APPENDIX D FLOOD IMPACT ASSESSMENT

Muskerry Solar Power Station Flood Impact Assessment

FINAL REPORT

06 January 2022

alluvium

Edify™

Alluvium recognises and acknowledges the unique relationship and deep connection to Country shared by Aboriginal and Torres Strait Islander people, as First Peoples and Traditional Owners of Australia. We pay our respects to their Cultures, Country and Elders past and present.

Artwork by Vicki Golding. This piece was commissioned by Alluvium and has told our story of water across Country, from catchment to coast, with people from all cultures learning, understanding, sharing stories, walking to and talking at the meeting places as one nation.

This report has been prepared by Alluvium Consulting Australia Pty Ltd for Edify Energy.

Authors:	Davide Di Mauro Christopher Power
Review:	Andrew Chapman
Approved:	Andrew Chapman
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Abbreviations

Alluvium	Alluvium Consulting Australia Pty Ltd
AEP	Annual Exceedance Probability
BESS	Battery Energy Storage System
PV	Photovoltaic
DEM	Digital Elevation Model

1 Introduction

Alluvium has been commissioned by Edify Energy to develop a response to the flooding risk associated with the installation of a proposed Photovoltaic (PV) array and Battery Energy Storage System (BESS) located approximately 30 km East of Bendigo, Victoria (Figure 1). The design and configuration of the project will comprise 250 MW of generating solar capacity, as well as 200 MW/800 MWh (4-hr peak duration) BESS over a development footprint of approximately 700 ha.

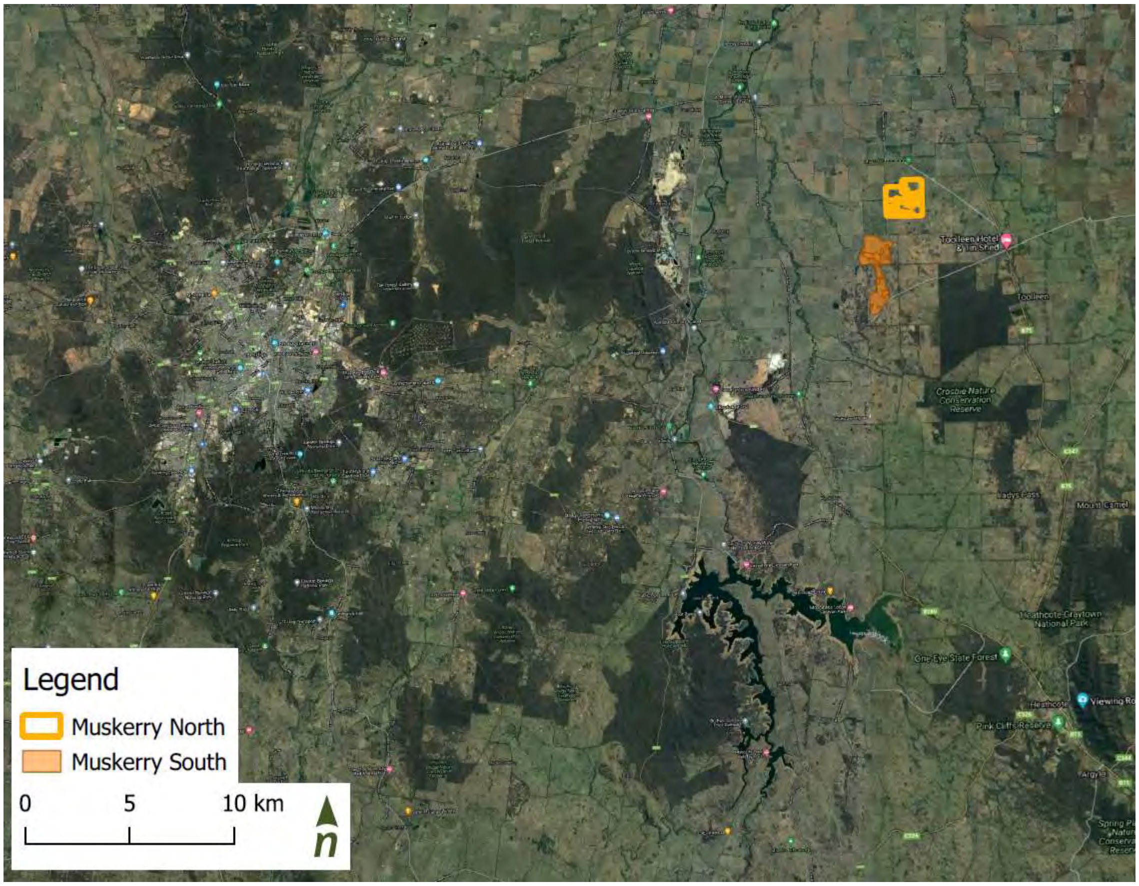

Figure 1. *Locality Plan of the proposed development footprints (North and South) in relation to Bendigo township (to the west)*

The Muskerry footprints comprise two separate study areas, Muskerry North and Muskerry South (Figure 2). Within the study area of Muskerry North two possible deployments of Substation and BESS modules are considered (Option A and B). Option A locates the Substation and BESS modules on the western side of the development footprint whereas Option B places them on the eastern side (Figure 3).

Both these Options measure approximately 3.0 ha and sit atop land primarily being used for grazing and pastures. Muskerry South, in turn lies on land used primarily for farming, grazing, rural residence with a scattering of water storages (farm dams).

This study serves as a flood impact assessment as supporting documentation for the Development Application for the project, as such it will be suitable for submission to the Department of Environment, Land, Water and Planning of the State of Victoria. The development footprints are not located within a designated flood affected land.

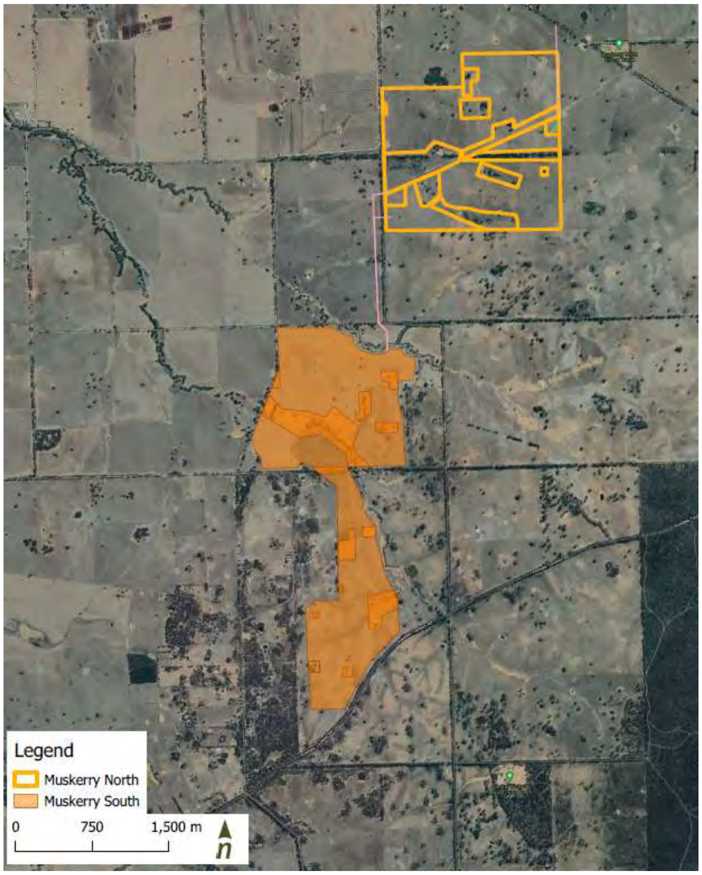

Figure 2. *Development footprints – divided into northern and southern sections*

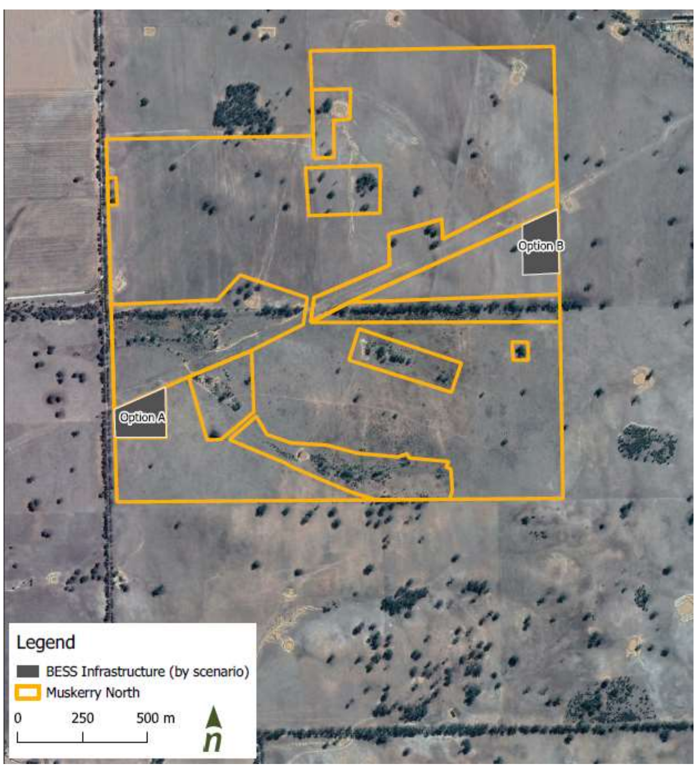

Figure 3. *Muskerry North layout with Options A and B for the Substation and BESS infrastructure*

2 Flood Modelling

2.1 Overview of both sites

The assessment aims to address the localised flooding which originates from rainfall runoff impacts through both the development footprint and areas immediately downstream of the proposed development. For the Muskerry South development, flood impacts from Back and Burke Creek were also considered, as they are the major flow paths near or adjacent to the proposed development.

For the purpose of this study, only the impacts from the 1% Annual Exceedance Probability (AEP) were investigated, which included flood levels, depths, velocities, and hazards.

Alluvium has not conducted a water quality analysis of either Muskerry North or South. Although, we note the batteries are going to be hermetically sealed in modules that are housed within climate-controlled enclosures, and therefore will not be in direct contact with stormwater runoff.

Muskerry North

The proposed north site is comprised of two options, A and B, for the preferred locations of the Photovoltaic (PV) arrays, Battery Energy Storage Systems (BESS), substations and other buildings, in the south-western end of the northern footprint (Option A) and to the east of the footprint (Option B) (Figure 3).

Option A has an area of 2.95 ha and sits atop of a sub catchment of roughly 400 ha that drains to the west into Back Creek. Option B has an area of 3 ha and is located in a smaller sub catchment (approximately 120 ha), which drains into a system of roughly 15 km of creeks and gullies before discharging into the Campaspe River.

The average slope of the two proposed options span from 1.9 degrees oriented towards the south-west (Option A) and 2.2 degrees in elevation facing an eastward aspect (Option B). Retaining dams were found in the areas surrounding the proposed options and would likely pond water within the Muskerry North site.

Muskerry South

The proposed south site contains a development with an area of approximately 2.4 km^2. Overall, it sits within a catchment with two main creeks, Back and Burke Creek. These two watercourses present the greatest risk of riverine flooding. The two catchment areas were 6.9 km^2 for Back Creek and 11.9 km^2 for Burke Creek. However, to appropriately capture any impacts downstream from the development a larger catchment area (32.2 km^2) was modelled (Figure 4).

2.2 Data analysis & limitations

Coverage of the ground surface in and around both the sites was sourced from the publicly available LiDAR data acquired from ELVIS (Elevation - Foundation Spatial Data https://elevation.fsdf.org.au/). The resolution of the Digital Elevation Model (DEM) was 1 m x 1 m, which formed the basis of the localised overland flood modelling.

As it was unclear whether the retaining basins were engaged with ponding water or filled over, no terrain adjustments were made in the DEM to compensate for the volume of water in each basin, or the lack thereof. However, these stock dams are small and will typically fill early in a storm event to not impact the peak should the basins be filled as part of the project.

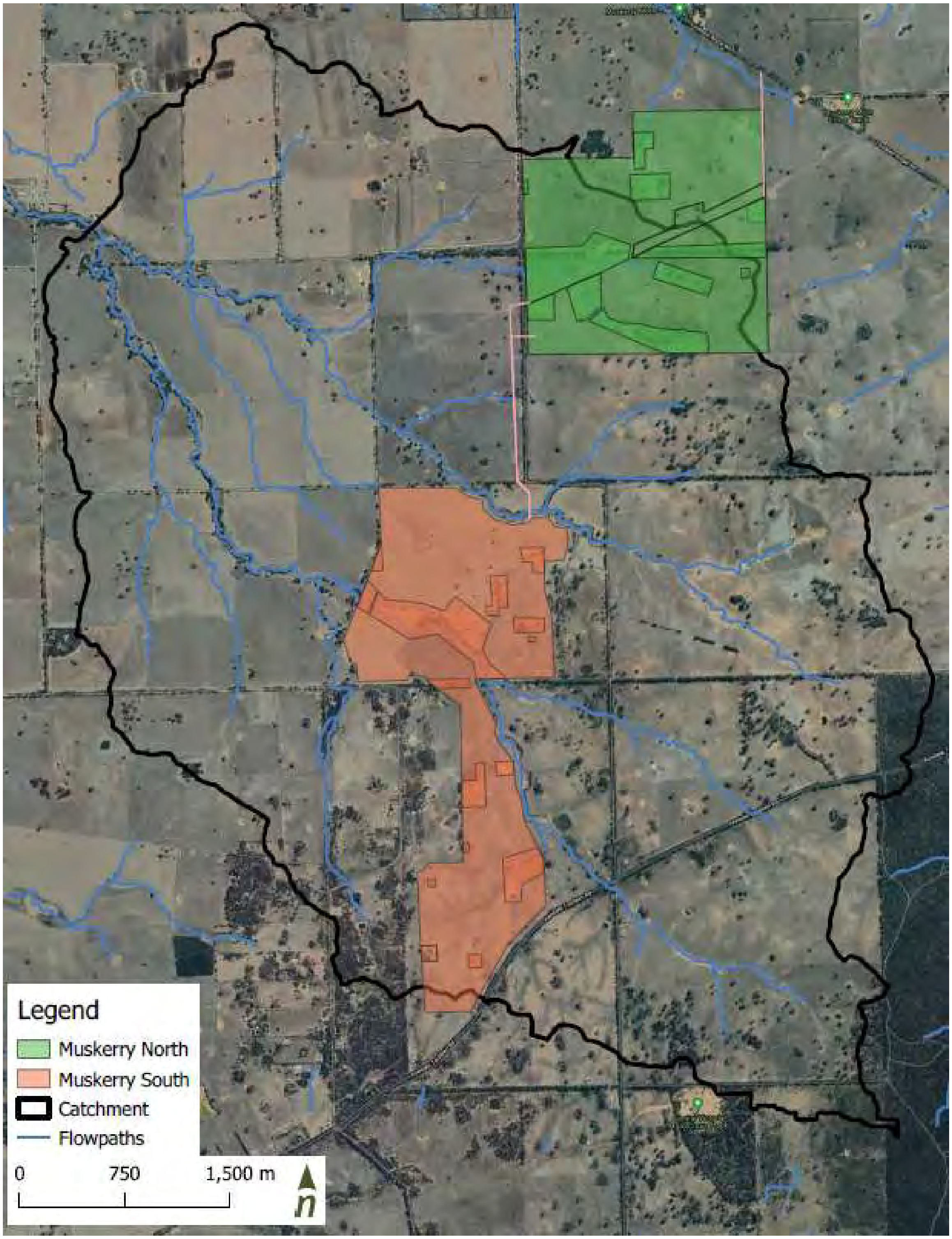

Figure 4. *Catchment modelled for Muskerry South. Part of Muskerry North drains into another catchment*

2.3 Modelling rationale

Runoff conditions with PV panels

In terms of the study area and its associated solar panels generating additional local stormwater runoff, a literature review was conducted on the topic. The summaries of the literature review are as follows:

Cook and McCuen, 2013. Journal of Hydrologic Engineering, ASCE. Hydrologic Response of Solar Farms.

- The solar panels themselves do not have a significant effect on catchment runoff.
- If the runoff characteristics of the final ground cover under the panels is increased (increased impervious hard-stand area, or decreased roughness) then runoff may increase.

Water Solutions, 2017. Lower Wonga Solar Q1 Renewable Energy Generation Facility Flood study.

- There are no expected changes to the runoff volumes, peaks, or times to peak for flood events in the catchment due to all the additional surface area of solar panels provided the surface coverage is maintained.
- Considered that a healthy cover of vegetation will ensure similar levels of infiltration as currently experienced at the study area.

It may be concluded that so long as the study area vegetation conditions are reinstated similar to pre-developed conditions following construction, additional runoff from the study area is unlikely to occur. Small increases in imperviousness are unlikely to increase peaks due to hydrograph timing effects. Therefore, the modelled existing conditions are likely to reflect the impact of the solar panels on the downstream runoff. As such a post-solar farm construction scenario was not required for the panels themselves.

Muskerry North

A 2-dimensional (2D) flood model was built using the TUFLOW software based on current conditions. A direct rainfall approach was employed for the flood modelling. This approach involves a rainfall hyetograph applied to every model cell within the catchment contributing to drainage through the study area. A 5 m cell resolution was considered adequate for the purposes of the 2D flood model and flood maps (Figure 5). Design scenario models were then built adopting the proposed development envelopes (Substation Options A and B provided by Edify) to compare the flood level differences to the existing case.

Muskerry South

Along with Muskerry North, a 2D TUFLOW model was constructed based on the existing ground conditions. A direct rainfall approach was utilised across the whole catchment (Figure 6). A 5 m cell resolution was used along with a sub-grid-scaling value of 1m to better capture the creeks and smaller flow paths.

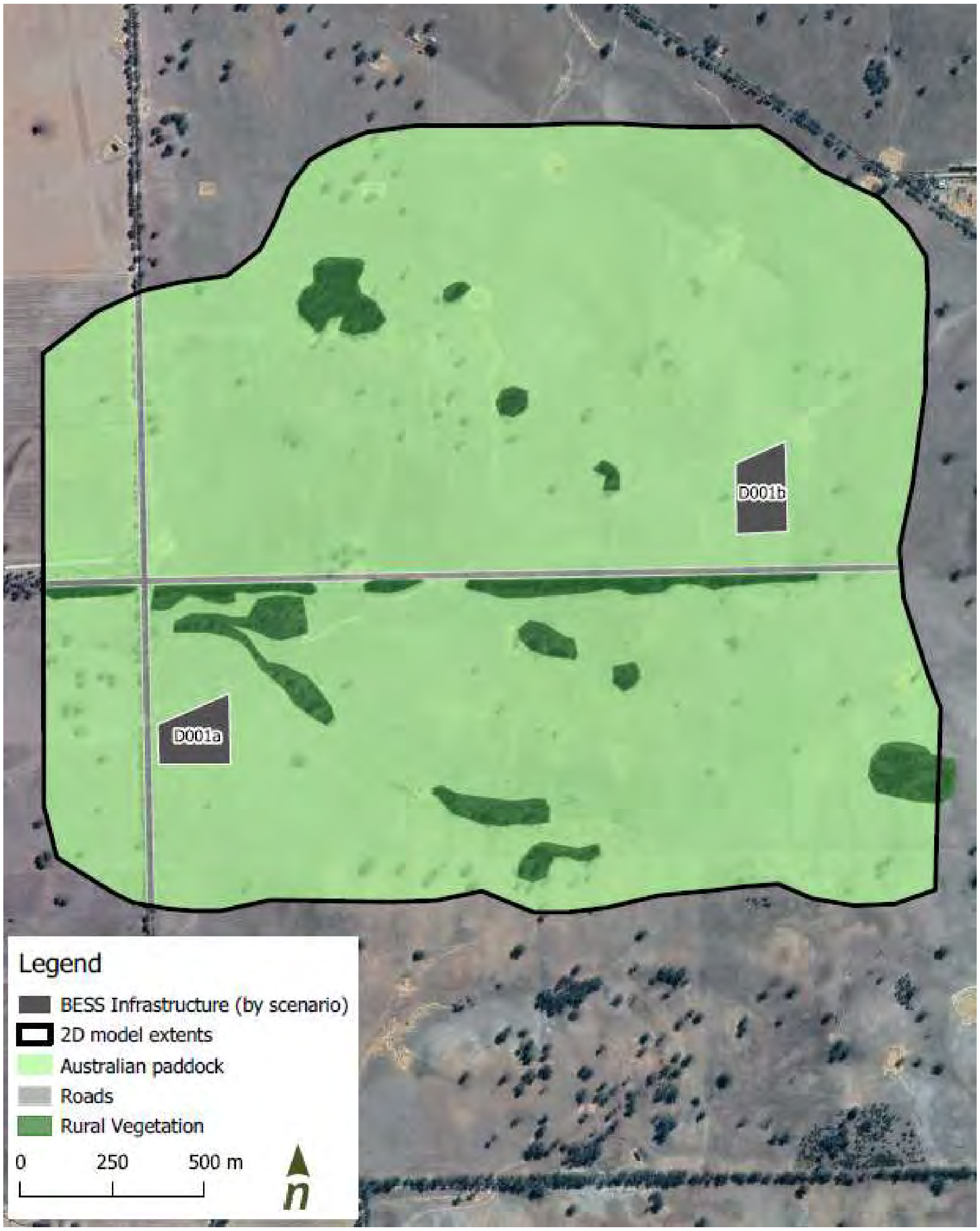

Figure 5. *Extent of the 2D TUFLOW model for Muskerry North*

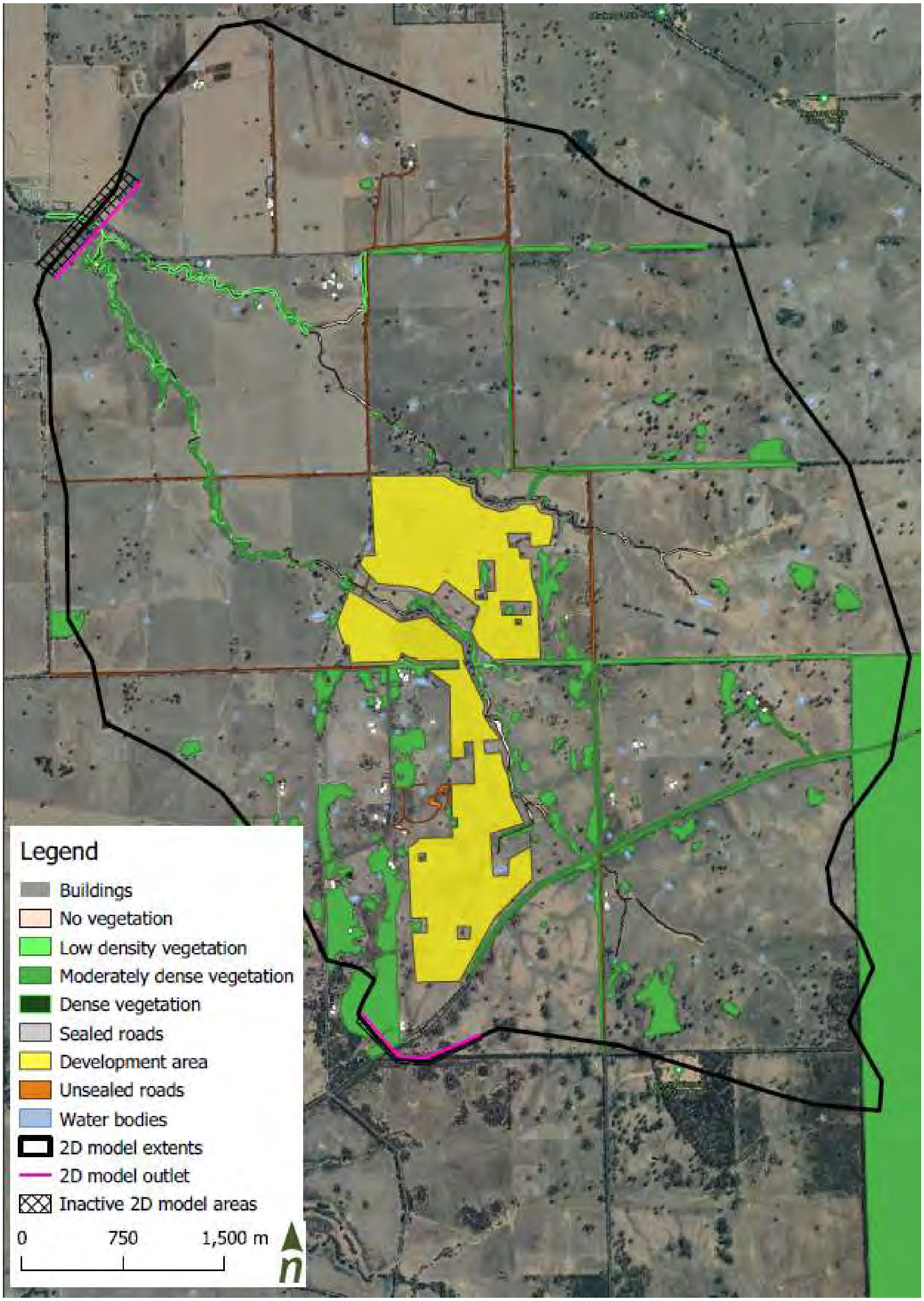

Figure 6. *Extent of the 2D TUFLOW model for Muskerry South*

2.4 Hydrological simulation

Muskerry North

Rainstorms were applied directly to the cells in the model for the 1% AEP event for a wide range of storm durations. For small-sized catchments a typical critical duration can range between 10 minutes to 6 hours. As such, the range of storm durations selected to run included 12 storms ranging from 10 minutes up to the 360 minute storm. The longer storm durations were included to ensure the critical storm is correctly identified including for areas immediately downstream of the project site.

The ARR2019 guidelines represent a culmination of new research into hydrograph estimation methods including updates to rainfall intensities, rainfall losses and temporal patterns. The most widely applied method within ARR2019 is the temporal pattern ensembles which include a set of ten patterns for each storm duration. The critical duration of each AEP design event is defined as the duration that results in the highest median peak flow rate of the associated temporal pattern ensembles.

From the 10 temporal pattern results for each duration, the median result was calculated and then the maximum of all median results is used as the final flood result for the 1% AEP event. Overall, 360 different TUFLOW models were simulated for the existing and design scenarios. An allowance for the increase in runoff volume in the Developed case was included by assigning a 75% imperviousness factor to the proposed site buildings, substation options and BESS modules within the project footprint where the infiltration into the soil would be reduced.

Muskerry South

Hydrologic modelling was initially conducted using RORB (v6.32) to reduce the number of TUFLOW simulation required for the larger catchments at the southern site. RORB is a runoff-routing model that simulates attenuation and delay of a hydrograph to produce design flood estimates at specified catchment locations. One RORB model was prepared for the overall Muskerry South catchment extending down to the confluence of Back Creek and Burke Creek.

The RORB model was built by delineating the catchment into 123 sub-areas. Rainfall inputs in the form of Bureau of Meteorology (BoM) 2019 IFDs were used for all design flood estimation, with temporal patterns and aerial reduction factors from Australian Rainfall and Runoff 2019 (ARR2019). Table 2-1 presents the adopted parameter values applied in the RORB model. The Kc value was defined for the catchment using the Victoria specific equation for areas with mean annual rainfall of less than 800mm (Figure 7). A ‘m’ parameter value of 0.8 was adopted.

$$k_c = 0.49A^{0.65}$$

Figure 7. *RORB routing parameter, kc equation for Victoria with annual rainfall less than 800mm (Hansen 1986)*

Table 2-1. Adopted runoff routing model parameters

Catchment	Catchment area (sq km)	Initial Rainfall Loss, IL (mm)	Continuing Rainfall Loss, CL (mm/h)	Routing storage coefficient, kc	Routing exponent, m
Muskerry South catchments	32.2	25	4.7	4.68	0.8

The initial loss in Table 2-1 is the recommended loss obtained from the ARR Data Hub. It represents the depth of rainfall infiltration prior to the commencement of surface runoff for a complete storm. However, when design bursts are used, rather than complete storms, then the burst initial loss needs to be reduced to account for the pre-burst rainfall. The median pre-burst rainfall has also been sourced from the ARR Data Hub.

Burst initial loss (for rural catchments) was calculated from the ARR Data Hub values by applying the formula:

Burst Initial Loss = Storm Initial Loss – Pre-burst

This means that burst initial loss varied for each duration and AEP. For durations less than 60 minutes the median pre-burst rainfall is interpolated to the storm initial loss. Where the pre-burst gave a negative burst initial loss the burst initial loss was assumed to be zero.

To reduce the range of storm durations and respective temporal patterns to be modelled in TUFLOW, the software program Storm Injector was employed. The Storm Injector program processes all the storm event, duration and temporal pattern combinations using the RORB model to identify the most critical runs for simulating in TUFLOW. This was achieved through the determination of the critical durations and their respective temporal pattern. Whenever a storm duration was found to be a critical duration for a sub-catchment of interest, it was run in the TUFLOW model.

Hydraulic roughness

Manning's n roughness coefficients were adopted based on the Victoria land use (2017) spatial layer with refinement of the land use conducted through inspection of aerial photography. Hydraulic roughness values were adjusted with depth between 0.05 m and 0.1 m and values outside those depth ranges were then interpolated by the software as per Table 2-2.

Table 2-2. Manning's n for the Muskerry South

Land use	Roughness Value below 0.1 or 0.05 water depth (m)	Roughness Value Linear interpolation between depth	Roughness Value after 0.1 or 0.05 water depth (m)
Light Vegetation	0.1	Between and 0.05 water depths 0.1	0.035
Moderately dense vegetation	0.1	Between and 0.05 water depths 0.1	0.06
Dense vegetation	0.1	Between and 0.05 water depths 0.1	0.08
No vegetation	0.1	Between and 0.05 water depths 0.1	0.035
Unsealed roads	0.1	Between and 0.05 water depths 0.1	0.035
Sealed roads	0.025	Constant value of 0.025	0.025
Buildings	0.1	Constant value of 0.1	0.1
Water bodies	0.015	Constant value of 0.015	0.015
BESS Infrastructure (design cases)	0.025	Between 0.1 and 0.05 water depths	0.012

3 Flood Impacts

Muskerry North

Generally, there are two potential impacts the development at Muskerry North could have on flooding and runoff external to the study area.

- Impacts on flood levels due to the study area obstructing flow, OR
- Impacts on flood levels due to the study area producing extra runoff.

Increases in imperviousness are expected to raise runoff and potentially create higher peak flood levels due to hydrograph timing effects.

As such, a developed case scenario was configured in the 2D model with adjusted rainfall losses within the project footprint (the area that will be disturbed) for the substation options, BESS modules and site buildings as advised by Edify to model the impact from the development (if any) in the downstream areas. As mentioned previously, a 75% imperviousness proportion was applied to these areas.

Given the sloping nature and contour of the land, overland flows travel quickly into drainage paths and flow downstream without any natural ponding, other than the constructed stock dams. Flood depths over the vast majority of the site were below 0.1 m with more concentrated flow paths reaching depths of between 0.5 to 1.0 m. (Figure 8 & Figure 9). Flow velocities between 0.2 and 0.5 m/s are common at the initiation points of overland flow, with higher velocities between 1.0 to 2.0 m/s in the concentrated drainage paths (Figure 10).

Flow conditions were found to be benign with no vulnerability constraints in 95% of the study area. Small patches of unsafe zones for humans, vehicles and buildings were only recorded at the concentrated flow paths and stock dams (Figure 11).

The comparison between water levels (afflux) in the existing and Option B scenario resulted in a slight reduction (up to 0.05 m) within the draining flow path of the substation footprint (Figure 9). A small increase in afflux up to 0.05 m is caused by the additional runoff however this is located on the property boundary at the limit of the substation footprint. Nil afflux was recorded for Option A (Figure 8).

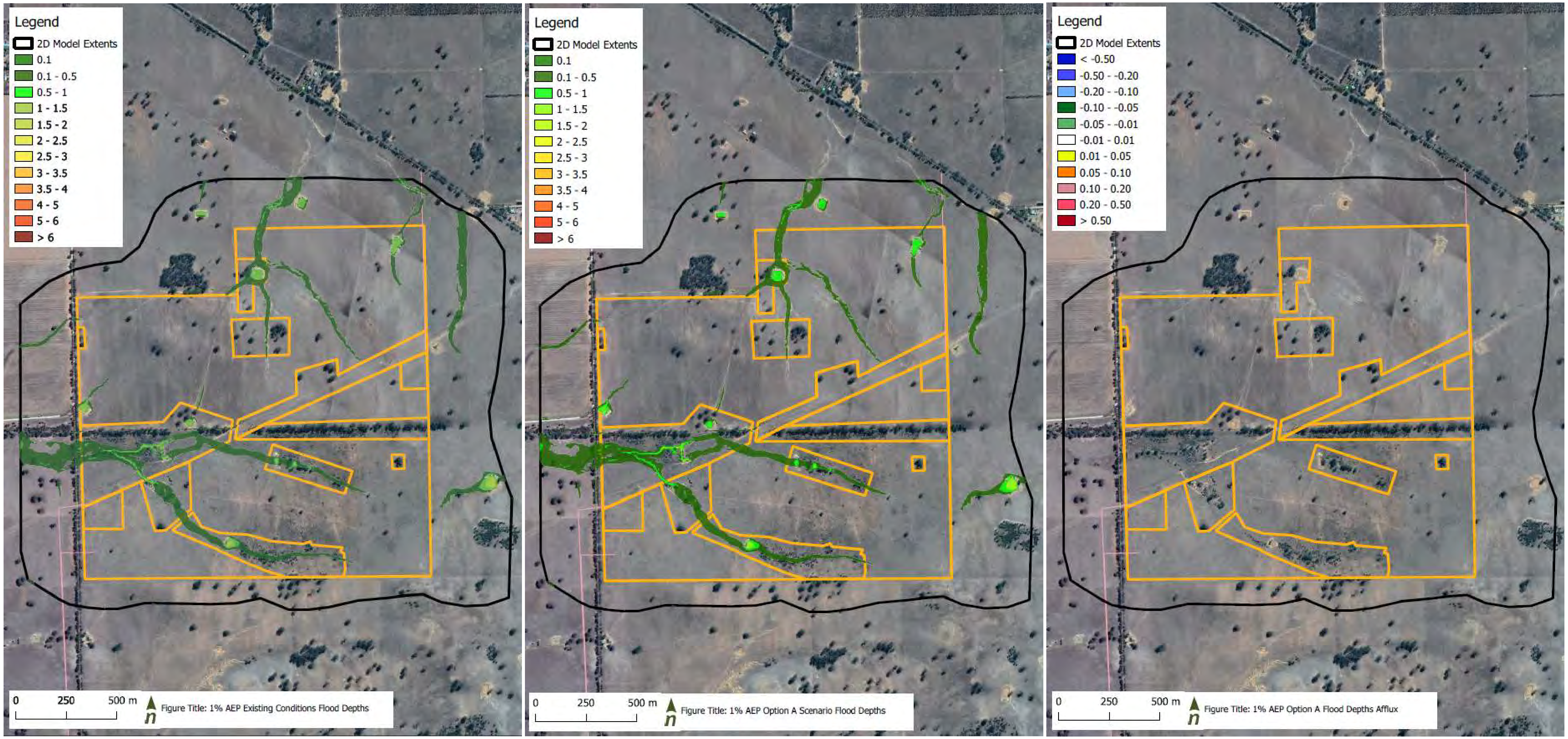

Figure 8. *Muskerry North with Option A (Left) Existing conditions 1% AEP flood depths (Middle) Substation Option A - 1% AEP flood depths (Right) Option A Afflux*

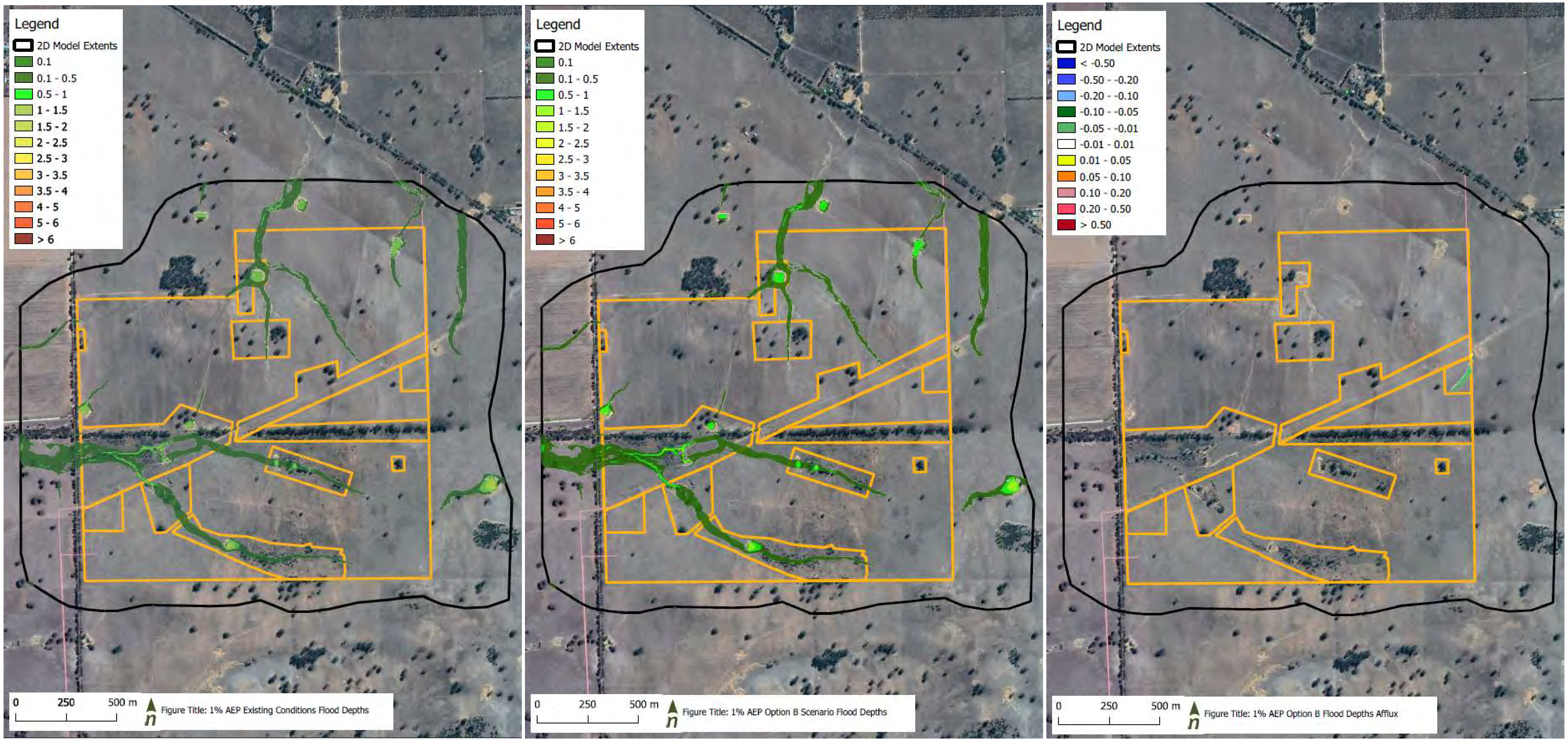

Figure 9. *Muskerry North with Option B (Left) Existing conditions 1% AEP flood depths (Middle) Substation Option B - 1% AEP flood depths (Right) Option B Afflux*

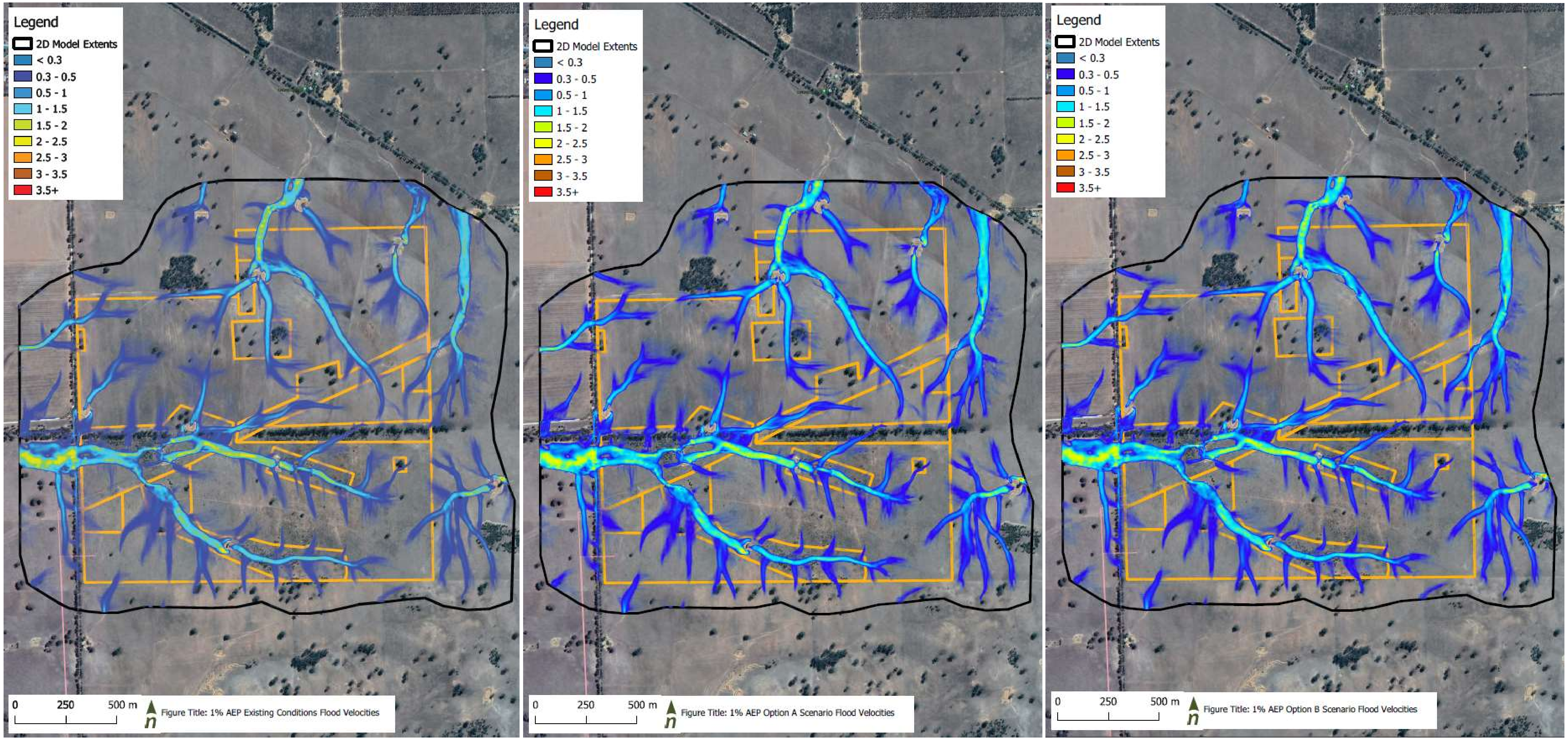

Figure 10. *Muskerry North flood velocities (Left) Existing conditions 1% AEP flood velocities (Middle) Option A - 1% AEP flood velocities (Right) Option B - 1% AEP flood velocities*

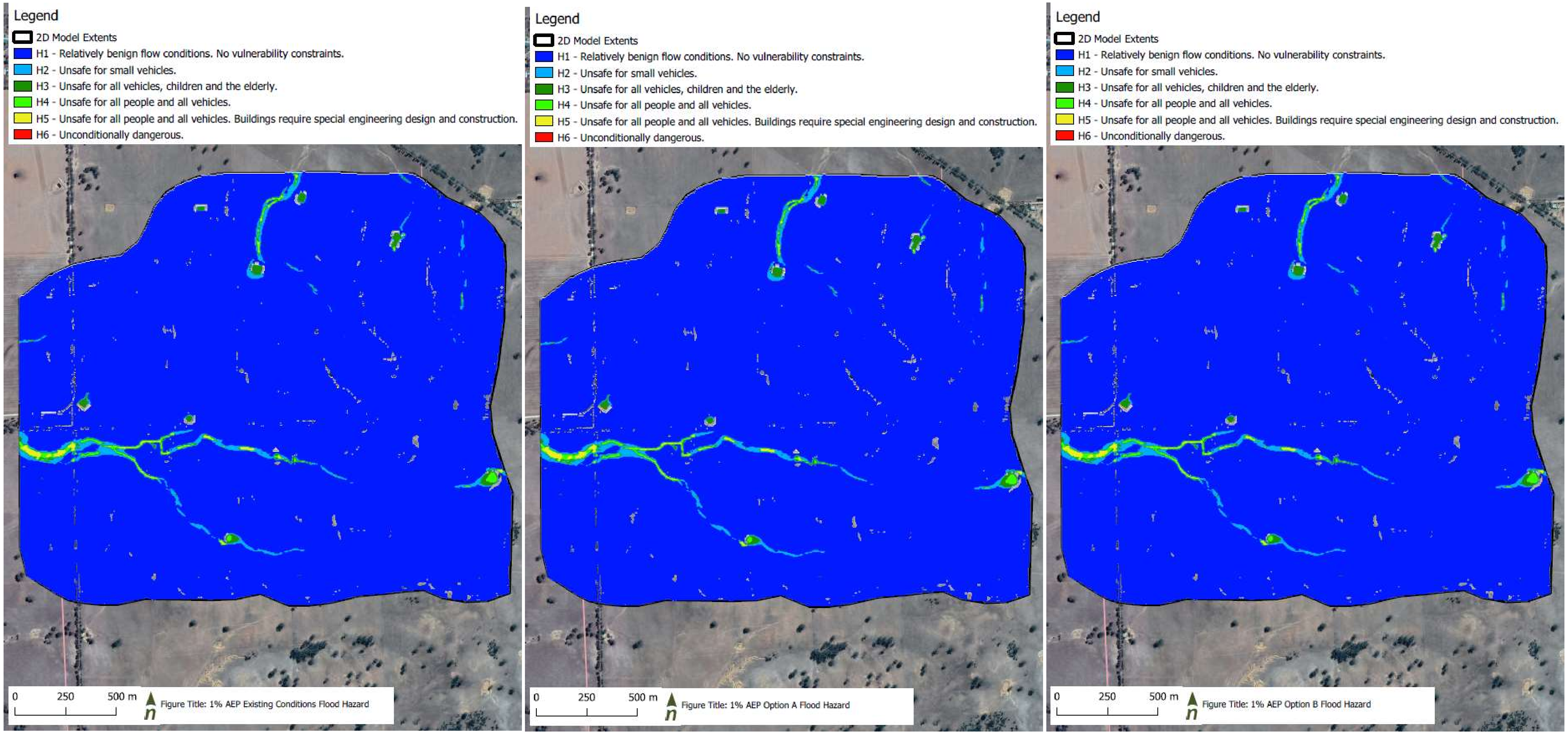

Figure 11. *Muskerry North Hazards (Left) Existing conditions 1% AEP flood hazards (Middle) Option A - 1% AEP flood hazards (Right) Option B - 1% AEP flood hazards*

Muskerry South

The steep slopes of the eastern portions of the catchment rapidly direct flow towards the proposed development area. In several locations the flow briefly ponds as it enters small farm dams. Within Burke Creek the flow velocities varied between 1.0 and 2.4 m/s as it passes through the Muskerry South development area.

Across the non-riverine sections of the development area, the velocities varied between less than 0.1 to 1.5 m/s with an average velocity of 0.16 m/s. Higher velocities were typically concentrated in areas where the runoff is leaving the proposed development area, with the exception of the southern portions, where flow rapidly runs off the hills and into the site.

Maximum flood depths of up to 1.6m were recorded and these typically occurred around the edges of Burke Creek or within farm dams (which are likely to be filled and levelled as part of the project). The majority of the proposed Muskerry South Solar Power Station site experiences flood depths below 0.1m.

Existing flow conditions were found to be typically safe – within the H1 "Relatively benign flow conditions, no vulnerability constraints" hazard category. Only isolated locations near Burke Creek were found to exhibit a higher hazard risk category.

There are no flood impacts for Muskerry South as the PV cells are assumed to not alter the infiltration or runoff characteristics of the site (as discussed in Section 2.3).

Creek Crossings

There are a few vehicle entry options to the solar farm and internal access roads within the solar farm will also be required for delivery of construction materials and for operations and maintenance longer term. Access in the Muskerry North site only needs to consider standard civil drainage as the catchments are very small and flows are distributed. However, accessing the Muskerry South site will require crossing both Back Creek and Burke Creek.

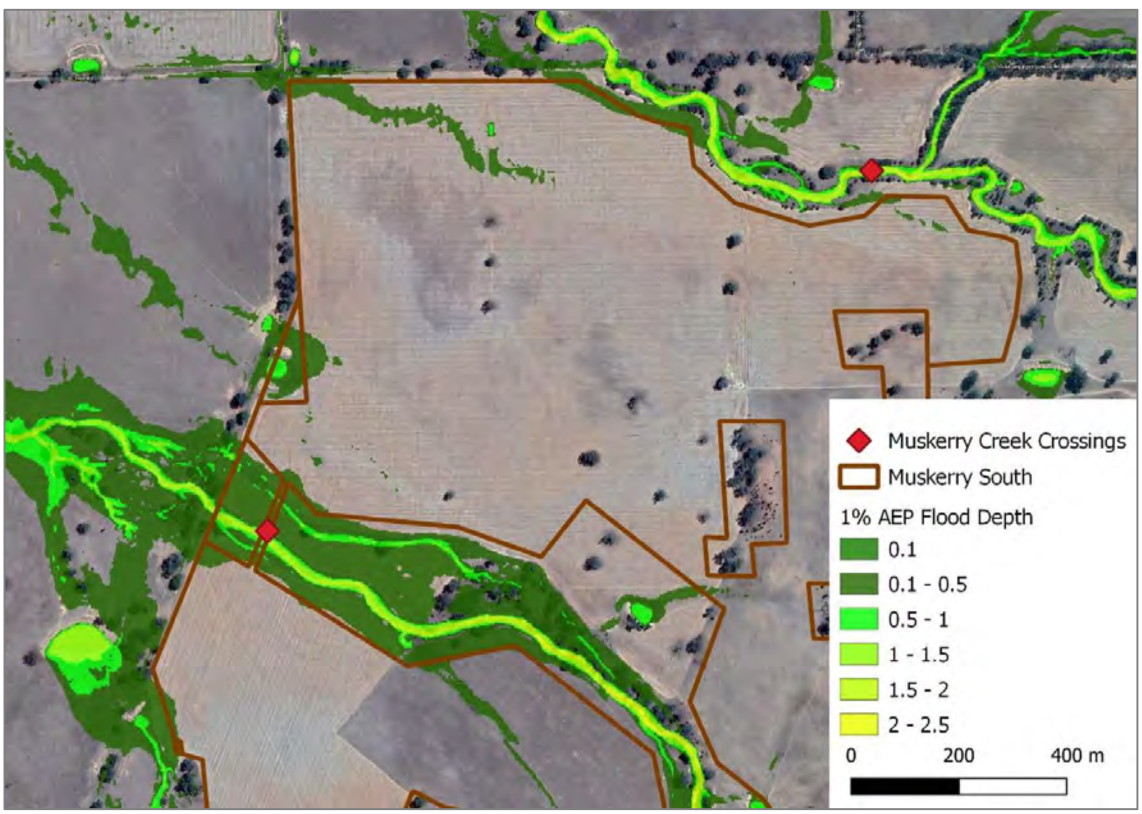

Figure 12. Proposed crossing locations at Muskerry South for Back Creek (top) and Burke Creek (bottom)

Previous projects that Edify has established also involved creek crossings within the development footprint which typically involve construction of compacted rock/earth causeways (Figure 13). These low profile crossings allow water to flow over the road and do not store or impede the flow to downstream properties, nor create a backwater impact on upstream landholders. During times of flooding these causeways are impassable but are the preferred option over raised crossings with culverts.

Figure 13. Example of a low profile causeway across a watercourse on previous Edify projects (left) under construction and (right) following rainfall.

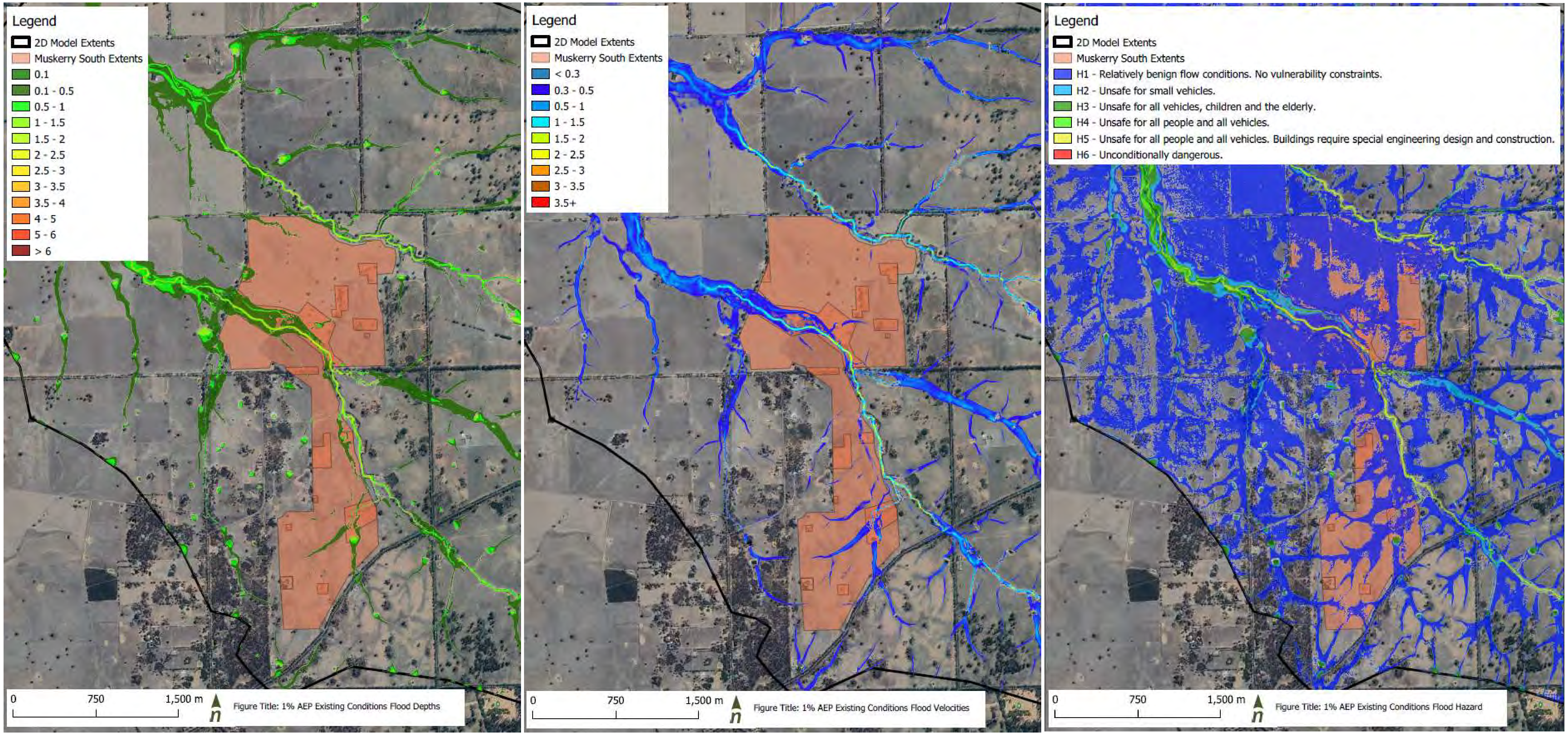

Figure 14. *Muskerry South (Left) Existing conditions 1% AEP flood depths (Middle) Existing conditions 1% AEP flood velocities (Right) Existing conditions 1% AEP flood hazard*

4 Conclusions & Recommendations

This investigation has been undertaken to provide a flood risk assessment in support of an approval application to the State Government of Victoria (DELWP) for a construction of PV arrays, BESSs, and other related infrastructure for the two sites (north and south) associated with the Muskerry Solar Power Station.

Existing conditions flood modelling was undertaken for the 1% AEP event for the two sites in order to provide guidance on the planning of internal infrastructure and to assess the external impacts of the site development.

Flood prone areas have been mapped and areas of higher flood risk identified. The majority of the North and South sites have a high level of flood immunity. Riverine flooding is present only in the southern site and found to be primarily contained within the creeks with only minor incidences of flows breaking out of the creeks and onto the development area in the 1% AEP event.

The assessment of flood prone areas has no implications for the current conceptual project design in relation to deep or fast flowing water. The facilities should still be designed with consideration of the flood modelling results to ensure assets are set to an appropriate height above ground to avoid nuisance flooding from local runoff.

The substation options, BESSs and site buildings for Muskerry North have been assigned a 75% imperviousness factor to represent additional runoff from these areas, as well as modified hydraulic roughness. This resulted in negligible changes for Substation Option A, and very small changes in the Option B footprint due to faster moving flows. There is no impact from the southern study area because the PV arrays are assumed to not alter the rainfall infiltration of overall hydraulic roughness of the site. The analyses conducted suggest that the risk to human life and infrastructure is considered to be very low.

5 References

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