Sensitivity: General

Grid Injection Point for Haldon Solar Farm

Flood Risk Assessment

Prepared for Lodestone Energy Limited
Prepared by Beca Limited

18 October 2024

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Revision History

Revision Nº	Prepared By	Description	Date
	Roisin Blundell-Dorey	Issue to client	18/10/2024

Document Acceptance

Action	Name	Signed	Date
Prepared by	Roisin Blundell-Dorey		18/10/2024
Reviewed by	Mark Megaughin		18/10/2024
Approved by	Khalid Simjee		18/10/2024
on behalf of	Beca Limited		

Executive Summary

Lodestone Energy Limited has requested that an additional design event be carried out to determine the flood risk relating to the required Transpower Grid Injection Point (GIP) for Haldon Solar Farm.

Beca developed a 2D flood model to estimate the flood risk at the site, testing the 450-year average recurrence interval (ARI) rainfall, with an allowance for the effects of climate change (Representative Concentration Pathway (RCP) 8.5 to 2100), for wet antecedent runoff conditions.

The 450-year ARI, RCP 8.5 (2100) inundation extent (Figure 0-1) shows multiple overland flow paths crossing the site, with areas unaffected by flooding in between. The majority of the inundated area experienced an average depth of less than 0.2 m, with a maximum depth of 0.79 m occurring in limited locations along the main flow path. Typical velocities within the flow paths are 0.9 m/s, with a maximum of 1.91 m/s.

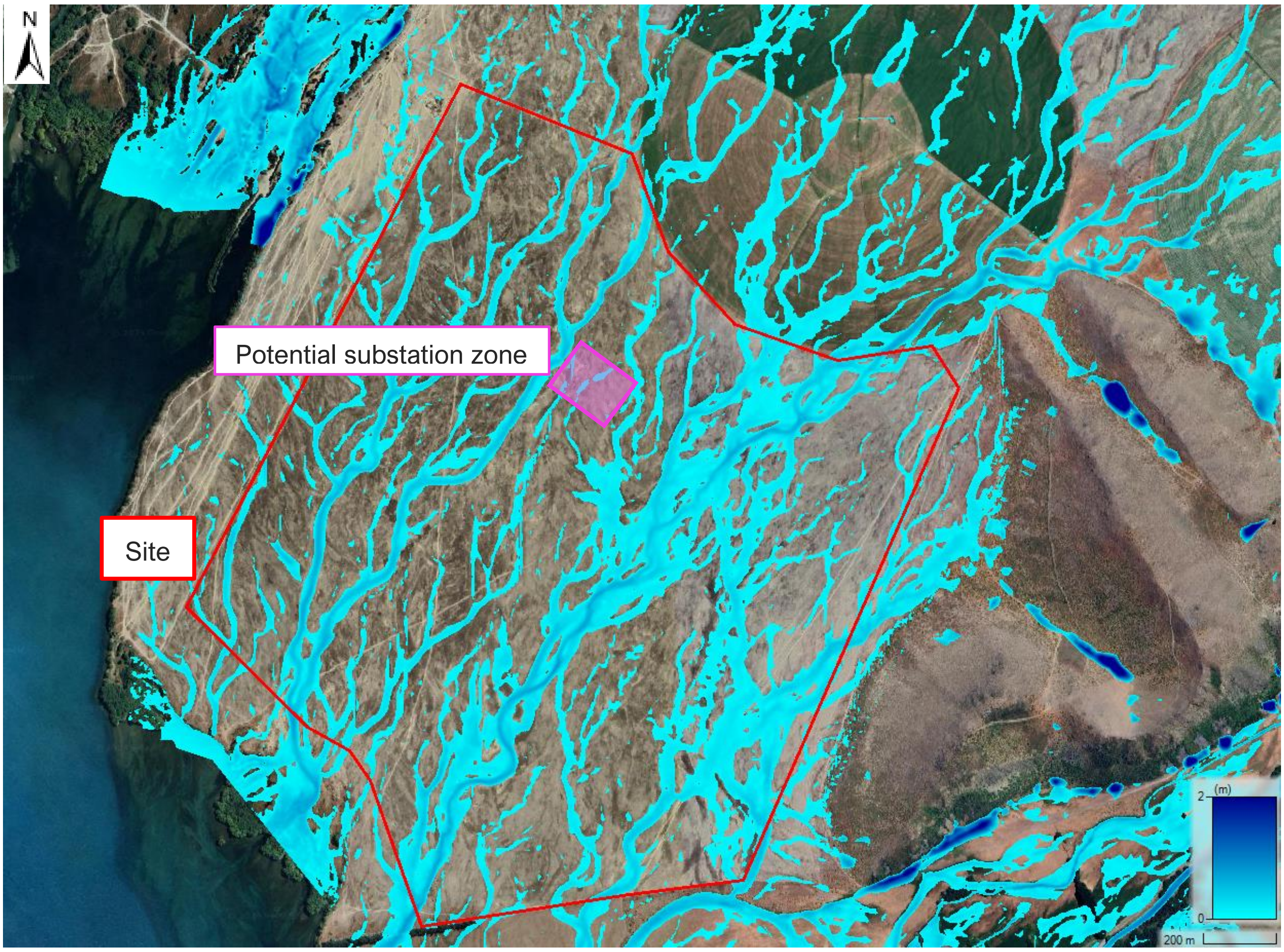

Figure 0-1: 450-year ARI, RCP 8.5 (2100) inundation extent

The following should be considered as part of the GIP design:

1. **Maintain overland flow paths** – The overland flows paths shown should be maintained as part of the site development, and not blocked. Where features such as roads are required to cross overland flow paths consideration should be given to ford crossings, or culverts. Given the narrow nature of the channels it would be feasible to construct minor diversion channels to create a platform of sufficient size to locate the GIP and associated infrastructure.

2. **Minimum design levels** – The GIP platform should be constructed 300mm above the 450-year water levels adjacent to the proposed site. These water-levels should be reassessed to include any effects of the platform required, and levels amended accordingly.
3. **Setback from lake** – The areas identified at risk from dam break and high lake levels should be avoided, where possible.

Given the above recommendations, a potential zone for the GIP is shown (Figure 0-1). This location is outside of the hydro-electric potential floodable area (area inundated if a dam or canal breached), does not block overland flow paths, is on high ground and is central on the site.

1 Context

Lodestone Energy Limited (Lodstone) has requested that a flood risk assessment be carried out to inform the siting of a Grid Injection Point (GIP) facility to deliver power generated by the Haldon Solar Farm to the National Grid.

Transpower's design event is the 450-year average recurrence interval (ARI) rainfall, with an allowance for the effects of climate change. We have used Representative Concentration Pathway (RCP) 8.5 to 2100 and wet antecedent runoff conditions in assessing the 450-year event.

To assess the flood risk we have used a two-dimensional hydraulic model (HEC-RAS v6.5) previously prepared by Beca to assist with the development of solar farm infrastructure. *Beca (2024)* (Appendix B) provides details of this work.

Provided below are the details of the model elements that differ from the *Beca (2024)* work, and the results of the 450-year ARI assessment.

2 Initial flood risk screening

To determine the potential modes of flooding at the site we undertook an initial flood risk screening. No publicly available evidence of historic flooding at the site was found.

The potential sources of flood risk identified were:

- High flows within adjacent rivers (Tekapo, Pukaki, Ohau Rivers, and Stoney Creek),
- High lake levels in Lake Benmore,
- Runoff from surrounding land.

2.1 High flows within adjacent rivers

We have completed a high-level assessment of peak flows with the adjacent rivers. Should the Tekapo River, Pukaki River or Stoney Creek overtop, we do not expect that their floodwaters would pose a risk to the site in Lodestone's design event.

2.2 High lake levels in Lake Benmore

As part of the Mackenzie district plan the hydro-electricity inundation hazard areas (Figure 2-1) identify areas that could potentially be affected by inundation in the unlikely event of a dam or canal breach. They do not reflect any natural hazards, for example flooding from rivers (Mackenzie District Council, 2016). Whilst this map does not show the 450-year flood extent, it does show the worst-case flood extent for an upstream dam breach. The potential floodable area covers the southeast section of the site.

We have also assessed maximum water levels in Lake Benmore. The Probable Maximum Flood (PMF) is estimated as 363.05 mRL (NZVD2016) under current management rules, and 361.85 mRL (NZVD2016) under an optimised set of rules currently being adopted (Damwatch Engineering Ltd, 2023). The PMF is the largest flood event that can be generated by atmospheric conditions and the lake level generated by the PMF is well beyond that which would be generated by Transpower's 450-year design event. Figure 2-2 shows that a small portion of the site is inundated by the PMF.

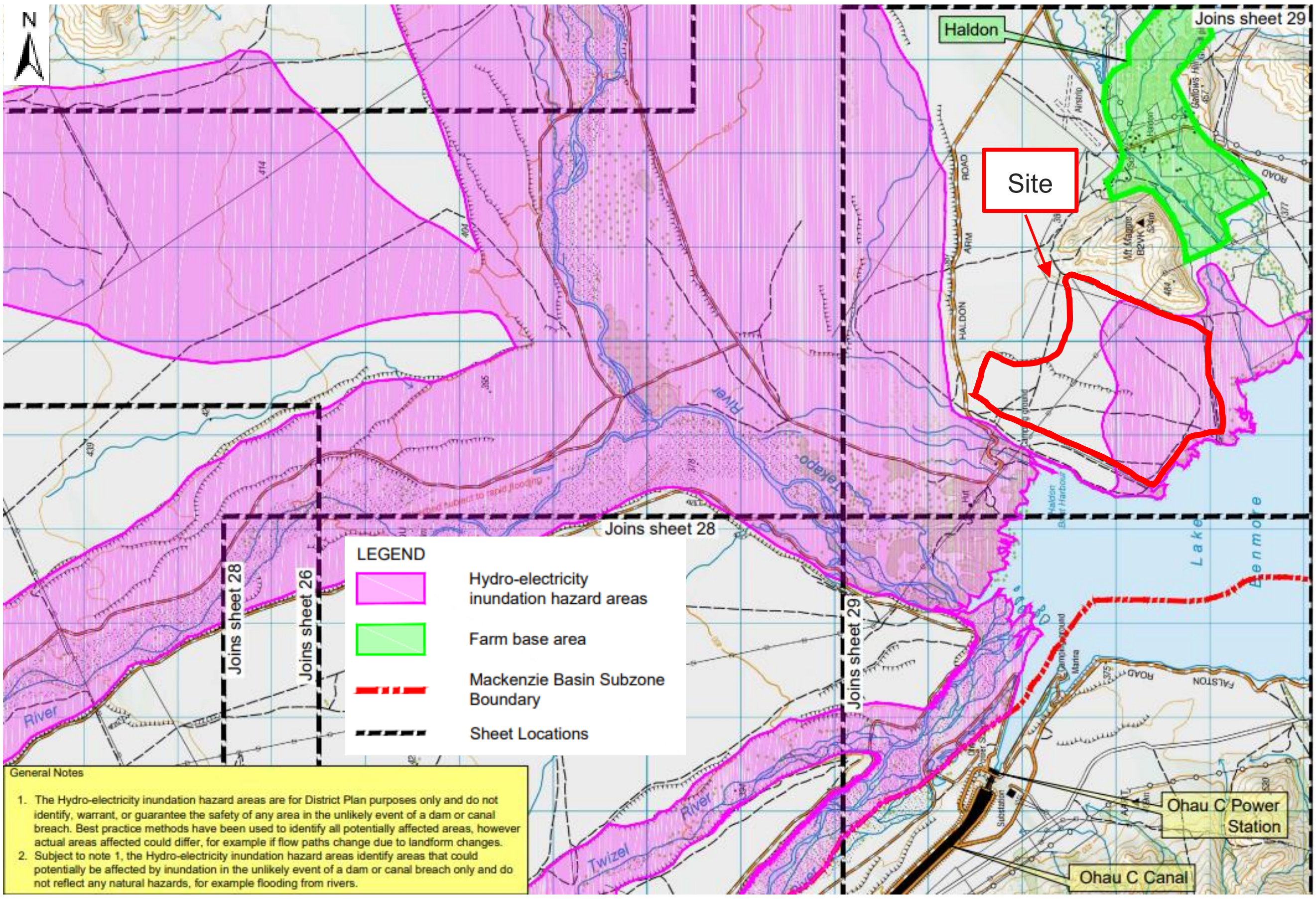

Figure 2-1: Hydro-electricity inundation hazard area maps obtained from the Mackenzie District Council (Mackenzie District Council, 2016).

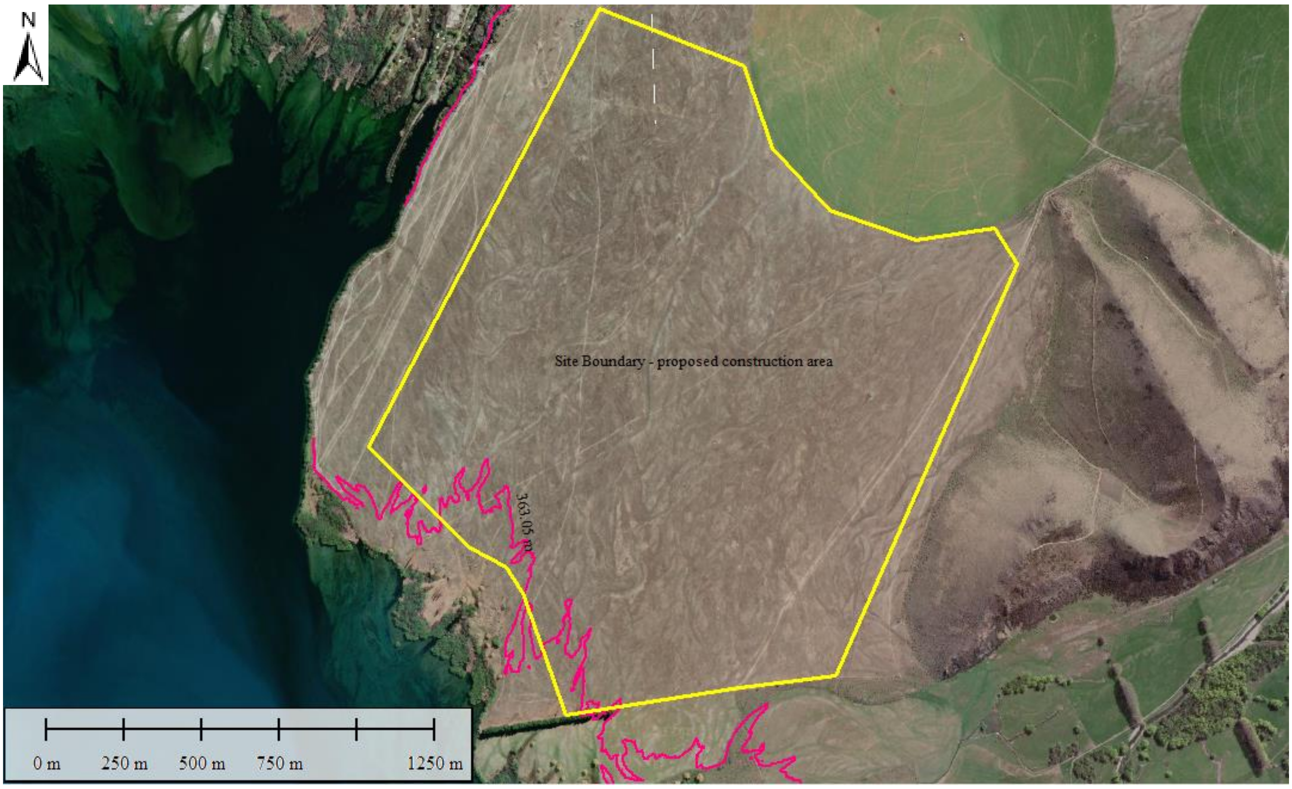

Figure 2-2: The site with the PMF generated lake-level contour (363.05 mRL pink line)

3 Model approach

The modelling approach is as per that laid out in *Beca (2024)* (Appendix B). The only difference in the work reported here is that the 450-year rainfall event has been used in the assessment.

Beca obtained rainfall estimates from NIWA's High Intensity Rainfall Design System (HIRDS v4) webtool at the centroid of the catchment (Table 2-1). We used these rainfall depths to generate 24-hour nested storm, with the peak rainfall occurring at 12 hours (Figure 3-1).

Table 3-1: HIRDS v4 rainfall depths.

ARI	Storm Duration							
	10 min	20 min	30 min	60 min	2 hrs	6 hrs	12 hrs	24 hrs
450-year RCP8.5 (2100)	21.3	28.7	34.8	48.4	66.8	106.6	136.7	166.9

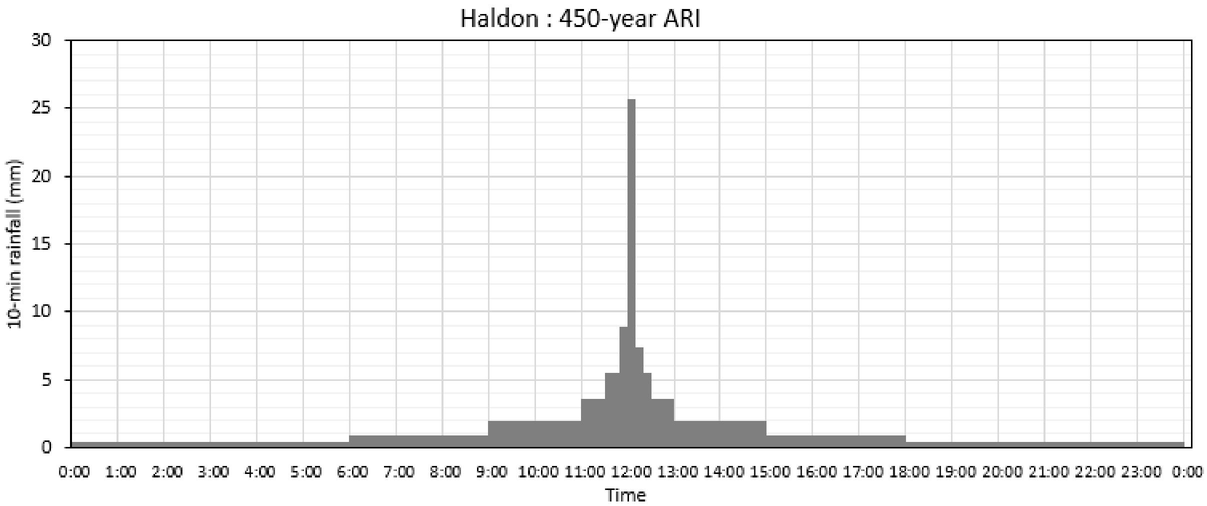

Figure 3-1: 450-year nested storm hyetograph

4 Results

4.1 General findings

The flooding on site in the 450-year RCP8.5 2100 event is limited to the overland flow paths (Figure 4-1) that cross the site, flowing towards the lake. The main source of flooding is runoff from the land upslope of the site, flowing towards Lake Benmore. There are three main overland flow path systems of note (No. 1, No. 2 and No. 3 in Figure 4-1). These overland flow paths follow local drainage paths that have naturally developed over a long period of time to drain the local area. On site, these paths are noticeable depressions in the landscape.

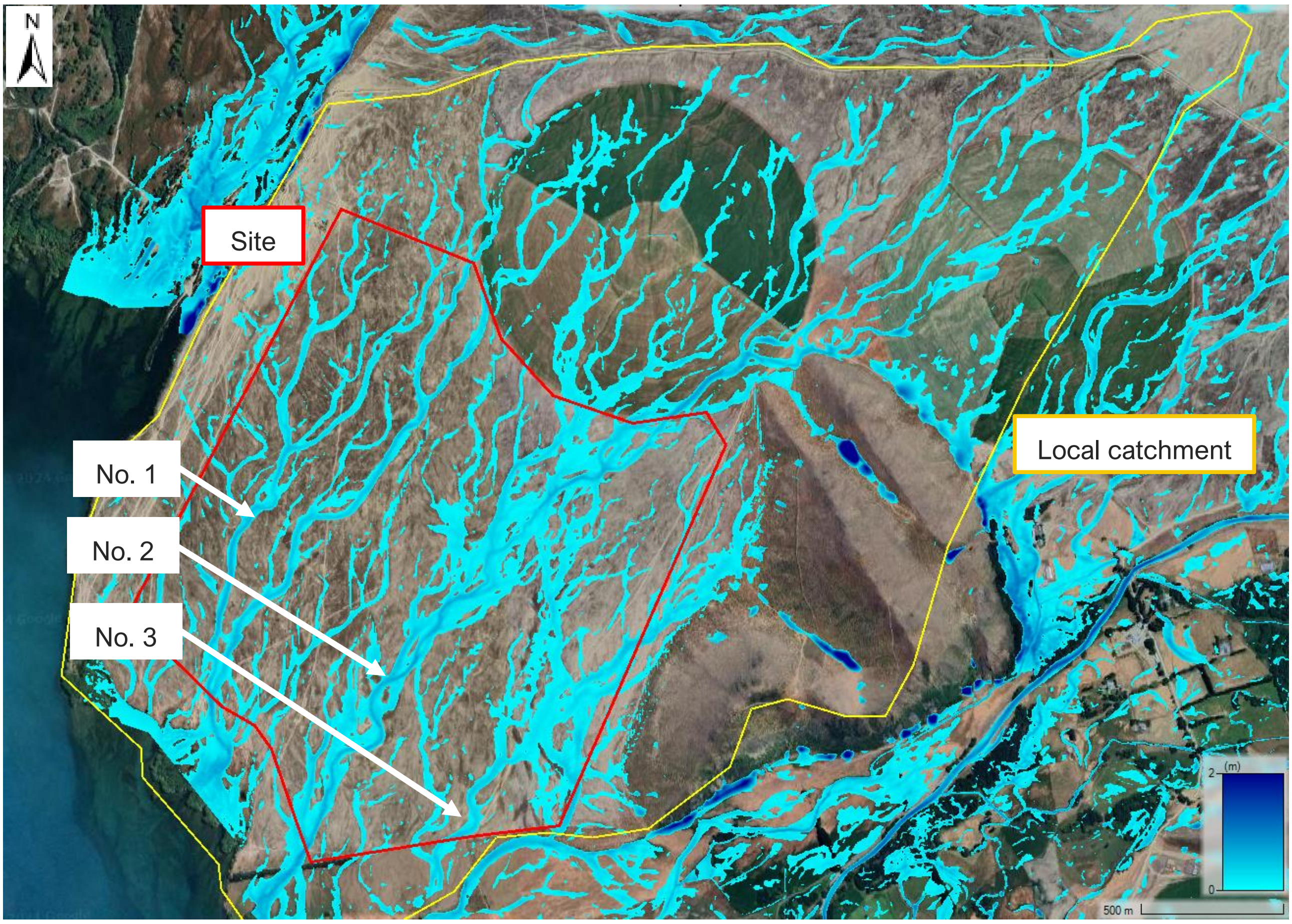

Figure 4-1: 450-year ARI, RCP 8.5 (2100) inundation extent.

4.2 Flood depths and velocities

We have extracted depths and velocities from the model, with a focus on overland flow paths 1 and 2. These results are presented below (Table 4-1), with Appendix A providing result maps illustrating (1) surface terrain, (2) maximum depth, (3) maximum velocity, and (4) maximum water surface elevation. We have used 5 reporting locations to demonstrate the conditions around the site (Figure 4-2).

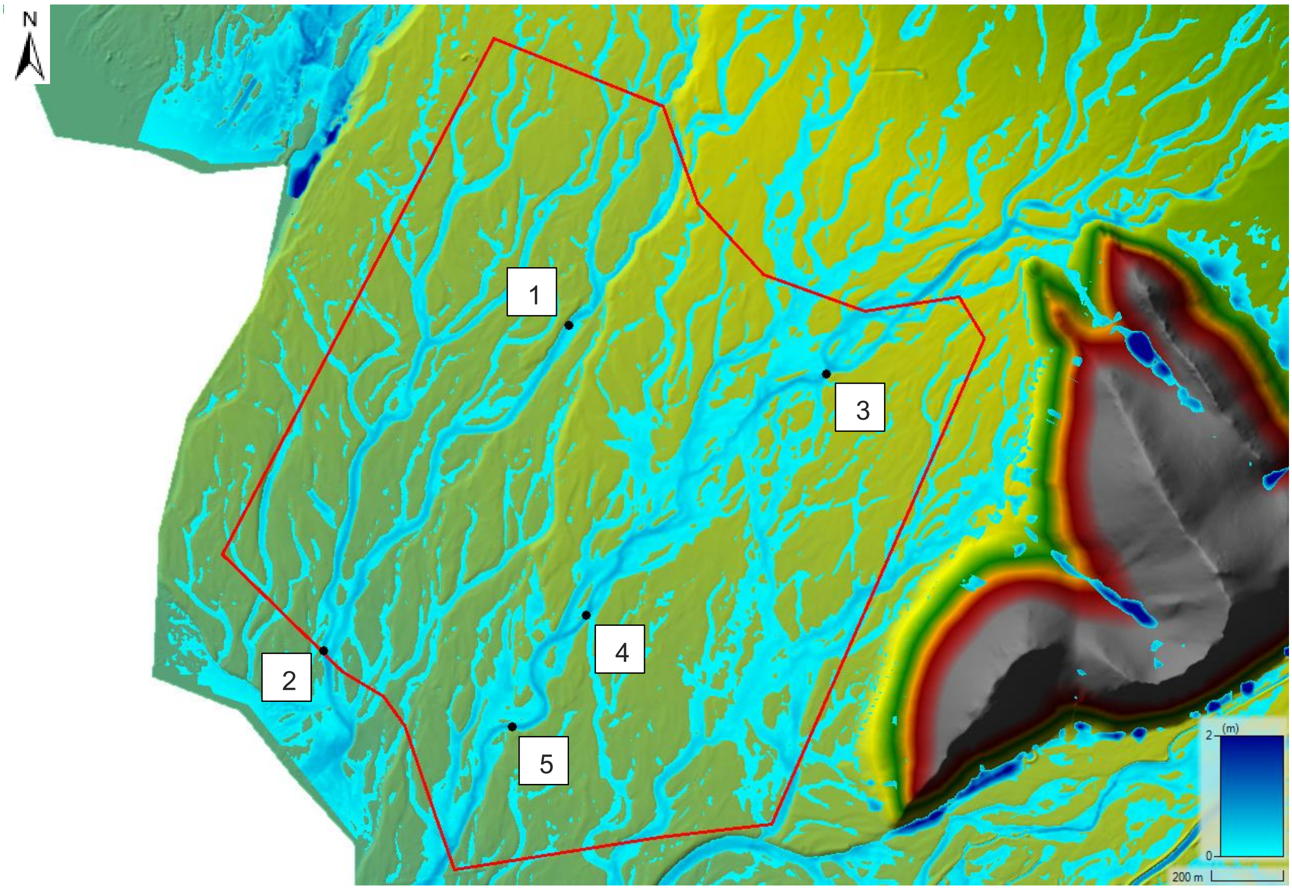

Figure 4-2: Reporting point locations in the 450-year ARI event (RCP8.5 2100)

Table 4-1: Model water level results at specified reporting points

Reporting point	Model flood results			
	Depth (m)	Velocity (m/s)	WSE (mRL)	Ground level (mRL)
1	0.46	0.85	368.14	367.68
2	0.68	0.87	362.56	361.88
3	0.61	1.91	372.98	372.37
4	0.79	0.99	367.74	366.95
5	0.59	1.61	364.90	364.31

4.3 Flood hazard

Flood hazard categories integrate the risks posed by water depth and water velocity, as reported above, into a single number that relates to the potential impact on people, vehicles, and buildings. The categorisation used below (Figure 4-3) is from New South Wales government guidance (Department of Planning and Environment, 2022). It describes in general terms the risk to typical urban settings and, whilst not specific to solar installations, is a useful guide as to the hazard at Haldon Station.

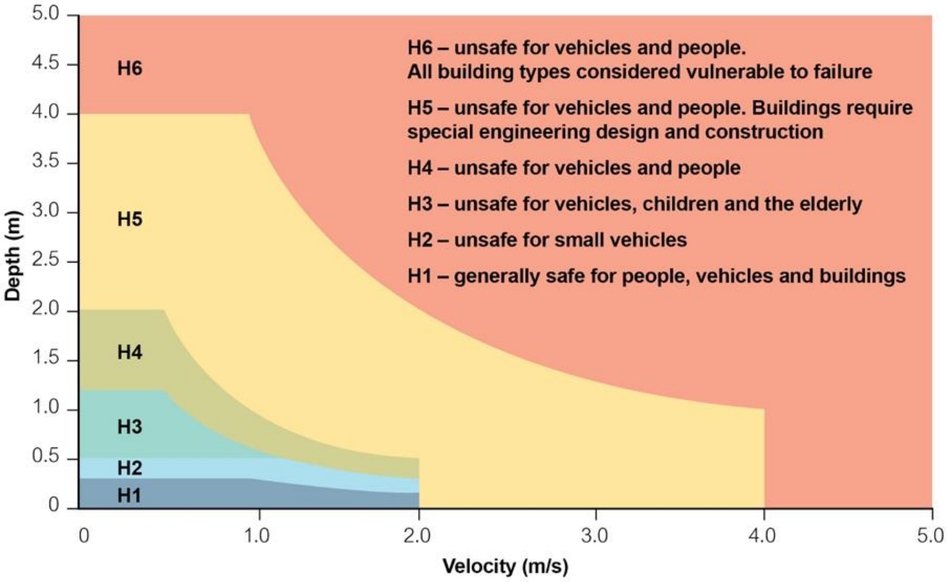

Figure 4-3: General flood hazard vulnerability curve.

We have used this method to define hazard categories at Haldon (Figure 4-4). Most of the site is categorised as no hazard, with small areas of H1 to H4 limited to the main overland flow paths. Overall, there is a low flood hazard on the site, with small areas of moderate hazard.

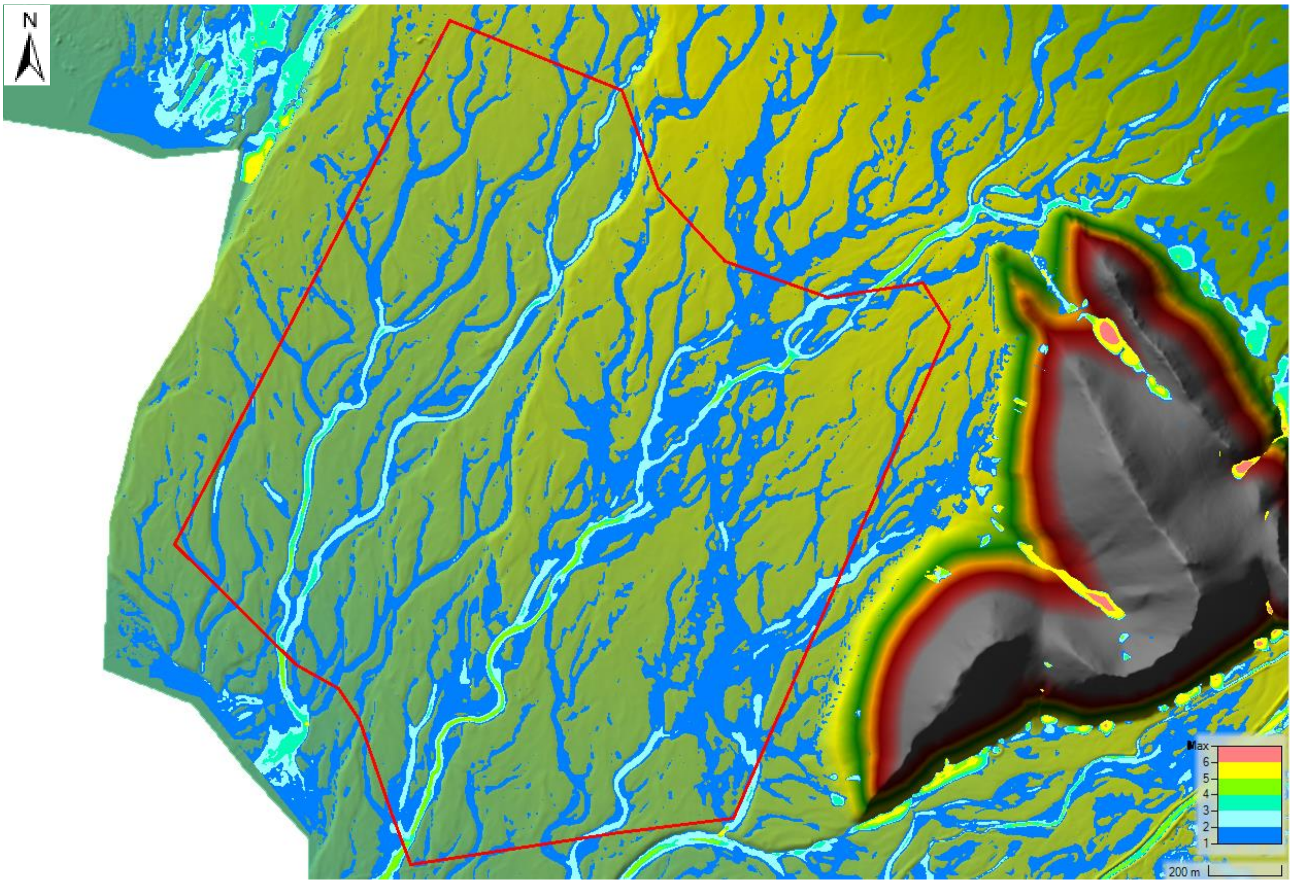

Figure 4-4: Hazard vulnerability classification

4.4 Erosion risk

Water moving quickly through the site can cause erosion of surfaces, both the natural surface and prepared surfaces such as roads and yard areas.

The maximum velocity in our modelling was 1.91 m/s, within an overland flow path. We have compared this to the erosion susceptibility for various surfaces to determine whether there is an erosion risk (Figure 4-5). For this assessment we have assumed that the maximum velocity would occur for no longer than 5 hours, and that the site surfaces are 'plain grass – poor cover'.

Figure 4-5 shows that the maximum velocity on site could be sufficient to start causing erosion in areas of poor cover. However, the assumption the peak velocity would last for 5 hours is conservative and therefore we do not consider mass erosion to be a risk that needs to be specifically managed at the site. Small-scale localised erosion remains possible.

Development of any GIP related infrastructure would be unlikely in any areas impacted by these maximum velocities.

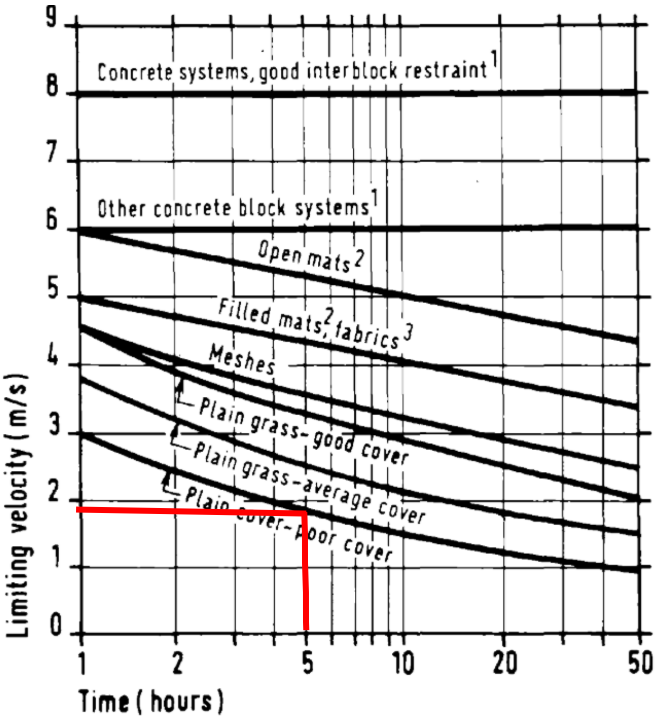

Figure 4-5: Limiting values for erosion resistance of plain and reinforced grass (CIRIA, 1987).

5 Conclusions

5.1 General

Overall, flooding on the site is limited to the overland flow paths in the 450-year ARI, RCP 8.5 (2100). The majority of the inundated area is inundated to an average depth of less than 0.2 m, with a maximum depth of 0.8 m occurring in a discrete locations along the main flow path. Typical velocities within the flow paths are 0.9 m/s, with a maximum of 1.91 m/s.

Outside of the overland flow paths no inundation occurs, with rainfall on the site soaking quickly to ground.

Most of the site is categorised as no hazard, with areas of H1 to H4 limited to the main overland flow paths. Overall, there is a low flood hazard on the site, with small areas of moderate hazard.

Velocities across the site are unlikely to cause mass erosion of grassed surfaces, although localised erosion could occur.

Both high lake levels, and the effects of an upstream dam break can result in the lower part of the site being inundated. Whilst both these events are well beyond the 450-year design standard, it would be prudent to avoid these areas for major infrastructure, such as a GIP.

5.2 GIP recommendations

The following should be considered as part of the GIP design:

1. **Maintain overland flow paths** – The overland flows paths shown should be maintained as part of the site development, and not blocked. Where features such as roads are required to cross overland flow paths consideration should be given to ford crossings, or culverts. Given the narrow nature of the channels it would be feasible to construct minor diversion channels to create a platform of sufficient size to locate the GIP and associated infrastructure.
2. **Minimum design levels** – The GIP platform should be constructed 300mm above the 450-year water levels adjacent to the proposed site. These water-levels should be reassessed to include any effects of the platform required, and levels amended accordingly.
3. **Setback from lake** – The areas identified at risk from dam break and high lake levels should be avoided, where possible.

Given the above recommendations, a potential zone for the GIP is shown (Figure 5-1). This location is outside of the hydro-electric potential floodable area (area inundated if a dam or canal breached), does not block overland flow paths, is on high ground and is central on the site.

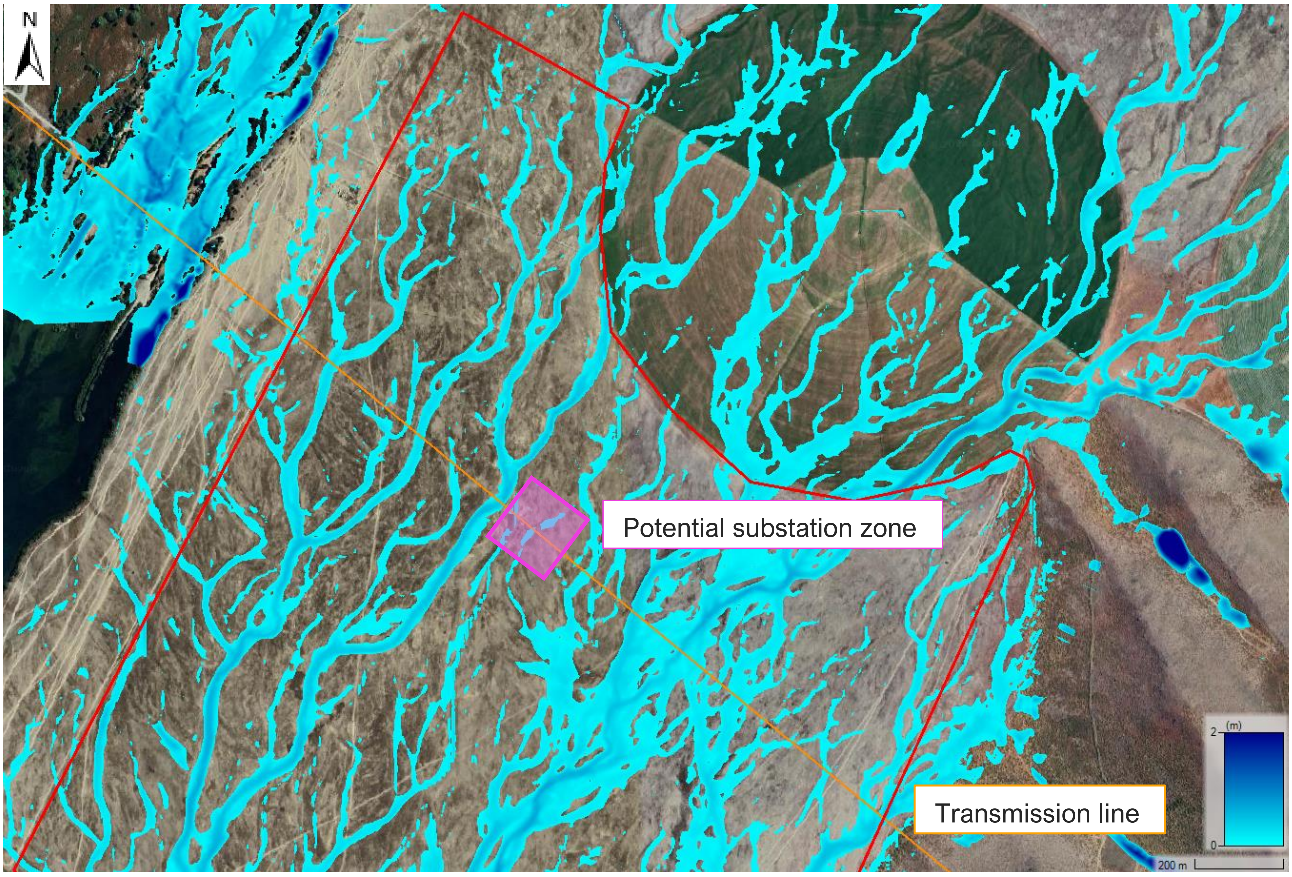

Figure 5-1: Potential substation location

Limitations

This modelling estimates flood risk at the proposed site. It is intended to inform our client on potential locations for a GIP from the Haldon Solar Farm and should not be used for any other purpose, nor by any other party.

The model is based on third party rainfall and terrain information. As a conservative approach, the model does not include on-site drainage systems and small culverts which would likely become blocked during significant rainfall events. A freeboard allowance must be applied to all modelled water levels to derive minimum design levels for the site.

6 References

CIRIA (Construction Industry Research and Information Association). (1987). Design of reinforced grass waterways – Report 116, reprinted 2003.

Damwatch Engineering Ltd. (2023). *Waitaki Hydro System Revised Flood Rules Commentary.* Retrieved from file:///C:/Users/RB968/Downloads/CRC240441CRC240442CRC240443CRC240444CRC240445CRC240446CRC240447CRC240448CRC240449CRC240450CRC240451CRC240452CRC240453CRC240454CRC240455CRC240456CRC240457CRC240458CRC240459RevisedFloodRulesCommentary%20(1).PDF

Mackenzie District Council. (2016). *Appendix-U-Flood-Hazard-Inundation-Maps.* Retrieved from https://www.mackenzie.govt.nz/__data/assets/pdf_file/0020/514208/Appendix-U-Flood-Hazard-Inundation-Maps.pdf

Appendix A – Result Maps

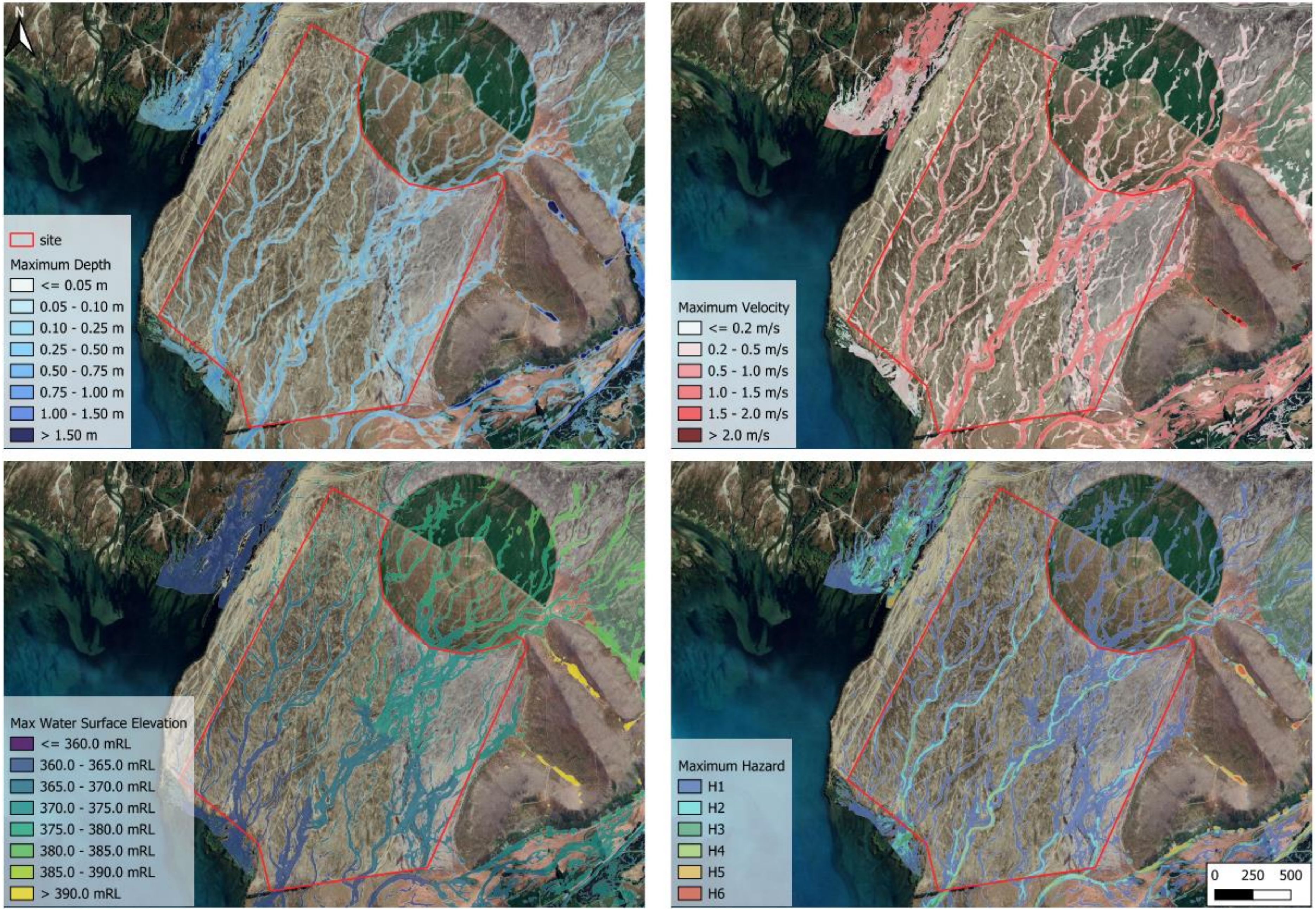

Figure 6-1: 450-year ARI RCP8.5 2100 Scenario

Appendix B – 100yr Haldon Flood Risk Assessment

Beca

Haldon Solar Farm

Flood Risk Assessment

Prepared for Lodestone Energy Limited
Prepared by Beca Limited

18 October 2024

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Appendices

Appendix A - Hydrology Tables

Appendix B - Results Maps

Revision History

Revision Nº	Prepared By	Description	Date
1	Roisin Blundell-Dorey	Issue to client	13/09/2024
2	Roisin Blundell-Dorey	Reissue with client comments	18/10/2024

Document Acceptance

Action	Name	Signed	Date
Prepared by	Roisin Blundell-Dorey		18/10/2024
Reviewed by	Mark Megaughin		18/10/2024
Approved by	Khalid Simjee		18/10/2024
on behalf of	Beca Limited		

Executive Summary

Lodestone Energy Limited has requested that a flood risk assessment be carried out to determine the flood risk posed to a proposed solar farm at Haldon Station.

Beca developed a 2D flood model to estimate the flood risk at the site. Lodestone's design event is the 100-year average recurrence interval (ARI) rainfall, with an allowance for the effects of climate change (Representative Concentration Pathway (RCP) 8.5 to 2060), for wet antecedent runoff conditions.

The 100-year ARI, RCP 8.5 (2060) inundation extent (Figure 0-1) shows multiple overland flow paths crossing the site, with areas unaffected by flooding in between. The majority of the inundated area experiences an average depth of less than 0.15 m with a maximum depth of 0.69 m occurring along a main flow path. Typical velocities within the flow paths are 0.8-0.9 m/s, with a maximum of 1.48 m/s.

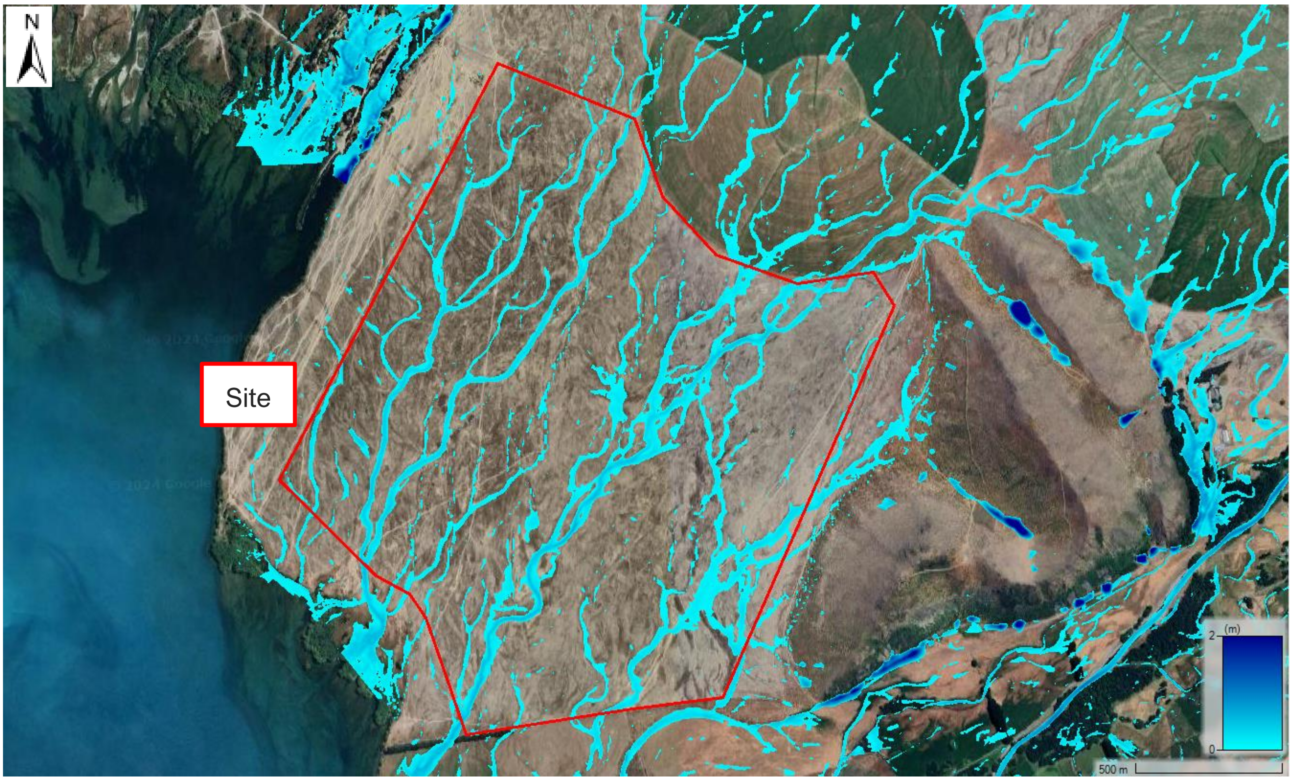


Figure 0-1: 100-year ARI, RCP 8.5 (2060) inundation extent

Solar farm infrastructure

Due to the sloped nature of the site water surface elevations vary between the top and bottom of the site. It is therefore not practical to set a single minimum design level for the site. To set minimum design levels for water-sensitive equipment across the site the shapefile of water surface elevation produced in the model can be used to set individual minimum design levels across the site. This would need to include a freeboard allowance of 300 mm.

In general, the flood risk is unlikely to significantly impact the development of the solar array, however the design and installation of equipment located in and around the three overland flow paths should be considered in terms of the higher depths and velocities present.

The following should be considered as part of developing the site design:

1. **Maintain overland flow paths** – The overland flows paths shown should be maintained as part of the site development, and not blocked. Where features such as roads are required to cross overland flow paths consideration should be given to ford crossings, or culverts.
2. **Lake buffer** – The consented lake setback means the design elevation of 361.41 mRL, maximum consented level of the lake plus a 300 mm freeboard, will not encroach the lowest point on site. The residual risk relating to extreme lake levels can also be managed by specification of standard equipment stands.
3. **Overland flow path buffer** – Where possible equipment should not be placed within the overland flow paths identified. Where this is not possible a minimum elevation for sensitive equipment should be used. We recommend a minimum elevation of the 100-year water level plus a 300mm allowance for freeboard for sensitive equipment in, or adjacent to, overland flows paths. Using 300 mm of freeboard assumes there will be no earthworks on site that will influence the flow of water. The freeboard allowance accounts for (1) errors in the base data used, (2) inaccuracies in the modelling, (3) wave action around the site during floods, and (4) afflux caused by structures such as the solar array stands.
4. **Minimum level of sensitive equipment** – For equipment not within an identified inundation area all water-sensitive equipment should be at least 300mm above ground level.

1 Context

Lodestone Energy Limited (Lodestone) is currently investigating the development of a solar farm at Haldon Station. Beca Limited (Beca) has been commissioned by Lodestone to undertake a flood risk assessment (FRA) of the site.

The proposed site is situated at Haldon Station on Haldon Road, Cattle Creek 7999. It is bounded by the Tekapo River to the north, Stoney Creek to the south and the Lake Benmore to the west. The site is approximately 300 ha in area (Figure 1-1). The main hydrological features surrounding the site. The site consists of generally flat farmland with well-defined local drainage channels that have developed to drain the local area towards Lake Benmore.

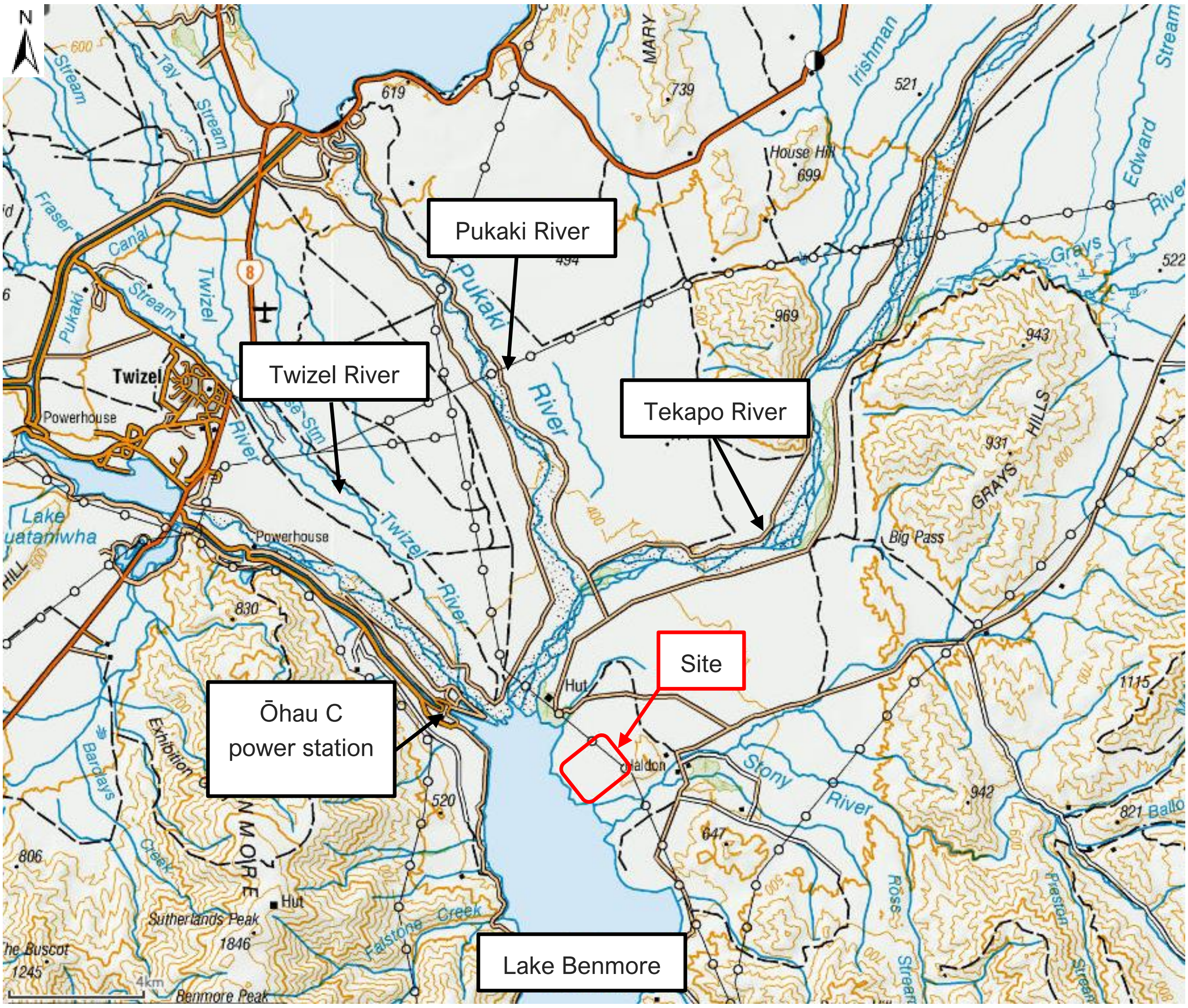


Figure 1-1: Proposed site location (red outline).

2 Initial flood risk screening

To determine the potential modes of flooding at the site we undertook an initial flood risk screening. No publicly available evidence of historic flooding at the site was found.

The potential sources of flood risk identified were:

- High flows within adjacent rivers (Tekapo, Pukaki, Ohau Rivers, and Stoney Creek),
- High lake levels in Lake Benmore,
- Runoff from surrounding land.

We have completed a high-level assessment of peak flows with the adjacent rivers. Should the Tekapo River, Pukaki River or Stoney Creek overtop, we do not expect that their floodwaters would pose a risk to the site in Lodestone's design event (Section 3).

Lake Benmore has a normal operating range of between 354.91 mRL (normal minimum control level) and 361.11 mRL (maximum consented storage level) (NZVD2016) (Damwatch Engineering Ltd, 2023). This has the potential to impact the site, which is considered below.

The risk of lacustrine tsunami is unlikely due to the slopes directly opposing the site being alluvial fan structures, with generally gently inclined slopes entering Lake Benmore. This risk is discussed further in the Geotechnical Report (Beca, 2024).

Runoff from surrounding land appears to be the key risk posed to the site, and this is the focus of this report.

3 Approach

To quantify the risk of flooding from surrounding land this flood risk assessment uses 2D HEC-RAS rain-on-grid hydraulic modelling of the site and surrounding catchment. We have used Lodestone's design standard of 100-year average recurrence interval (ARI) rainfall event, including an allowance for climate change for Representative Concentration Pathway (RCP) 8.5 to 2060. This pathway represents greenhouse gas concentrations continuing to increase over the 35-year design life of the solar farm.

4 Terrain

The main input to this model is the 2015 Canterbury - Mackenzie 1m LiDAR-based Digital Elevation Model (DEM). We imported this data from LINZ Data Service in the NZTM2000 projection and it uses the NZVD 2016 vertical datum. Figure 4-1 shows that the area, comprising extensive glacial outwash gravels has been repeatedly incised by nearby rivers. This process has resulted in the multiple channels and terraces visible in the landscape. Layered on top of the dominant landforms are multiple minor stream channels and paleochannels. These represent past and present overland flow routes which carry water during heavy rain.

The main terraces and river channel features developed prior to the development of the Waitaki Hydro Electric Scheme. The main rivers are now regulated by dams upstream of the site and this has all but removed the potential for future large-scale geomorphic change in these channels. The environment surrounding the site is therefore relatively stable. Minor aggradation of the Tekapo River-bed, and deposition fan at the head of the lake is possible, but this is unlikely to affect the flood risk posed to the site.

Figure 4-2 shows the local catchment and the channels running through the site towards Lake Benmore.

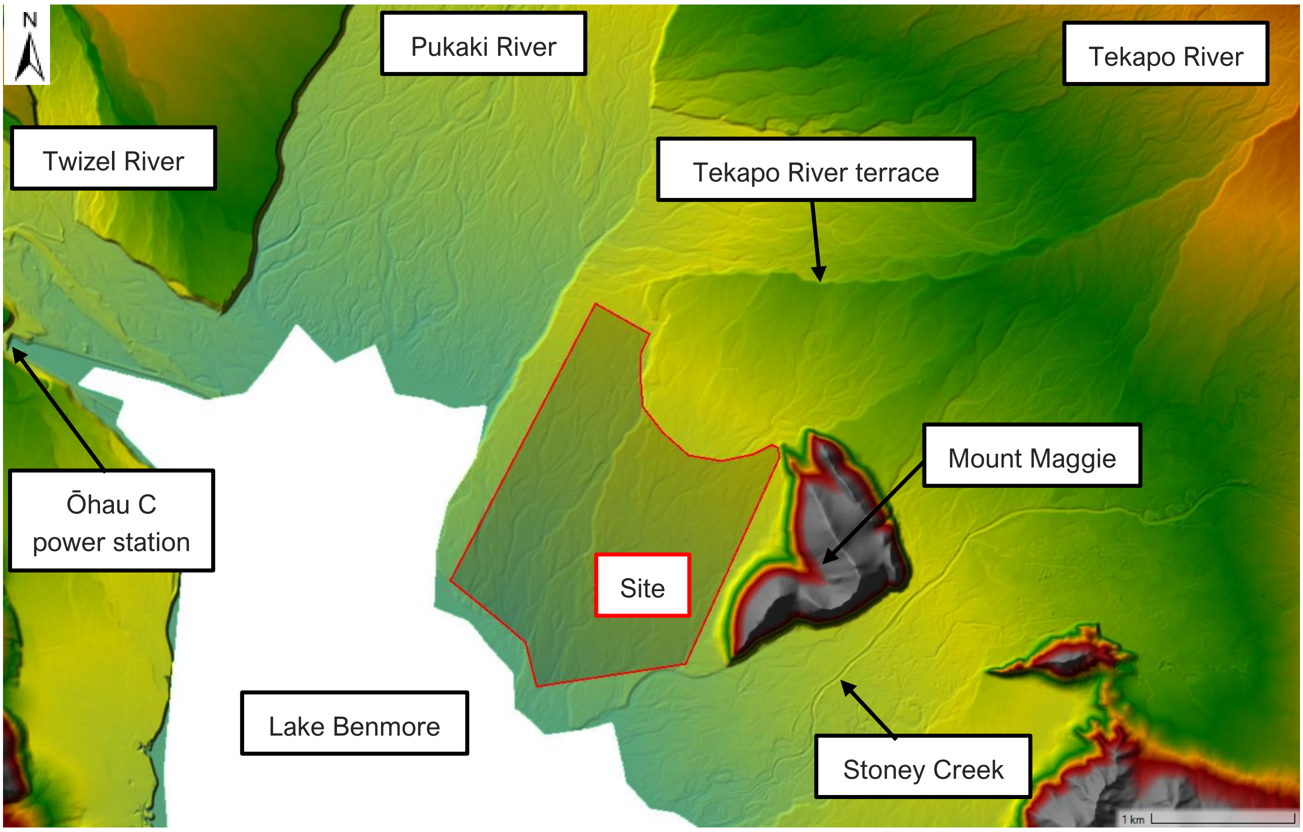


Figure 4-1: Terrain surface of main hydrological features

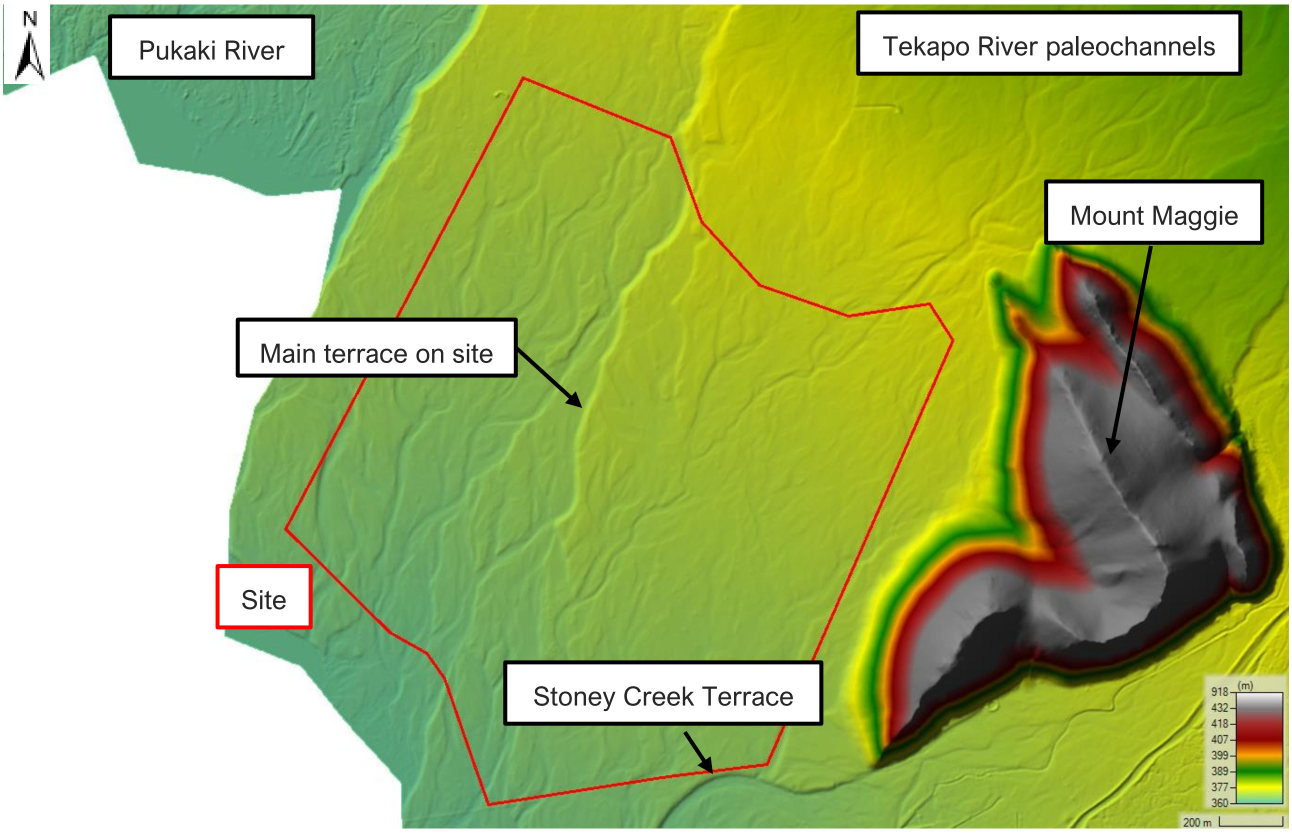


Figure 4-2: Terrain surface of the site

5 Hydrology

5.1 Rainfall

Beca obtained rainfall estimates from NIWA's High Intensity Rainfall Design System (HIRDS v4) webtool at the centroid of the catchment.

The client advised that their design standard is the 100-year ARI rainfall event, including an allowance for climate change for Representative Concentration Pathway (RCP) 8.5 to 2060. This time horizon represents greenhouse gas concentrations continuing to increase over the 35-year design life of the solar farm. Table A-1 in Appendix A provides the rainfall depths up to a 24-hour storm for the 100-year ARI rainfall event.

We used these rainfall depths to generate a 24-hour nested storm, with the peak rainfall occurring at 12 hours. Nested storms are commonly used for flood modelling because they embed all durations of a given return period within one profile. Figure 5-1 shows the nested storm hyetograph developed for the 100-year ARI event including climate change.

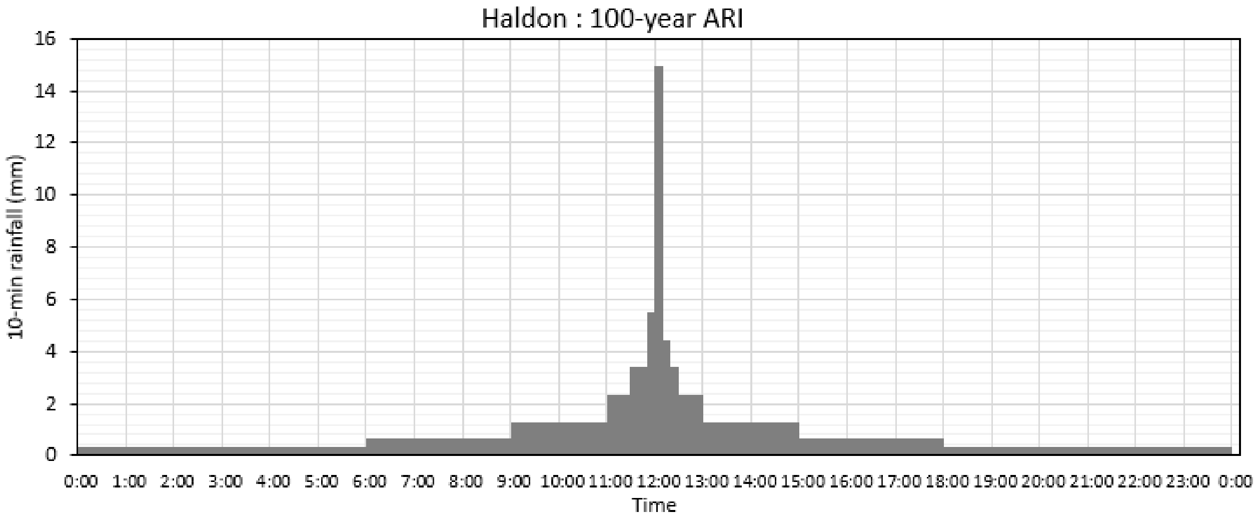


Figure 5-1: Nested storm hyetograph

We applied rainfall directly to the 2D surface as rain-on-grid and losses were modelled using the SCS loss method (SCS, 1986), as described in Section 5.2.

5.2 Rainfall losses

A hydrological soil group (HSG) and land cover map layer for the catchment were used to estimate the infiltration (Figure 5-2). Default soil group and land cover were applied to the uncoloured areas of Figure 5-2. Hydrologic soil groups were obtained from S-Map online viewer by Manaaki Whenua – Landcare Research which shows that the catchment consists of moderately well drained soils. The corresponding SCS Hydrological Soil Group is a combination of 'A' and 'C' for the catchment.

We determined the land cover types through the combination of aerial imagery and a site visit. Curve numbers for average antecedent conditions (CN_{II}) were assigned based on the combination of the hydrological soil groups and land cover.

Curve numbers for wet antecedent runoff conditions (CN_{III}) were derived using the adjustment method from Chow (1964):

$$CN_{III} = \frac{23CN_{II}}{10 + 0.13CN_{II}}$$

Assigned average and wet curve numbers are listed in Table A-2, Appendix A. Wet antecedent conditions have been used for all runs in this assessment as a conservative approach. Initial abstraction was set to 0.2S, as per SCS (1986).

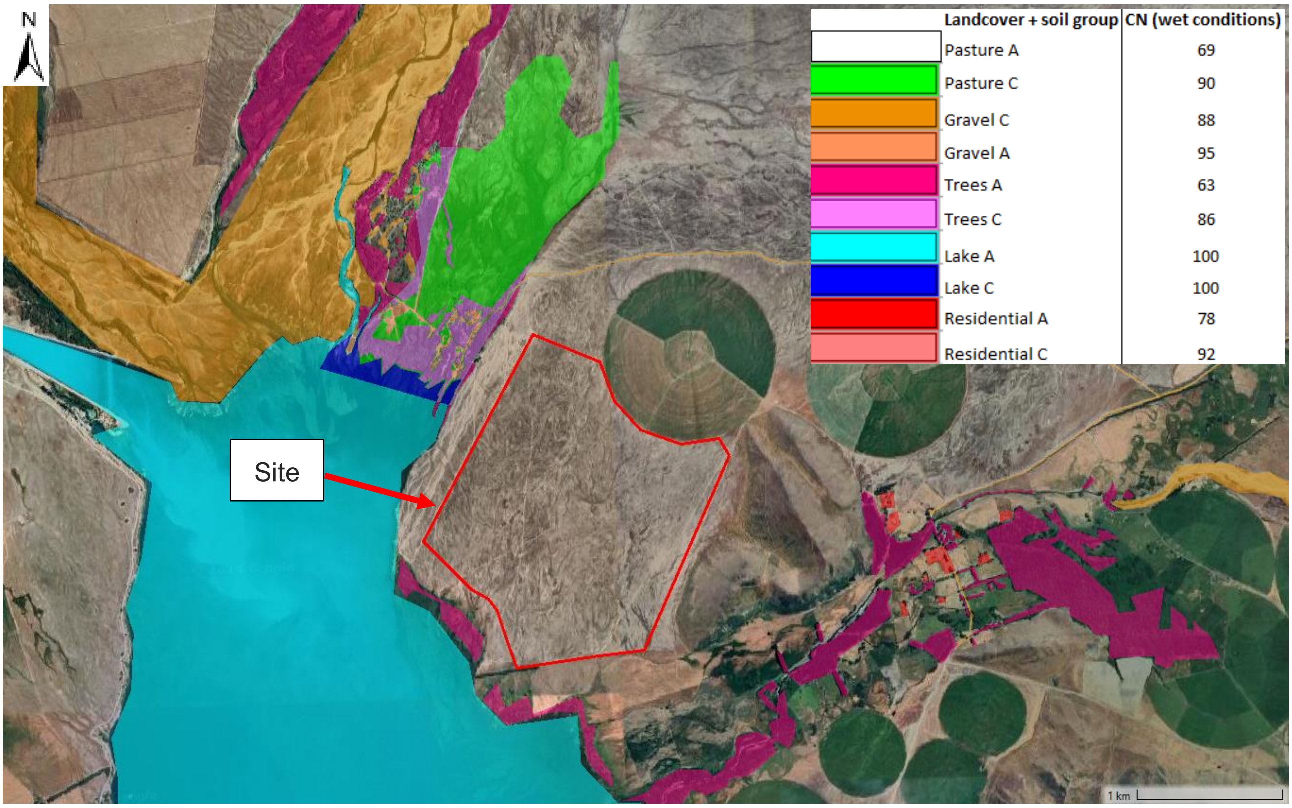


Figure 5-2: SCS CN map of the site and surrounding area

6 Hydraulic Model

We developed a two-dimensional hydraulic model in HEC-RAS v6.5. The 2D model extent covers the entire catchment, with a 50 m grid size. We specified normal depth boundary conditions along the edges on the model extent to allow runoff to flow out of the extent and prevent artificially high water-levels. We used a refinement region with a 10 m grid size for the site itself, and inserted break lines along roads that we considered to have a material effect on the flow of water though the catchment. These geometry features are shown in Figure 6-1.

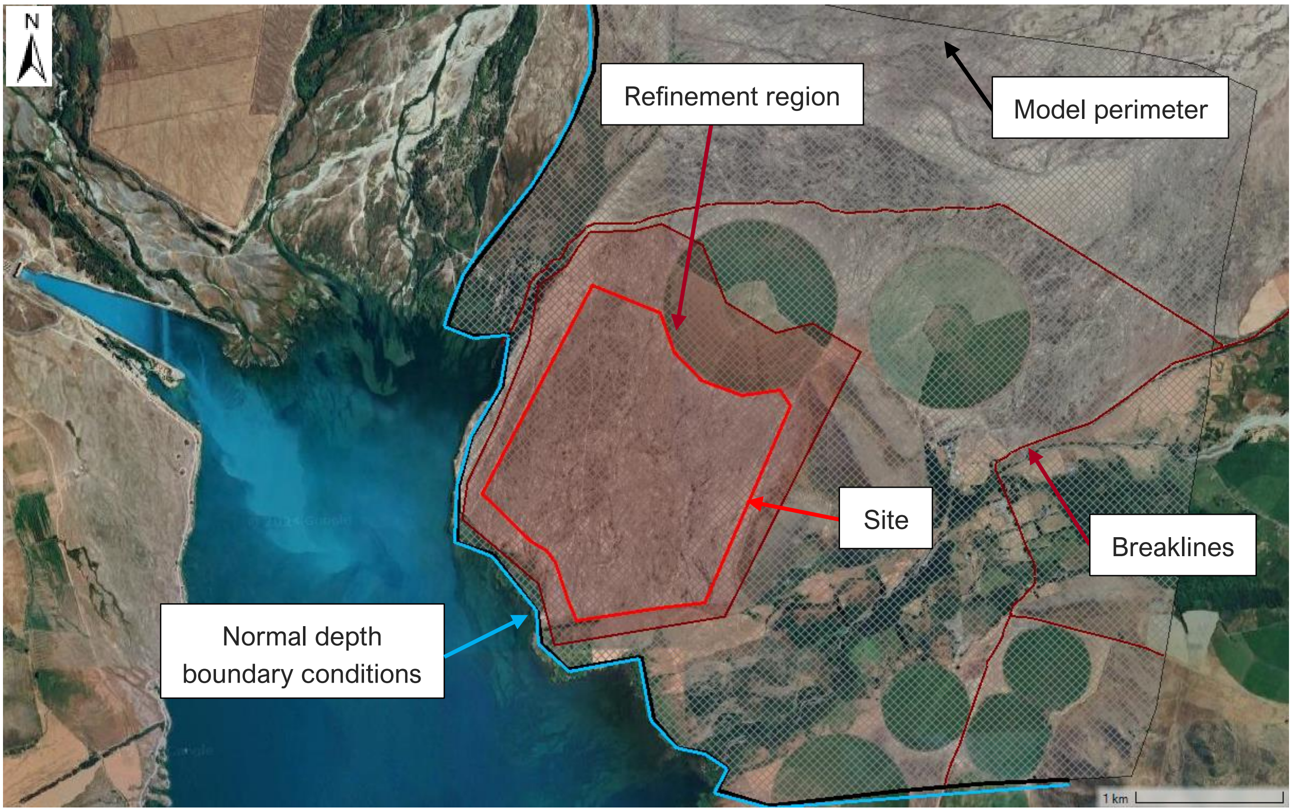


Figure 6-1: HEC-RAS model geometry showing model perimeter, boundary, refinement regions and breaklines (red lines)

6.1 Roughness

We created a Manning's layer within the model where we applied a default Manning's 'n' roughness of 0.035 (Chow, 1959) to represent the poorly vegetated gravel surface which covers most of the catchment (Figure 6-2). The rest of the layer was characterised using the Manning's 'n' values shown in Table A-3, Appendix A.

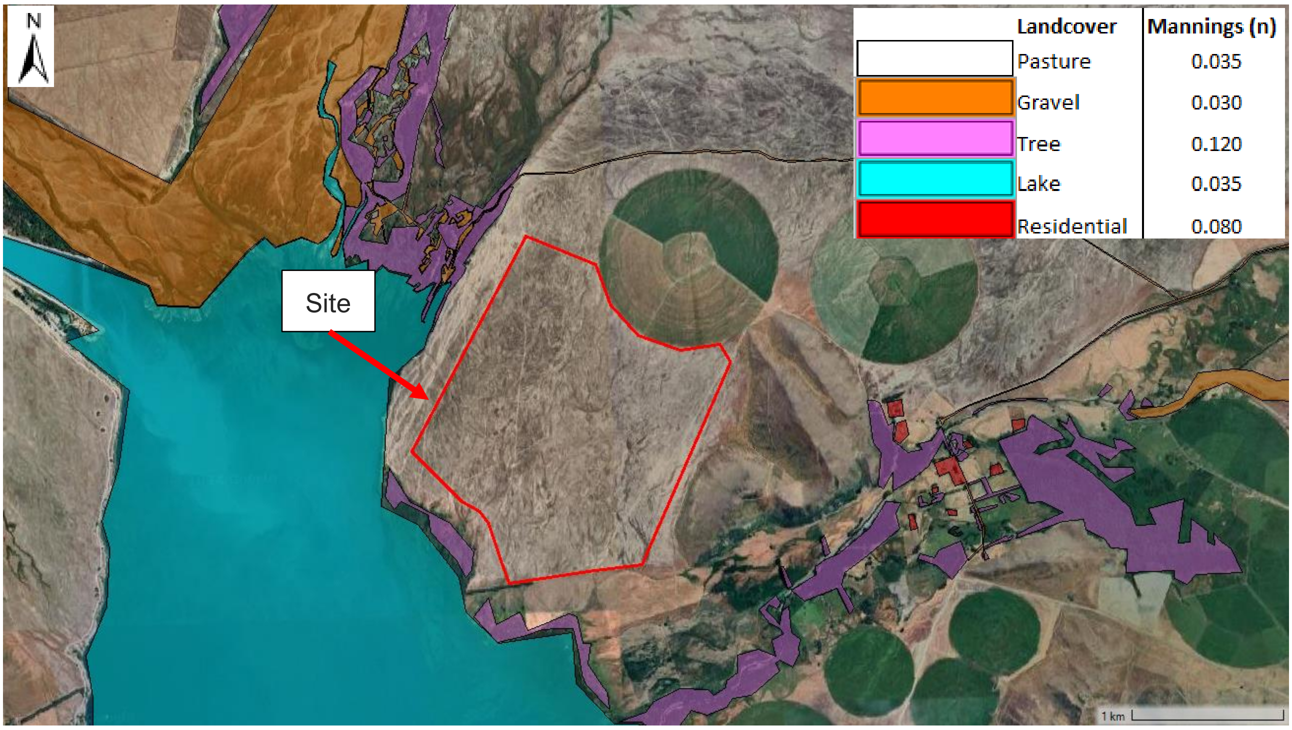


Figure 6-2: Roughness map

7 Results

7.1 General findings

The flooding on site in the 100-year RCP8.5 2060 event is limited to overland flow paths (Figure 7-1) that cross the site, flowing towards the lake. There are three main overland flow path systems of note (No. 1, No. 2 and No. 3 in Figure 7-1). These overland flow paths are following local drainage paths that have developed over a long period of time. These paths are noticeable depressions in the landscape.

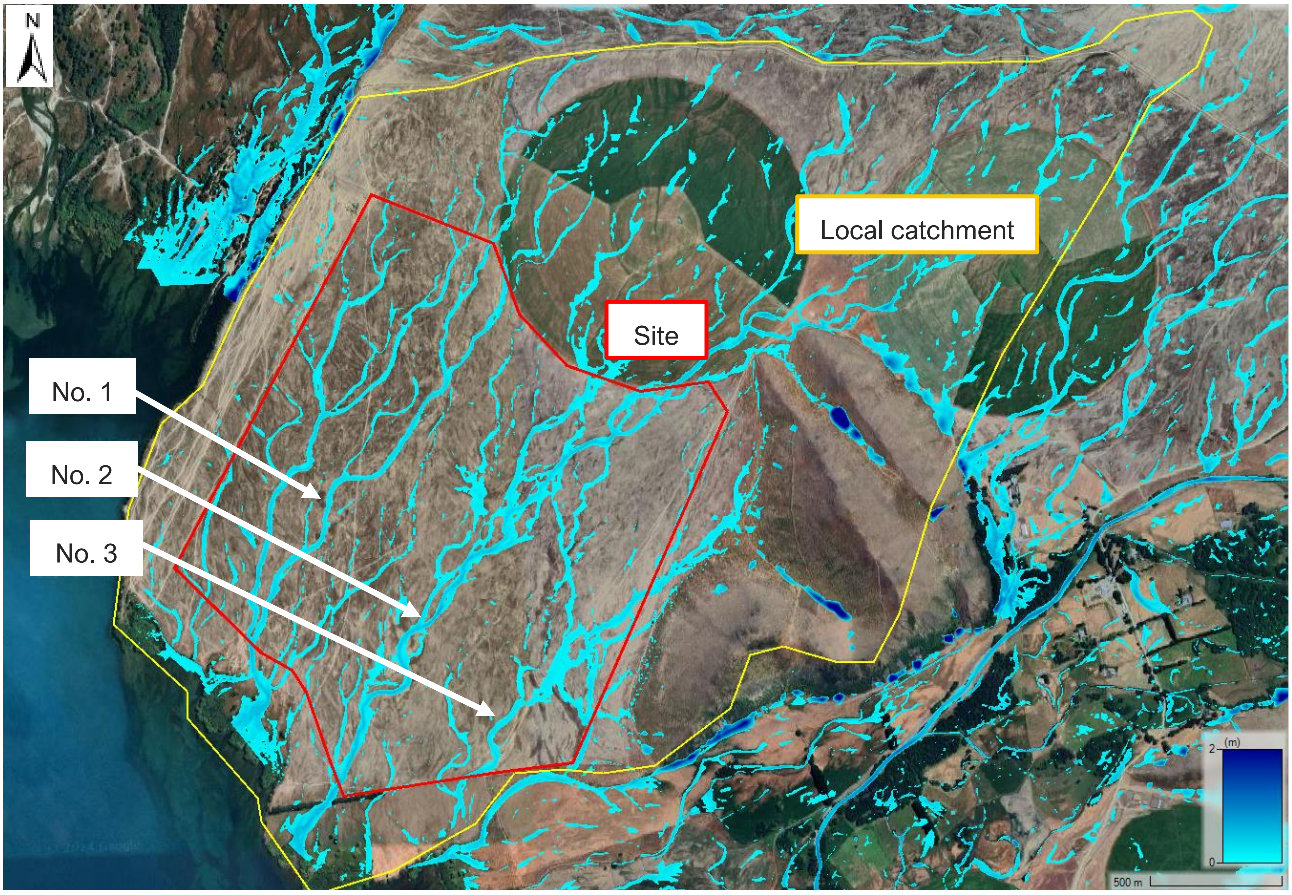


Figure 7-1: 100-year ARI, RCP 8.5 (2060) inundation extent.

7.2 Lake flooding

Lake Benmore has a normal operating range of between 354.91 mRL and 361.11 mRL (NZVD2016), these being the normal minimum control level and the maximum consented storage level respectively (Damwatch Engineering Ltd, 2023). Even with a freeboard allowance of 300mm added, the maximum consented storage level does not reach the lowest part of the site (361.6 mRL) and therefore no specific site design considerations are required to manage the risk of lake flooding for the development (Figure 7-2).

Beyond the maximum consented storage level higher lake levels are possible and hence any residual risk should be assessed. As laid out below normal design practices appear suitable to manage the residual risk.

The critical feature on Benmore Dam (the impounding structure for Lake Benmore) is the top of its low-permeability core, which is 362.6 mRL. A dam operation regime has been developed to prevent this level being exceeded, as above this there is a risk of dam failure (Damwatch Engineering Ltd, 2023). By applying dam operation rules under the Probable Maximum Flood (PMF i.e the largest flood theoretically possible) the maximum water level has been estimated by Damwatch as 361.85 mRL. This level is 0.25 m above the lowest point on the site (Figure 7-3).

Assuming stand heights of at least 0.25 m the residual lake flood risk would not impact solar arrays, even under the worst-case flood scenario.

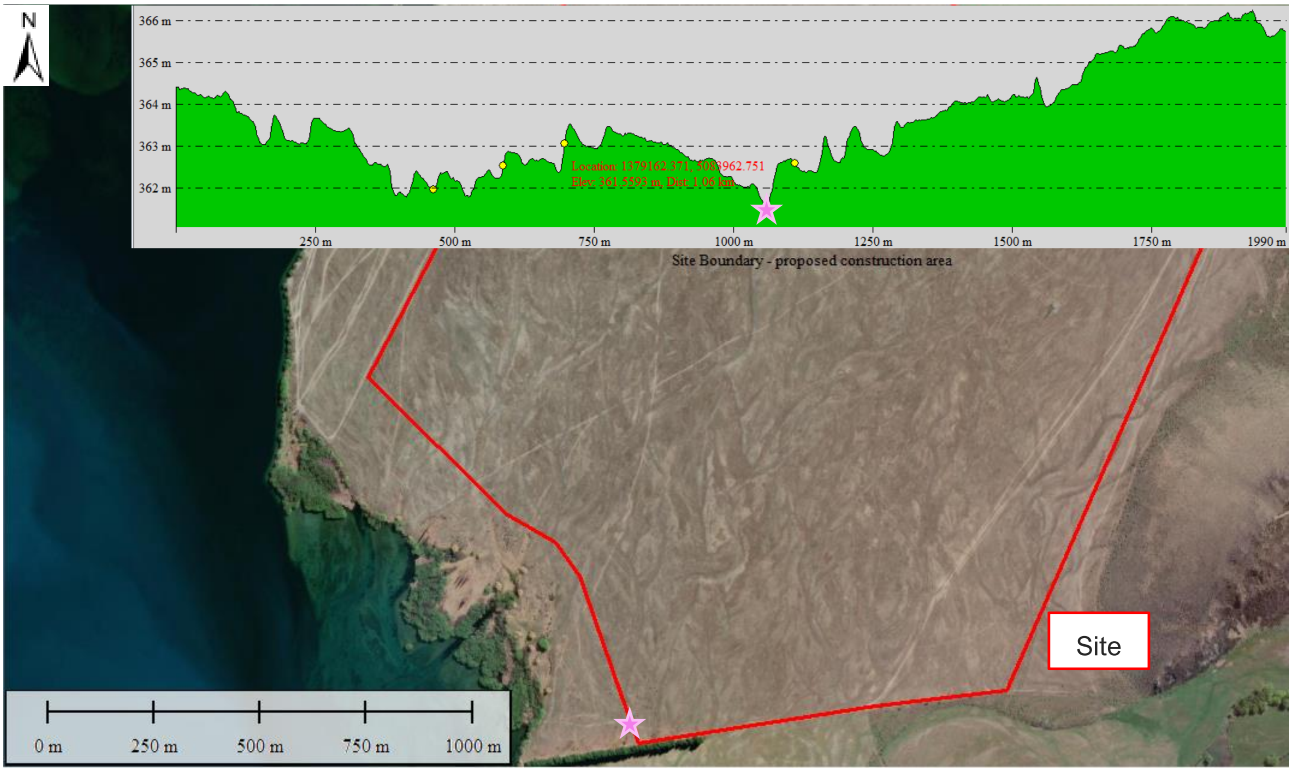


Figure 7-2: Terrain cross section along the site boundary indicating the lowest point on site (pink star)

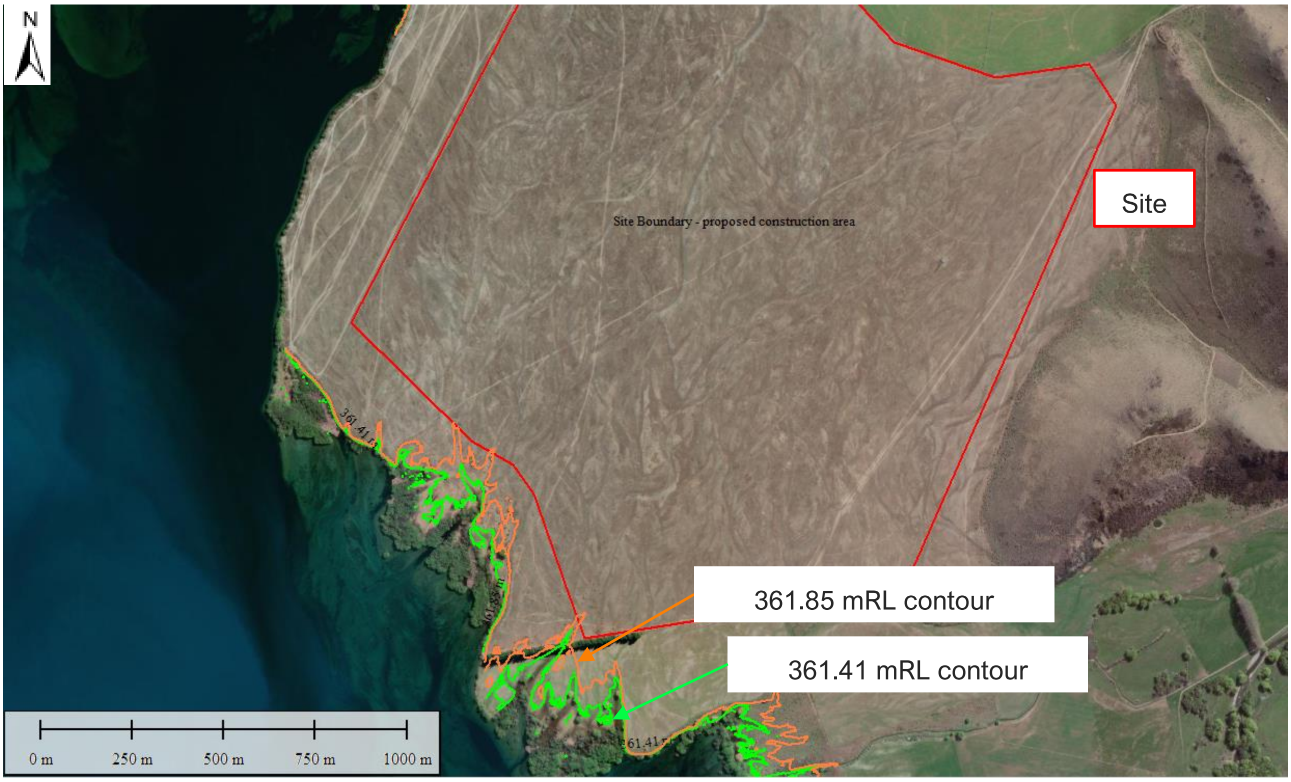


Figure 7-3: The site with the PMF contour (361.85 mRL orange line) and max consented level with freeboard contour (361.41 mRL green line)

7.3 Flood depths and velocities

We have extracted depths and velocities from the model, with a focus on the overland flow paths. These results are presented below (Table 7-1), with Appendix B providing result maps illustrating (1) surface terrain, (2) maximum depth, (3) maximum velocity, and (4) maximum water surface elevation. We have used 5 reporting locations to indicate the conditions around the site (Figure 7-4).

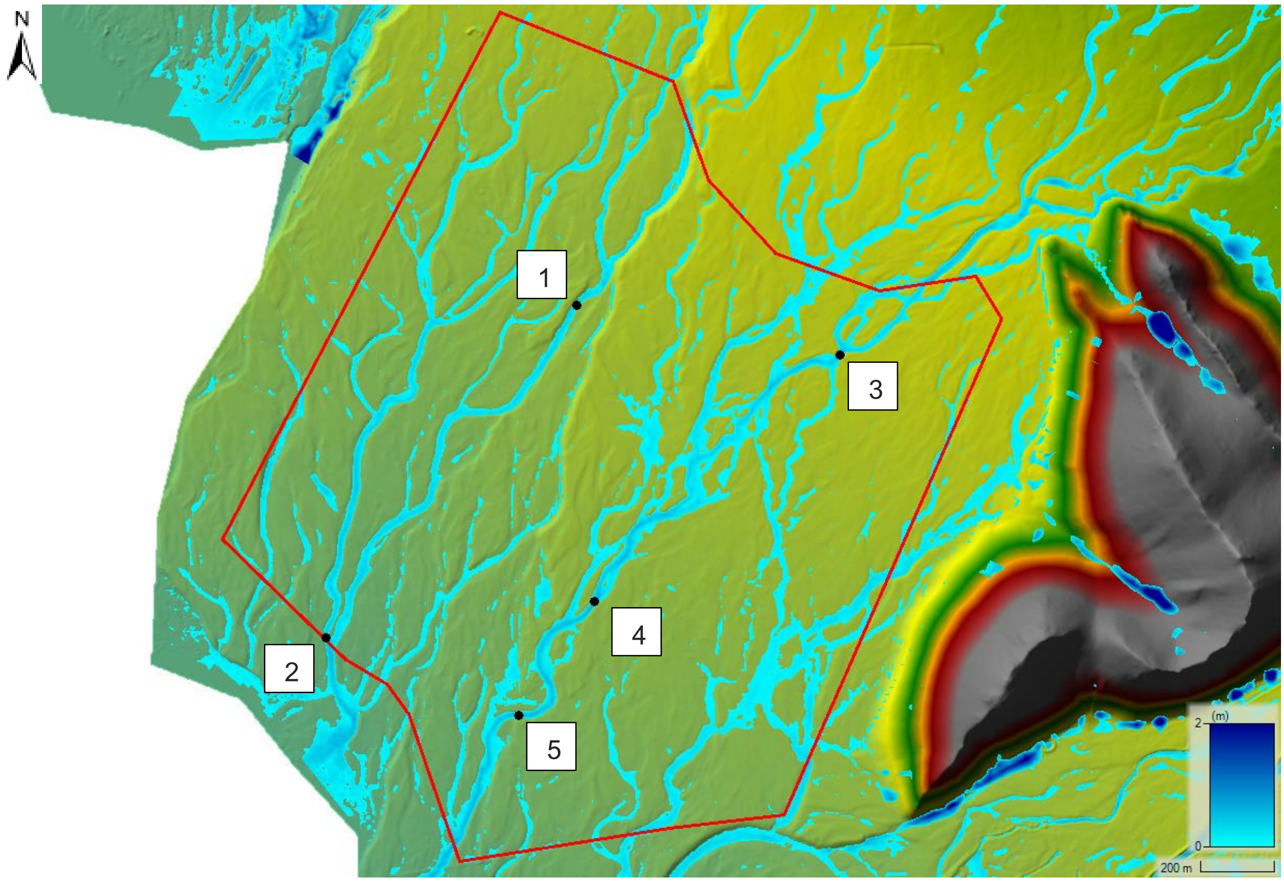


Figure 7-4: Reporting point locations

Table 7-1: Model water level results at specified reporting points (all levels stated use the vertical datum: NZVD 2016)

Return point	Model flood results			
	Depth (m)	Velocity (m/s)	WSE (mRL)	Ground level (mRL)
1	0.37	0.65	368.05	367.68
2	0.48	0.80	362.35	361.87
3	0.48	0.91	372.85	372.37
4	0.69	0.85	367.64	366.95
5	0.50	1.48	364.81	364.31

7.4 Flood hazard

Flood hazard categories integrate the risks posed by water depth and water velocity, as reported above, into a single number that relates to the potential impact on people, vehicles, and buildings. The categorisation used below (Figure 7-5) is from New South Wales government guidance (Department of Planning and Environment, 2022). It describes in general terms the risk to typical urban settings and, whilst not specific to solar installations, is a useful guide as to the hazard at Haldon Station.

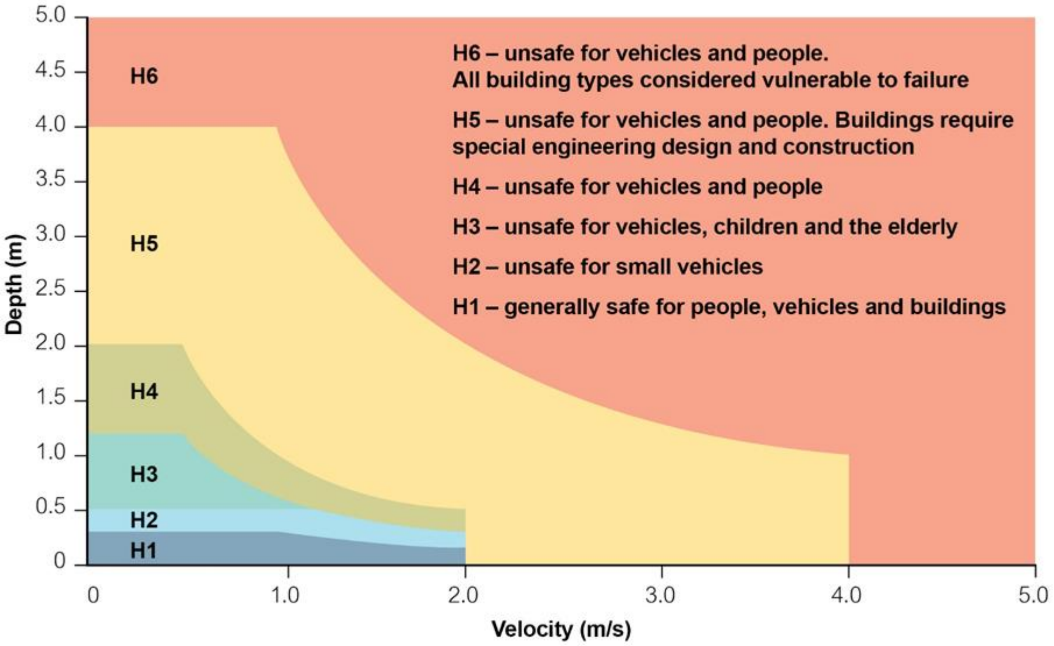


Figure 7-5: General flood hazard vulnerability curve.

We have used this method to define hazard categories at Haldon (Figure 7-6). Most of the site is categorised as no hazard, with areas of H1 to H3 limited to the main overland flow paths (Table 9-4, Appendix B).

Overall, there is a low flood hazard on the site, with small areas of moderate hazard.

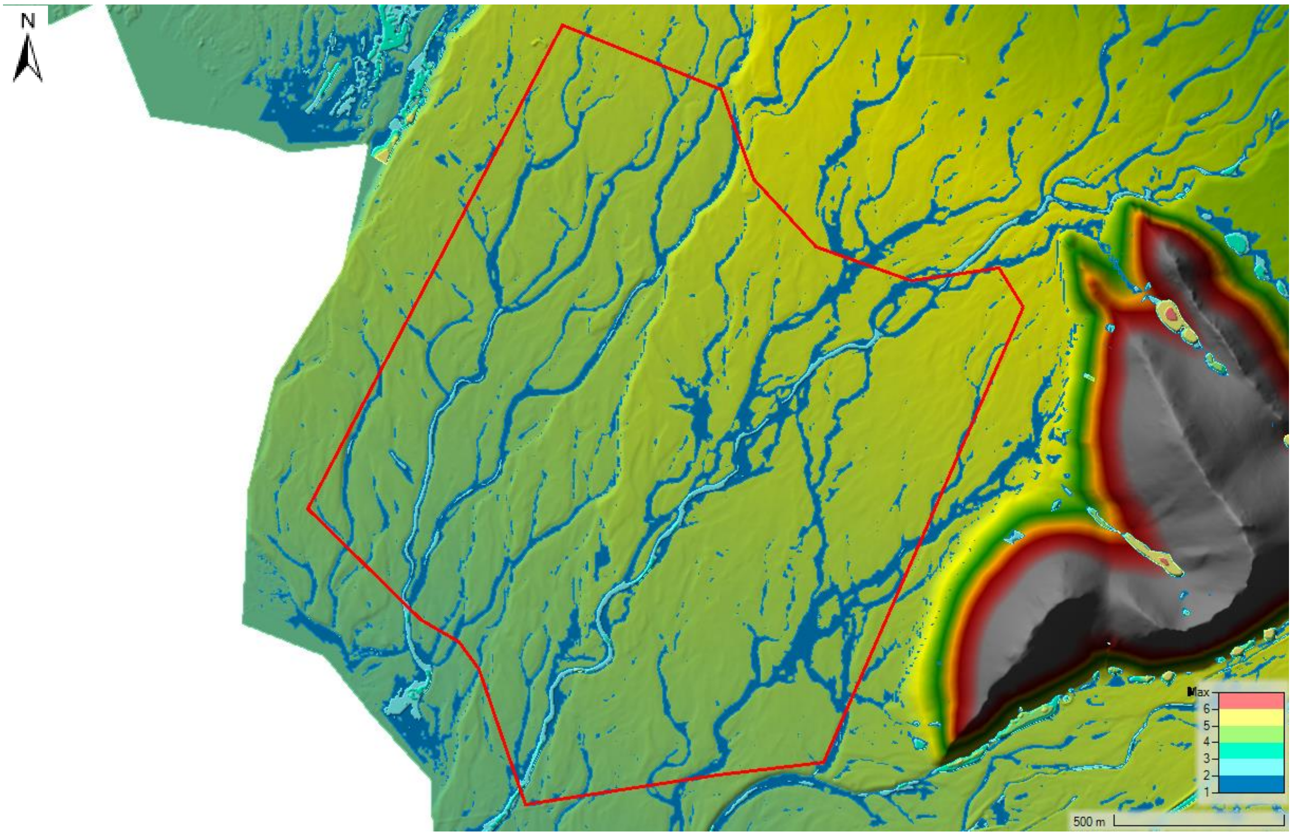


Figure 7-6: Hazard vulnerability classification

7.5 Erosion risk

Water moving quickly through the site can cause erosion of surfaces, both the natural surface and prepared surfaces such as roads and yard areas.

The maximum velocity in our modelling was 1.48 m/s. We have compared this to the erosion susceptibility for various surfaces to determine whether there is an erosion risk (Figure 7-7). For this assessment we have assumed that the maximum velocity would occur for no longer than 5 hours, and that the site surfaces are 'plain grass – poor cover'.

This shows that the maximum velocity on site is not sufficient to cause erosion, even if ground cover was worse than we have assumed. Mass erosion is therefore not a risk that needs to be specifically managed at the site, however small-scale localised erosion should not be ruled out.

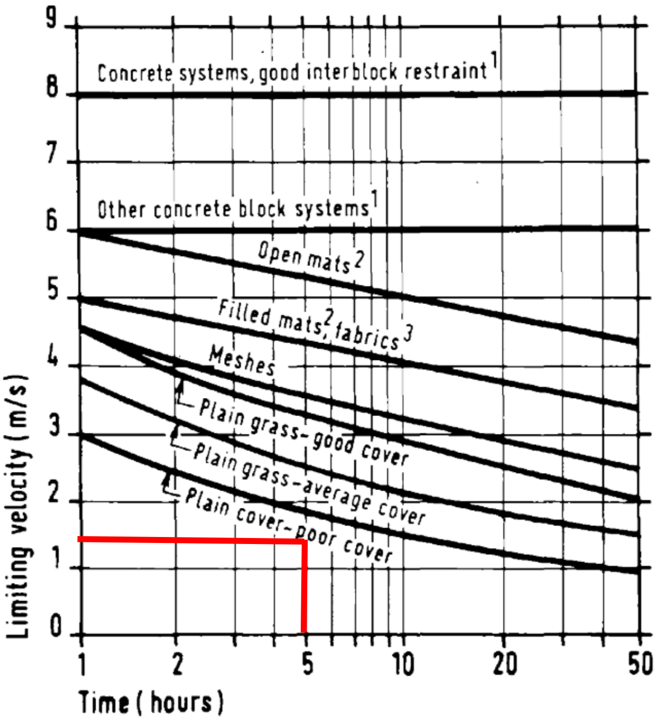


Figure 7-7: Limiting values for erosion resistance of plain and reinforced grass (CIRIA, 1987).

8 Conclusions

8.1 General

Overall, flooding on the site is limited to discrete overland flow paths in the 100-year ARI, RCP 8.5 (2060) event. The majority of the areas inundated experience low water depths and velocities in the design event.

Within the overland flow channels there is an average depth of less than 0.15 m and a maximum depth of 0.69 m. Typical velocities within the flow paths are 0.8-0.9 m/s, with a maximum of 1.48 m/s.

With regard to flood hazard, the majority of the inundated area is categorised as H1 with small areas of risk categories as high as H3 in narrower channels.

Velocities across the site are insufficient to cause mass erosion of grassed surfaces, although localised erosion could occur within parts of the overland flow network.

8.2 Solar farm infrastructure

The following should be considered as part of developing the site design:

1. **Maintain overland flow paths** – The overland flows paths shown should be maintained as part of the site development, and not blocked. Where features such as roads are required to cross overland flow paths consideration should be given to ford crossings, or culverts.
2. **Lake buffer** – The consented lake setback means the design elevation of 361.41 mRL, maximum consented level of the lake plus a 300 mm freeboard, will not encroach the lowest point on site. Residual risk from larger events is not significant, and can be managed by specifying standard solar array stand heights.
3. **Overland flow path buffer** – Where possible equipment should not be placed within the overland flow paths identified. Where this is not possible a minimum elevation for sensitive equipment should be used. We recommend a minimum elevation of the 100-year water level plus and 300mm allowance for freeboard, for sensitive equipment in or adjacent to overland flows paths.
4. **Minimum level of sensitive equipment** – For equipment not within an identified inundation area all water-sensitive equipment should be at least 300mm above ground level.

Due to the sloped nature of the site water surface elevations vary between the top and bottom of the site. It is therefore not practical to set a single minimum design level for the site. To set minimum design levels for water-sensitive equipment across the site the shapefile of water surface elevation produced in the model can be used to set individual minimum design levels across the site. This would need to include a freeboard allowance of 300 mm. Using 300 mm of freeboard assumes there will be no earthworks on site that will influence the flow of water. The freeboard allowance accounts for (1) errors in the base data used, (2) inaccuracies in the modelling, (3) wave action around the site during floods, and (4) afflux caused by structures such as the solar array stands.

Even within the H3 areas the velocities are not sufficient to cause erosion to the surface. Localised erosion may still be possible in areas of loose ground, or around the solar array stands.

Limitations

This modelling estimates flood risk at the proposed site. It is intended to inform the development of the Haldon solar farm by Lodestone Energy Limited and should not be used for any other purpose, nor by any other party.

The model is based on third party rainfall and terrain information. As a conservative approach, the model does not include on-site drainage systems and small culverts which would likely become blocked during significant rainfall events. As discussed in Section 8, a freeboard allowance must be applied to all modelled water levels to derive minimum design levels for the site.

9 References

Chow, V.T. (1959). Open-channel hydraulics: New York, McGraw-Hill Book Co., 680 p. Data accessed from https://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm
Chow, V.T. (1964). Handbook of Applied Hydrology. McGraw-Hill Book Co., New York.
CIRIA (Construction Industry Research and Information Association). (1987). Design of reinforced grass waterways – Report 116, reprinted 2003.

Damwatch Engineering Ltd. (2023). Waitaki Hydro System Revised Flood Rules Commentary. Retrieved from https://www.ecan.govt.nz/do-it-online/resource-consents/notifications-and-submissions/applications-being-heard/meridian-energy-limited/

Appendix A - Tables

Table 9-1: HIRDS v4 rainfall depths.

ARI	Storm Duration							
	10 min	20 min	30 min	60 min	2 hrs	6 hrs	12 hrs	24 hrs
100-year RCP8.5 (2060)	14.9	20.4	24.9	35.0	48.9	79.7	103.5	127.9

Table 9-2: Normal and wet antecedent condition curve numbers for HSG A of 'good' hydrological condition.

Land Cover	CN_{II}	CN_{III}
Forest	43	63
Pasture	49	69
Gravel	76	88
Residential	61	78

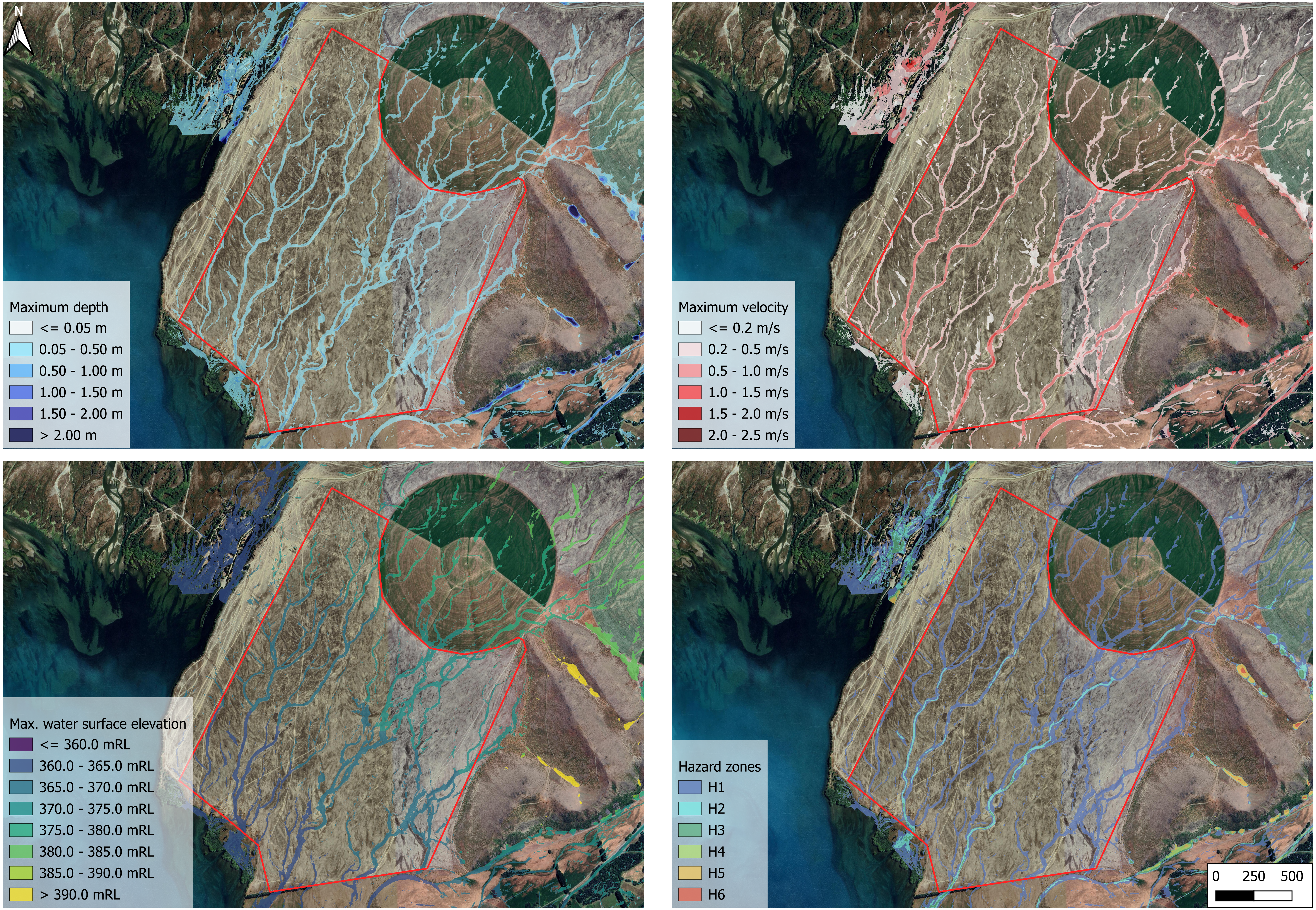
Table 9-3: Manning's 'n' roughness associated with the land cover over the catchment.

Land Cover	Manning's 'n'
Forest	0.12
Pasture	0.035
Gravel	0.03
Residential	0.08

Table 9-4: Hazard vulnerability classification for a 100-year ARI

Reporting points	Depth (m)	Velocity (m/s)	WSE (mRL)	Hazard definition
RP1	0.37	0.65	368.05	H2
RP2	0.59	0.88	362.18	H3
RP3	0.48	0.91	372.85	H2
RP4	0.69	0.85	367.64	H3
RP5	0.50	1.48	364.81	H3

Appendix B - Results Maps



100-year ARI RCP8.5 2060 Scenario