Memorandum

To:	Brent Thomas	**Of:**	Wongan Hills Limited
From:	Dr Jane Alexander	**Date:**	15th November 2022
Reviewed by:	Dr Andrew Dark CPEng	**Job no:**	RD23009
Subject:	**Kaituna Valley flood modelling**		

Executive Summary

Wongan Hills Limited (WHL) engaged Aqualinc Research Limited (Aqualinc) to carry out flood modelling of the Kaituna Valley catchment to predict flooding risk at four proposed composting barns on Kaituna Valley Road.

We carried out steady-state and transient 2D modelling of the lower part of the catchment, based on a conservatively estimated inflow of 131 m^3/s from the upper catchment (200-year ARI + climate change). We also generated flooding depths for an inflow of 175 m^3/s as used by Environment Canterbury (ECan) in preliminary modelling.

We included an inflow from the hill country located north of the proposed barns and modified the terrain to account for the proposed barn platforms and the existing road and swale between the hill country and the barns.

The modelling incorporated an assessment of the sensitivity to the level assumed for Te Waihora at the downstream boundary, the assumed surface roughnesses, and the shape of the flood hydrograph.

The modelling indicated that some shallow inundation (<0.05 m) at the entrance of the platforms for Barns 3 and 4 may occur during a 131 m^3/s event. However, the barn entrances could be protected from inundation by raising the proposed levels at the top of the entrance ramps to provide the additional freeboard required.

1 Background

Wongan Hills Limited (WHL) has engaged Aqualinc Research Limited (Aqualinc) to carry out flood modelling of the Kaituna Valley catchment, to evaluate the flood risk associated with four proposed composting barns located at Kaituna Valley Road.

Environment Canterbury (ECan) had previously carried out steady-state flood modelling using an estimated 200-year average return interval (ARI) flood flow of 175 m^3/s (based on a 2011 flood flow study) at an inflow point upstream of the proposed barns and concluded that there may be inundation risk at the site. This inflow includes a 35% increase to account for climate change.

We have created a 2D surface water flow model for the catchment using HEC-RAS, a river analysis software package. We have used the model to calculate maximum flood levels for the following inflows from the upper catchment:

- A steady flow of 131 m^3/s, based on NIWA flood statistics and Ministry for the Environment (MfE) projections
- A flow event recorded at the Kaituna Valley Road flow recorder in 2021 (peak flow 42 m^3/s)
- The above flow event, scaled to a peak flow of 131 m^3/s
- A steady flow of 175 m^3/s, as used by ECan in preliminary modelling

As well as the inflow from the upper catchment, we incorporated an inflow from the small sub-catchment north of the barns.

We generated flooding depth predictions for a semi-modified terrain which included the existing swale and road adjacent to the proposed barns, and a modified terrain which incorporated the proposed barn platforms as well as the swale and road.

We assessed the sensitivity of the modelled flood levels to the level of Te Waihora/Lake Ellesmere at the downstream boundary, the assumed Manning's n roughness values, and the shape of the flood hydrograph, using a second flow event from 1993.

2 Model settings and assumptions

2.1 Model extent

We used the model extent provided by ECan, which was used in their preliminary modelling of the area. The model extent and locations of the inflows are shown in Figure 2.1. We used the same location as the ECan model for the upper catchment inflow point, which accounts for contributions from the northern part of the catchment, which is not included in the model extent. The hill-country inflow point was placed in the valley upgradient of the barns.

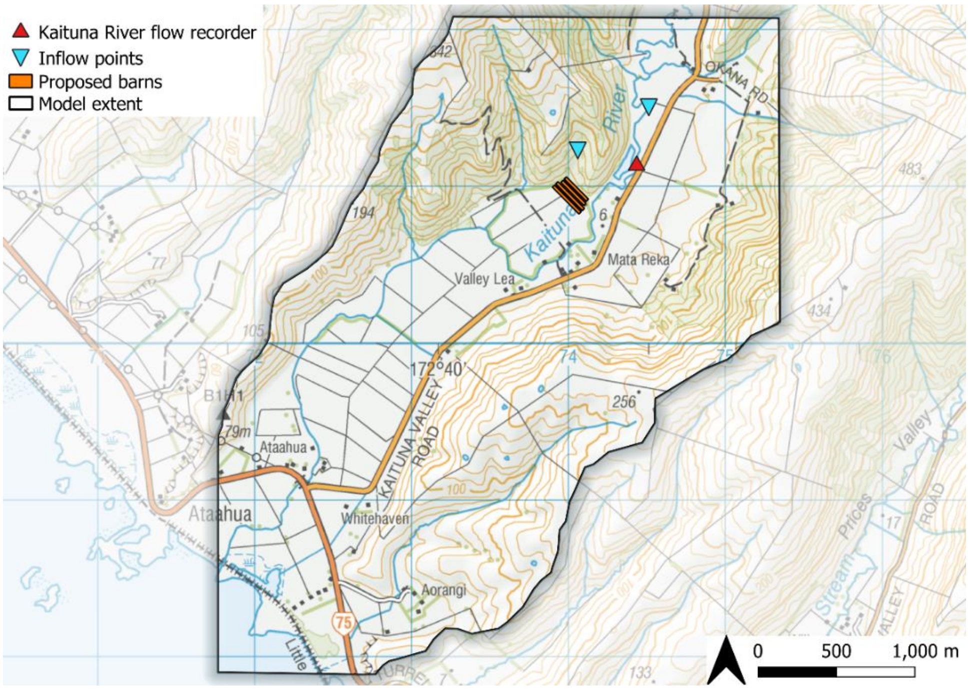

Figure 2.1: HEC-RAS model extent, inflow locations, and proposed barn locations

2.2 Terrain

We used the ground surface layer provided by ECan (*kaituna_3m_crop_Q_model_grid.asc*) to represent the model terrain. The digital elevation model (DEM) provided by ECan was based on a 3-metre grid, and is relative to the New Zealand Vertical Datum 2016 (NZVD2016).

The swale and road which run between the hill-country and the proposed barn platforms were adequately represented in the DEM, except at the location where the swale emerges from the wooded area to discharge into the Kaituna River. These features convey water from the hill-country catchment to the Kaituna River, as shown in Figure 2.2, a photograph which was taken during a flood event corresponding to a peak flow of 42 m^3/s at the Kaituna River flow recorder. As such, we generated a semi-modified model terrain which incorporated the swale and road. We refined the model mesh to a cell size of 0.8 m in the vicinity of the modifications to ensure the geometry was captured by the model.

The actual dimensions of the swale and road were not known. As such, we tuned the dimensions to accommodate the estimated 200-year ARI flow (a flow of 0.6 m^3/s from the hill-country catchment – refer to

Section 2.4). WHL have confirmed that, if necessary, the swale and road cross-sections can be modified as part of the earthworks required to construct the barns. The locations of the centrelines of the swale and road are shown in Figure 2.3. An example cross-section of the swale and road geometry incorporated into the model terrain is shown in Figure 2.4. The true right of the swale is set at a higher level than the road, to allow the road to act as a secondary floodplain during larger flow events. We note that the ground level modifications shown in Figure 2.4 to achieve the cross-sections are likely over-estimated, as the DEM does not currently adequately represent the road or swale.

We have represented the road and swale using simplified geometry due to the unrealistic DEM between the barns and hill-country. **The key specification for the swale and road cross-section is that it should have sufficient capacity to convey a 0.6 m^3/s flow rate.**

Figure 2.2: Photograph of the proposed barn site, showing the swale located to the north-east of the barns during a 2022 flood event. Barn 1 is proposed to run along other side of the shelter belt which borders the swale.

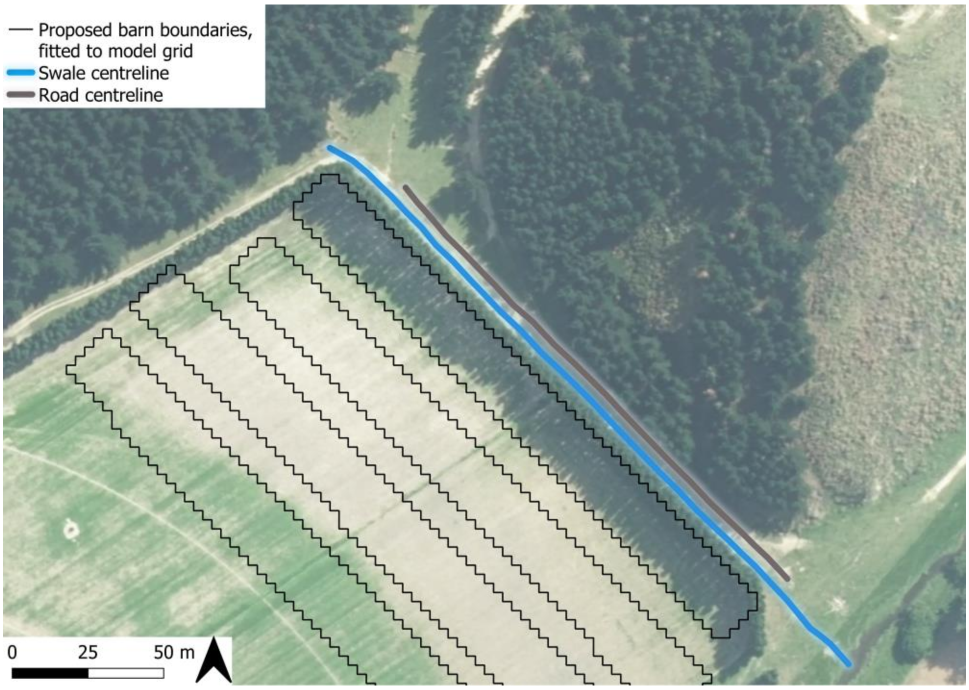

Figure 2.3: Road and swale incorporated into the model terrain

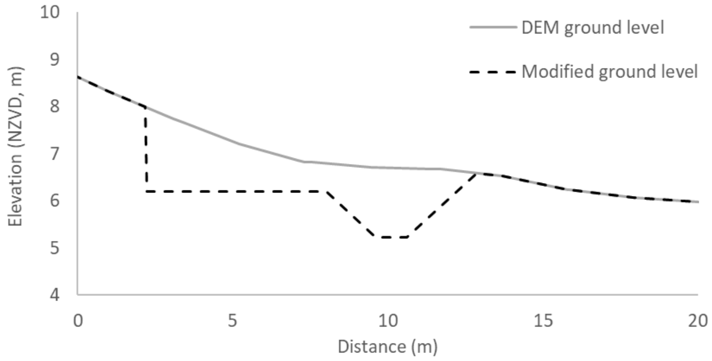

Figure 2.4: Approximate cross-section of the semi-modified terrain incorporating the swale and road, looking downstream

To calculate the flood levels under the barn scenario, we generated a layer representing the elevation at the proposed barn footprints, based on the levels provided. We used this layer to set the post-development model terrain. We based the barn levels on the following information provided by WHL:

- The proposed level of the entrance to Barn 4 (the south-east end) is 5.585 m NZVD2016. There will be a short ramp leading to the platform, which will be at a level of 5.785 m.
- There will be a 0.5% fall along the length of the barn. The upper end of Barn 4 (the north-west end) will be at a level of 6.785 m.
- The barns will be stepped at 150 mm, with Barn 4 being the lowest and Barn 1 being the highest.

Based on this information, we generated levels for the barns at the same grid resolution as the terrain model and set the terrain elevation in the model equal to the proposed platform elevations. The road and swale described previously were also included in the terrain for the modified scenario.

The barn elevations and the change in elevation relative to the unmodified state are shown in Figure 2.5. We added grid refinement to the HEC-RAS model to fit the model grid to the edges of the barn platforms. The largest increase in elevation relative to the existing ground level will be at the north-west end of Barns 3 and 4. The ground level will be lowered relative to the unmodified state at the north-west end of Barn 1.

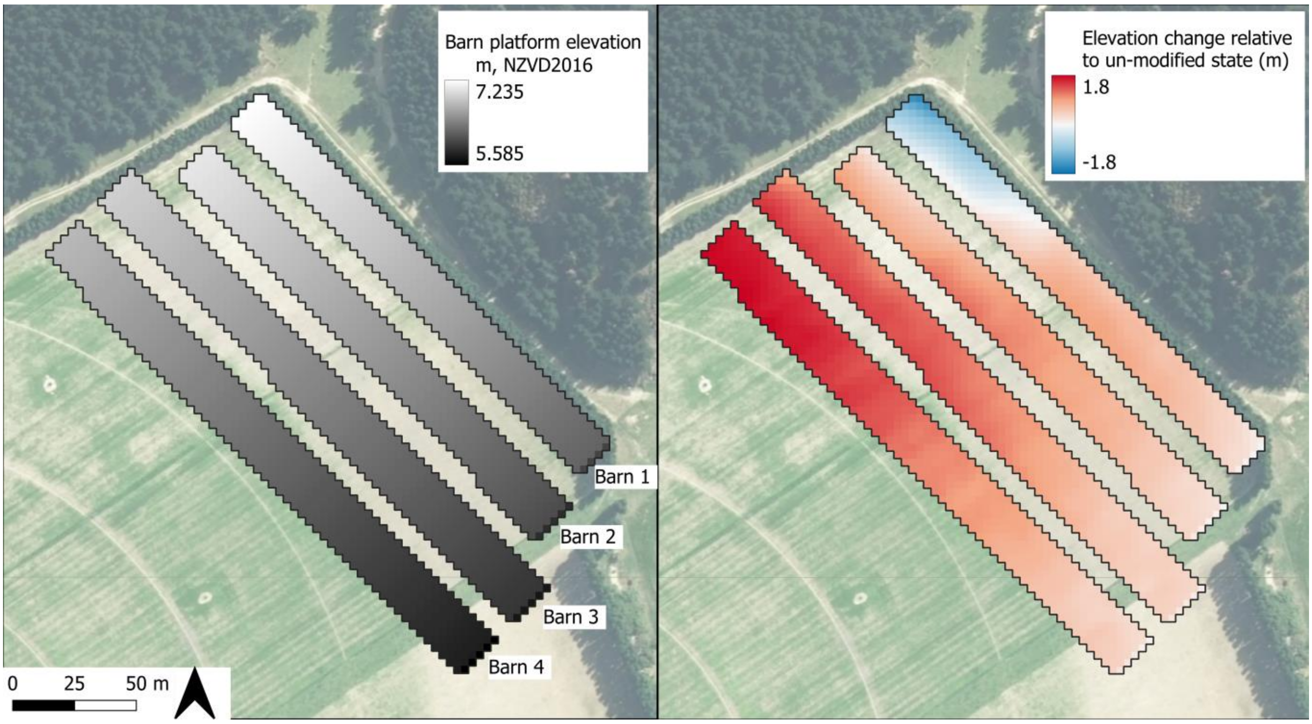

Figure 2.5: Barn platform elevations, and the elevation change at each grid cell relative to the unmodified elevation

2.3 River bed and floodplain resistance

We assigned Manning's n roughness values within the model extent based on visual inspection and the Land Cover Database Version 5 (LCDB5)[1]. Figure 2.6 shows the land cover classes within the catchment. Any unshaded areas were assumed to be pasture. The flooding extent will primarily be affected by the roughnesses assumed for the Pasture, Riparian, and River classes, which cover the valley floor where the majority of the inundation occurs. Table 2.1 summarises the Manning's n roughness values assumed for each land cover type. The values were sourced from previous projects in New Zealand which have related land cover classes from the LCDB5 to Manning's n[2]. We carried out a sensitivity assessment for the assumed values, running model simulations using roughnesses adjusted by ±25%.

Table 2.1: Manning's n roughness values assumed in the surface water model, and adjusted values used in sensitivity testing

Land cover type	Manning's n	+25%	-25%
River	0.04	0.050	0.030
Estuarine Open Water	0.035	0.044	0.026
Pasture	0.07	0.088	0.053
Gorse/Broom	0.14	0.175	0.105
Exotic forest	0.15	0.188	0.113
Broadleaved indigenous hardwoods	0.13	0.163	0.098
Manuka/kanuka	0.13	0.163	0.098
Riparian	0.1	0.125	0.075

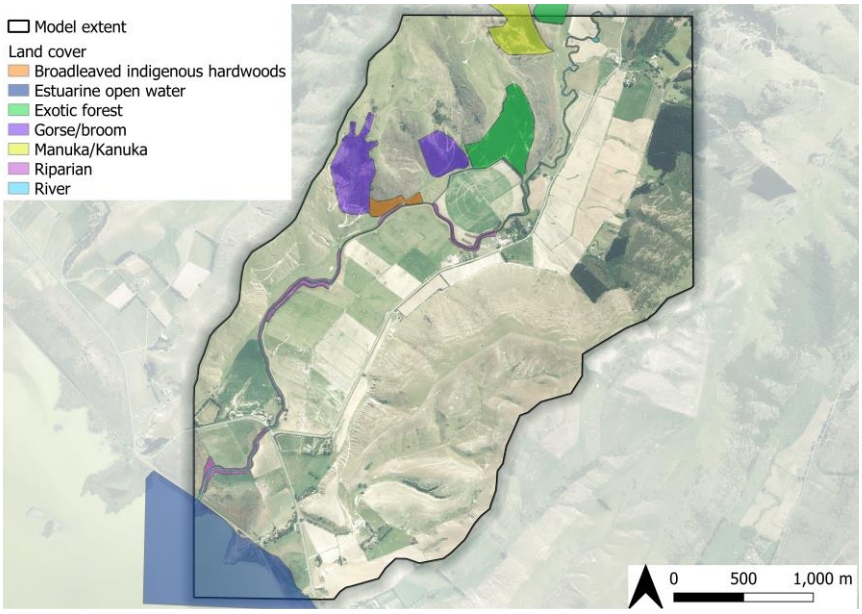

Figure 2.6: Land cover classifications within the model extent. Unshaded areas were assumed to be pasture.

2.4 Flood hydrographs

We investigated four flow scenarios for the inflow from the upper catchment:

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[1] https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/

[2] GHD, 2022. *Stormwater Management Strategy – Plan Change G.* Palmerston North City Council.
Jacobs, 2022. *Hurunui District Multi Hazards – Coastal Inundation Modelling*. Hurunui District Council.
Tonkin and Taylor, 2015. *Coastal Hazard Assessment Report – Appendix F.* Christchurch City Council.

- A steady flow of 131 m³/s
- A flow event hydrograph recorded at the Kaituna Valley Road flow recorder in May/June 2021, with a peak flow of 42 m³/s
- The 2021 flow event hydrograph, scaled to a peak flow of 131 m³/s.
- A steady flow of 175 m³/s

Our assumed peak flow of 131 m³/s was based on NIWA flood statistics[3] and MfE's climate projections guidance[4]. NIWA's New Zealand River Flood Statistics database indicates that the 200 year ARI flow at the Kaituna Valley Road flow recorder is approximately 105 m³/s, with a standard error of 13%. MfE's 2022 climate projections guidance document, based on IPCC6, notes that flood peaks in some NZ rivers may increase by 5 – 10% by 2050 (which is the appropriate timeframe for the consents being applied for). **We have therefore conservatively assumed a peak flood flow of 131 m³/s at the upper catchment inflow point.** This is based on applying the standard error estimate and the upper end of the 2050 climate projection range. We have also included ECan's peak flow of 175 m³/s for completeness, although note that we consider this to be over-conservative.

The inflow hydrograph for the 2021 flow event and the scaled hydrograph are shown in Figure 2.7. We tested an inflow hydrograph in addition to the steady flow used in ECan's preliminary model as a more realistic representation of the flow variation in the catchment during a storm event. We selected the 2021 flow event as the hydrograph was relatively wide, with multiple peaks and a larger area under the hydrograph curve than other high-flow events which have occurred during the flow record. The hydrograph therefore represents a conservative estimate of how flow may vary in the river during a flood event.

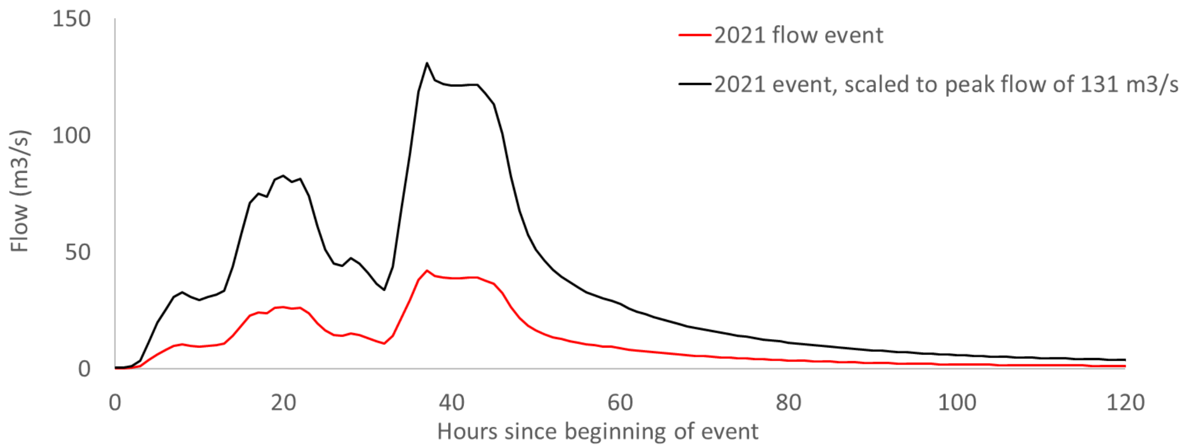

Figure 2.7: Upper catchment flow hydrograph for the 2021 flow event, and corresponding hydrograph scaled to a peak flow of 131 m³/s

As requested by ECan, we incorporated an inflow from the small hill-country sub-catchment north of the proposed barn location. We estimated the catchment area for the hill country at approximately 17.8 ha, compared to the area of approximately 3,915 ha contributing to the upper catchment inflow. We based the hill country inflow hydrograph on the upper catchment inflow hydrograph, scaled by the relative contributing area. A peak flow of 131 m³/s at the upper catchment inflow corresponds to a peak flow of 0.6 m³/s at the hill-country inflow.

2.5 Te Waihora level

To set a downstream boundary condition for the model, we obtained water level monitoring data for the lake levels in Te Waihora from the Kaituna and Seabridge monitoring sites. The Seabridge site replaced the Kaituna monitoring site in 2015. The recorded water levels are shown in Figure 2.8. We conservatively estimated the

[3] https://niwa.maps.arcgis.com/apps/webappviewer/index.html?id=933e8f24fe9140f99dfb57173087f27d (web app providing data from Henderson and Collins (2018))
[4] https://environment.govt.nz/assets/publications/Climate-Change-Projections-Guidance-FINAL.pdf

lake level used in the flood simulation as the 95th percentile level (1.6 m). We tested the sensitivity of this assumption using the mean lake level (1.4 m) and the maximum recorded lake level (2.2 m).

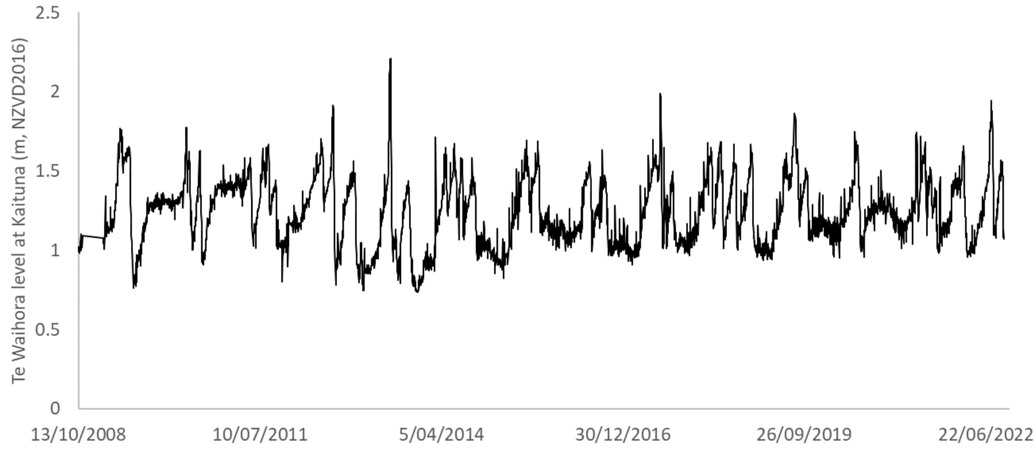

Figure 2.8: Lake levels recorded for Te Waihora at the Kaituna (2008-2015) and Seabridge (2015-2022) monitoring sites

3 Baseline and modified terrain scenarios

3.1 Model execution

The transient flood models were run over a time period of three days (72 hours). We experimented with longer time periods to ensure that the maximum water depths resulting from the flood hydrographs were captured by the model duration. We used a time step of 15 seconds.

We initialised the water levels in the model using the mean flow at the Kaituna River flow recorder over the 36 years of available record (0.5 m^3/s).

Baseline scenarios using the un-modified terrain were run as part of the model set-up. This included a sensitivity assessment. The assessment did not suggest that the peak flooding depths predicted at the barns were significantly sensitive to the Te Waihora lake level, Manning's n roughnesses assumed, or hydrograph shape.

3.2 Semi-modified terrain scenario

We carried out a semi-modified terrain scenario which included the road and swale but not the barn platforms. We used an assumed lake level of 1.6 m and the assumed Manning's n roughness values to generate peak flooding depths for the 2021 hydrograph and the 2021 hydrograph scaled to a peak flow of 131 m^3/s. Figure 3.1 and Figure 3.2 show the predicted maximum flooding depths for these scenarios. Note that the grid in the vicinity of the swale and road, which was refined for modelling, has been generalised to the 3-metre model grid for mapping.

The swale diverts the flow originating from the hill-country catchment into the Kaituna River. Flow was generally located in the swale during the flood event, though some wetting of the road occurred as water flowed across or along the road into the swale. During the 131 m^3/s peak flow event, some inundation of the proposed barn sites was predicted due to overflow from the Kaituna River.

Note that the model results for the 2021 flood hydrograph are consistent with the photographs of the site from the 2022 flood event – i.e., flow from the small sub-catchment is captured by the existing swale and does not cross the proposed barn site.

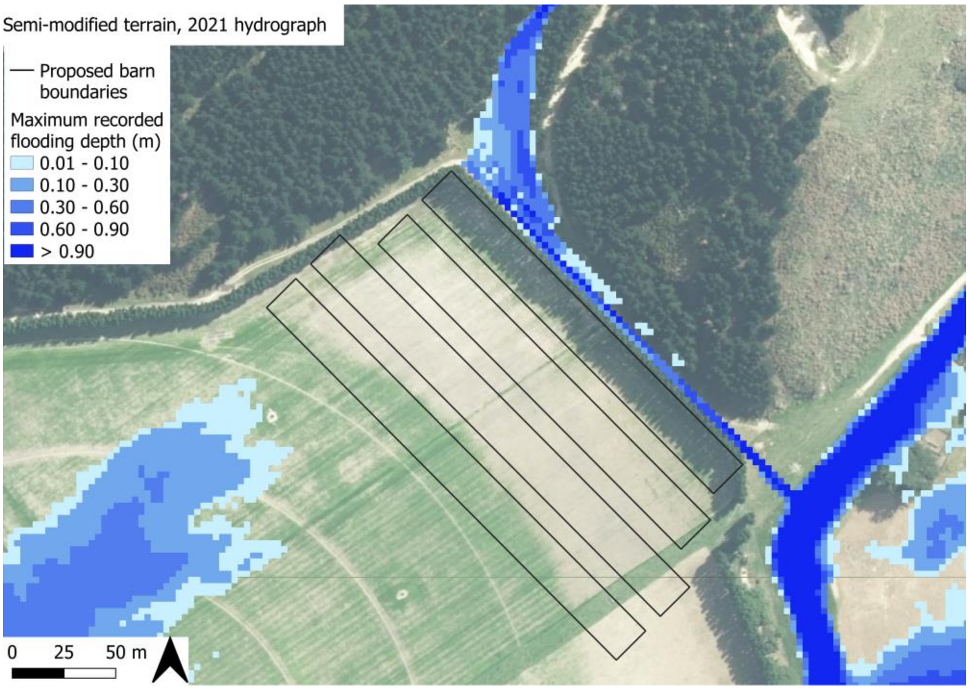

Figure 3.1: Modelled maximum flood depths for the 2021 hydrograph, with terrain including the swale and road but not including the barn platforms

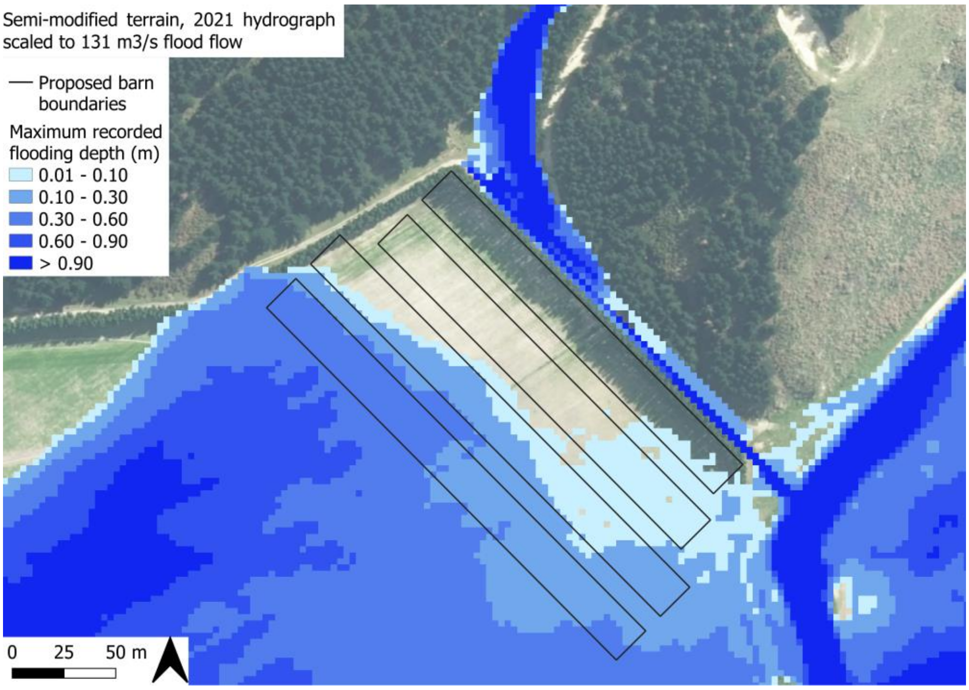

Figure 3.2: Modelled maximum flood depths for the 2021 hydrograph scaled to a peak flow of 131 m3/s, with terrain including the swale and road but not including the barn platforms

3.3 Modified terrain scenarios

Using the barn-modified terrain, an assumed lake level of 1.6 metres, and the assumed Manning's n roughness values, we generated flooding depths for a steady 131 m^3/s inflow, the 2021 flood hydrograph scaled to a peak flow of 131 m^3/s, the 2021 flood hydrograph, and a steady 175 m^3/s inflow. The hill country inflow for each of these scenarios was scaled based on the relative contributing area.

Figure 3.3, Figure 3.4, Figure 3.5, and Figure 3.6 show the modelled maximum flooding depths in the vicinity of the proposed barns for the inflow scenarios listed above. Note that the grid in the vicinity of the swale and road, which was refined for modelling, has been generalised to the 3-metre model grid for mapping.

The structure of the composting barns means that if flooding on the ramp overtops the level at the top of the ramp, water will enter the composting area, which is 800 mm below the level of the top of the ramp. The row of grid cells at the south-east end of each barn corresponds to the ramp. The levels of the ramp cells in the model were set to the proposed level of the toe of the ramps. The second row of grid cells is set to the level of the top of the ramp (0.2 m above the toe). If there is wetting at the second row of grid cells, it means the ramp has overtopped and there is a risk of flooding within the barns. Table 3.1 summarises the predicted maximum depth at the top of each proposed barn ramp under the inflow scenarios, except the 2021 hydrograph scenario which did not predict any flooding on the barn ramps.

For a peak flow of 131 m^3/s, additional freeboard was only required for Barns 3 and 4. The required additional freeboard was 0.043 m for Barn 4 and 0.018 m for Barn 3 under a steady 131 m^3/s flow event, and 0.031 m for Barn 4 only under a transient 131 m^3/s event.

The mapping shows that the road and swale caused flow from the hill country to be directed towards the main channel of the Kaituna River, rather than to the south-west across the centre-pivot area, providing adequate protection for the cut section of Barn 1. For the steady 131 m^3/s, minor wetting is shown at one grid cell on the barn platform. The height of the wetting was approximately 6 cm. We note that a 40 cm smooth concrete wall will be constructed around the boundary of the barn platform, which will not be overtopped by the minor wetting.

Table 3.1: Peak depth at the top of the ramp of proposed barns for the inflow scenarios with modified terrain. Wetting at the top of the ramp means that water may overtop the ramp and enter the barn.

Barn	Steady, 131 m^3/s	Scaled 2021 hydrograph	Steady, 175 m^3/s
1	-	-	**0.113**
2	-	-	**0.157**
3	**0.018**	-	**0.206**
4	**0.043**	**0.031**	**0.260**

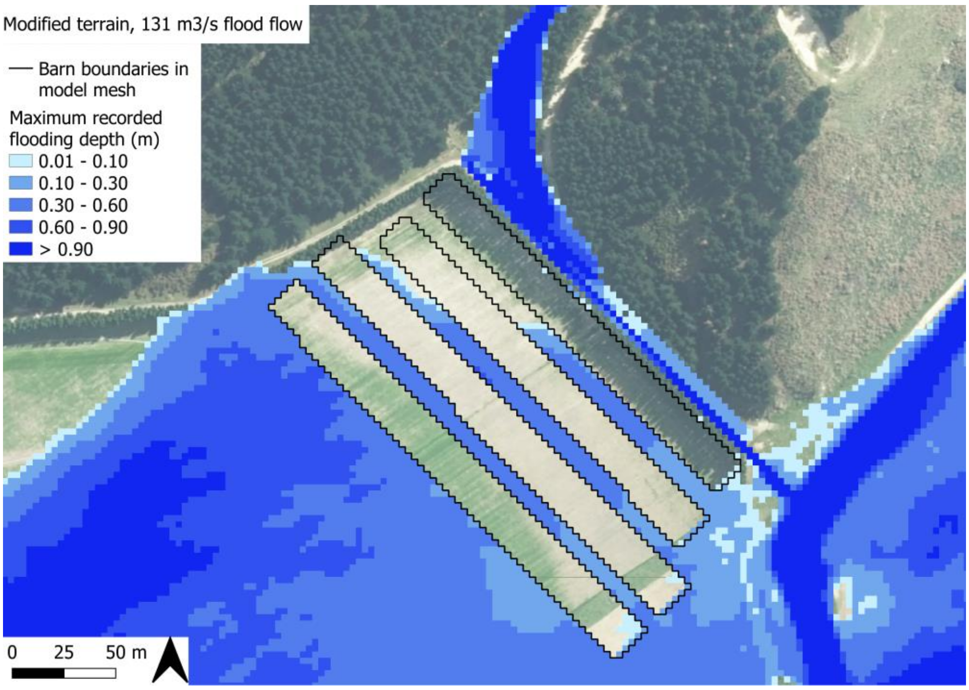

Figure 3.3: Modelled flood depths for a 131 m^3/s steady flood flow, with modified terrain

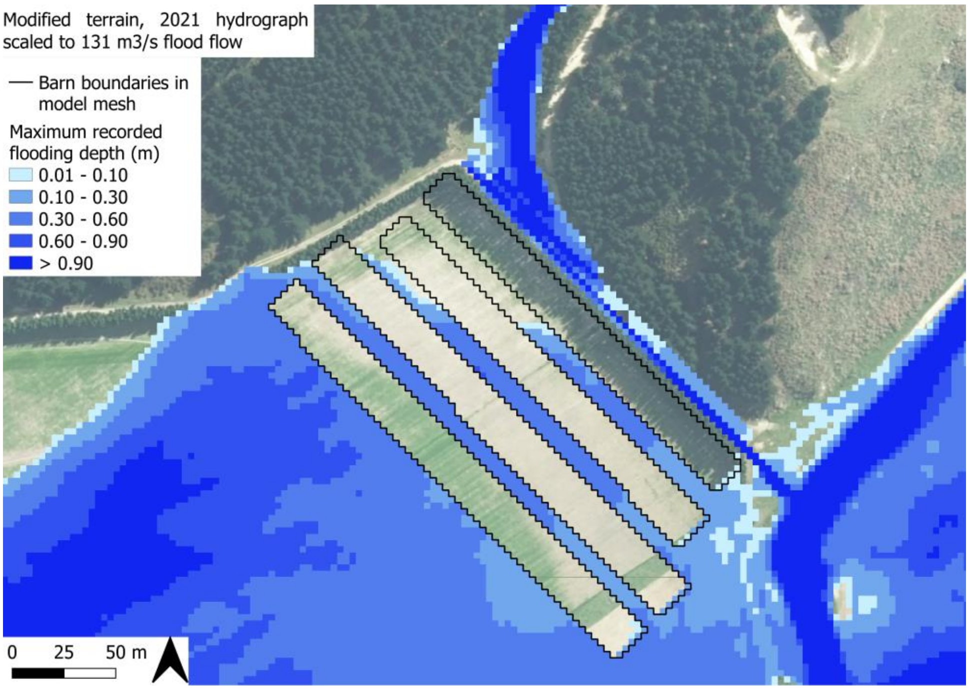

Figure 3.4: Modelled maximum flood depths for the 2021 hydrograph scaled to a peak flow of 131 m^3/s, with modified terrain

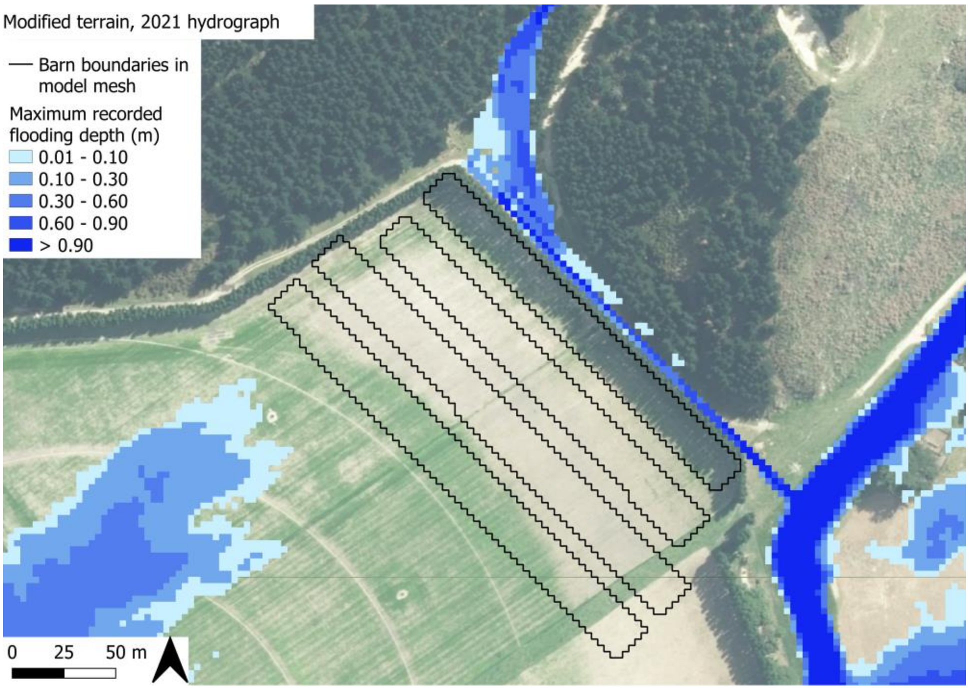

Figure 3.5: Modelled maximum flood depths for the 2021 hydrograph, with modified terrain

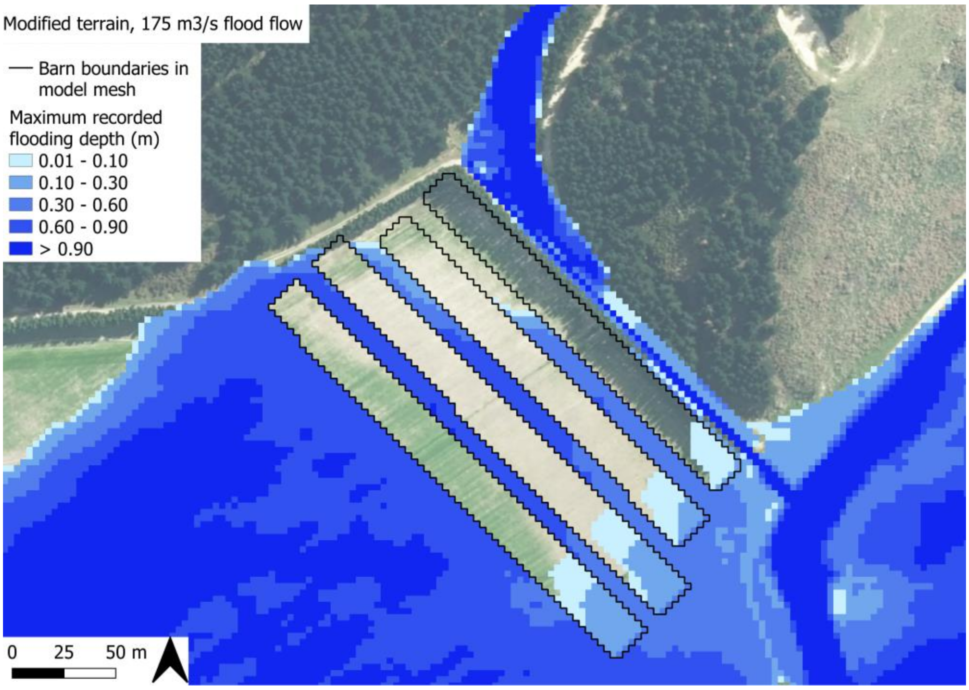

Figure 3.6: Modelled flood depths for a 175 m^3/s steady flood flow, with modified terrain

4 Conclusions

We carried out steady-state and transient 2D modelling of the lower part of the catchment, based on a conservatively estimated inflow of 131 m^3/s from the upper catchment (200-year ARI + climate change). This inflow was estimated by interpolating data from NIWA's New Zealand River Flood Statistics database to estimate the 200-year ARI flow at the Kaituna Valley flow recorder. We incorporated the standard error referenced in the NIWA database and an allowance for climate change based on MfE's 2022 climate projections guidance document. We also generated flooding depths for an inflow of 175 m^3/s as used by ECan in preliminary modelling.

Based on the modelling completed for the semi-modified terrain and modified terrain for a range of flood scenarios, we have drawn the following conclusions:

- Without flood flow protection, the north-west corner of Barn 1 may be subject to inundation, as ground surface mapping indicates that a cut will be required to achieve the proposed platform level. WHL have confirmed that it will be possible to modify the cross-section of the existing road and swale as part of the earthworks if necessary to protect this corner.

- The DEM does not adequately represent the road and swale between the hill-country and the barns, which routes flow into the Kaituna River. We have used a simplified geometry to represent these features, and we note that the key requirement of the road and swale is that the cross-section has a capacity of approximately 0.6 L/s to convey outflow from the hill-country catchment past the barns.

- For the terrain including the barn platforms, road, and swale and a 131 m^3/s flood (200-year ARI + climate change), shallow inundation was predicted over sections at the entrances of Barn 3 and 4. The inundation within the barn platforms (the composting area), may be overcome by raising the level of the top of the barns' entrance ramps by less than 0.05 m.

- The conclusions hold within the sensitivity ranges tested with regard to the Te Waihora water level, the hydrograph shape, and Manning's n. Of these, the model is most sensitive to the assumed Manning's n; a higher Manning's n may result in additional flooding at the south-east end of the barn platforms.