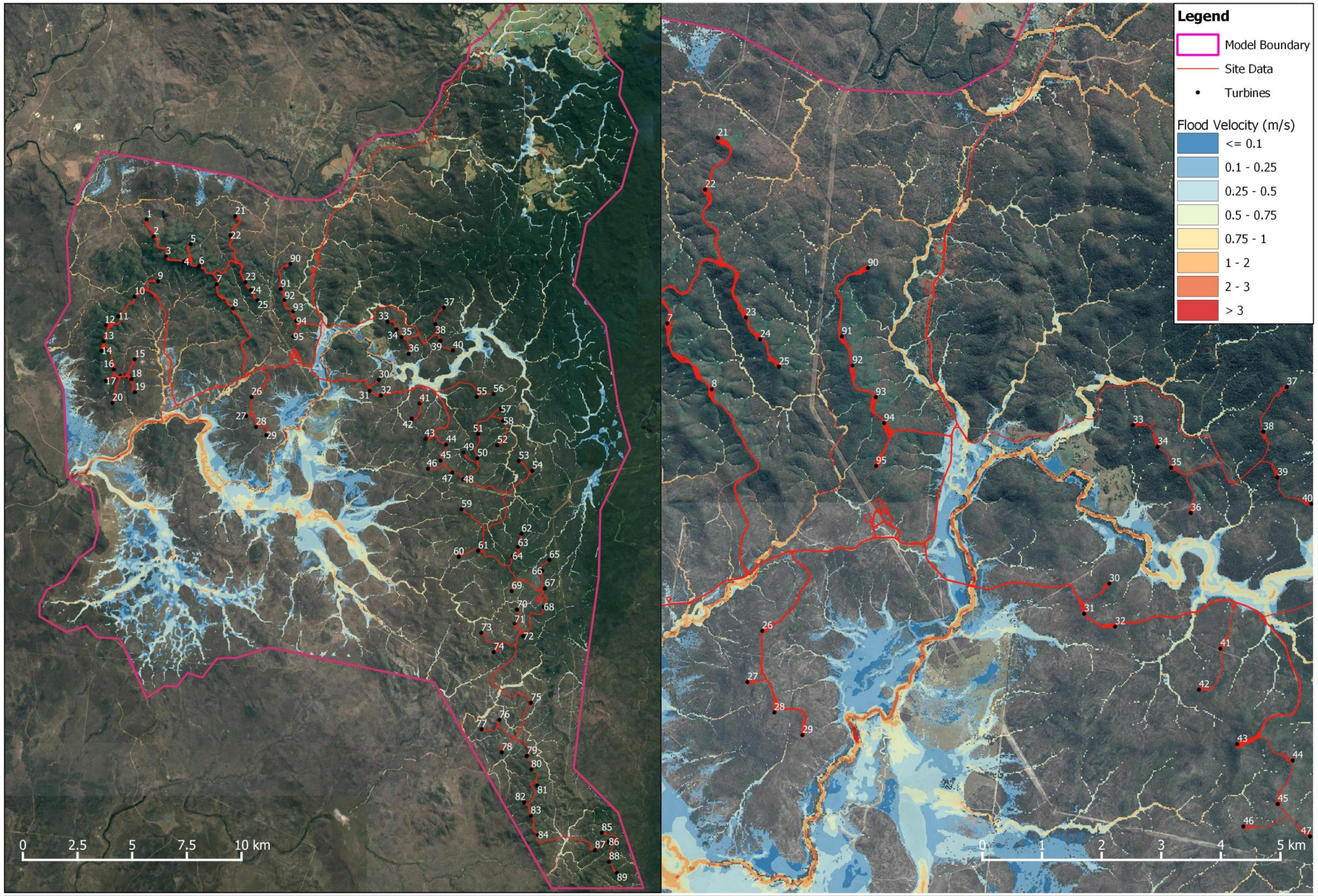

Size: A3
Imagery Source: Google 2021
Projection: GDA2020 MGA

Chalumbin Wind Farm Floood Study
2% AEP Flood Velocity

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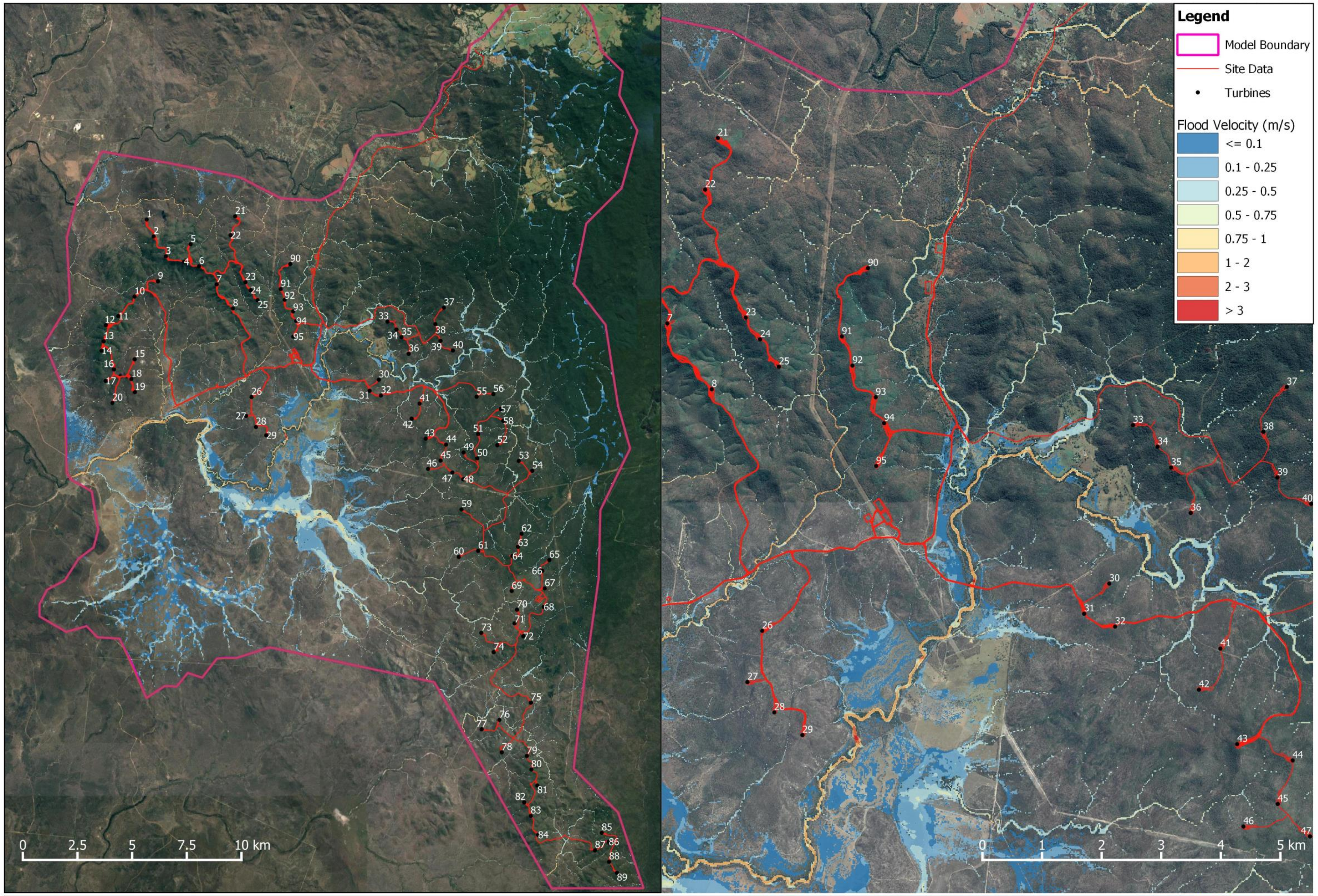
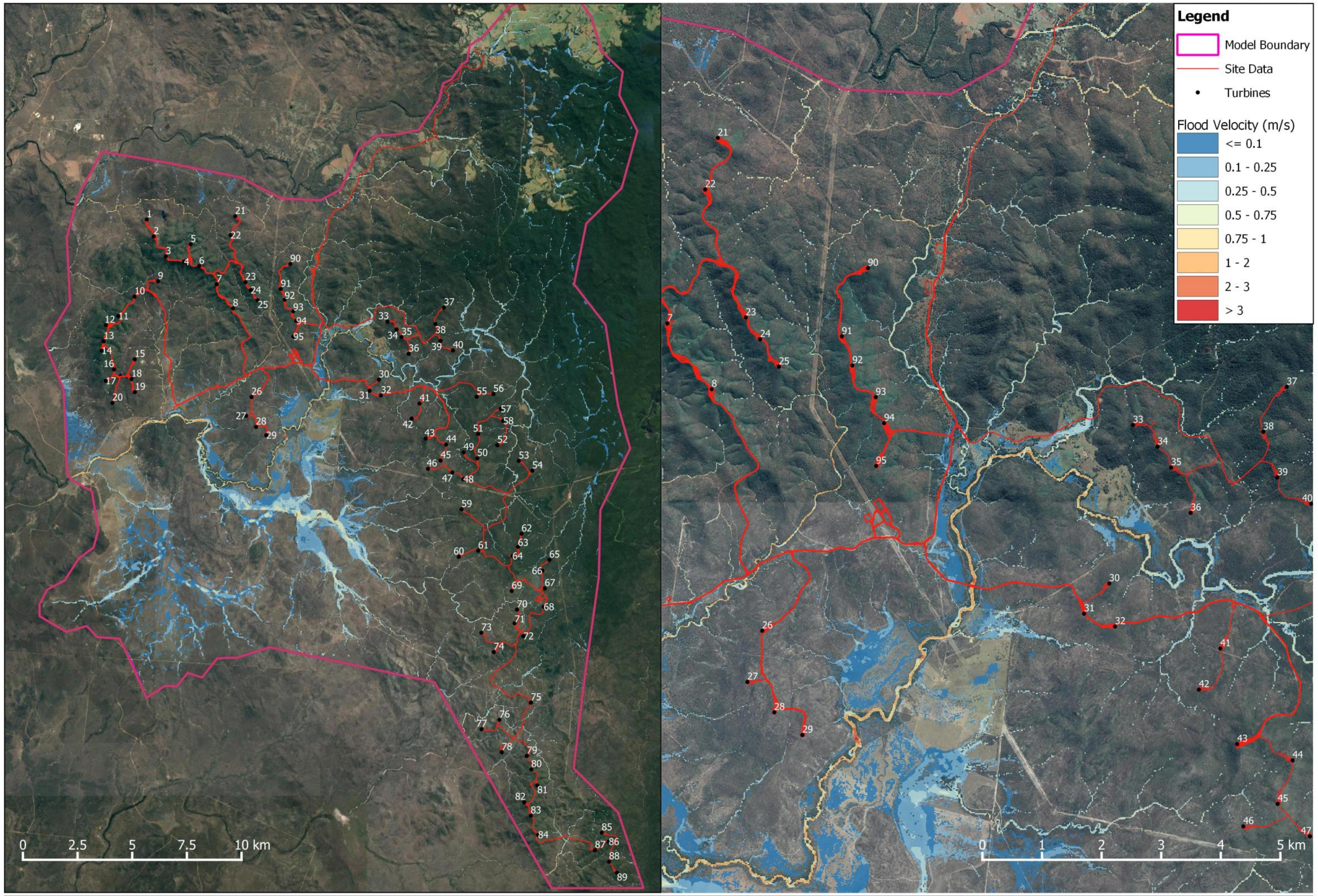


Size: A3
Imagery Source: Google 2021
Projection: GDA2020 MGA

Chalumbin Wind Farm Floood Study
50% AEP Flood Velocity

21-05-25T09:39:37.558

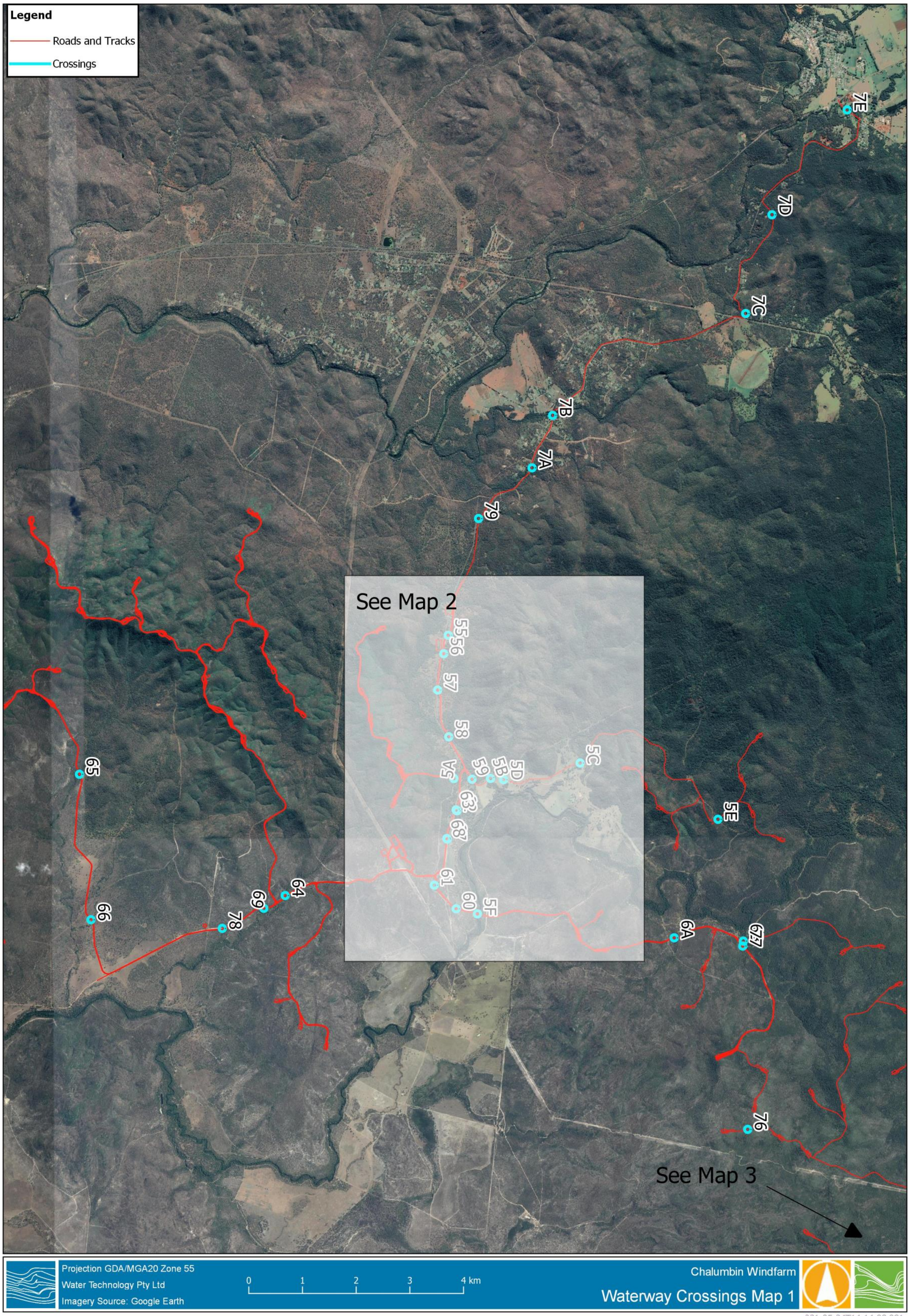


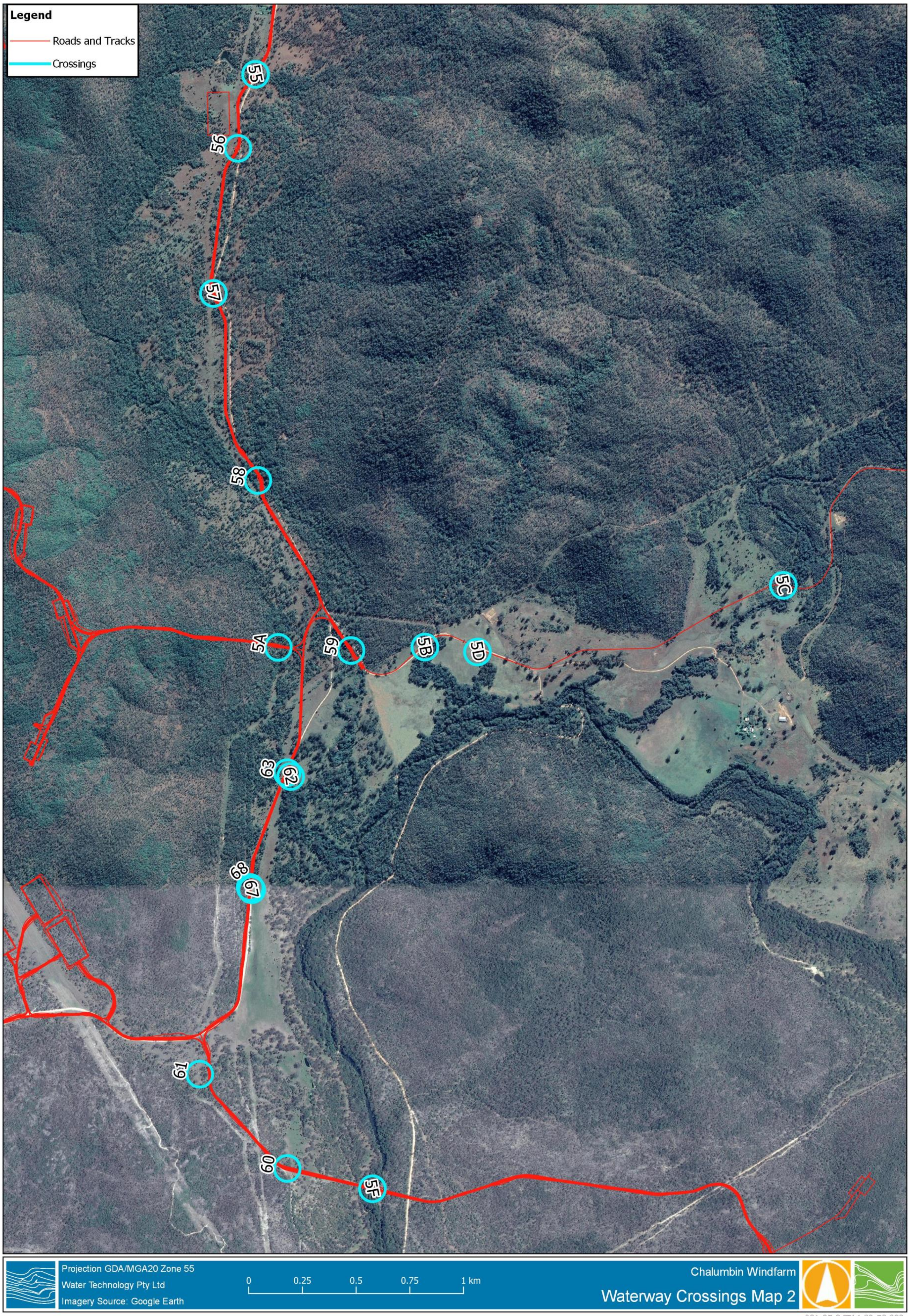
Size: A3
Imagery Source: Google 2021
Projection: GDA2020 MGA

Chalumbin Wind Farm Floood Study
63% AEP Flood Velocity

321-05-26T09:50:24.654

APPENDIX C WATERWAY CROSSING PEAKFLOWS


Legend
Roads and Tracks
Crossings
7E
7D
7C
7B
7A
79
See Map 2
55
56
57
58
5A
59
5B
5D
5C
5E
63
68
61
60
5F
65
66
78
69
64
6A
67
76
See Map 3
Projection GDA/MGA20 Zone 55
Water Technology Pty Ltd
Imagery Source: Google Earth
0
1
2
3
4 km
Chalumbin Windfarm
Waterway Crossings Map 1


Legend
Roads and Tracks
Crossings
55
56
57
58
5A
59
5B
5D
5C
63
62
68
67
61
60
5F
Projection GDA/MGA20 Zone 55
Water Technology Pty Ltd
Imagery Source: Google Earth
0
0.25
0.5
0.75
1 km
Chalumbin Windfarm
Waterway Crossings Map 2

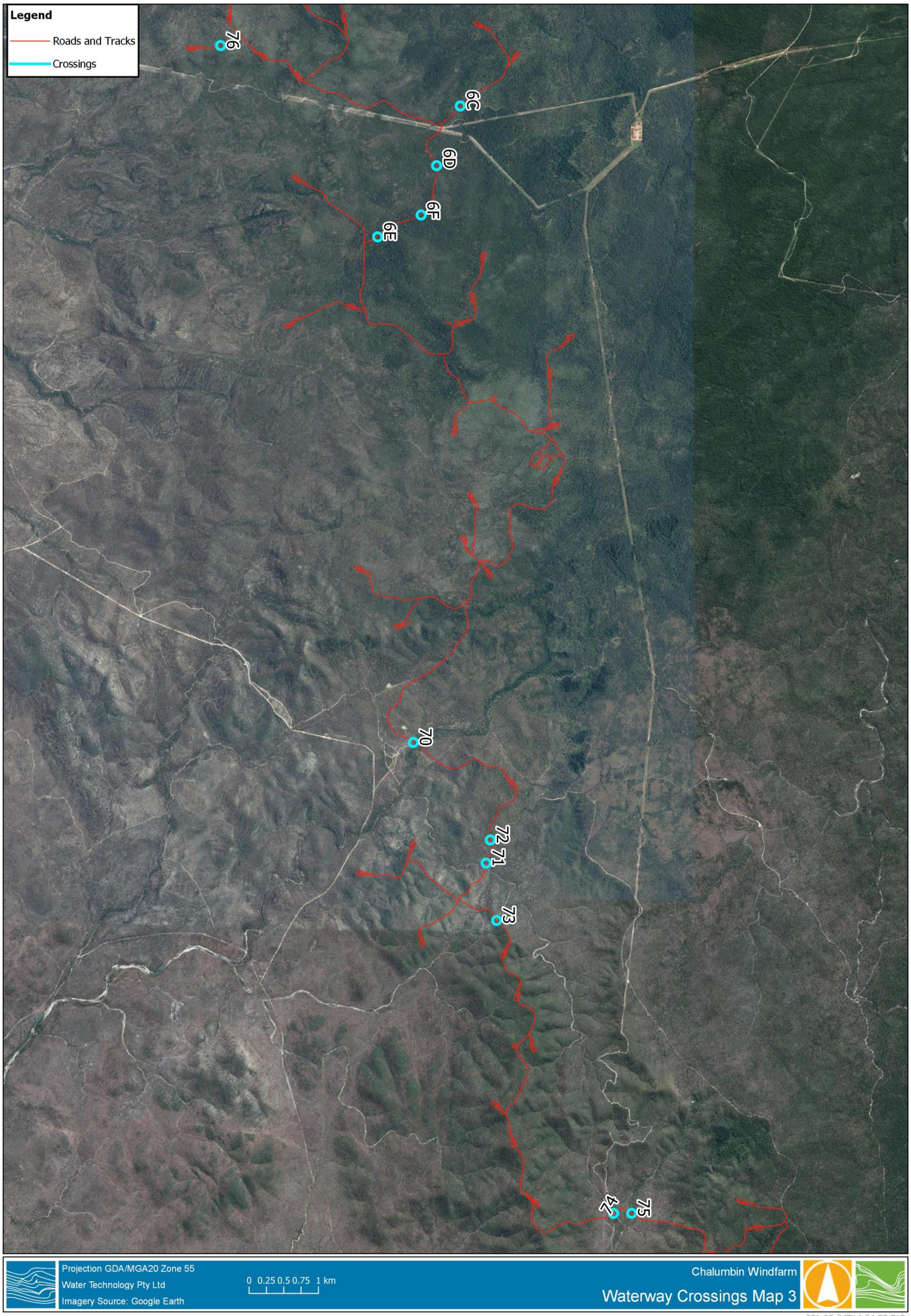

Legend
Roads and Tracks
Crossings
76
6C
6D
6F
6E
70
72
71
73
74
75
Projection GDA/MGA20 Zone 55
Water Technology Pty Ltd
Imagery Source: Google Earth
0 0.25 0.5 0.75 1 km
Chalumbin Windfarm
Waterway Crossings Map 3

TABLE 6 WATERWAY CROSSING PEAKFLOWS

Waterway Crossing ID	0.5% Peakflow (m^3/s)	1% Peakflow (m^3/s)	2% Peakflow (m^3/s)	50% Peakflow (m^3/s)	62.3% Peakflow (m^3/s)
65	149.73	121.10	106.17	26.23	20.54
66	92.31	76.92	66.18	15.81	12.15
78	30.13	25.38	21.95	6.05	4.67
69	22.86	19.49	16.91	4.62	3.51
64	171.03	142.40	126.16	29.37	20.42
55	23.16	19.17	16.36	4.53	3.58
56	1.04	0.86	0.72	0.18	0.14
57	9.12	7.84	6.44	1.65	1.28
58	216.11	185.04	164.79	44.29	32.86
5B	80.12	67.58	59.70	15.11	11.05
5D	4.51	3.73	3.25	0.81	0.58
5A	44.96	31.51	23.38	0.73	0.55
79	19.11	15.88	13.56	3.72	3.02
7A	171.13	146.72	131.41	36.19	26.57
7B	266.27	151.07	130.21	33.24	22.34
7C	98.55	80.25	71.50	20.30	16.04
7D	79.09	62.97	53.65	15.57	12.39
7E	176.22	99.63	80.80	15.31	10.52
5C	154.34	128.23	113.50	28.30	21.59
5E	13.27	11.31	9.86	2.82	2.18
77	40.38	33.61	28.37	8.03	6.31
6B	140.47	117.23	103.86	26.82	21.06
6A	80.08	66.40	56.49	15.79	12.41
63	32.24	24.89	19.48	2.92	2.14
61	23.16	19.53	16.54	4.23	3.22
60	29.88	9.36	4.74	0.96	0.66
5F	822.86	681.04	574.22	109.40	72.56
76	2.87	2.48	2.21	0.61	0.45
6C	164.91	141.26	124.62	33.17	26.10
6D	95.01	79.46	70.25	19.18	14.94
6F	21.66	18.18	15.80	4.77	3.70
6E	36.13	29.57	25.40	7.09	5.61
70	123.20	107.57	94.27	19.68	13.19
72	20.46	17.30	14.60	3.18	2.28
71	99.88	87.12	77.36	19.17	14.06
73	0.03	0.03	0.02	0.01	0.01
74	54.08	45.00	38.91	10.65	8.22
75	65.54	55.59	48.53	11.15	8.57
62	55.60	44.26	36.68	3.10	2.15
67	1.74	0.52	0.47	0.19	0.15
59	146.73	133.08	124.10	42.06	29.82

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