Report

Liverpool Ranges Wind Farm Flood Assessment

i3 consulting Pty Ltd

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WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

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1 INTRODUCTION

1.1 Objectives and Project Scope

Water Technology was engaged by i^3 consulting Pty Ltd to conduct a flood assessment of a proposed Wind Farm, located in the Liverpool Ranges, near Bundella and Coolah, NSW. The objective of the flood assessment is to understand the potential impacts of surface water to the construction and ongoing operation areas of the Liverpool Ranges Wind Farm. This pre-development assessment determines the flood risks on site and along major roadways leading to the site.

1.2 Study Area

The proposed Wind Farm, located between Coolah and the Coolah Tops National Park in NSW, is spread across multiple Local Government Authorities (LGA), and spread across numerous waterway catchments. The bulk of the infrastructure appears to sit along ridge lines and near the tops of the catchments, however cabling and roadways to connect the key infrastructure does cross numerous waterways and gully/drainage lines.

The study site (Figure 1-1) spread across three catchments, which are considered as a combined catchment for the hydrological and hydraulic assessment. The main waterways drain in a south-west direction, covering a total catchment area of 1224 km^2 at the confluence with the Talbragar River, part of the Macquarie River and Darling River Basin. The land use of the study catchment is typically forest with a low impervious surface.

Waterways in the upper ranges near the proposed turbines include Coolah Creek, Tureevale Creek, Yarrawonga Creek and Corella Creek.

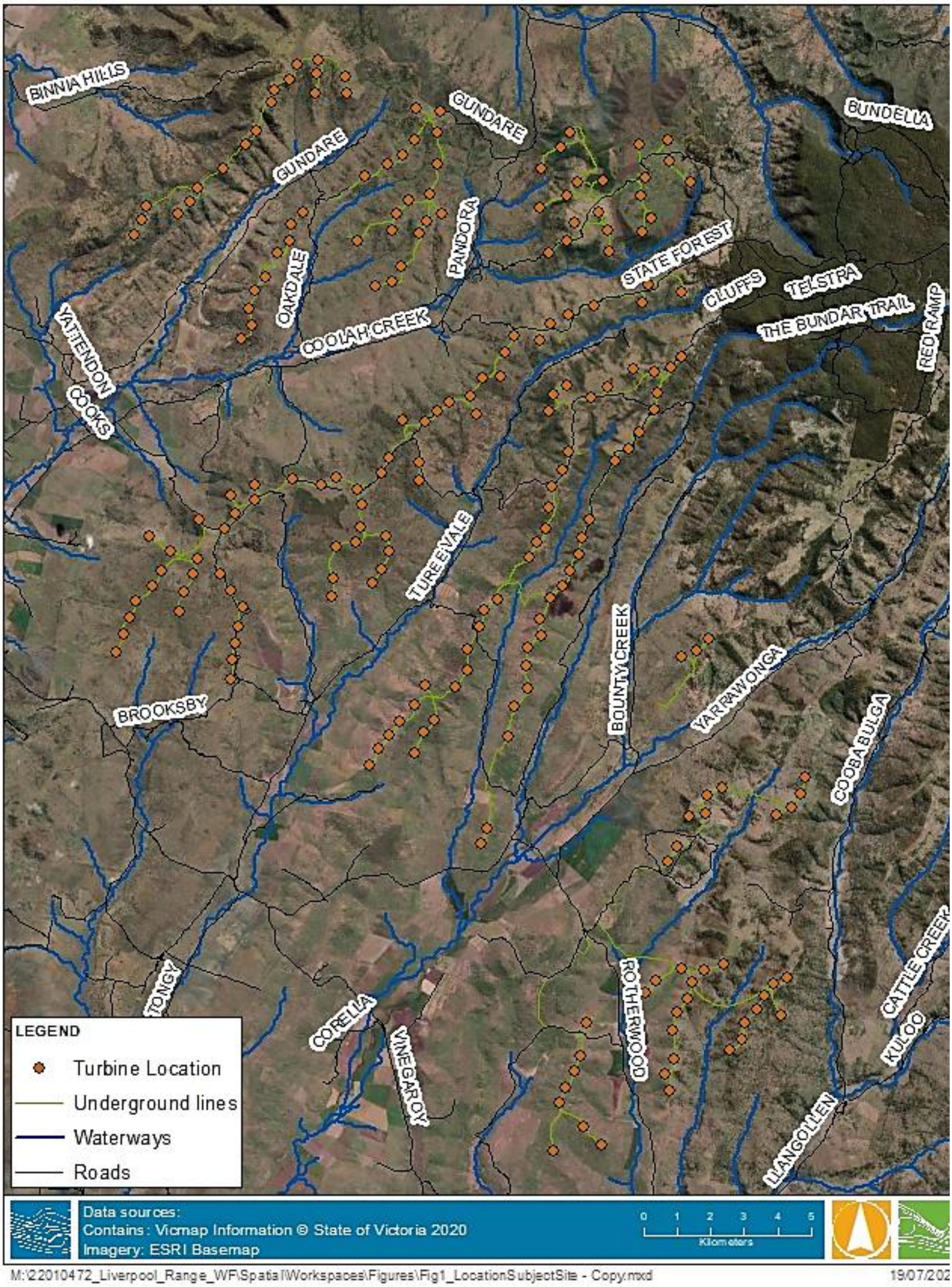

Figure 1-1 Location of the subject site

1.3 Methodology

1.3.1 Overview

The objective of this report is to provide i^3 Consulting with a comprehensive assessment of the existing site flood risk where infrastructure including turbines and underground cable locations are to be placed. The flood risk covers the wind farm areas as well as identification of the roadways that may be subject to inundation leading to these sites and locations for new access tracks to be used in the construction of the infrastructure.

The study area incorporates areas of the Upper Hunter (to the East) and the Warrambungle (to the West) shires encompassing a large study area. Developing a flood mapping to identify flood risk for the turbine locations, underground cable alignment and roadways across the study area required the use of hydraulic modelling. Two-dimensional models allow the simulation of overland flow generated from rainfall on a grid, representative of the site topography.

Two hydraulic models were developed for this assessment:

- A rain-on-grid model to identify flow paths in the upper slopes in areas where turbines are proposed to be located.
- A traditional direct-flow model which used hydrologic outputs (flow hydrographs) which captures the larger waterway flows through along the valley flows to identify roadways subject to inundation.

To undertake the flood risk assessment, the hydraulic models were used in the following steps:

- Modelling of 10%, 5%, 1% and 0.5% AEP events;
- Simulation for multiple duration events (30min to 2-hour for the upper catchments);
- Longer durations (12-48-hour) for the lower valley floor and larger catchments where the downstream end with longer critical durations.

Flood modelling results can be used to assess the suitability, design, condition and construction standard of the relevant public roads and access points as well as recommend any required upgrades to accommodate construction traffic. The outputs from the model include depth and velocity outputs, identify flows and water levels at road crossing throughout the study area.

1.3.2 Consideration of Hydrologic Impact of Wind Farms

Typically wind farm projects (post construction) have minimal impact on the overall hydrologic regime of receiving waterways and catchments. The area of impervious surfaces in relation to the turbine and transmission network are not likely to result in a noticeable increase of runoff from the site.

Roadways and access tracks constructed or modified for construction, operation and maintenance purposes which traverse overland flow paths have the potential to impact on how flows leave the site. The identification of flow paths and flood risk in these areas is an important consideration of the hydrological impact of windfarms. Flood modelling results allow for the design of cross-road conveyance structures in these locations.

2 DATA

2.1 Topography and Features

The study area is located in the Liverpool Ranges covering elevations between 500 – 1100 m AHD with steep slopes across the site. The turbine locations are located at the head of several catchments that drain southward from the Coolah Tops, going on to join the Macquarie River at Dubbo or the Goulburn River to the southeast.

Several topographic datasets were available for the site. These included:

- A DEM (Digital Elevation Model) constructed from topographic contour lines provided by i^3. Analysis showed irregularities and interpolation artefacts reduced the quality of the DEM and it was decided to use other data for the analysis.
- A Digital Terrain Model (DTM) with 30 m resolution, extending across the entire catchment, was available through ELVIS. This DTM is a raster representation of the area, capturing details of natural relief features across the catchment. The vertical and horizontal accuracy of this DTM is quite coarse at ± 5 m and ± 12.5 m respectively (relative to Australian Height Datum (AHD)).
- 5m LiDAR data sets mosaicked using the following data from ELVIS.
  - Mosaic
  - Blackville
  - Coolah
  - Mendooran

The datasets are shown in Figure 2-1.Other land feature information such as major roads, waterways, water bodies and localities was available through NSW Spatial Services.

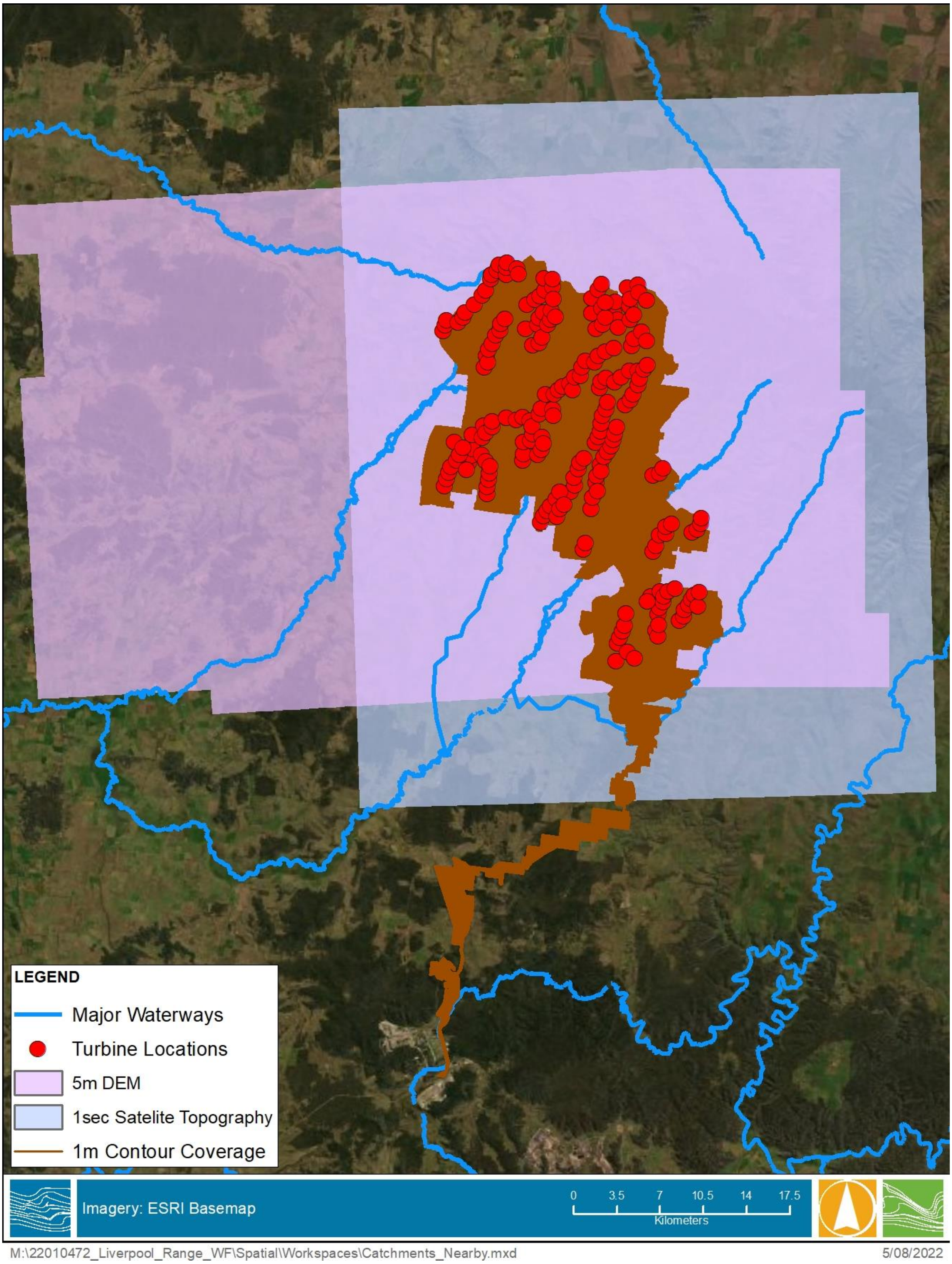

Figure 2-1 Topographic data coverage

2.2 Stream Flow

No streamflow gauges were identified within the modelled catchments. Downstream of the sites, a gauge is located on the Talbragar River at Dunedoo, approximately 45 km downstream of Coolah. This only has a short period of record. Other streamflow gauges within the Hunter River catchment to the east have longer streamflow records.

3 HYDROLOGY

3.1 Overview

The hydrologic assessment used a runoff routing approach, modelled using RORB software. Design modelling was completed using Ensemble approaches within RORB, as recommended in the Australian Rainfall and Runoff guidelines (ARR2019).

The methodology used to determine the 1% AEP design flows using RORB at the site is summarised below:

- RORB model development.
  - Catchment delineation.
  - Determination of routing parameters (kc and m).
  - Identification of design inputs (e.g., IDF, temporal patterns, Design losses).
- Model verification
- Extraction of inflow hydrographs for hydraulic modelling

Details of these steps are provided in the following sections.

3.2 Catchment Delineation

There are three adjacent catchments (with areas ranging from 200 km^2 to 580 km^2) contributing to the study site. Coolaburragundy River is the western most catchment, Talbragar River (central) and Munmurra River (eastern most). The catchments flow south, with the Coolaburragundy River outfalling to the Talbragar River and Munmurra River outfalling to the Goulburn River southeast of Cassilis. For the purpose of this assessment, the three catchments were analysed in a single RORB catchment in the hydrology assessment with print locations (where peak flow rates and hydrographs could be extracted) located downstream of the study area. The sub catchments were delineated based on satellite topography data processed in ESRI and used in the construction of the RORB model (sub catchments), using ArcRORB. Reaches and nodes were also created in ArcRORB, which represent the routing characteristics of the catchment to be used in the RORB model. The reaches were all defined as 'natural' except the dummy reaches connecting the three catchments to the outlet.

The resulting RORB model had 75 sub-catchments encompassing a total catchment area of approximately 1224 km^2. The turbine locations are flowing from the upper end of the catchment towards the downstream along the mountain ridges as shown in Figure 3-1.

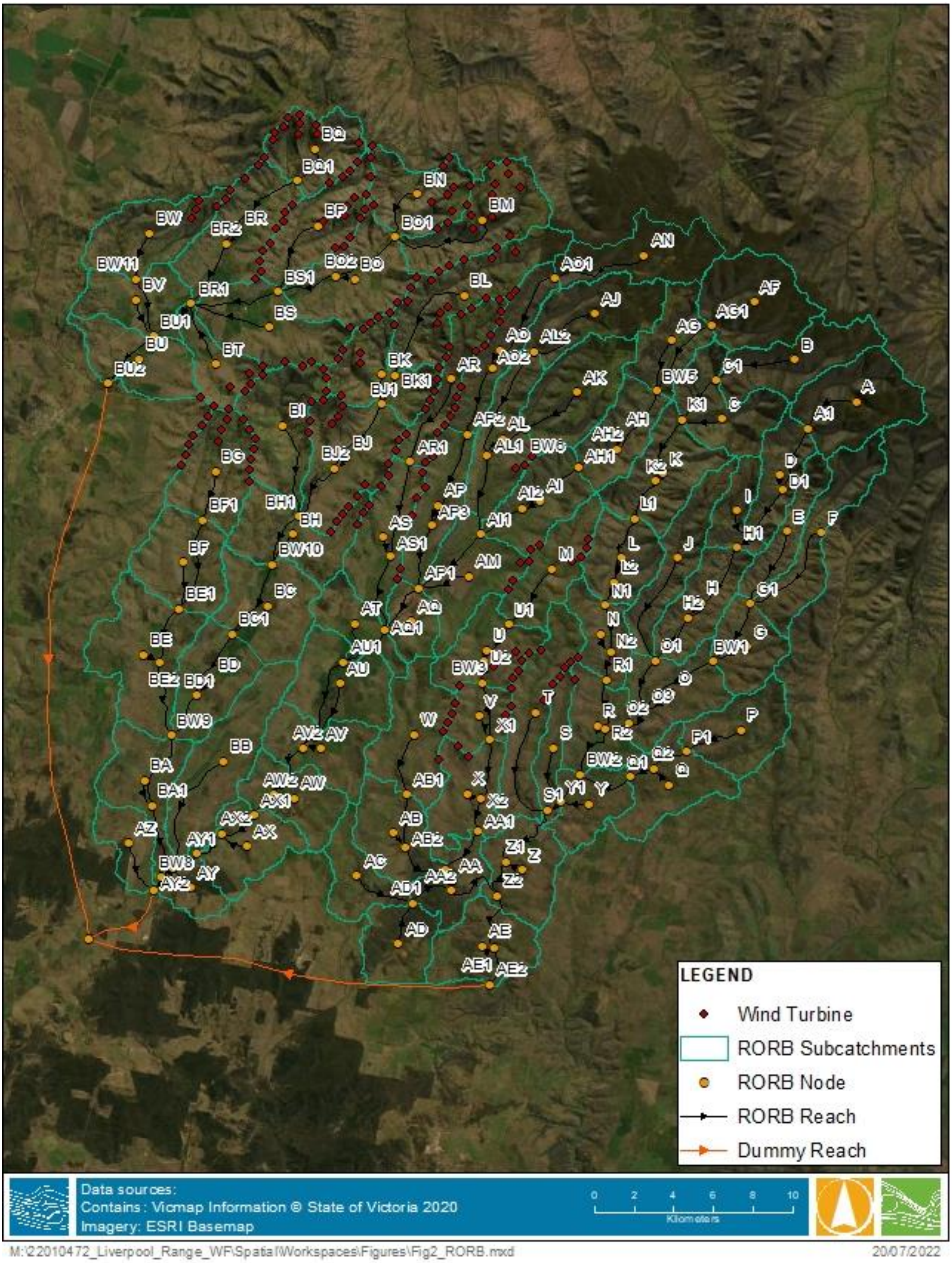

Figure 3-1 RORB Model catchment delineation

3.3 RORB Validation

No streamflow gauges or previous flood information exist for the waterways within the study area to calibrate the RORB model. The two western catchments within the study area drain to Talbragar River (also the main waterway within the central catchment). A streamflow gauge exists on the Talbragar River at Dundeoo, however the period of record is extremely short (less than 10 years). A nearby gauged catchment (Merriwa River at Merriwa streamflow gauging station 210091) with around 25 years of streamflow records dating back to the 1980s (excluding 1992-2010) is located east of the study area (Figure 3-2). The Merriwa River catchment originates from the same mountain range as the study catchment and has a similar magnitude catchment size to the three catchments within the study area. Flood Frequency Analysis (FFA) information available on BoM website for this station was used to validate the 1% AEP flow in the RORB model using catchment area regression method. The following equation was used to calculate peak flow estimates at the study catchment outlets.

$$Q_c = \left(\frac{A_C}{A_G}\right)^{0.7} Q_G$$

Where, A_C is the area of the unregulated catchment and A_G is the area of the gauged catchment (Grayson et al, 1996). The Merriwa Creek catchment (gauging station 210091) was selected as the gauged catchment for this study based on the proximity and the similarity in area. The peak flow estimates for the three catchments is shown in Table 3-1.

Table 3-1 Catchment Area Regression

Catchment	Area km^2	1% AEP Flow Rate (m^3/s)
Merriwa River at Merriwa	420	1060*
Western	201	632
Middle	582	1331
East	471	1148

*Based on BoM FFA

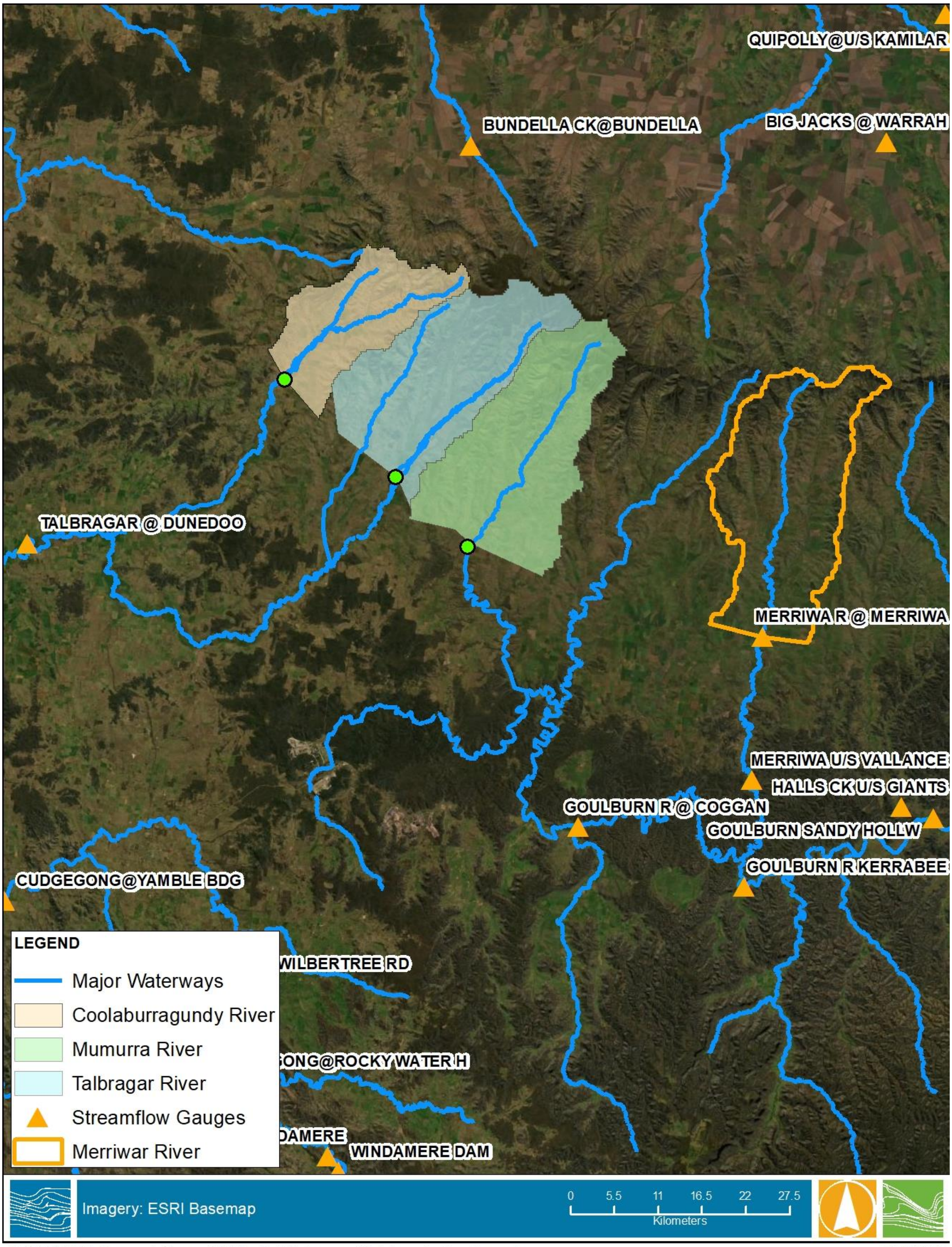

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Figure 3-2 Catchments and Gauged Catchment used for Regression Analysis

3.3.1 RORB Parameters

RORB uses two key routing parameters that influence the flow hydrographs through the catchment. The *kc* value was shown by McMahon and Muller (1983) to be directly proportional to the average flow distance (d_{av}), which is the weighted average flow distance of all RORB model nodes to the catchment outlet. The relationship is expressed as: $k_c = C_{0.8}\ d_{av}$ where, $C_{0.8}$ is a characteristic of the catchment that is independent of the catchment size.

Varying routing parameter *kc* were tested based on known kc prediction equations and then compared with the peak flow estimated by regression to then select an appropriate *kc* parameter.

A summary of the results using varying *kc* equations is shown in Table 3-2. This shows the RORB model using kc =21.01 estimated the most comparable peak flows to the values obtained through regression.

The other routing parameter '*m*' was kept at 0.8 for this study. Walsh and Pilgrim (1993) found that most catchments had values of m in the range 0.75 to 1.0 and adopted a fixed value of m = 0.8 for all catchments.

Table 3-2 - 1% AEP peak flow estimates for different kc values

Equation / Catchment	Catchment Regression	Aus wide Yu (kc=21.01)	Aus Wide Dyer (kc=24.94)	East NSW (kc=31.43
Western	632.8	405.1	311.6	284.7
Middle	1331.9	974.9	721.6	634.3
East	1148.5	845.6	638.8	575.1

3.4 Design Inputs

3.4.1 Intensity-Frequency-Duration (IFD)

Rainfall depths for the 1% AEP event were estimated for the centroid of the subject site using the Intensity-Frequency-Duration (IFD) information available from the Bureau of Meteorology. The design rainfall IFD estimates for the study area are shown in Table 3-3.

Table 3-3 1% AEP Design Rainfall Depths (mm)

Duration	12 hr	18 hr	24 hr	30 hr	36 hr	48 hr	72 hr	96 hr
Rainfall	123	149	169	187	201	224	254	270

3.4.2 Temporal Patterns

The design storm temporal patterns were downloaded from the ARR2019 Data Hub and were used to simulate the distribution of burst rainfall depth during each storm event modelled. Areal temporal patterns were used for all the inflow locations. Each of the 10 Temporal Patterns was selected and compared for the peak flow at each inflow location. The temporal pattern generating the peak flow closest to the mean peak flow (of the 10 temporal patterns) was selected for generating the hydrographs.

3.4.3 Design Losses

An initial/continuing loss model was applied for the RORB modelling. Losses were initially determined using the ARR online datahub. The ARR Datahub suggested losses were 47 mm initial loss and 2.3 mm/hr continuing loss. The data hub continuing loss of 2.3 mm/hr was lowered based on state-wide advice to modify these losses indicating that they are too high, and that consideration should be given to regionally appropriate losses where information is available. For NSW catchments, it is advised to use an appropriate regional loss based on the review of catchments throughout the state or adopt the default ARR data hub continuing losses with a multiplication factor of 0.4. Having regard to this a continuing loss of 1 mm/hr was adopted (nearly 40% of ARR continuing loss).

The initial loss adopted (47mm) is based on the ARR Datahub and is inline with nearby catchments reviewed following the release of the initial DataHub losses.

3.5 1% AEP Flow Verification

The adopted *kc* and rainfall losses provided in Table 3-4 were verified by comparing the RORB modelled peak flows at the model outlet with the peak flows produced by the ARR Regional Flood Frequency Estimation (RFEE) method (Rahman et al, 2012), through catchment area regression and Hydrological Recipes estimate (Equation 7.6.5 in Grayson etal, 1996).

A comparison of peak flows between the RORB model and other flow estimation methods is shown in Table 3-5. This highlights the RORB flows are on the lower end of the estimates, however were higher than the hydrological recipes estimate and close to or within the RFFE confidence limits.

As the RORB model estimated peak flow value is within the range of peak flow values estimated by other methods, the adopted parameters were deemed acceptable for estimating 1% AEP flow for this site.

Table 3-4 Adopted RORB Model Parameters for Design Modelling

Parameter	Adopted Value
k_c	21.01
m	0.8
IL	47 mm
CL	1 mm/hr

Table 3-5 Comparison of Peak Flow Estimates

1% AEP Estimation Method	Coolaburragundy River	Talbragar River	Mumurra River
RFFE	1180 (480-2790)	1540 (642-3720)	1080 (449-2600)
RORB	405.1	974.9	845.6
Catchment Area Regression	632.8	1331.95	1148.5
Hydrological Recipes (Rural catchments)	267	601	511

3.6 RORB Results

To determine the peak 1% AEP estimate and select an appropriate temporal pattern to use within design modelling, the Australian Rainfall and Runoff (2019) recommended approach for determining the 1% AEP event was used. The approach entails the following:

- An ensemble approach simulation, using the ten-design rainfall temporal patterns for the critical durations at the three outlet locations was undertaken.
- Analysis of the ensemble approach was used to determine the design rainfall temporal pattern which produces the median peak flow value. Excess flow hydrographs for the median temporal pattern (for each duration) were then extracted and used as inflows for each subcatchment within the hydraulic model.

4 HYDRAULIC MODELLING

To represent accurate flows at the road crossings as well as model impacts at the proposed turbine locations, two hydraulic models were developed. These include a rain-on-grid model, with rainfall applied directly onto the model cells, and a traditional direct-flow model which used the hydrologic outputs from the RORB modelling described prior.

Both models were developed based on a 5 m x 5 m topographic resolution. This resolution was considered sufficient to represent the drainage channels within the model extent, it also corresponded to the highest resolution of the LiDAR data sets available.

Rain-on-grid models allow the simulation of overland flow generated from rainfall on to a two-dimensional grid, representative of the site topography in the upper reaches of the catchment. Rainfall, less catchment losses, are applied directly to each grid cell within the model. Overland flows then move across the grid based on the topography of the site and the runoff characteristics. Within the rain-on-grid model, no other additional flows were applied. The extent of this model includes the upstream catchments of all proposed turbines but may not include all potential catchment of the streams which cross important roads. The benefit of this model is that the shallow, high velocity runoff from the steep slopes is accurately captured. This may help with the placement of turbines and critical assets, as even the highest points in the catchment are still simulated with surface water flows.

As the rain-on-grid model does not include the full catchment for all streams of interest (through the Golden Highway), a second model was developed. This includes a large area in the east, where turbines are not proposed but the Munmurra River is formed, flowing through Cassilis and crossing a number of important roadways. This model used excess runoff hydrographs determined via the hydrologic (RORB) model that were placed within key drainage lines within each sub-catchment. This runoff is applied to the top of the stream and permitted to flow naturally through the model to determine velocities and water levels at important road crossings downstream.

In the presentation of results, both models are combined to present the maximum likely flood impacts.

The domain of each model is shown in Figure 4-1 below, extending south to the townships of Coolah in the west and Cassilis to the east.

Hydraulic resistance was varied across the extent and determined through aerial imagery. Most cells within the domain were represented by a Manning's 'n' value of 0.05, representative of vegetated areas and pastures. Lower values were applied for roads and watercourses representing surfaces with lower resistance, and a higher roughness value adopted for patches of dense bushland.

Several constant water level boundaries were applied at the downstream end of major flow paths on the edge of the model. These boundaries were located a sufficient distance from the impacted road crossings site such that they did not influence flood behaviour.

Several bridges and culverts exist within the model domain. On major watercourses these have been removed from the terrain such that they do not impede flow, and no structures have been explicitly included in the model.

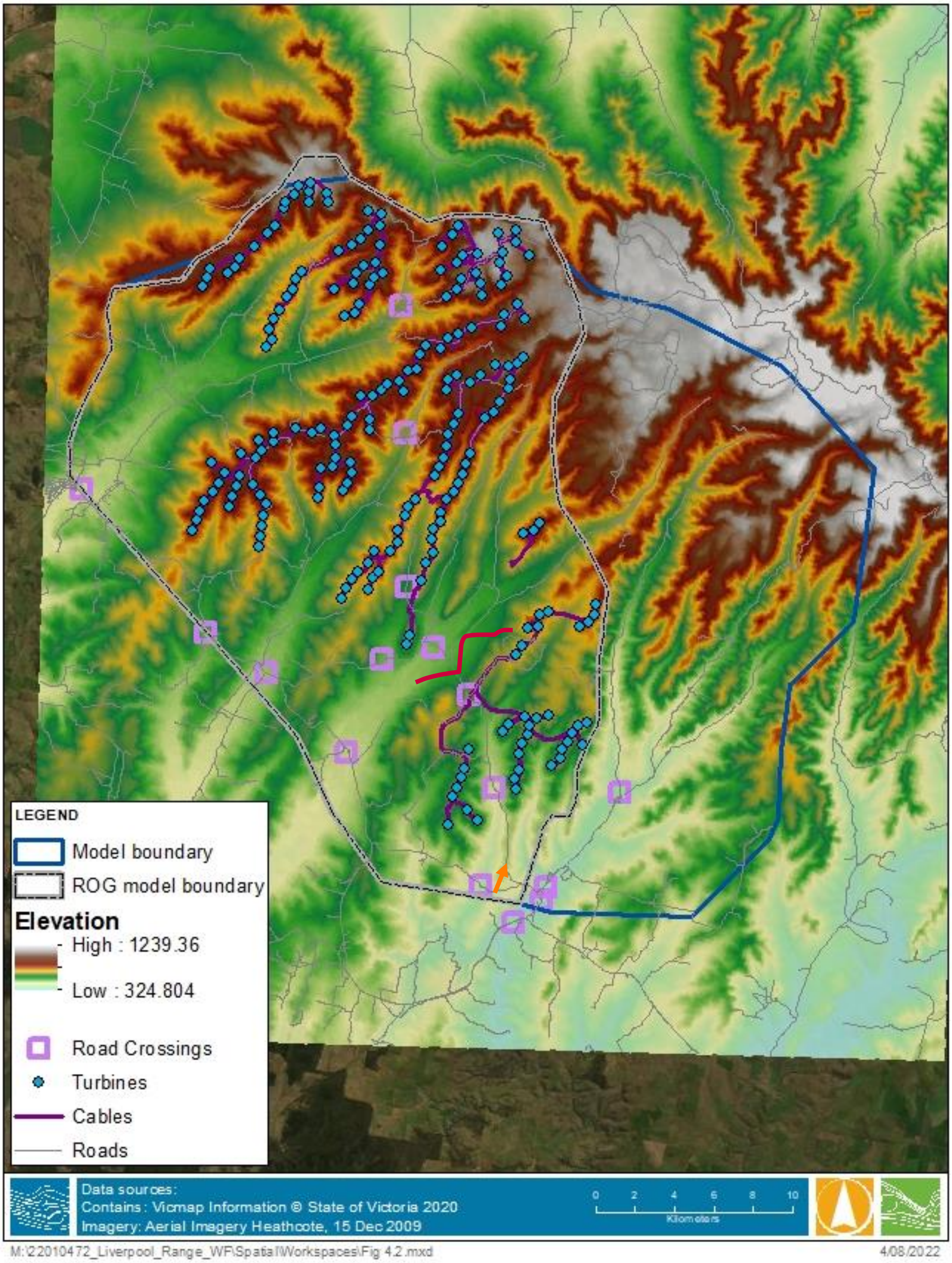

Figure 4-1 Hydraulic model domains

5 RESULTS

Figure 5-1 to Figure 5-28 show the 1% and 10% AEP event results, in terms of maximum depths and velocities across the site. The 5% and 0.5% AEP results are provided in Appendix A. Mapping has been separated into seven key map locations focused around the proposed turbines and major road crossings.

As shown in the mapped results, the steep terrain causes high velocities and generally well defined drainage paths, preliminary turbine locations are not within any ponding areas. Due to the steep terrain, peak velocities are relatively high, mostly between 1 and 5 m/s (and above, locally), which creates risk of erosion, in particular at track crossings.

The intersections of the major overland flow paths and existing roads have been circled on the maps. Results at these crossings have been extracted using Plot Output (PO) lines placed in the TUFLOW model, and summarised within Table 5-1

Table 5-1 Peak Flows and Water Levels for the 1% AEP and 10% AEP existing scenarios

ID	Road Name	X (Zone 56)	Y (Zone 56)	Peak Flow 1% AEP (m³/s)	Peak WL 1% AEP (mAHD)	Peak Flow 10% AEP (m³/s)	Peak WL 10% AEP (mAHD)
4	Coolah Road	211910.5	6454973.59	258.71	424.02	138.52	423.73
5	Corella Road	203798.5	6460108.18	915.78	488.14	446.70	487.92
8	Brooksby Road	196678.9	6470687.16	78.59	600.73	49.77	600.46
9	Brooksby Road	197774.6	6470297.05	121.87	589.39	75.51	589.66
17	Pandora Road	206589.5	6486472.45	49.38	697.71	33.46	697.42
20	Coolah Creek Road	204965.9	6482608.59	57.28	639.50	34.46	639.47
21	Coolah Creek Road	198620.8	6480514.6	42.03	559.52	26.53	559.42
22	Coolah Creek Road	203944.7	6482298.8	17.25	620.15	11.06	620.02
23	Coolah Creek Road	203531.7	6482138.16	38.68	618.24	20.71	618.18
24	Coolah Creek Road	200208	6481102.12	144.0	575.48	87.50	575.35
25	Oakdale Road	200930.3	6483263.77	202.66	607.77	116.85	607.43
26	Oakdale Road	200892.7	6482470.91	3.72	593.66	2.18	593.62
27	Oakdale Road	201185.3	6481661.99	518.81	581.38	320.65	580.97
28	Gundare Road	197883.6	6483880.69	320.98	583.49	191.35	583.18
29	Tureevale Road	206236.7	6476114.34	52.66	626.94	33.78	626.84
30	Tureevale Road	201992.1	6471238.07	225.80	562.24	134.17	562.12
31	Tureevale Road	203723.9	6472918.85	51.11	583.25	33.56	583.14
33	Coolah Road	208130.8	6456649.57	185.15	471.57	114.59	471.17
34	Bounty Creek Road	211740.8	6470187.59	337.60	559.10	150.42	558.40
35	Rotherwood Road	208482.6	6467264.17	841.05	528.31	351.90	528.04
36	Rotherwood Road	209089.6	6466907.94	123.22	531.58	70.44	531.50
37	Rotherwood Road	211640.9	6461840.75	10.44	510.43	6.97	510.37
38	Rotherwood Road	211589.3	6462844.72	41.63	519.61	24.16	519.29
40	Rotherwood Road	206287.2	6466349.11	179.19	527.40	109.67	527.17
42	Yarrawonga Road	209605	6467037.03	121.69	538.06	77.25	537.89

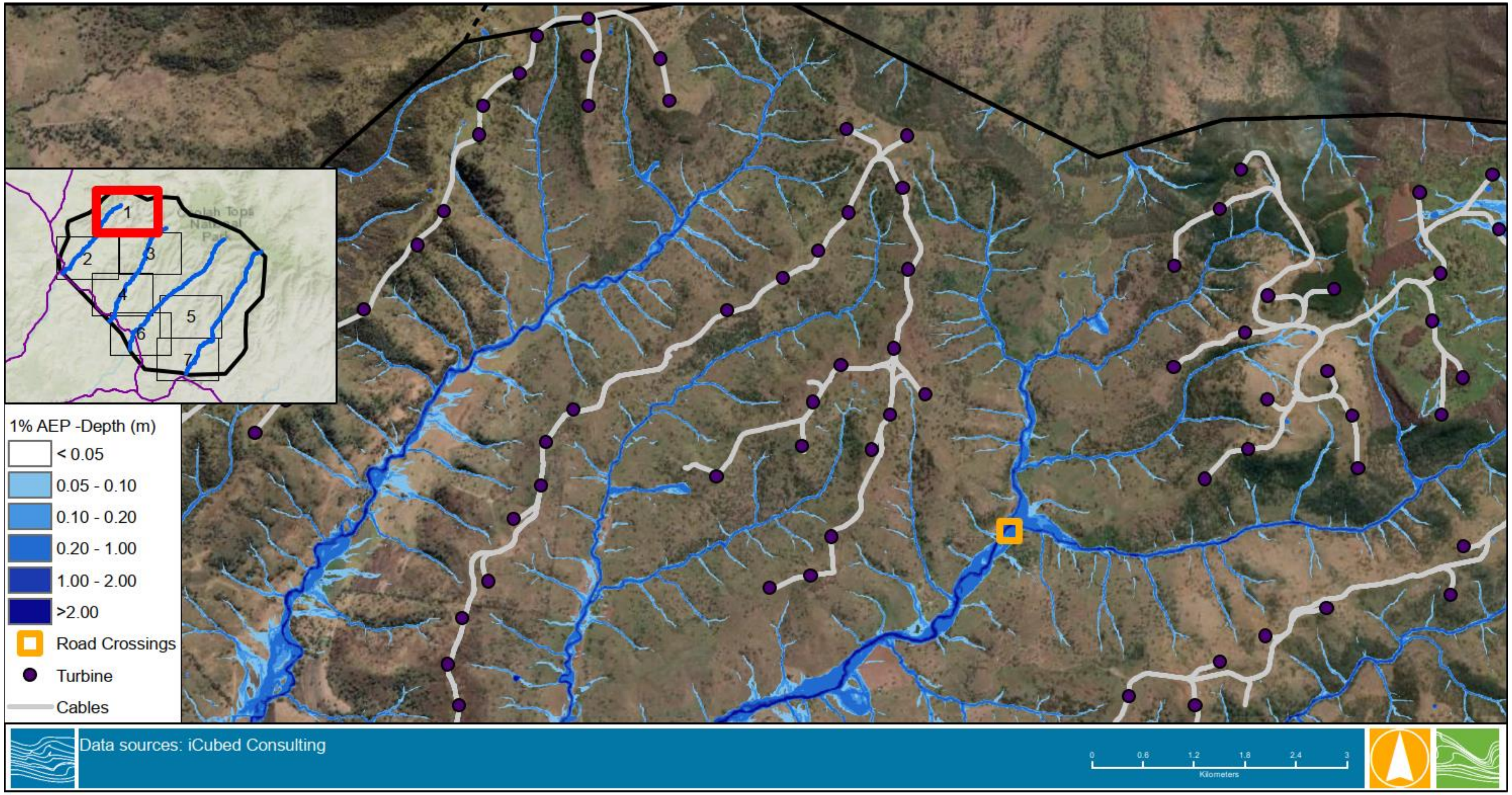

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Figure 5-1 1%AEP depth map (1)

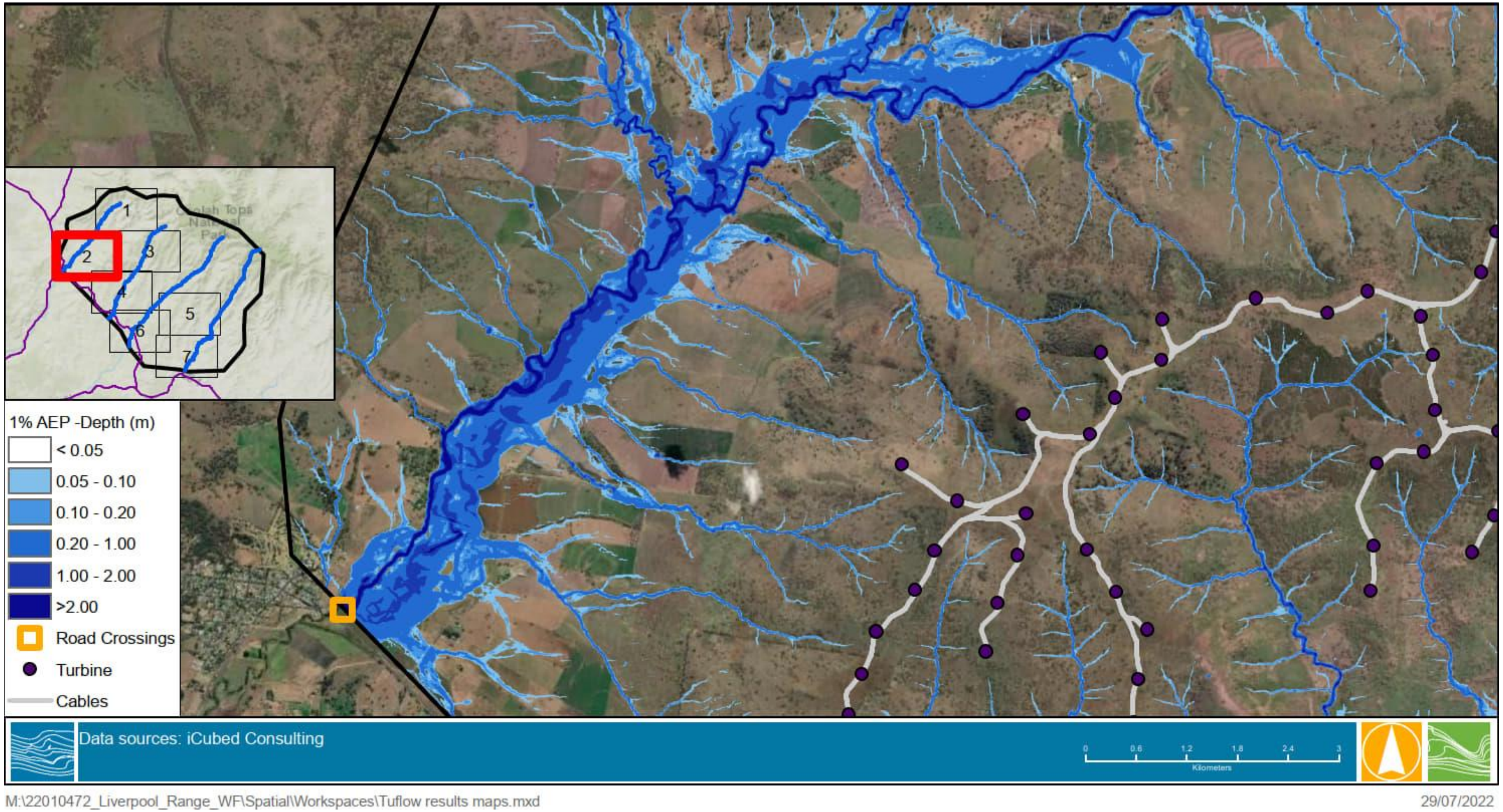

Figure 5-2 1%AEP depth map (2)

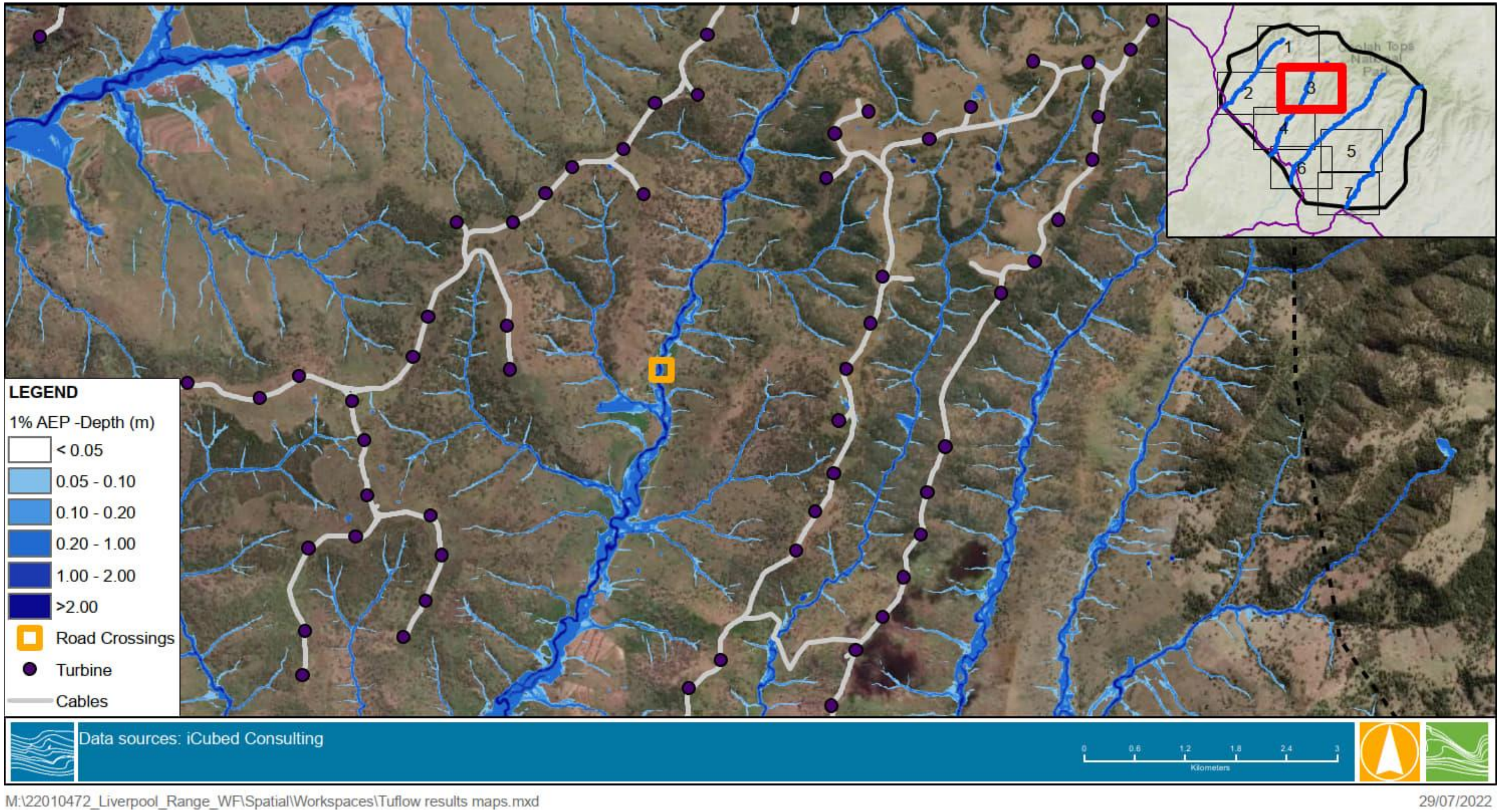

Figure 5-3 1%AEP depth map (3)

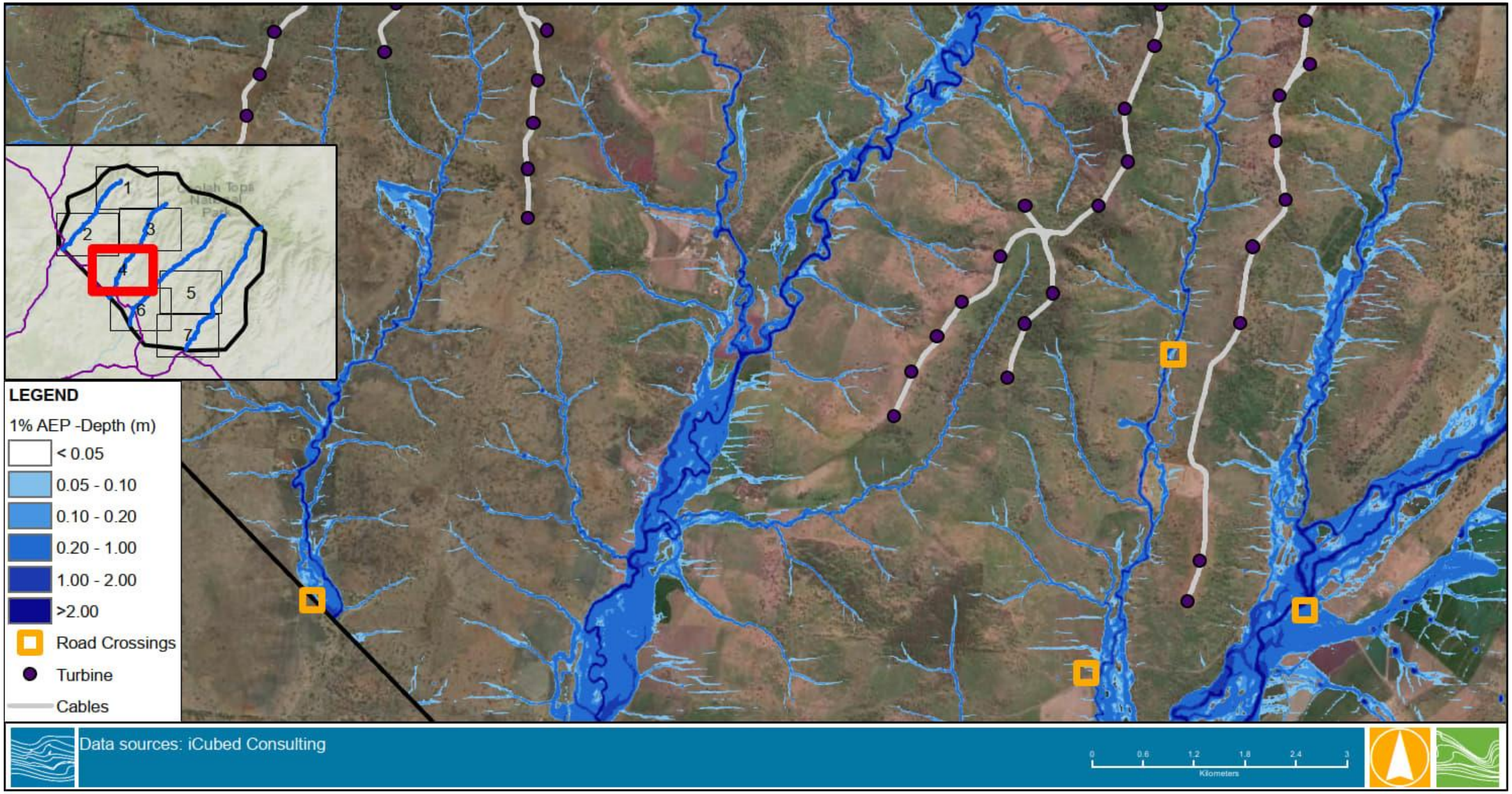

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Figure 5-4 1%AEP depth map (4)

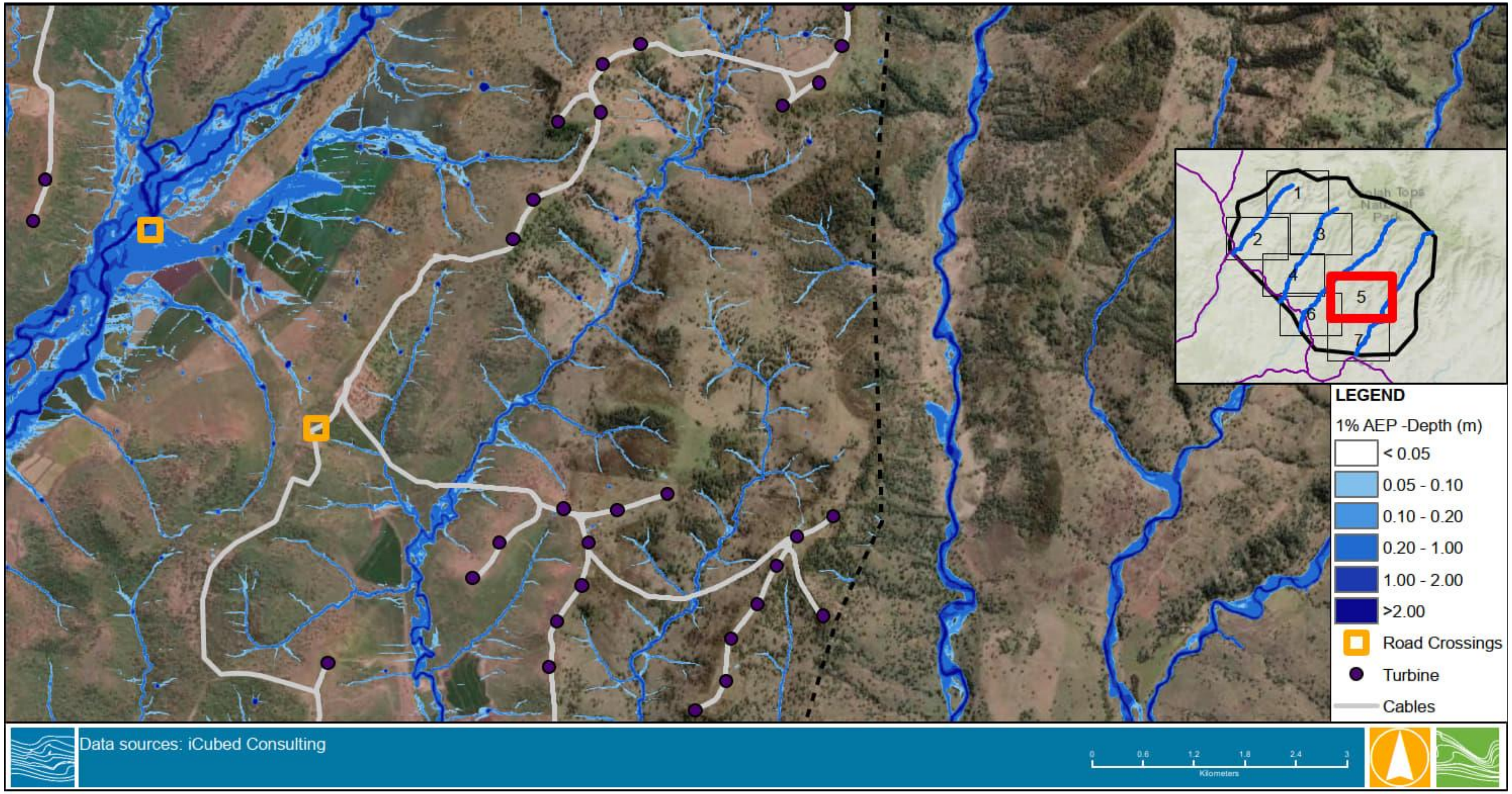

Figure 5-5 1%AEP depth map (5)

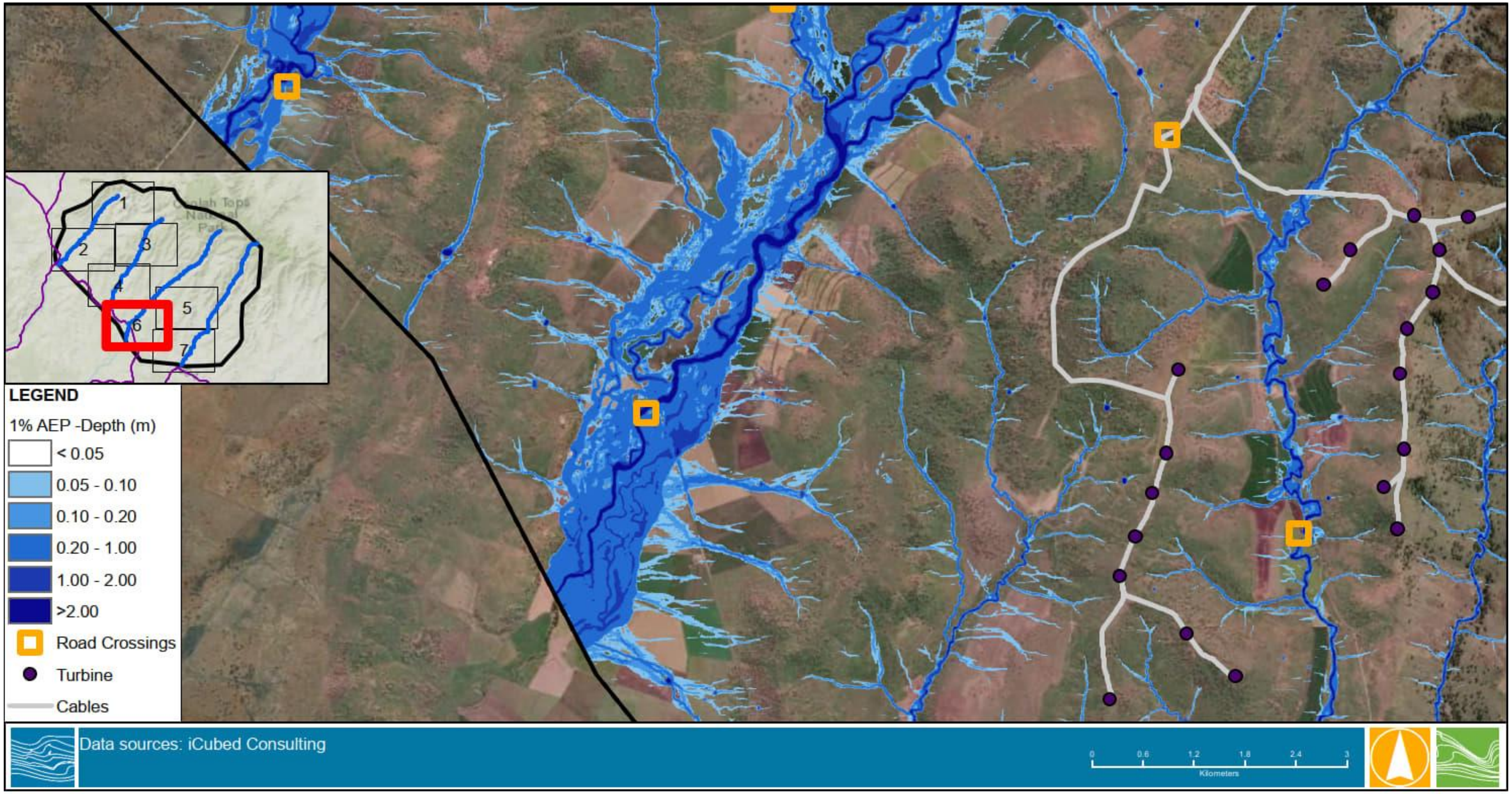

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Figure 5-6 1%AEP depth map (6)

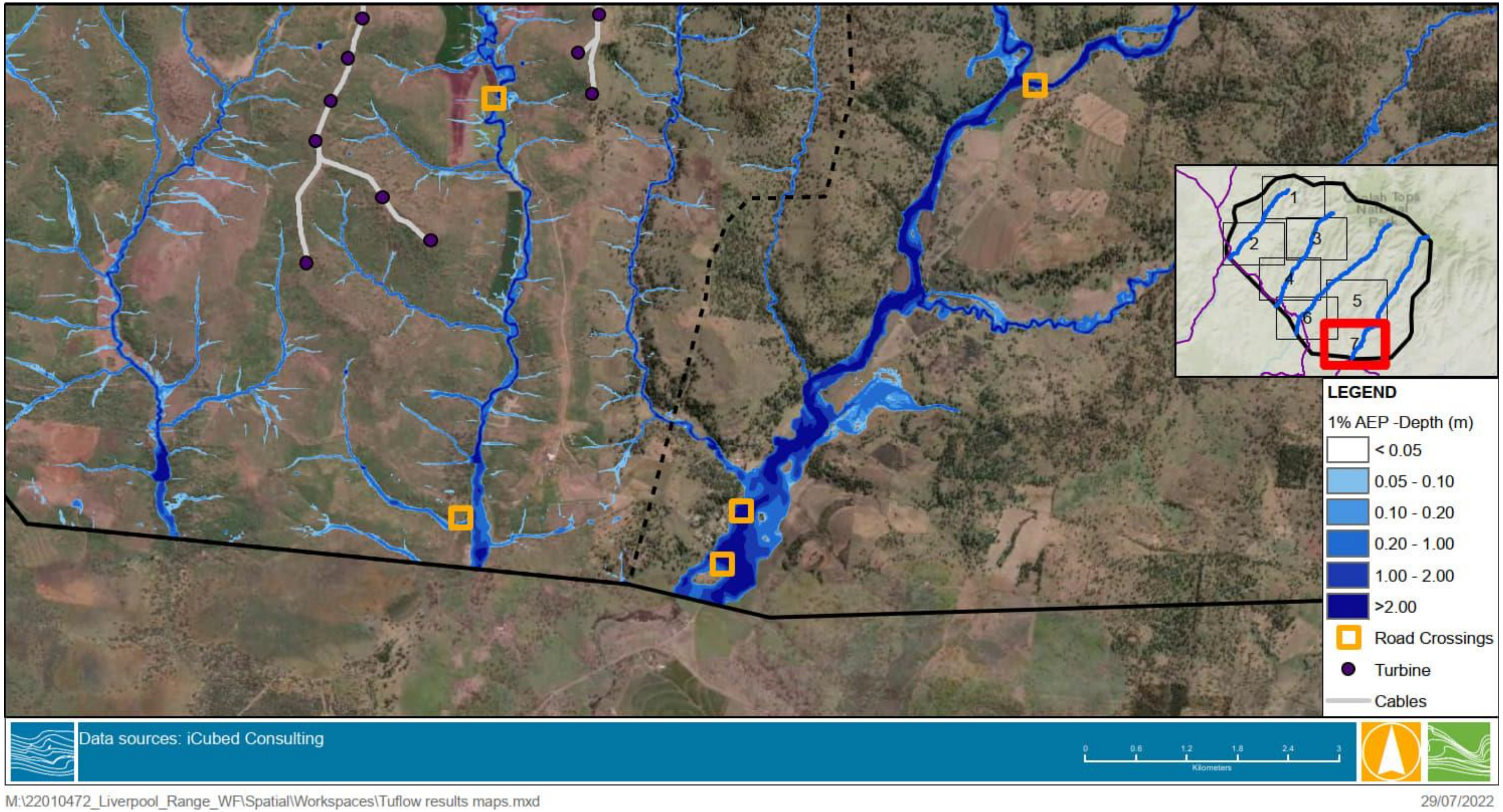

Figure 5-7 1%AEP depth map (7)

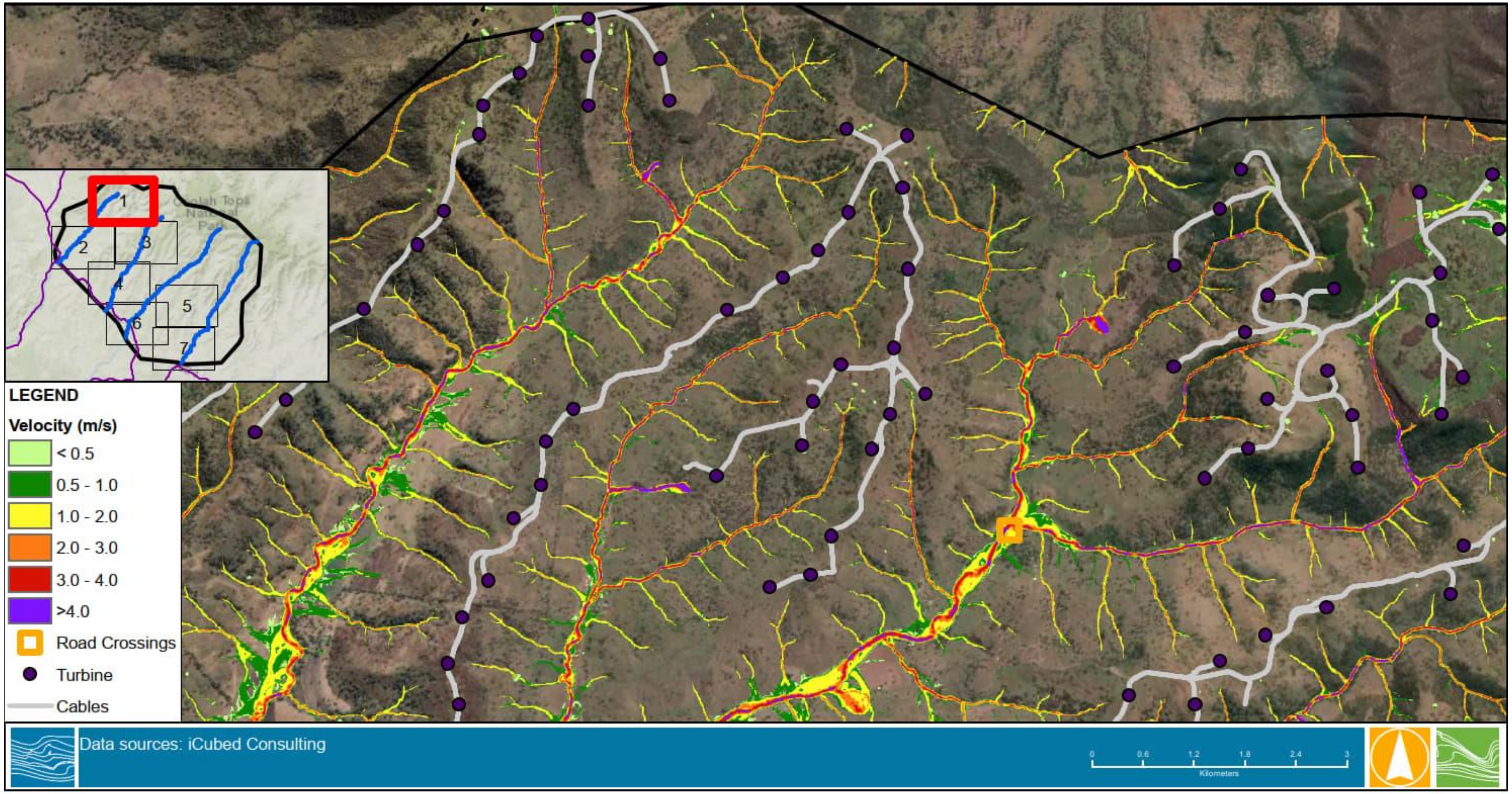

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Figure 5-8 1%AEP velocity map (1)

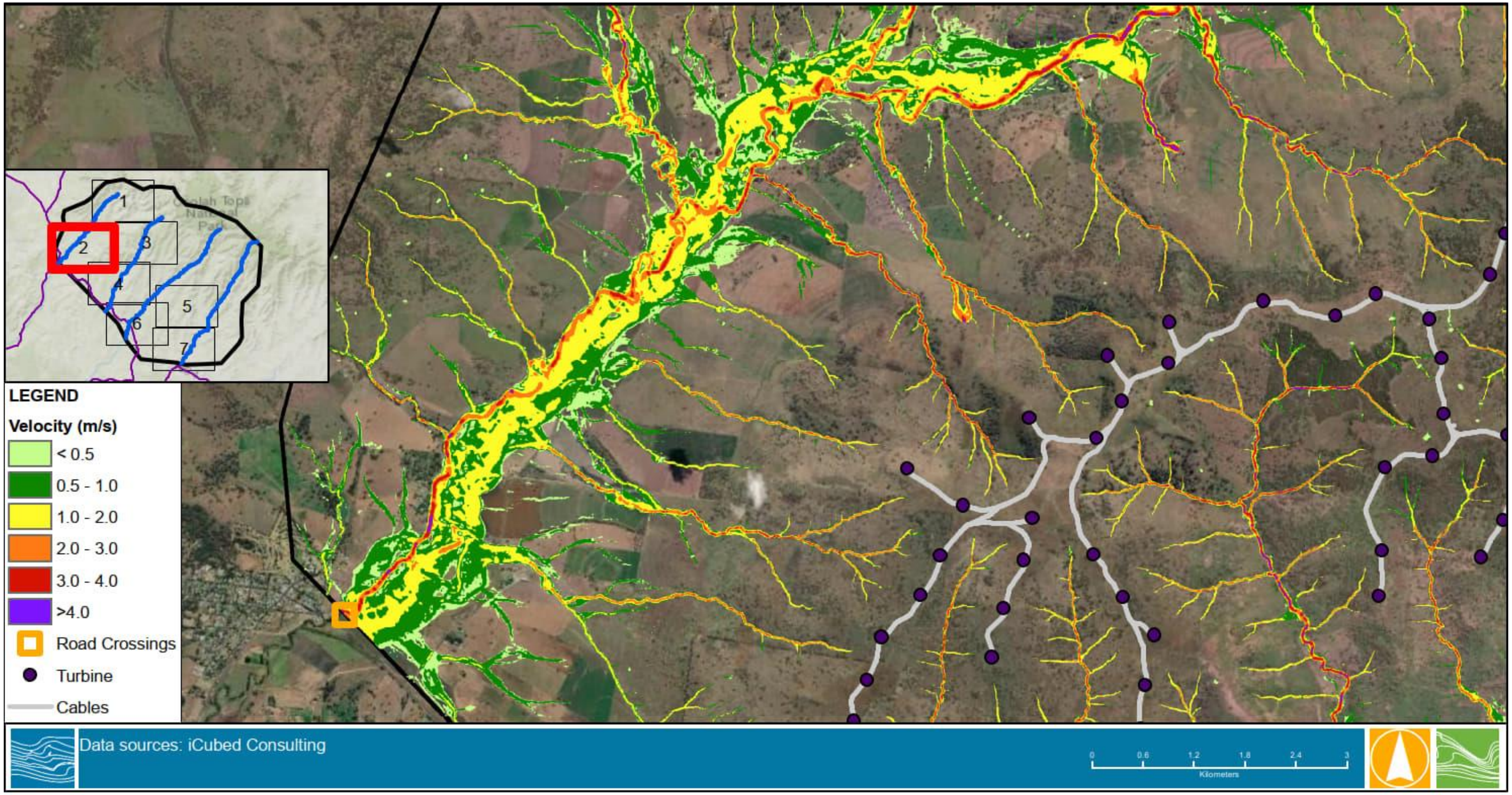

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Figure 5-9 1%AEP velocity map (2)

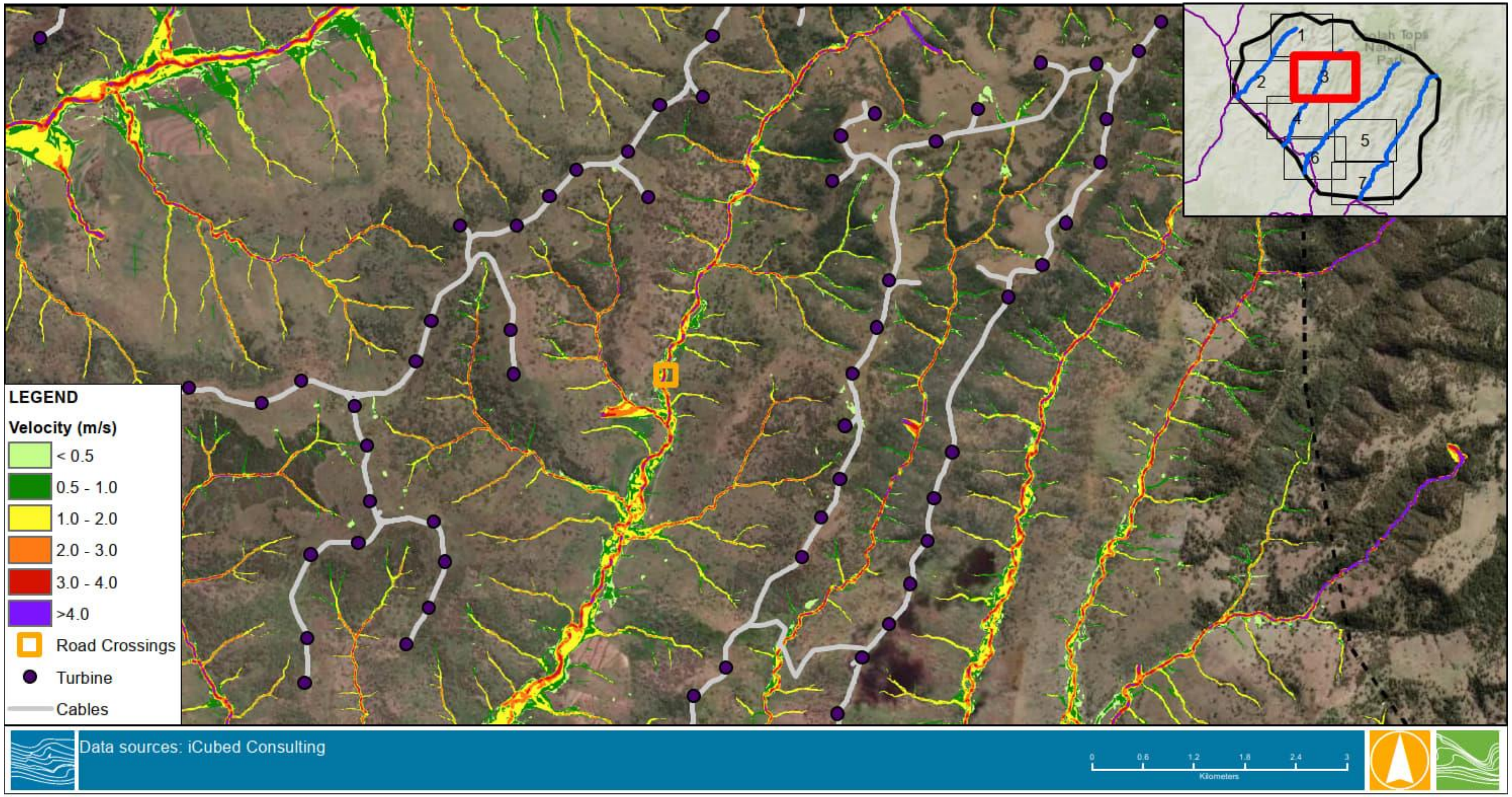

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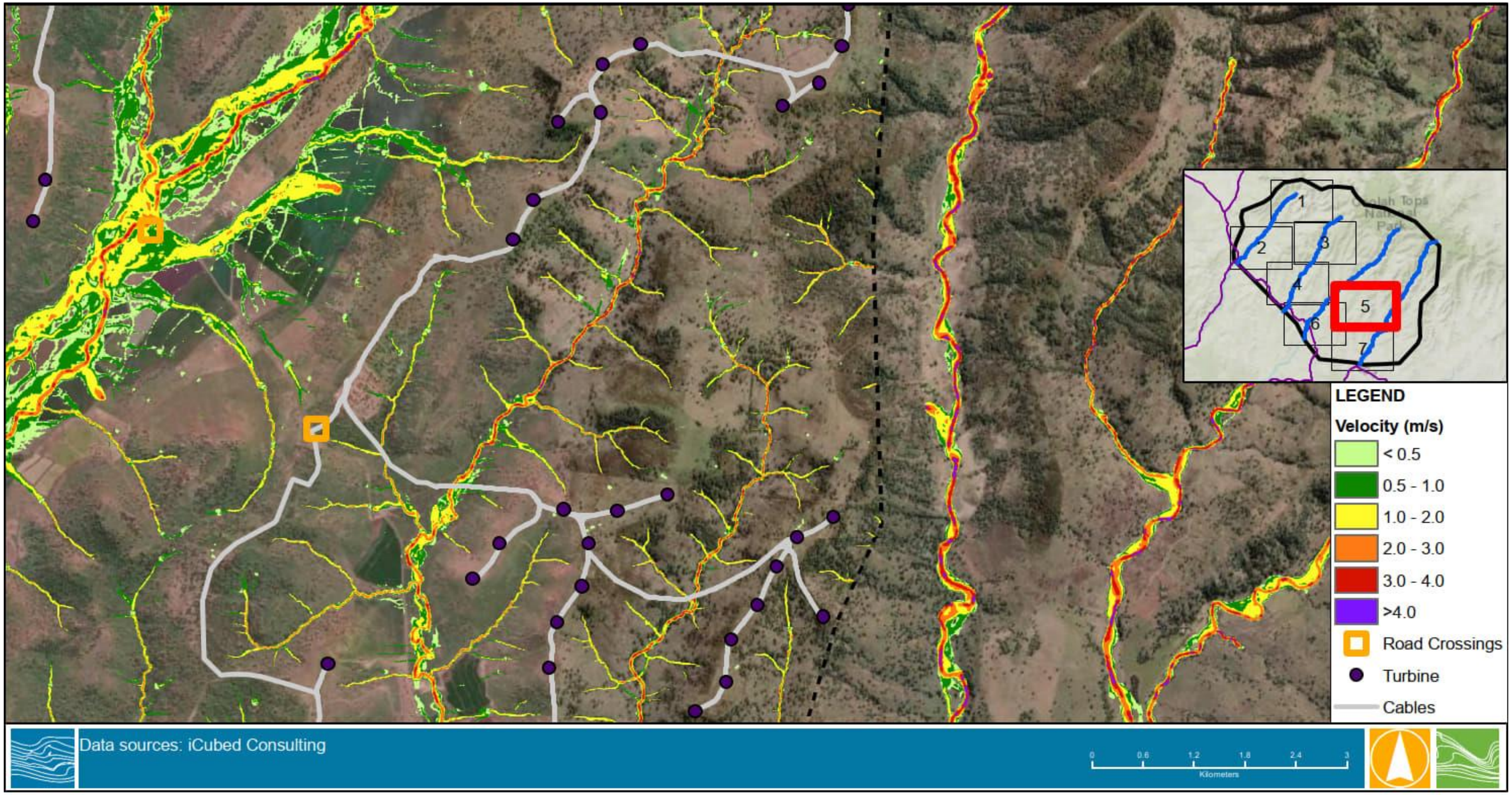
Figure 5-10 1%AEP velocity map (3)



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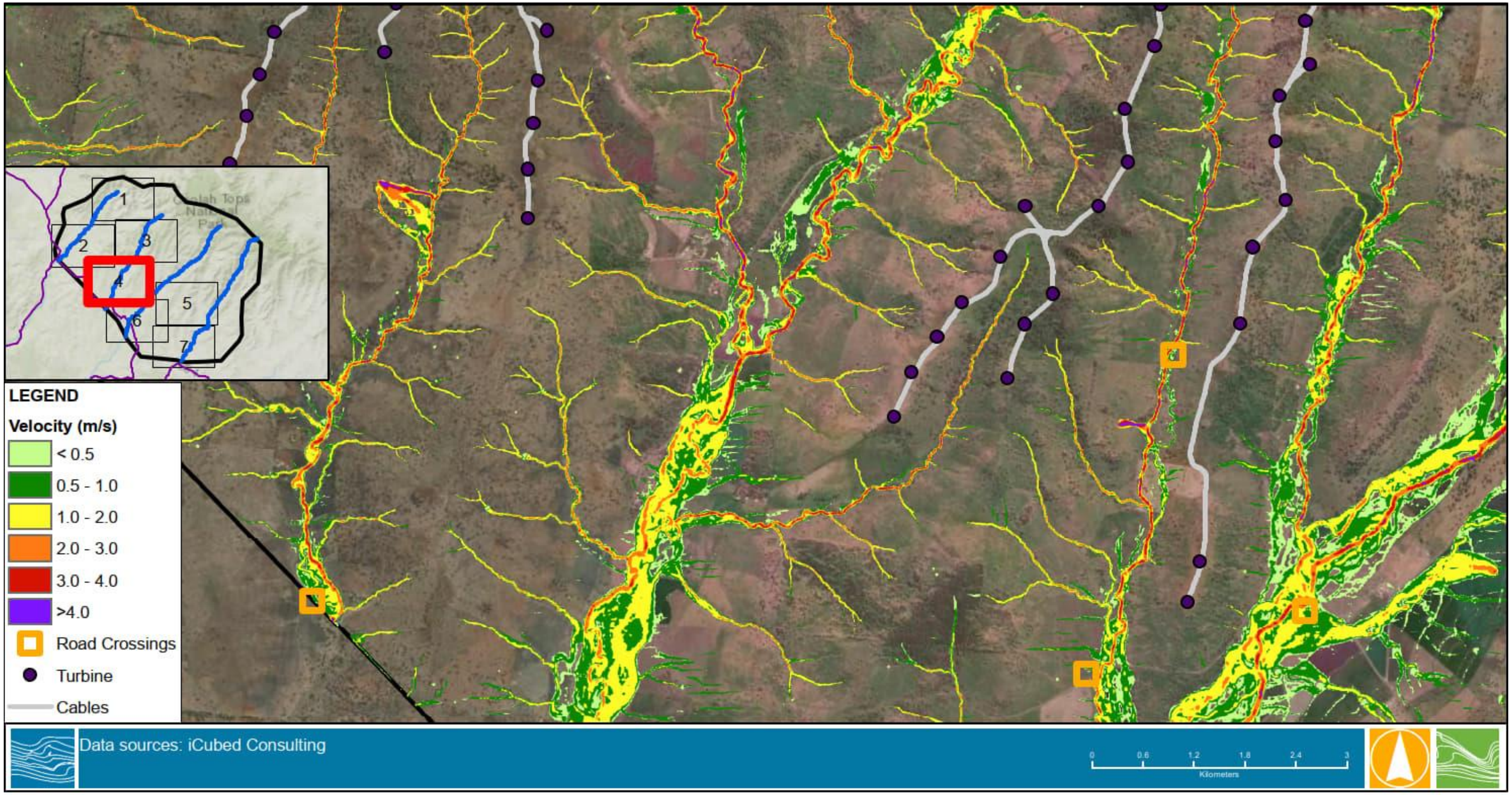

Figure 5-11 1%AEP velocity map (4)

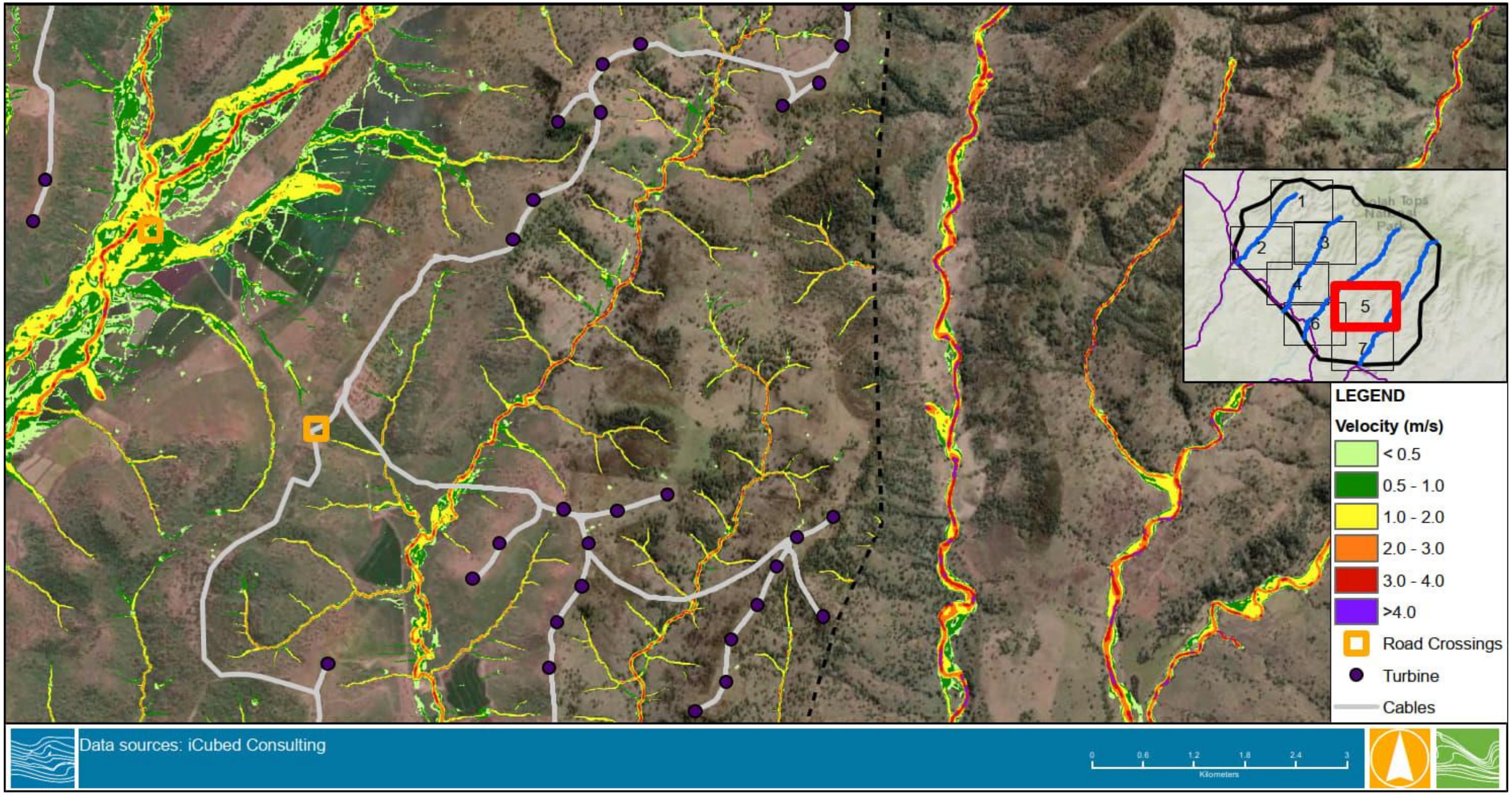

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Figure 5-12 1%AEP velocity map (5)

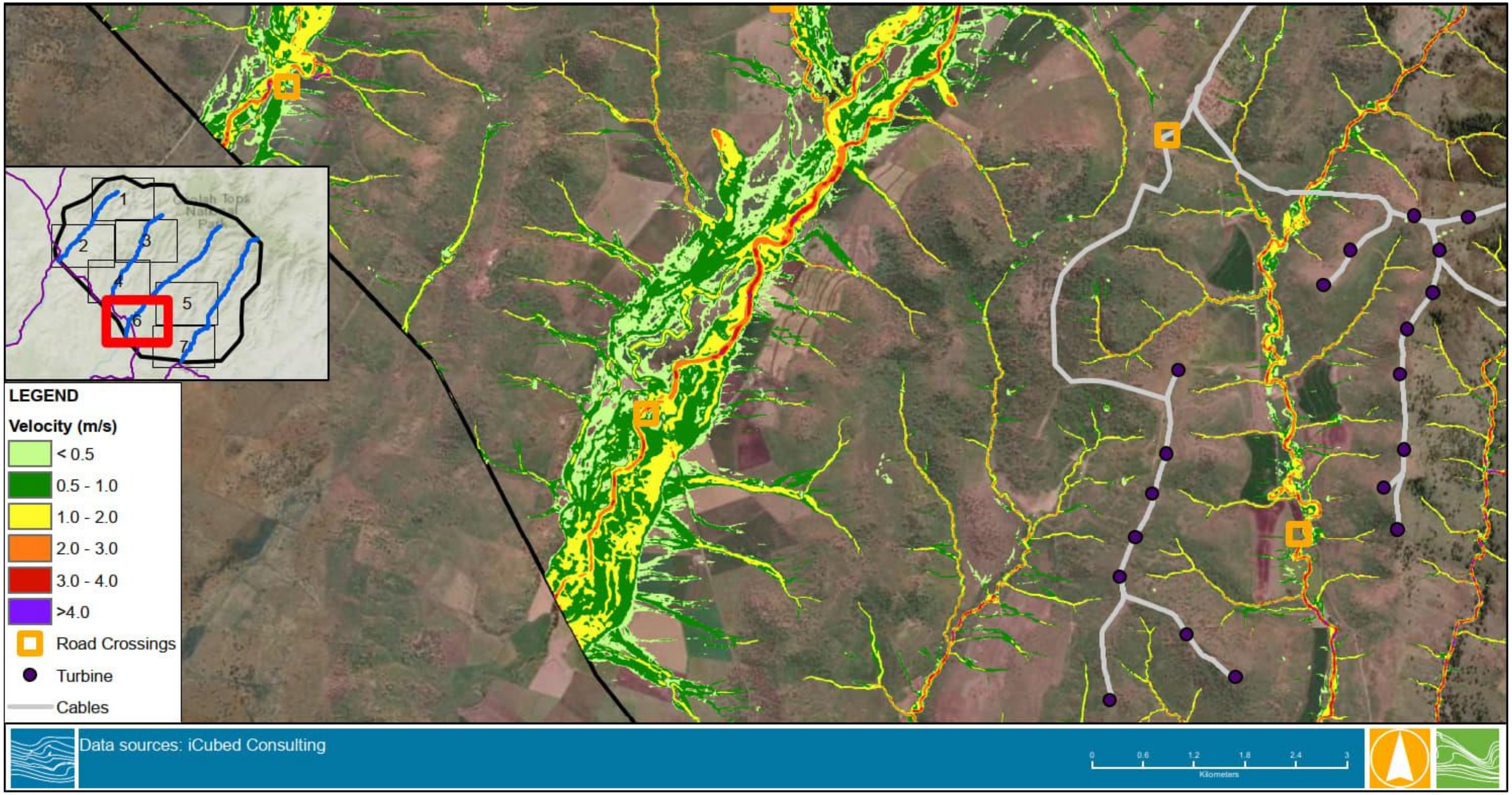

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Figure 5-13 1%AEP velocity map (6)

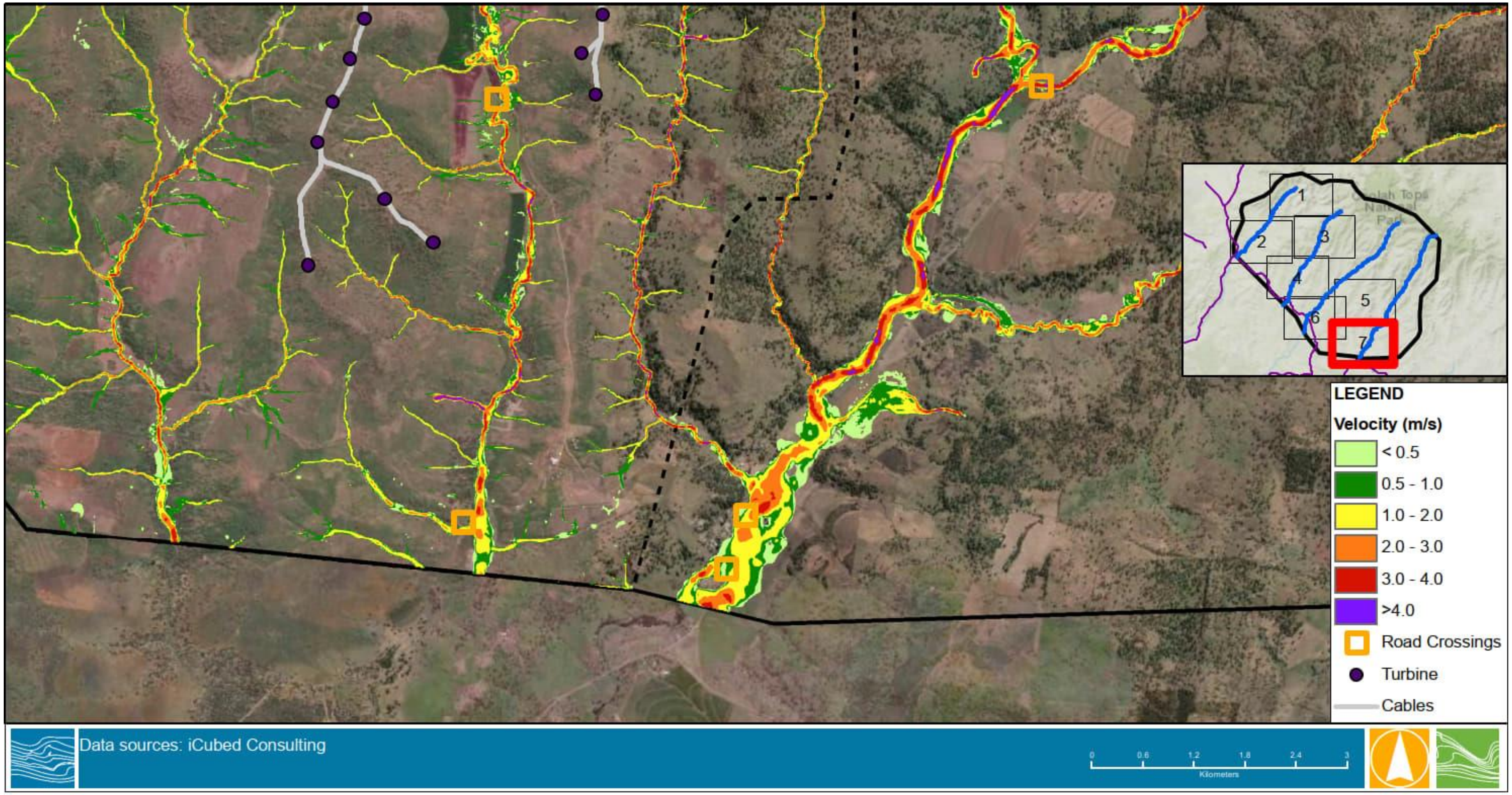

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Figure 5-14 1%AEP velocity map (7)

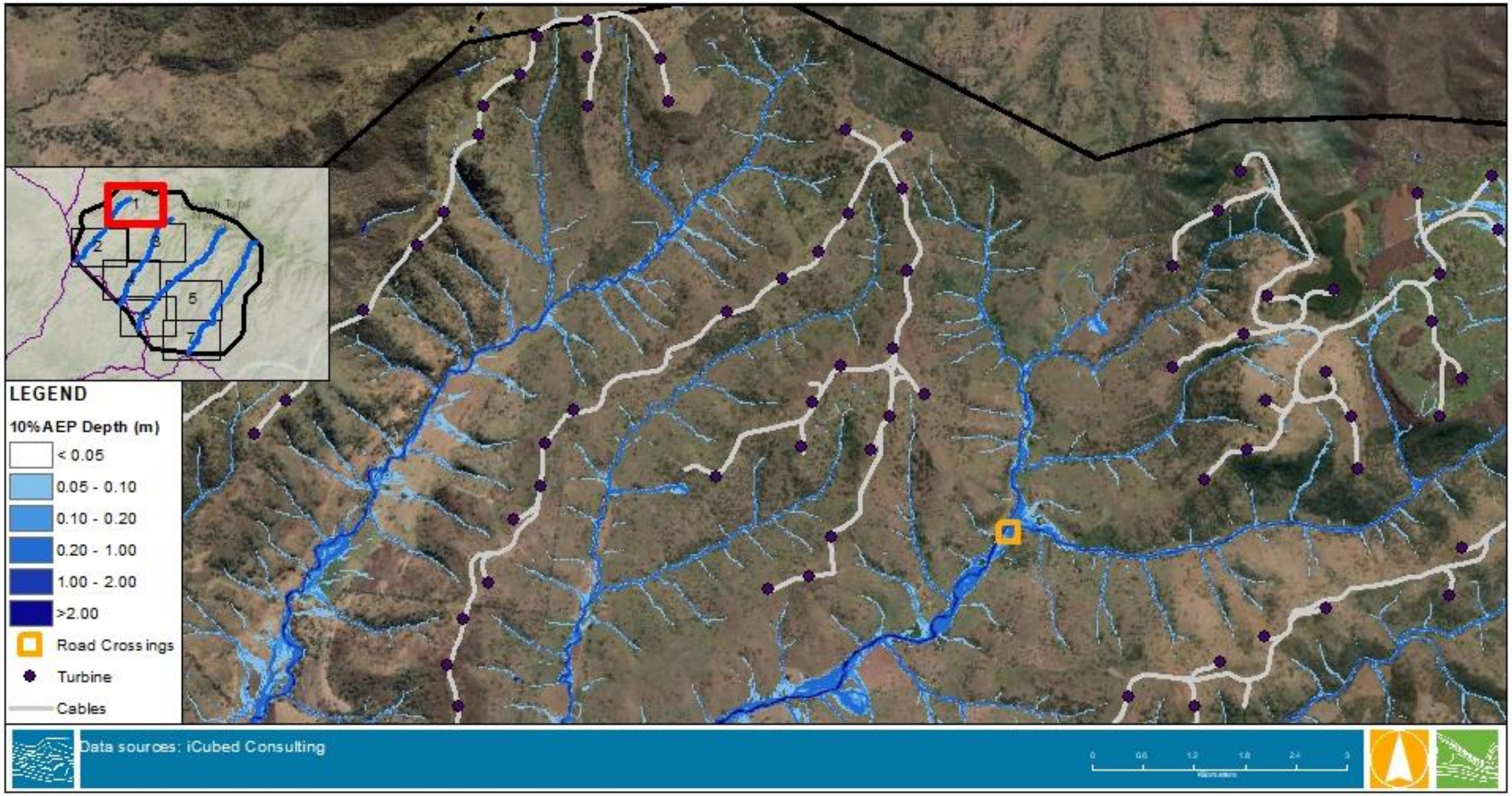

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Figure 5-15 10%AEP depth map (1)

Figure 5-16 10%AEP depth map (2)

Figure 5-17 10%AEP depth map (3)

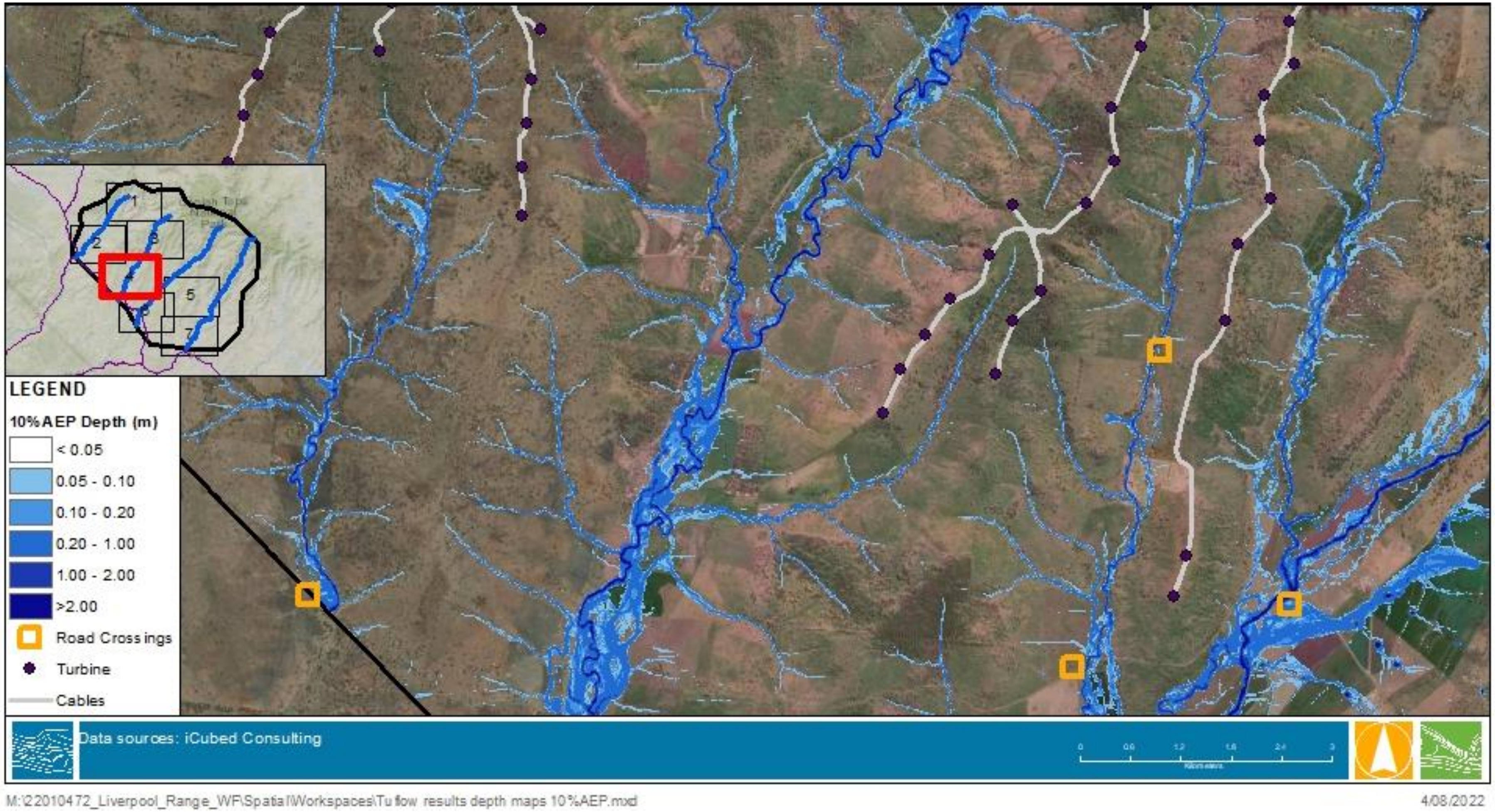

Figure 5-18 10%AEP depth map (4)

Figure 5-19 10%AEP depth map (5)

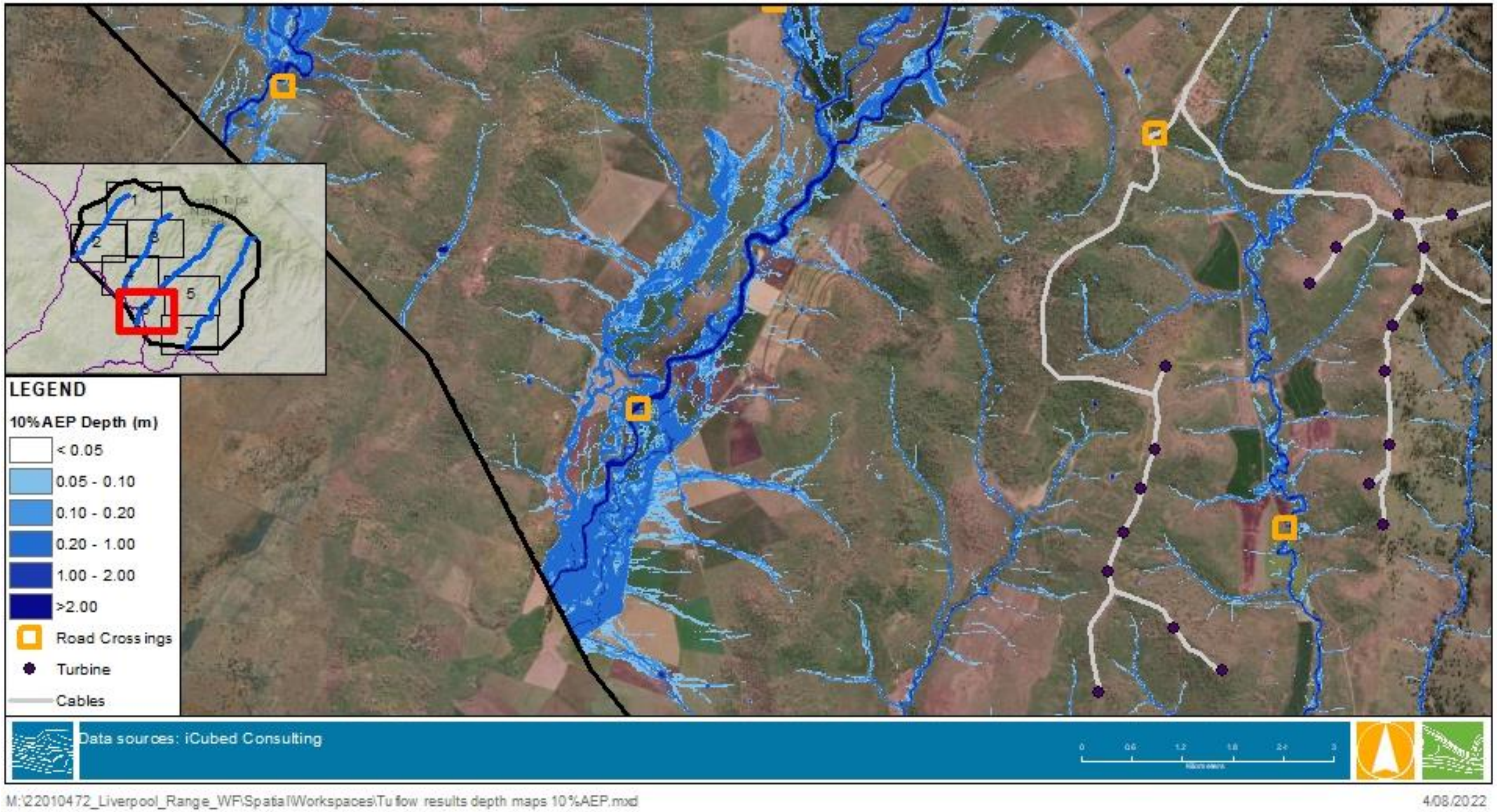

Figure 5-20 10%AEP depth map (6)

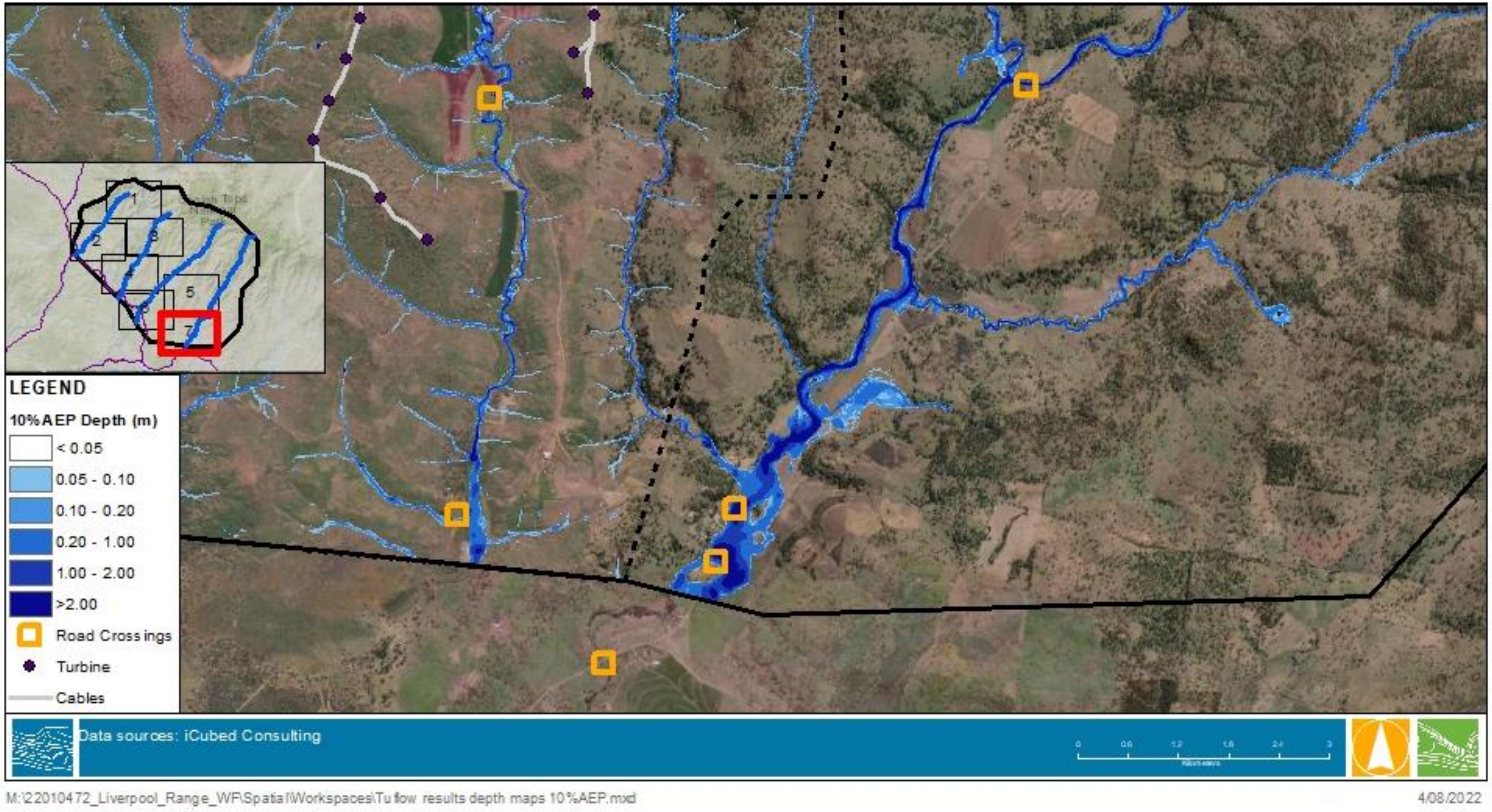

Figure 5-21 10%AEP depth map (7)

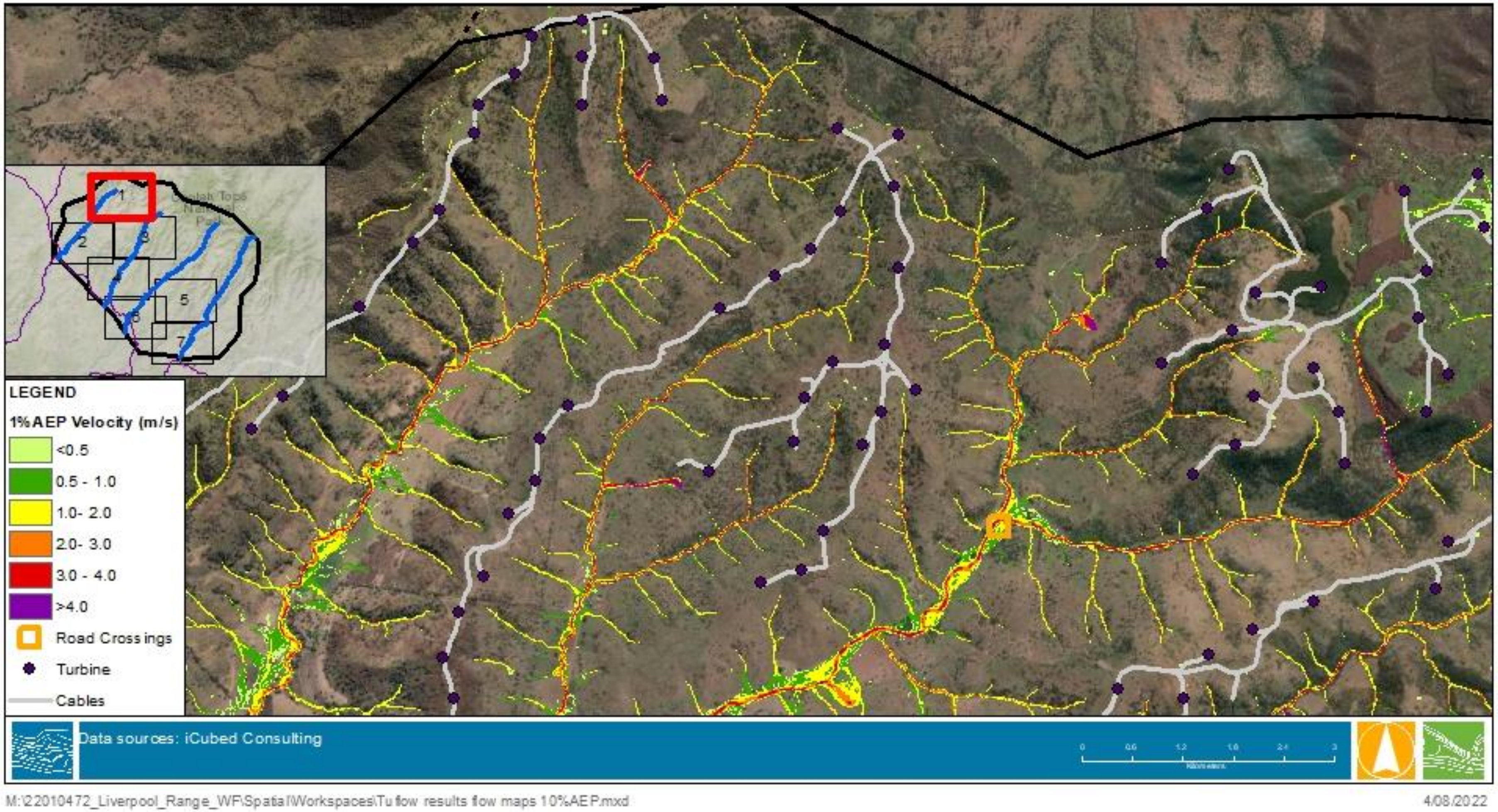

Figure 5-22 10%AEP velocity map (1)

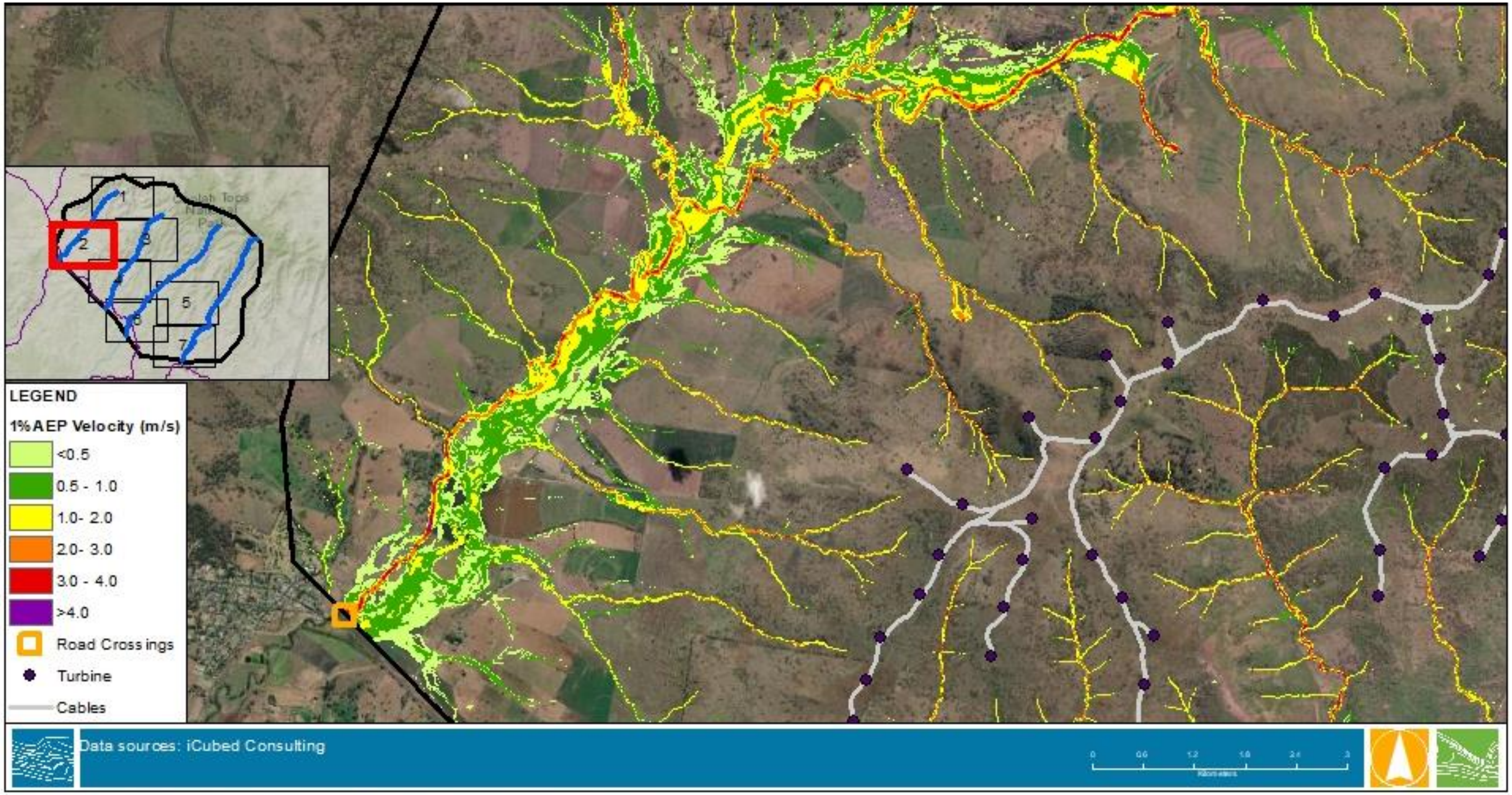

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Figure 5-23 10%AEP velocity map (2)

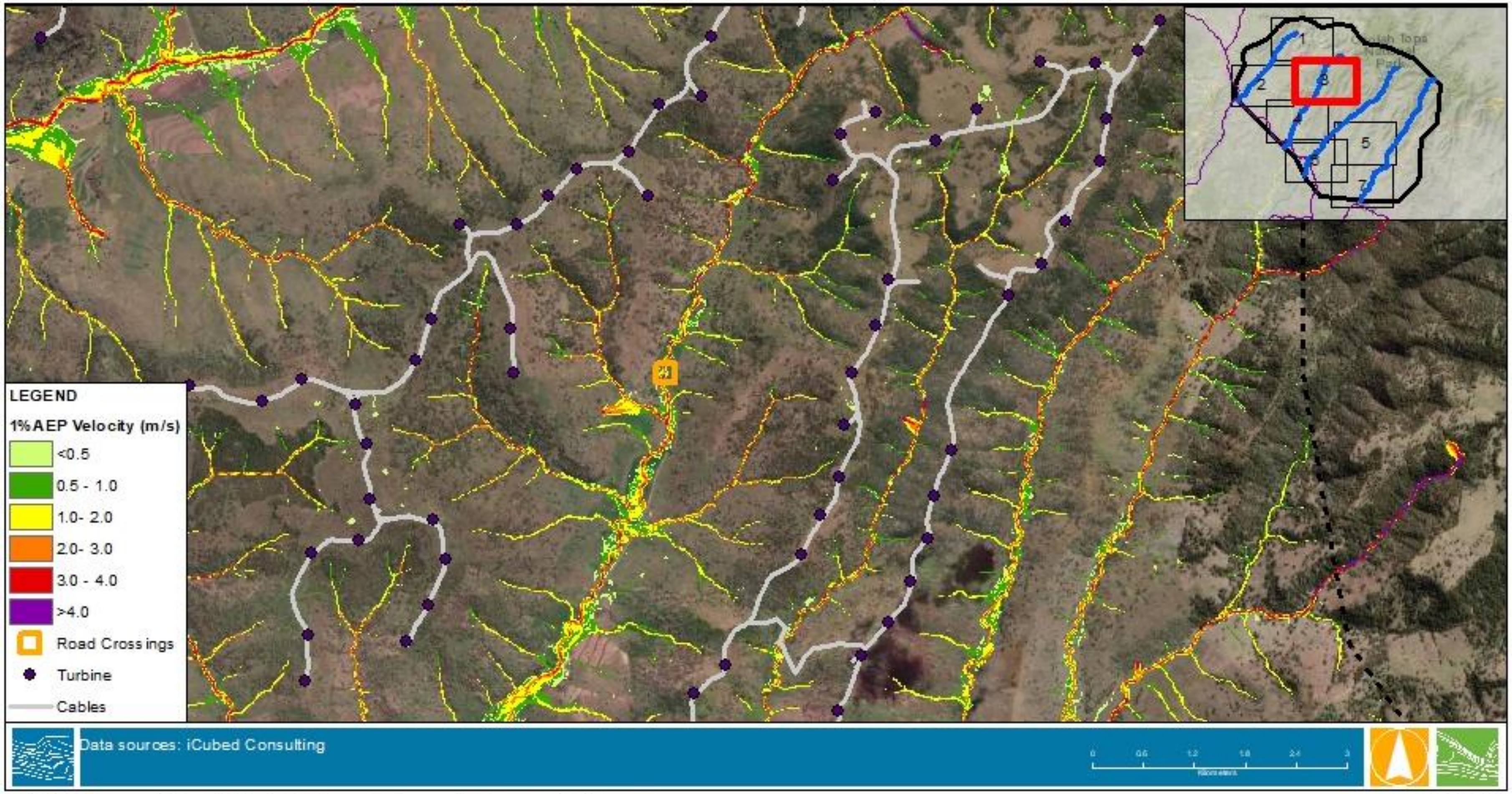

Figure 5-24 10%AEP velocity map (3)

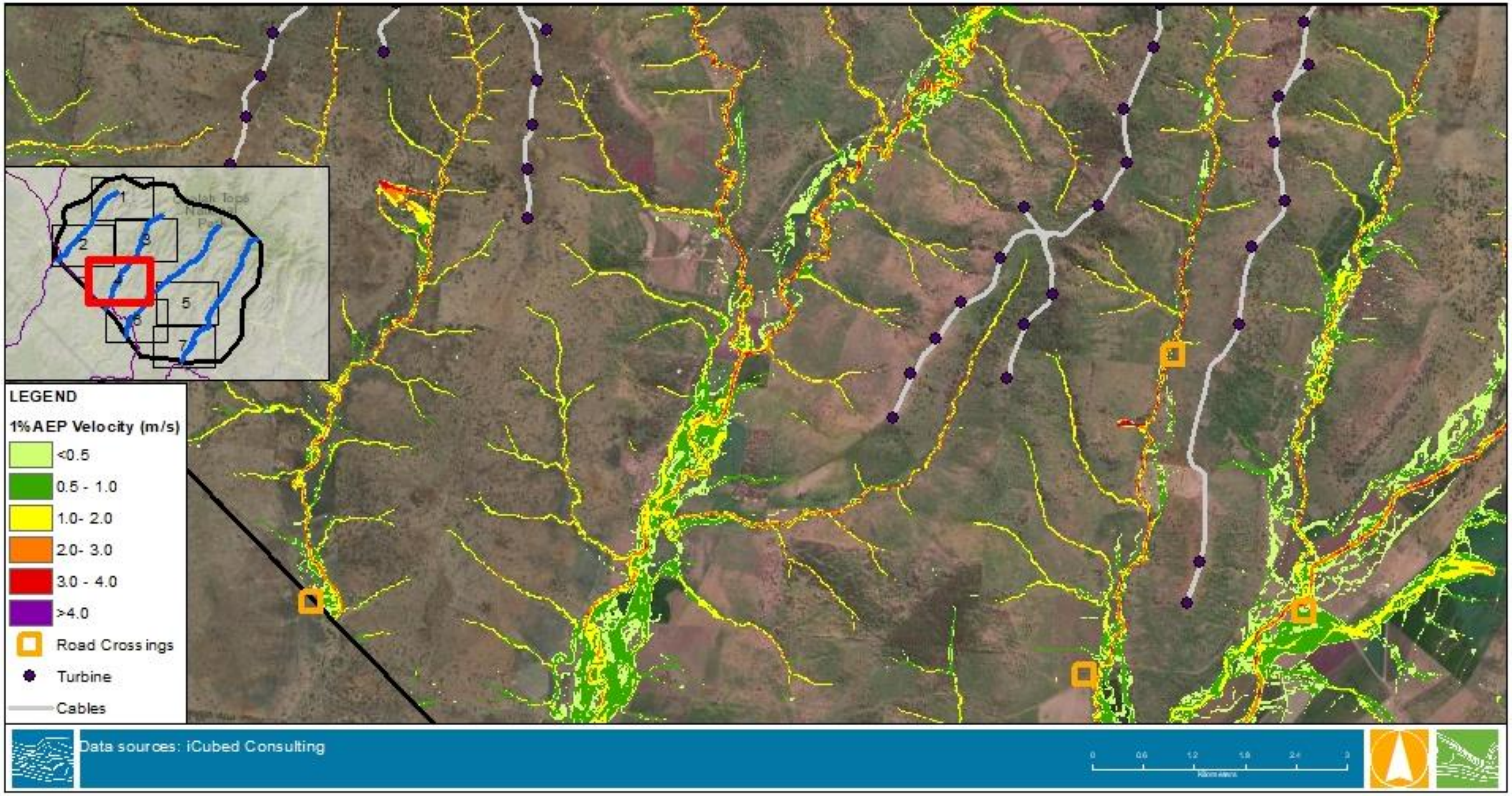

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Figure 5-25 10%AEP velocity map (4)

Figure 5-26 10%AEP velocity map (5)

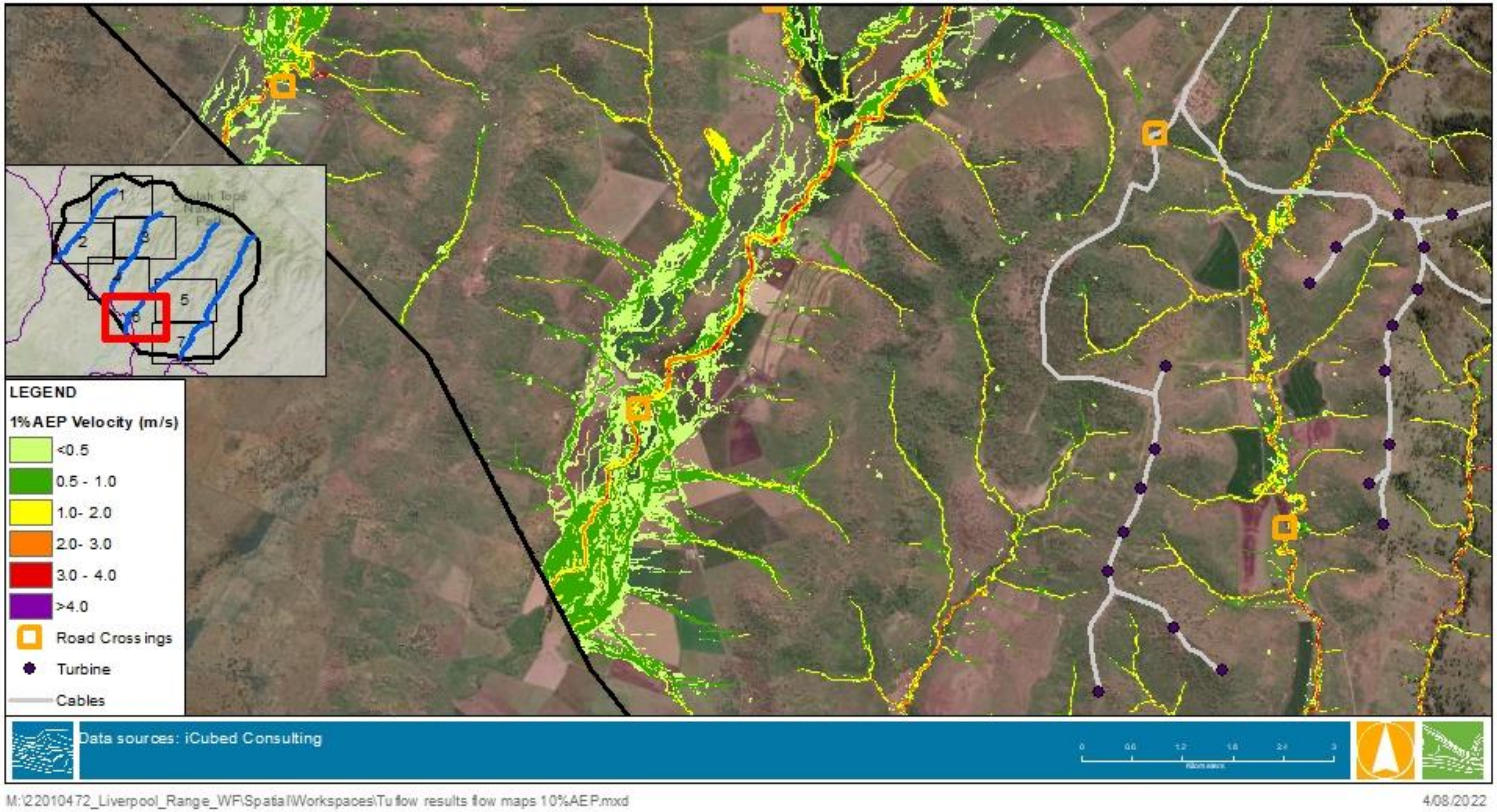

Figure 5-27 10%AEP velocity map (6)

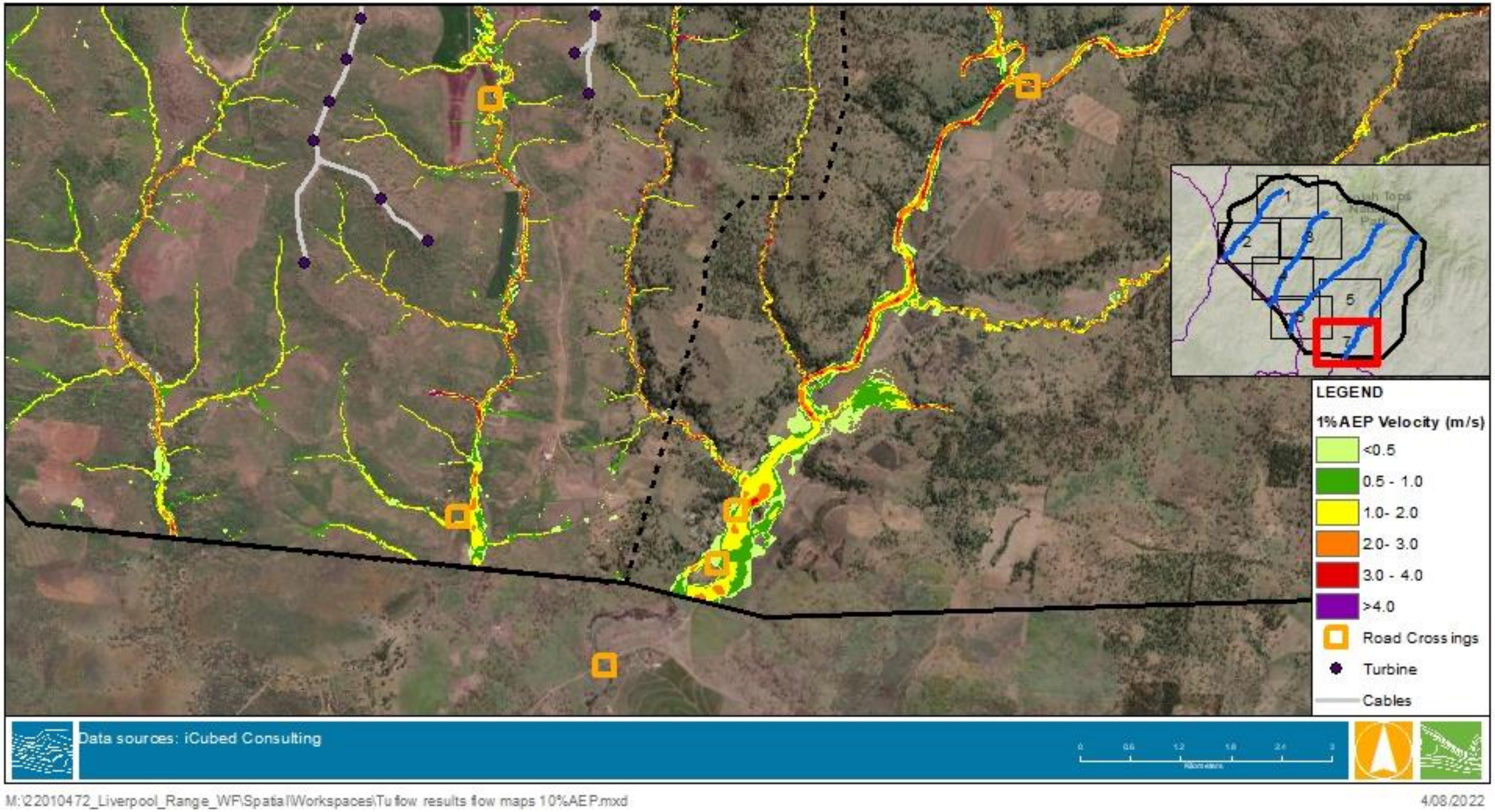

Figure 5-28 10%AEP velocity map (7)

6 DISCUSSION

The hydrology and hydraulic models developed for the pre-development flood risk assessment show that in the upper slopes where the turbines are proposed, flow paths are generally confined to minor gullies. There is the potential for erosion and scour risk in these locations and the placement of access tracks should aim to avoid these where possible. Due to the steepness of the terrain velocities are commonly above 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.

It is recommended that further modelling be undertaken for the preliminary design layout plans. Modelling of the 10% and 1% AEP events should be undertaken to determine if access track drainage arrangements are adequate to avoid overtopping and if any, locate where road overtopping could occur. This entails design of fords or culverts at drainage path crossings and swales to direct flow around infrastructure as required.

If further verification of design capacity and flood immunity of key roadways is required, culvert and bridge dimensions in should be sourced throughout the study area. Currently, no hydraulic structures have been incorporated into the hydraulic model. It is understood that flood immunity for major roads should be at least to a 1% AEP standard.

7 SUMMARY

To understand site drainage behaviour and the location of flow paths on the windfarm site, a detailed rain-on-grid flood model and catchment wide model was developed using topography data in the form of a DEM with a 5x5 m resolution. Flood modelling results including mapping for depth and velocity have been included within this report along with peak flow rates at critical road crossings throughout the study area.

All results from the pre-development modelling will be provided in GIS format (maximum depth, water level and velocity for the 10%, 5%, 1% and 0.5% AEP storm events.

APPENDIX A
5% & 0.5% AEP FLOOD MAPPING RESULTS

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Sydney
Suite 3, Level 1, 20 Wentworth Street
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South Brisbane QLD 4101
Telephone (07) 3105 1460

Adelaide
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Eastwood SA 5063
Telephone (08) 8378 8000

Perth
Ground Floor, 430 Roberts Road
Subiaco WA 6008
Telephone (08) 6555 0105

New Zealand
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Cambridge New Zealand 3434
Telephone +64 27 777 0989

Wangaratta
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Wangaratta VIC 3677
Telephone (03) 5721 2650

Geelong
51 Little Fyans Street
Geelong VIC 3220
Telephone (03) 8526 0800

Wimmera
597 Joel South Road
Stawell VIC 3380
Telephone 0438 510 240

Gold Coast
Suite 37, Level 4, 194 Varsity Parade
Varsity Lakes QLD 4227
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