Otago Regional Council

TAIERI GORGE RAILWAY CULVERT FLOODWATER CONVEYANCE ASSESSMENT

FINAL REPORT

24 APRIL 2024

PUBLIC

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FINAL REPORT

Otago Regional Council

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REV	DATE	DETAILS
0	15/03/2024	Draft for client review
1	24/04/2024	Issued as final, revised from client comments

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EXECUTIVE SUMMARY

WSP was commissioned by Otago Regional Council (ORC) to investigate floodwater conveyance of March Creek through Middlemarch, with a particular focus on the Taieri Gorge Railway culvert.

A hydraulic model was developed representing March Creek through Middlemarch and the wider contributing catchment. The creek through Middlemarch has been represented in detail based on survey data of the creek cross section and bridges. The catchment model is less detailed, relying predominantly on geospatial inputs.

Radar-derived rainfall data was reviewed, which confirmed there is substantial variation in rainfall cross the catchment area contributing to March Creek. The highest rainfall is observed in the upper catchment along the ridge of the Rock and Pillar range, with lower depths recorded in the plains.

Three historical events were used to validate the hydraulic model, including:

- 1 January 2021 (estimated Average Recurrence Interval (ARI) of 40-100 years)
- 3 March 2021 (estimated ARI of less than 2 years)
- 28 May 2021 (estimated ARI of 2 - 5 years)

The capacity of March Creek was assessed for the 2 and 20 ARI design storms and the wider catchment was assessed for the 2 and 50 year ARI storms. This investigation concluded the following:

- The railway culvert was confirmed to be a constraint in March Creek affecting floodwater conveyance through Middlemarch. The Tawe Street bridge directly upstream also presents a constraint.
- For larger rainfall events, such as the 20 year ARI event, floodwater conveyance of March Creek through Middlemarch is limited by capacity of the creek and other structures in the creek. This has been confirmed by running model scenarios with the railway culvert and Tawe Street bridge removed.
- Under existing conditions, the water level in March Creek downstream of the railway culvert does not substantially affect conveyance through Middlemarch during large rainfall events.
- The catchment model shows Dewar Creek overtops its banks and contributes to March Creek during large rainfall events. This was predicted by the model for historical 1 January and the 50 year ARI design storm.
- The catchment model predicts March Creek overtops its banks upstream of the State Highway 87 bridge during large rainfall events (downstream of the inflow from Dewar Creek). This flow runs overland across properties before re-entering March Creek downstream of the Tawe Street bridge.

The following recommendations are made for the next stages of this project to address flooding issues along March Creek:

- Further modelling should be completed to assess if increases to structure capacity (railway culvert and Tawe Street bridge) are feasible and provide a substantial reduction in flood risk in Middlemarch.

- The assessment of increased structure capacity should consider the downstream implications of increased flows. It is recommended further survey of the downstream creek and bridges is undertaken so they can be accurately represented in the model for this assessment.

The following recommendations are made for the next stages of this project to investigate flooding in the wider catchment contributing to March Creek:

- Further survey should be undertaken to improve the model's representation of the capacity of March Creek and Dewar Creek upstream of Middlemarch, with a particular focus on the locations where they are predicted to overtop their banks during large rainfall events.
- Hydrological inputs to the model should be refined to better represent the observed variation in rainfall across the catchment and runoff during wetter periods (ex: validation event 3). When developing flooding mitigation options, the effects of climate change should be incorporated into these inputs.
- Opportunities attenuating runoff in the upper catchment should be investigated (such as reforestation, check dams and contour trenching).
- When refining the catchment model, the model should be expanded to include all creeks that may contribute overland flow through Middlemarch (ex: Browns Creek catchment).

PLAIN ENGLISH SUMMARY

WSP was commissioned by Otago Regional Council (ORC) to investigate the floodwater conveyance capacity of March Creek through Middlemarch, with a particular focus on the Taieri Gorge Railway culvert.

A hydraulic model was developed to represent flows in March Creek and the wider contributing catchment during large rainfall events. Modelling has identified the following issues as the likely causes of historical flooding adjacent to March Creek:

- The railway culvert was confirmed to be a restriction in the creek, resulting in upstream flooding through Middlemarch. The Tawe Street bridge directly upstream of the railway culvert is also a constraint.
- During large rainfall events, floodwater conveyance through Middlemarch is limited by capacity of structures along March Creek and the capacity of the creek itself.
- In the upper catchment, modelling predicts Dewar Creek overtops its banks during large rainfall events and contributes flow to March Creek. Downstream of this inflow, modelling predicts March Creek overtops its banks and flows outside of the main channel towards Middlemarch. This flow runs overland across properties before re-entering March Creek downstream of the Tawe Street bridge.

It is recommended that further modelling is completed to assess if increasing capacity of the railway culvert and Tawe Street bridge leads to a substantial reduction in flood risk and does not result in an increased flood risk downstream.

The recommended next steps for investigating flooding in the wider Middlemarch area include:

- Further survey should be completed and the model updated to improve the accuracy of the creeks upstream of Middlemarch, with a focus on areas where the creeks are predicted to overtop during large rainfall events.
- A detailed analysis of rainfall variation across the catchment area contributing to Middlemarch should be completed to ensure that any improvements to reduce flood risk account for this variability.
- Opportunities for reducing peak runoff in the upper catchment should be investigated to reduce downstream flood risk (such as reforestation, check dams and contour trenching).
- The model should be expanded to include all catchments that may contribute to the Middlemarch area during large rainfall events.

1 INTRODICTION

1.1 PURPOSE

WSP has been commissioned by Otago Regional Council (ORC) to investigate floodwater conveyance of March Creek through Middlemarch, with a particular focus on the Taieri Gorge Railway culvert. Heavy rain events have flooded multiple properties near the creek, and there is a perception by some landholders that the railway culvert may be a constraint affecting floodwater conveyance.

The assessment described in this report will support the development of options to mitigate the flood hazard in this area.

1.2 SYSTEM DESCRIPTION

The March Creek catchment drains the Rock and Pillar Range, flowing southeast across the Strath Taieri, through the township of Middlemarch and outletting to the Taieri River. The extent of the March Creek catchment is shown on Figure 1-1.

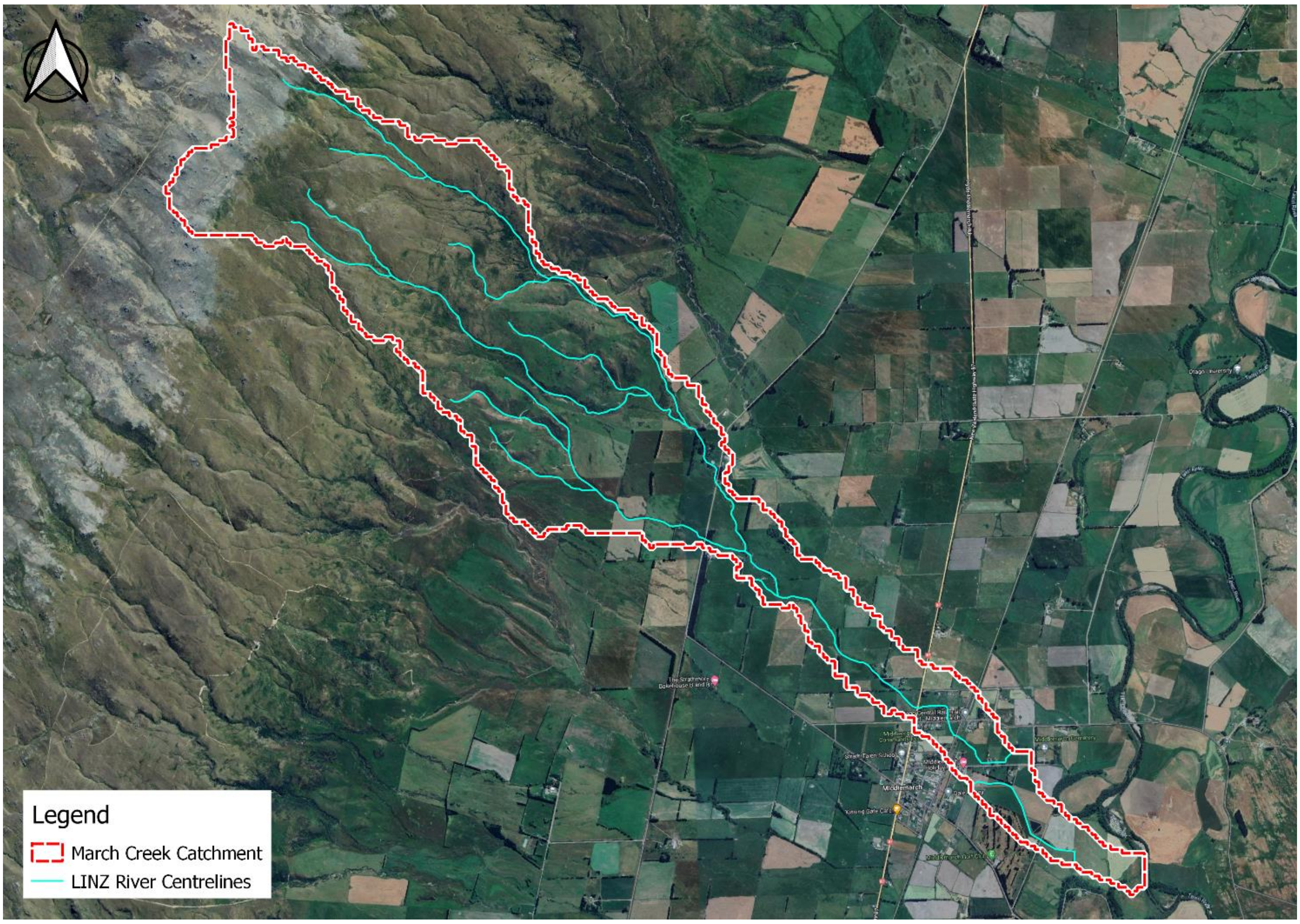

Figure 1-1: March Creek Catchment Area

March Creek's catchment area at its outlet to the Taieri River is approximately 9.4 km^2. The upper catchment consists primarily of alpine tussock. Several gullies with scrub vegetation lead into flat plains, which are utilized as farmland. The two main branches of March Creek combine into a single channel downstream of Gladbrook Road from where the creek flows to the Taieri River.

There are several built structures crossing the creek, including road crossings at Gladbrook Road, State Highway 87, Cardigan Street, Tawe Street, Mold Street, Cemetery Road and the railway line crossing.

Figure 1-2 shows detail of March Creek through Middlemarch, which is the focus of this investigation. Of particular note, there is a high flow diversion of the creek downstream of the railway culvert. This diversion is controlled by a manual gate which is closed to divert flows away from Mould Street during high flow events. This diversion rejoins the main March Creek channel before the Cemetery Road crossing.

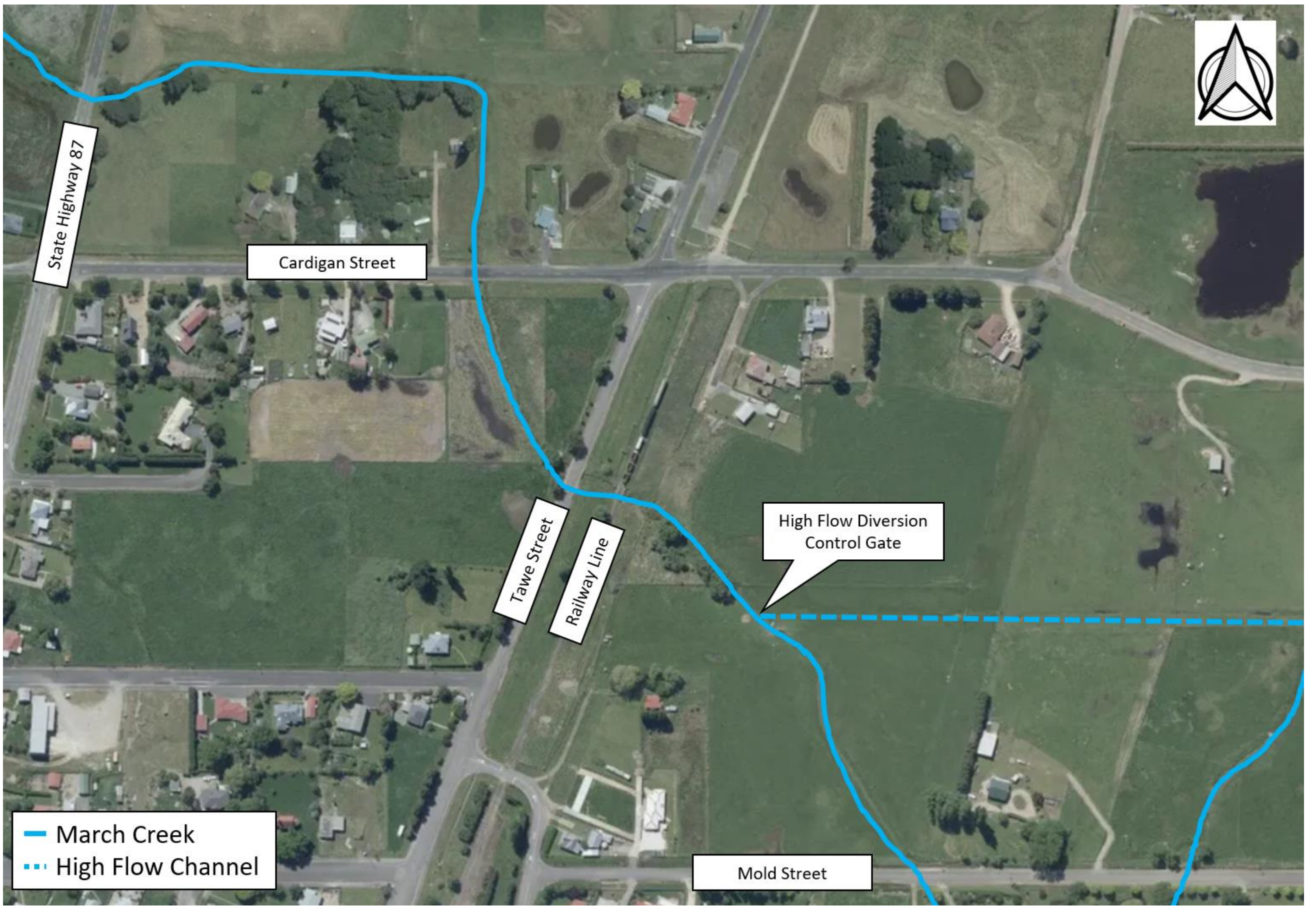

Figure 1-2: March Creek Through Middlemarch

1.3 SITE VISIT

WSP engineers undertook a size visit with ORC staff on 2 November 2023. March Creek through Middlemarch and all bridges were inspected as well as the upstream culverts below Gladbrook Road. ORC staff provided an overview of historical flooding issues through Middlemarch.

2 MODEL BUILD

2.1 OVERVIEW

A hydraulic model has been developed to inform this assessment. The model consists of a 1-dimensional flow model of the creek through Middlemarch and a 2-dimensional flow model of the contributing catchment.

The 1-dimensional model simulates flow and water levels along the creek's length, and was developed using survey data and field observations. This component of the model is useful for evaluating the creek's capacity by identifying any spill points or constrains (ex: bridge crossings) along the channel.

The larger 2-dimensional model represents water flow across the catchment, incorporating topography, land cover and infiltration characteristics. This component of the model is useful understanding the distribution of overland flow across the catchment during rainfall events and identifying potential hydraulic issues that could have downstream implications (ex: breakaway creeks). The 2-dimensional model has been developed predominantly using geospatial inputs.

All modelling has been completed in InfoWorks ICM hydraulic modelling software package.

2.2 CREEK MODEL

The extents of the creek model are shown on Figure 2-1. The model consists of five creek reaches and has four road/ rail crossings which have all been modelled as culverts.

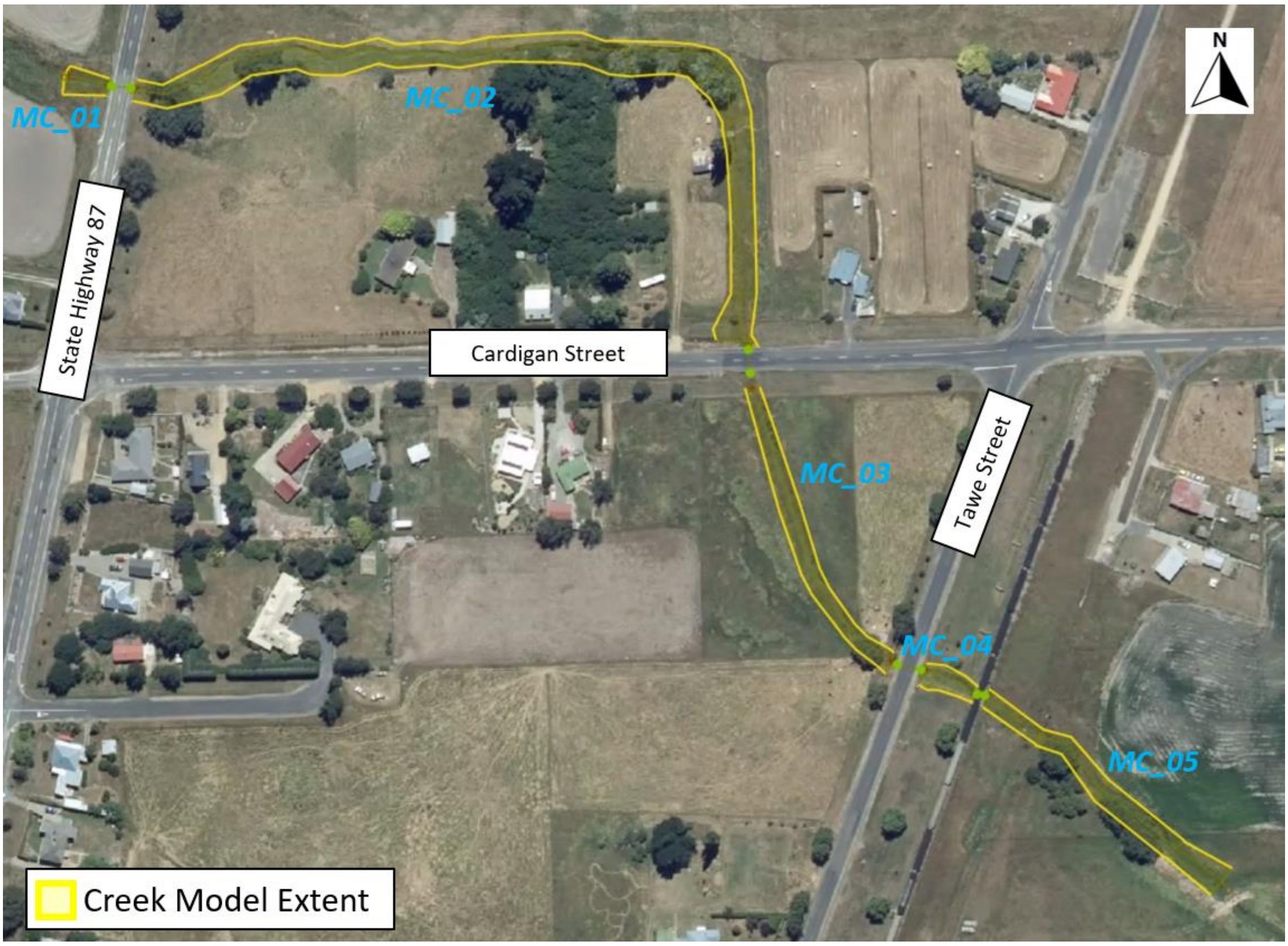

Figure 2-1: Creek Model Extents (Creek Reach References in Blue)

2.2.1 CROSS SECTION DATA

The following survey data was used to develop the creek model:

— GeomaticsNZ Ltd in 2021: This survey is from the State Highway 78 crossing to the railway culvert, consisting of 18 cross sections (creek reaches MC_01 to MC_05).

— WSP 2023: WSP collected an additional 8 cross sections of the railway culvert and downstream channel (creek reaches MC_04 and MC_05).

All cross sections were manually reviewed and achieve a positive relationship between water depth and flow. The extent of cross sections were adjusted to remove secondary low points outside of the creek's main channel.

2.2.2 CHANNEL ROUGHNESS

Channel roughness has been applied to each reach of the creek based on the channel condition observed during the site visit. Table 2-1 summarised roughness values adopted (Chow, 1959).

Table 2-1: Creek Model Roughness Values

CREEK REACH REFERENCE	DESCRPTION	MANNINGS N VALUE	PHOTO
MC_01	Excavated channel, stoney bottom with weedy banks. Some debris in flow channel.	0.035	
MC_02	Excavated channel, stoney bottom with weedy banks. Some debris and vegetation in flow channel.	0.035	
MC_03	Excavated channel, stoney bottom with weedy banks	0.035	

CREEK REACH REFERENCE	DESCRPTION	MANNINGS N VALUE	PHOTO
MC_04	Excavated channel, clean with vegetation recently cleared.	0.018	
MC_05	Excavated channel, stoney bottom with weedy banks. Some debris and vegetation in flow channel.	0.035	

2.2.3 STRUCTURES

All built structures (bridges) spanning the creek through Middlemarch are represented in the creek model. Structures were modelled as culverts, with dummy inlet and outlet links to represent turbulence losses. Dimensions and inverts of structures were sourced from GeomaticsNZ Ltd survey data and confirmed during the site visit, which are summarised Table 2-2.

Inlet flow coefficients were sourced from CIRIA's Culvert, Screen and Outfall Manual (CIRIA, 2019). Culvert outlets links were assigned a headloss coefficient of 1.0.

Table 2-2: Creek Model Structure

STRUCTURE	DIMENSIONS	PHOTO
State Highway 87	Width: 2,750 mm Height: 1,250 mm	
Cardigan Street	Width: 2,800 mm Height: 1,700 mm	
Tawe Street	Width: 2,750 mm Height: 900 mm	

STRUCTURE	DIMENSIONS	PHOTO
Railway Culvert	Irregular shaped culvert with dimensions sourced from GeomaticsNZ Ltd survey. Maximum Width: 5300 mm (directly below beams) Maximum Height: 829 mm	

2.2.4 BOUNDARY CONDITIONS

2.2.4.1 DOWNSTREAM WATER LEVEL

A downstream boundary condition (water level) for the creek model was estimated by reviewing photos taken following large rainfall events. Debris was observed on a fence line downstream of the railway culvert following a large rainfall event in May 2021 (see Figure 2-2 and Figure 2-3). It is estimated the debris line is 0.5 m above the creek bank.

This boundary condition was applied in model simulations as a constraint level at the downstream end of creek reach MC_05.

Figure 2-2: Debris on Fenceline Downstream of Railway Culvert (Looking Downstream)

Figure 2-3: Debris on Fenceline Downstream of Railway Culvert (Upstream Downstream)

2.2.4.2 CREEK BASE FLOW

The creek's base flow was represented in the model by applying a constant inflow at the upstream end of the creek model (inflow to reach MC_01). Base flow was estimated by inferring the flow from depth/ discharge plots produced by the model for the depth of flow observed on the date of the site visit.

2.3 CATCHMENT MODEL

2.3.1 MODEL EXTENT

The catchment model was developed using the Otago LiDAR 1 m DEM (2016) and New Zealand 8 m DEM (2012). The detailed LiDAR (Otago 2016) covers the extent of the Taieri River plain through Middlemarch to the lower gillies of the Rock and Pillar range. The two-dimension model surface was developed using this detailed LiDAR. It is noted that the accuracy of creek capacity in the catchment model is limited by LiDAR quality and is less accurate than where survey data was collected for sections of the creek through Middlemarch.

The 8 m DEM data was used to delineate rural catchment areas beyond the extents of the detailed LiDAR. These catchment areas were represented as 1D inflows (lumped sub-catchments) outletting to the two-dimension model surface.

Initial model simulations were completed for an expanded catchment model that included March Creek, Dewar Creek, Camlet Creek, and 6 Mile Creek to identify any interaction between March Creek and the surrounding catchments. Results of this simulation are presented on Figure 2-4, showing Dewar Creek can overtop and flow into March Creek however there is no interaction with the Camlet and 6 Mile Creeks further to the north. Following this assessment the 2-dimensional model surface was reduced to only include the Dewar Creek and March Creek catchments.

Catchments to the south (ex. Browns Creek) were not considered in this assessment.

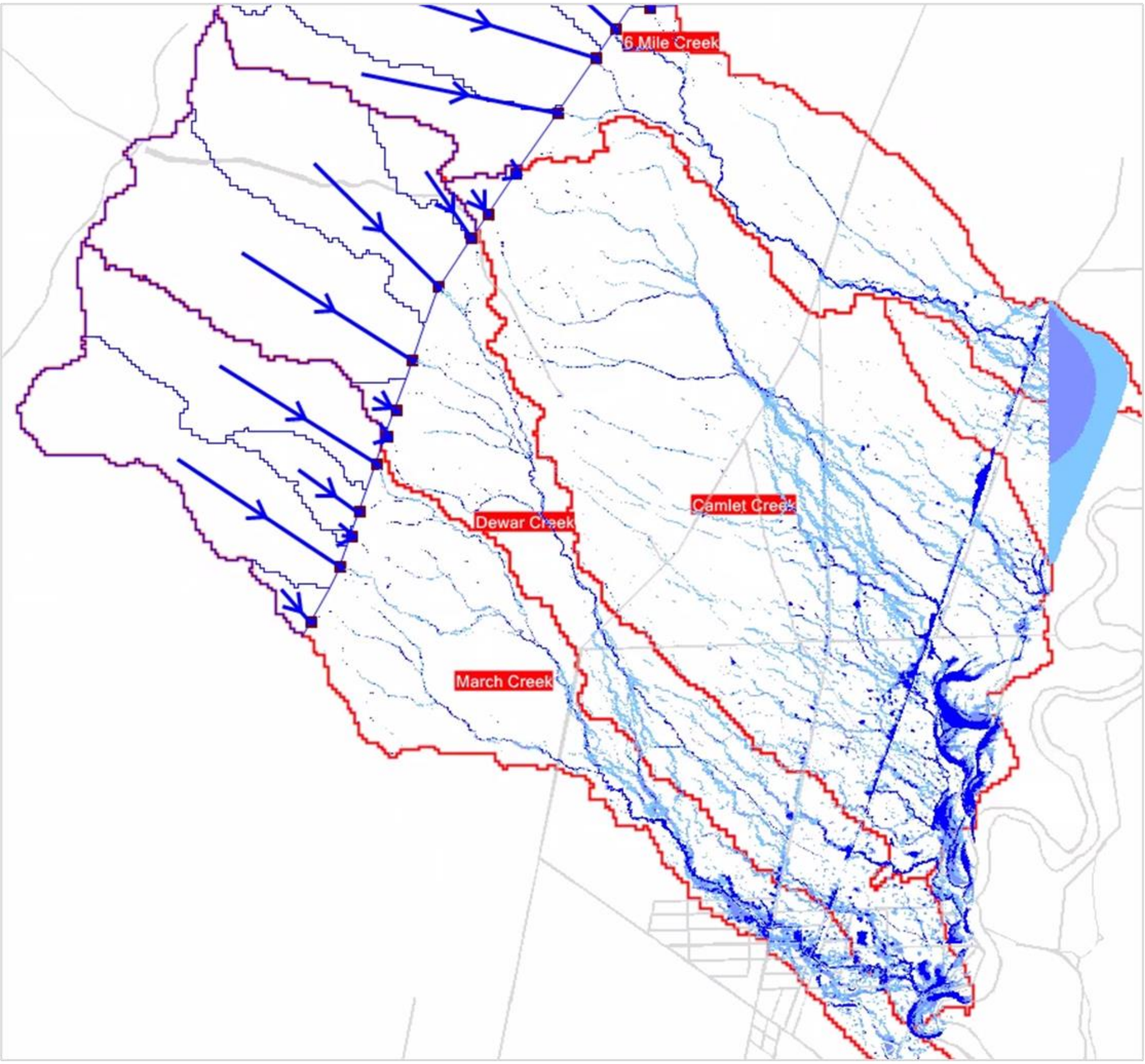

Figure 2-4: Initial Model Results for Expanded Catchment

2.3.2 CATCHMENT MODEL INPUTS

2.3.2.1 TOPOGRAPHIC DATA

The model's 2-dimensional mesh surface was developed based the Otago LiDAR 1 m DEM. The following default attributes were applied to the mesh:

- Minimum triangle - 25 m^2
- Maximum triangle - 100 m^2
- Default surface roughness (Manning's n) - 0.035
- Boundary condition – Normal hydraulic condition (where no boundary condition is applied).

2.3.2.2 SOIL DRAINAGE CLASSIFICATION (INFILTRATION PARAMETERS)

Infiltration parameters for the catchment model were applied based on soil drainage class shapefiles obtained from the Land Resource Information System (LRIS) and roadways. Soil drainage maps the catchment model are shown on Figure 2-5.

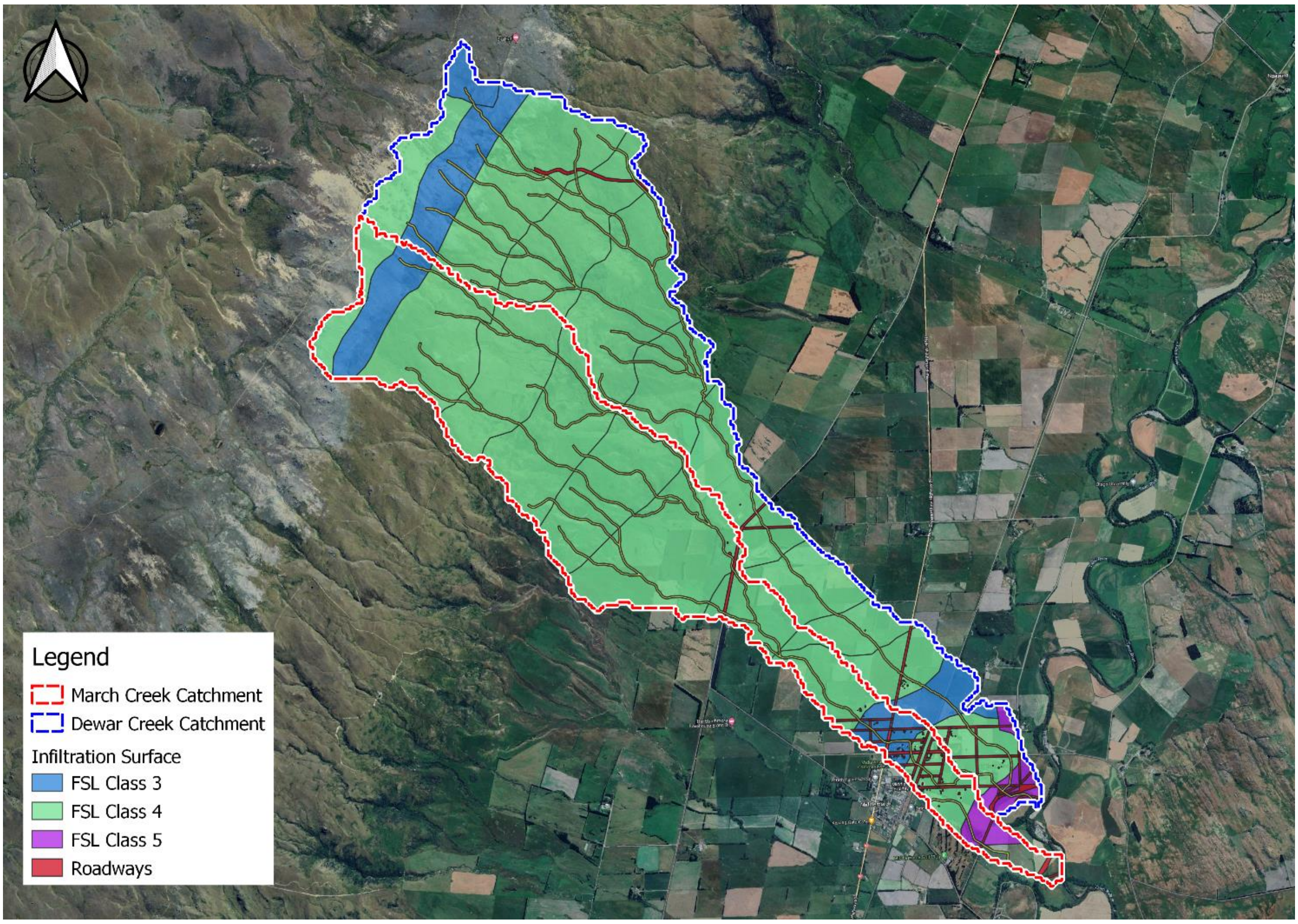

Figure 2-5: Infiltration Surfaces

The corresponding parameters for Horton's infiltration model (non-linear infiltration rate) were applied in these zones from the below sources:

- The initial infiltration rate was as defined in Urban Stormwater Hydrology: A Guide to Engineering Calculations (Akan, 1993).

— The terminal infiltration rate was based on the limiting infiltration rate for the predominant soil type obtained from S-MAPS.

Table 2-3 presents Horton's infiltration parameters that were applied in the model for the LRIS defined soil drainage classes contained within the modelled area.

Table 2-3: Infiltration Parameters for LRIS's Soil Drainage Classes in Catchment

DESCRIPTION	DRAINAGE CLASS	INITIAL INFILTRATION RATE (mm/hr)	FINAL INFILTRATION RATE (mm/hr)
Imperfectly Drained	3	25	3.8
Moderately Well Drained	4	51	7.6

A fixed runoff coefficient of 0.9 was applied to roadways.

2.3.2.3 SURFACE ROUGHNESS

Surface roughness was adjusted from the mesh surface default for areas with substantial tree/ bush cover, roadways and buildings. Areas where roughness was adjusted are shown on Figure 2-6, with corresponding values summarised in Table 2-4.

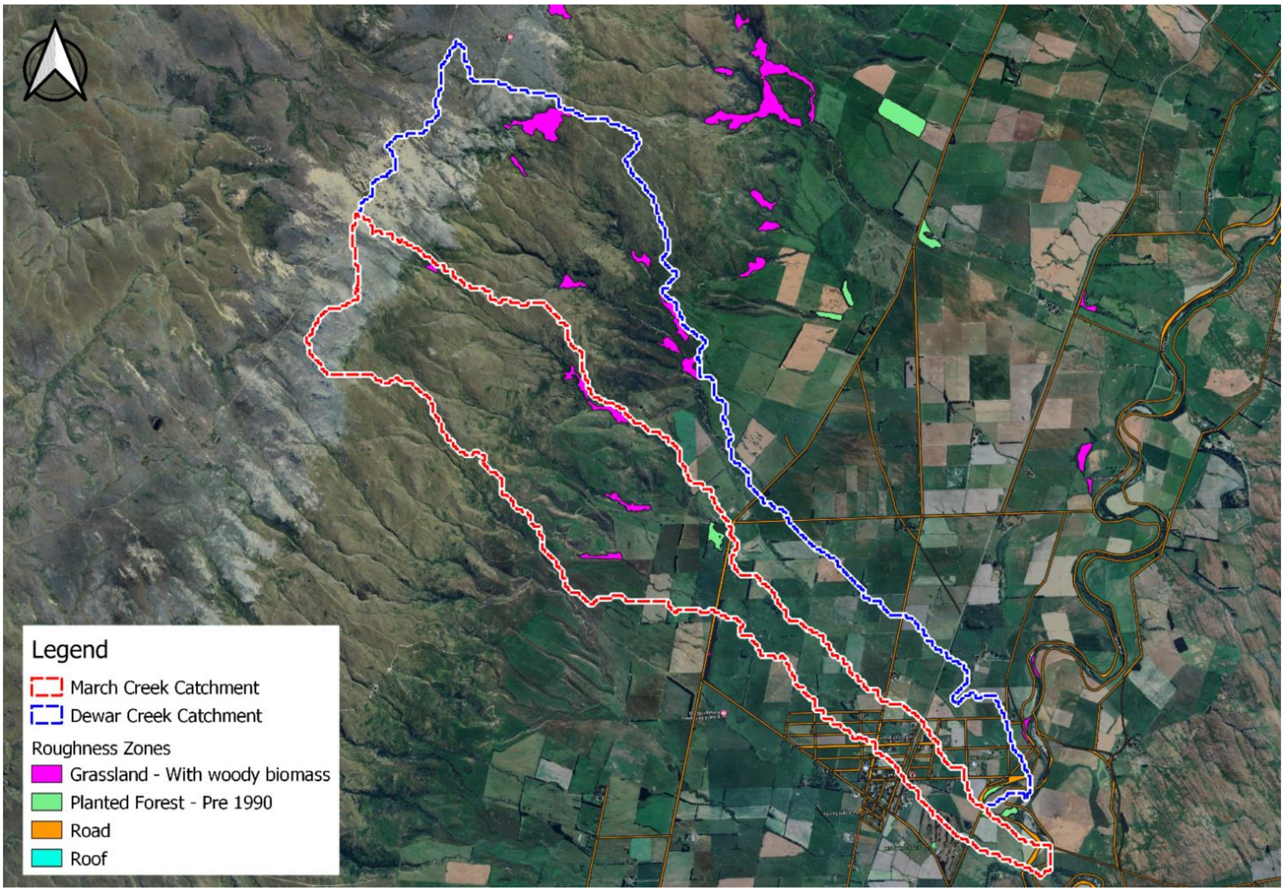

Figure 2-6: Model Roughness Adjustments

Table 2-4: Roughness Coefficients

DESCRIPTION	SURFACE ROUGHNESS (MANNING'S N)
Grassland - With woody biomass	0.0750
Planted Forest - Pre 1990	0.1500
Road	0.0160
Roof (Building Footprints)	1.0

2.3.2.4 ADDITIONAL CONTRIBUTING AREA

As described above catchment areas beyond the extent of the Otago LiDAR 1 m were represented in the model as 1D subcatchments with point inflows discharging to the 2D surface via a 'loading node'.

The extents of these catchments were defined using the New Zealand 8 m DEM, with infiltration/runoff parameters applied based on underling soil drainage class (as per values in Table 2-3).

2.3.3 DETAILED MESH ZONES

A refined mesh was applied along watercourses (LINZ watercourses) and along March Creek through Middlemarch with triangle areas ranging from 8 m^2 to a maximum of 15 m^2.

A detailed mesh was applied along watercourses to best capture the creek from LiDAR data.

2.3.4 UPSTREAM STRUCTURES

Upstream culverts where March Creek and Dewar Creek cross Gladbrook Road have been included in the model as conduits with 2-dimensional outfall nodes to the mesh surface to prevent water ponding. The dimensions of these culverts were measured on site.

3 MODEL VALIDATION

3.1 INPUTS TO VALIDATION

The model was validated using three historical rainfall events where flooding was observed, including:

- WWF1: 1 January 2021
- WWF2: 9 March 2021
- WWF3: 28 May 2021

Inputs to validation included the following:

- Radar rainfall data
- Gauge rainfall data (sourced from the Middlemarch Electronic Weather Station, Cliflo Agent Number 18437 and ORC's Rock and Pillar gauge).
- Evaporation data (sourced from the Middlemarch Electronic Weather Station, Cliflo Agent Number 18437).
- Flooding observations recorded by ORC staff (photos taken during or after events and marked-up maps).
- Discussions with ORC staff on site and during a Model Validation workshop.

Dunedin City Council flooding complaints were also requested to support validation however there were no records corresponding to the selected events.

3.2 RAINFALL ANALYSIS

Past rainfall data is available from the Middlemarch EWS and recently installed Rock and Pillar gauge (maintained by ORC). Figure 3-1 shows rain gauge locations relative to the March Creek and Dewar Creek catchments. Data for the Middlemarch EWS is available from August 2000 to present and data from the Rock and Pillar gauge is available from September 2023 to present. Data for both sites is available as rainfall depth at 5-minute increments.

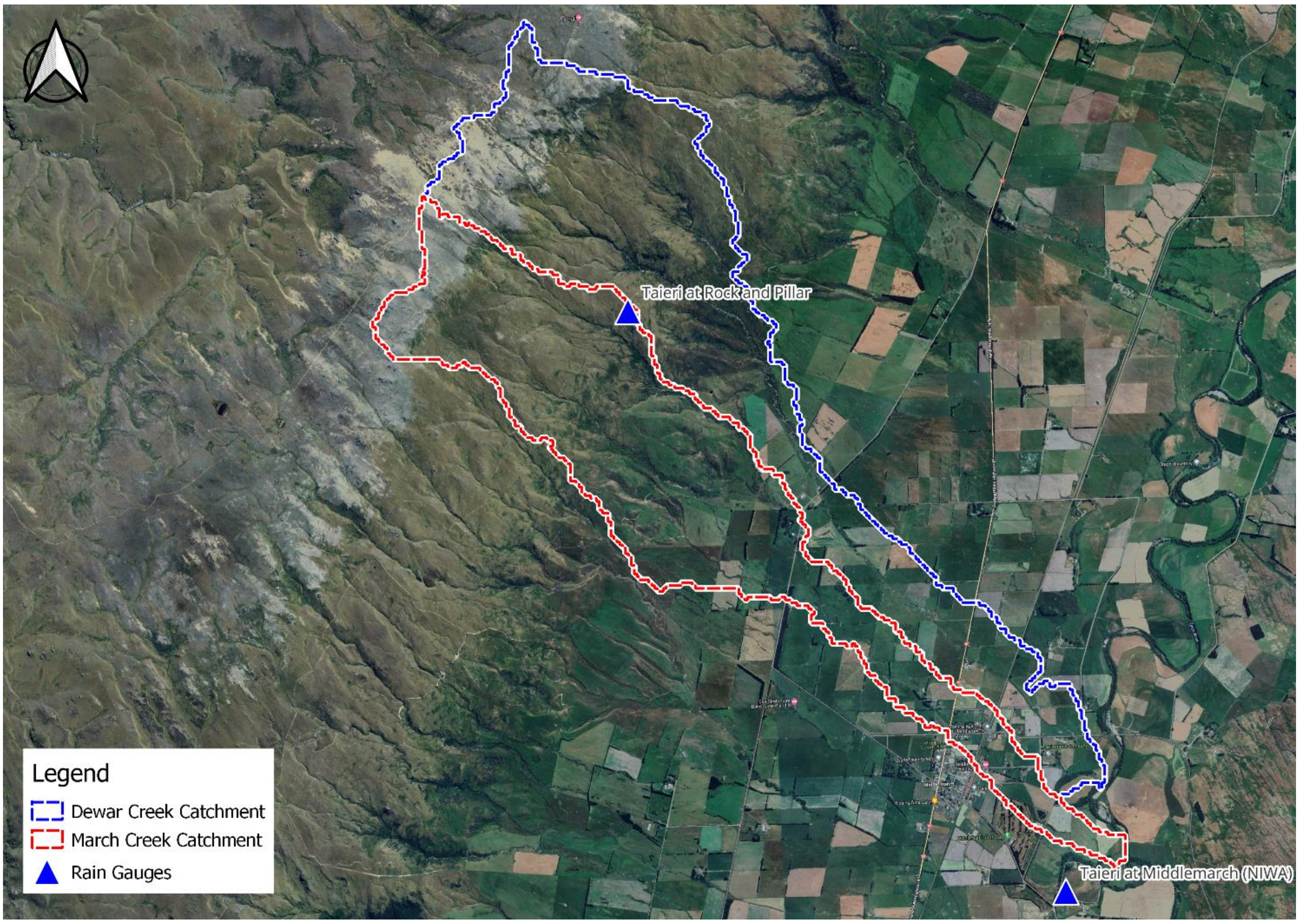

Figure 3-1: Rain Gauge Locations

An initial review of gauge rainfall data showed a substantial variation in rainfall in the plains relative to the upper reaches of the catchment in the Rock and Pillar Range. To improve the confidence in the model outputs, radar-derived rainfall data was used to capture the variation across the catchment. Radar rainfall was provided as 5-munite intensity for 111 pixels (500 m by 500 m square tiles) covering the extent of the Dewar Creek and March Creek catchments.

The accuracy of the radar rainfall data was verified to gauge data for two events that have occurred since the Rock and Pillar rain gauge was installed (overlap between all datasets). Figure 3-2 to Figure 3-5 show the gauge data for both gauges and the corresponding radar pixel for rainfall events on 22 September 2023 and 26 December 2023. Across all graphs, the peak hourly depth and total event volume align well, lending confidence to the accuracy of the radar data.

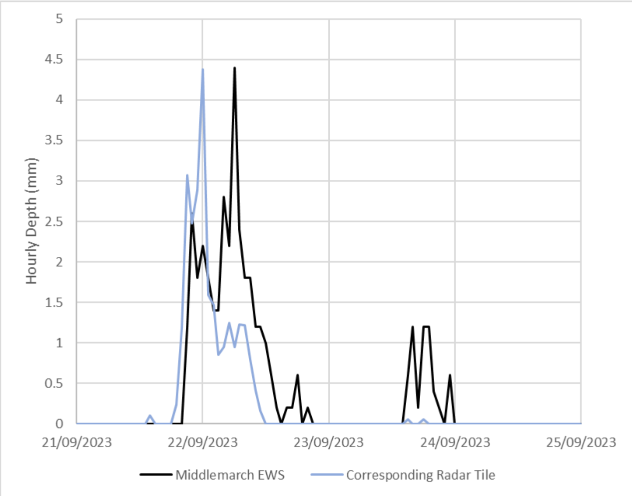

Figure 3-2: Middlemarch EWS Gauge vs Radar Data 22 September 2023 Event

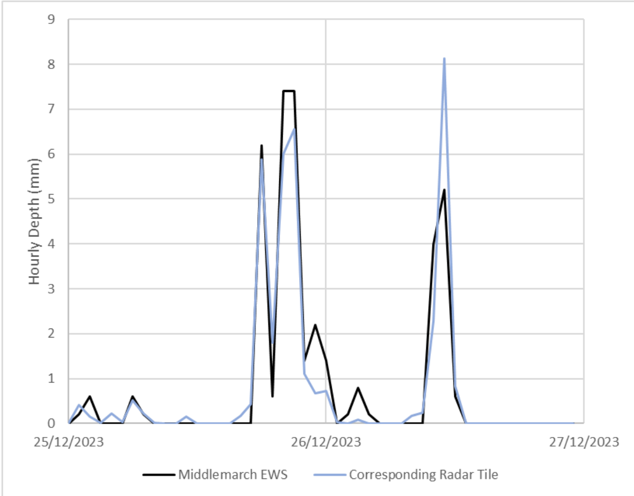

Figure 3-3: Middlemarch EWS Gauge vs Radar Data 26 December 2023 Event

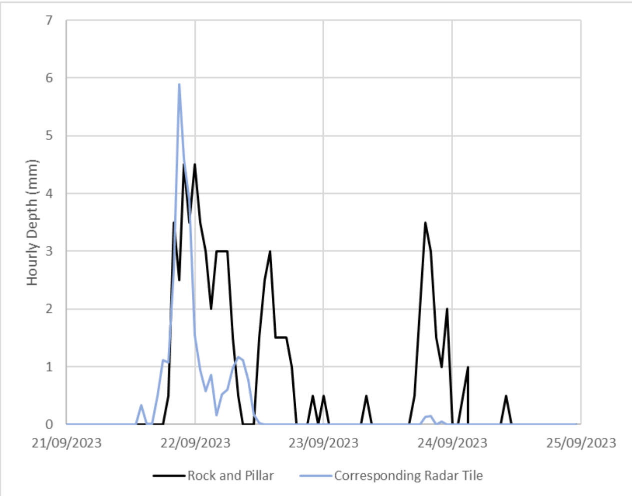

Figure 3-4: Rock and Pillar Gauge vs Radar Data 22 September 2023 Event

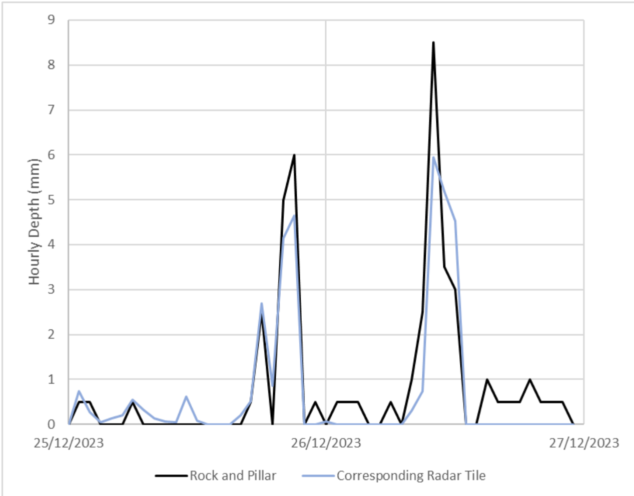

Figure 3-5: Rock and Pillar Gauge vs Radar Data 26 December 2023 Event

An Average Recurrence Interval (ARI) analysis of three validation events was undertaken using HIRDS ver4.0 data to understand the magnitude of the rainfall events. The results of this assessment and key rainfall statistics are presented in Table 3-1.

Table 3-1: Validation Event Rainfall Statistics and Estimated ARI

EVENT	DATE	LOCATION	PEAK 5-MINUTE INTENSITY (MM/HR)	DEPTH (mm)	ESTIMATED ARI
WWF1	1 January 2021	Middlemarch EWS (Pixel Ref: 4646055)	61.8	117.4	40 years
		Rock and Pillar (Pixel Ref: 4643886)	60	218.4	>100 years

EVENT	DATE	LOCATION	PEAK 5-MINUTE INTENSITY (MM/HR)	DEPTH (mm)	ESTIMATED ARI
WWF2	9 March 2021	Middlemarch EWS (Pixel Ref: 4646055)	5.9	16.1	< 2 years
		Rock and Pillar (Pixel Ref: 4643886)	15.1	29.5	< 2 years
WWF3	28 May 2021	Middlemarch EWS (Pixel Ref: 4646055)	23.9	55.5	2 years
		Rock and Pillar (Pixel Ref: 4643886)	22.9	75.6	2 - 5 years

Cumulative rainfall maps recorded by radar for the validation events are contained in Appendix A.

The following is noted for the validation events:

- WWF1 was the largest of the validation events, with rainfall depths exceeded 300 mm in the upper reaches of the catchment. There was substantial variation in rainfall across the catchment, with the highest depth recorded along the ridge of the Rock and Pillar range (325 mm) and lowest recorded in Middlemarch along the Taieri River (110). The estimated ARI of this event across the catchment ranges from 40 years to greater than 100 years.
- WWF2 was the smallest of the validation events. There was substantial variation in rainfall across the catchment, with the highest depth recorded along the ridge of the Rock and Pillar range (40 mm) and lowest recorded half way between the base of the Rock and Pillar range and the Taieri River (20 mm). The estimated ARI of this event is less than 2 years.
- WWF3 had the most consistent rainfall across the entire catchment, with depths ranging from approximately 60 to 85 mm. The estimated ARI of this event across the catchment ranges from 2 to 5 years.

3.3 VALIDATION RESULTS

3.3.1 1 JANUARY 2021 (WWF1)

The following was observed following the 1 January 2021 event:

- The banks of Dewar Creek overtopped at Gladbrook Road, with a portion of flows flowing overland and contributing to March Creek upstream of Middlemarch.
- March Creek overtopped its banks upstream of the State Highway 87 crossing. Flow outside of the main channel ran parallel to the creek (across State Highway 87, Cardigan Street and Tawe Street) re-entering the main channel upstream of the railway culvert.
- Brown Creek (south of March Creek) overtopped its banks, contributed to overland flows through Middlemarch on the south side of March Creek.

A markup of observed flow paths provided by ORC is shown on Figure 3-6. Figure 3-7 to Figure 3-9 show evidence of the overtopping of Dewar Creek and overland flow to March Creek.

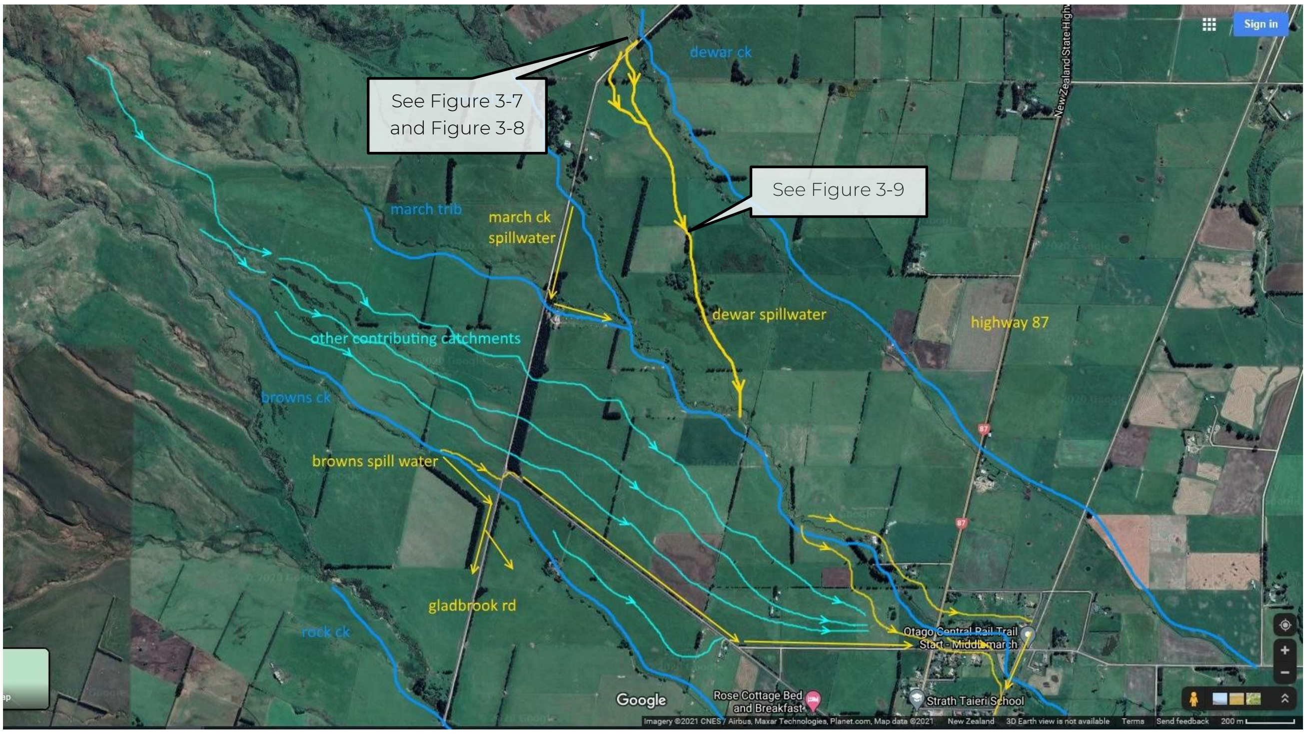

Figure 3-6: March Creek Flow Routes for 1 January 2021 Event (Map Provided by ORC)

Figure 3-7: Gladbrook Road Culvert Looking Downstream (Photo Provided by ORC)

Figure 3-8: Upstream end of Gladbrook Road Culvert with Yellow Circles Showing Approximate Locations (Photo Provided by ORC))

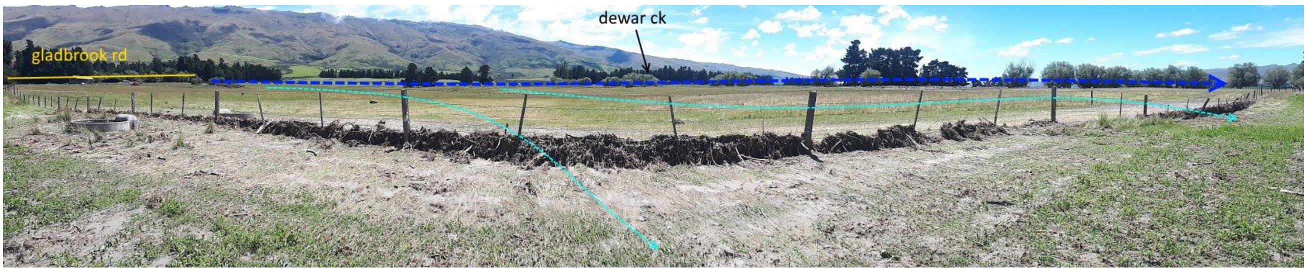

Figure 3-9: Evidence of Overland Flow from Dewar Creek to March Creek (Photo Provided by ORC)

Model results for the 1 January 2021 event for the upper catchment are shown on Figure 3-10 and March Creek through Middlemarch are shown on Figure 3-11.

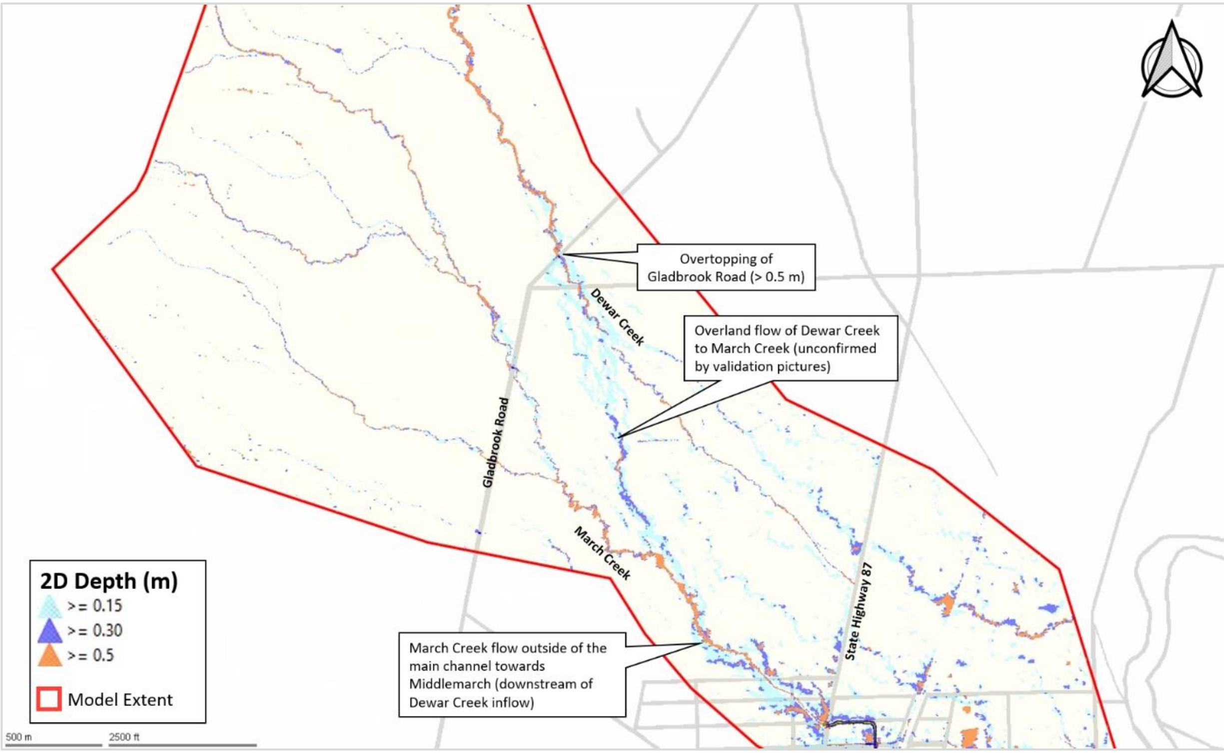

Figure 3-10: Validation Event 1 Model Results Upstream of State Highway 87

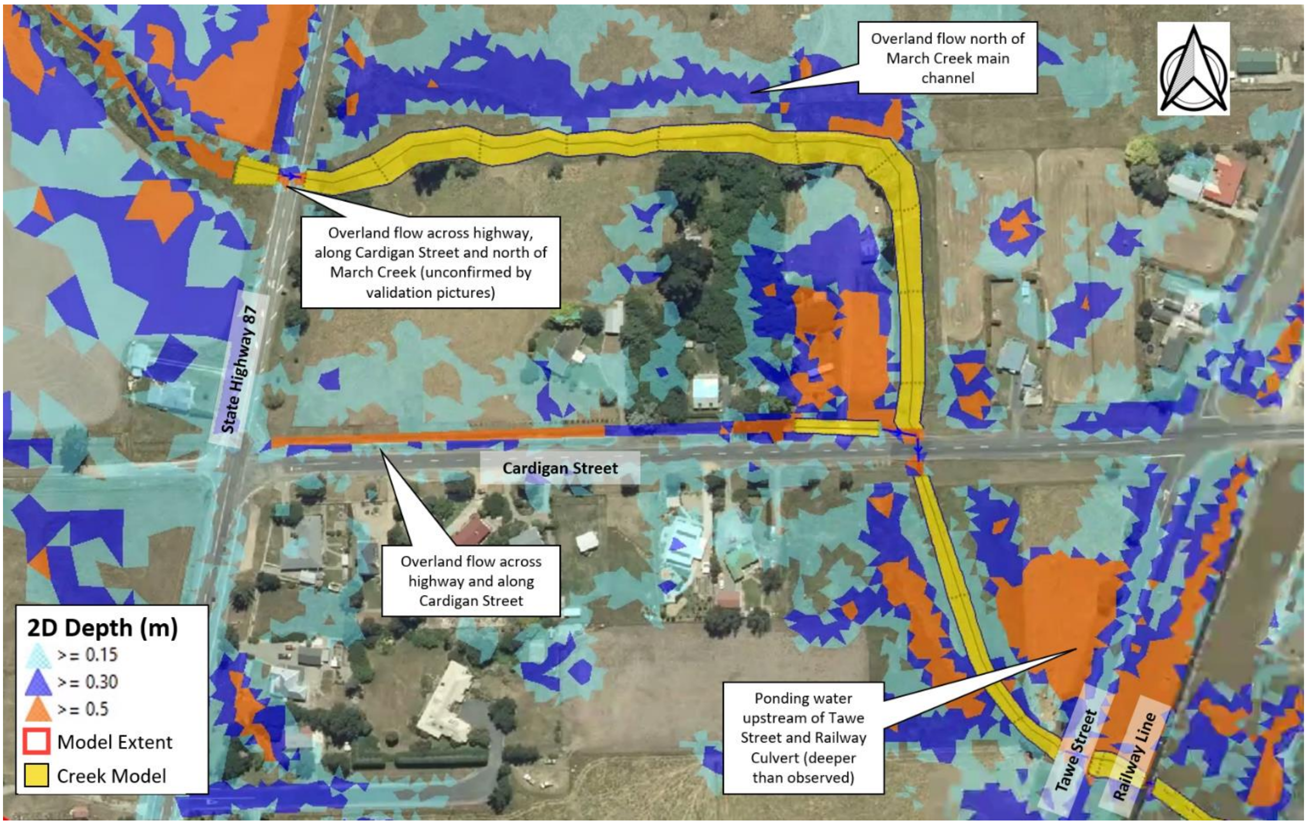

Figure 3-11: Validation Event 1 Model Results from State Highway 87 to Railway Culvert

The following is noted for the 1 January 2021 validation event:

— This large rainfall event (ranging from 40 to >100 year ARI across the catchment) has resulted in substantial flooding in Middlemarch and in the upper catchment, with multiple capacity constraints identified.

- The model has accurately represented Dewar Creek overtopping its banks at Gladbrook Road, and overland flow across farmland to March Creek upstream of State Highway 87.
- The model replicates March Creek overtopping its banks upstream of the State Highway 87 crossing, across the highway and outside of the main creek channel through Middlemarch.
- During peak flow in the creek, the State Highway 87, Cardigan Street and railway culvert are under capacity, resulting in channel flowing above the banks for all creek reaches upstream of the railway culvert. The railway culvert is the most constraint with flow backing up beyond the Tawe Street culvert.

3.3.2 9 MARCH 2021 (WWF2)

The following was observed following the 9 March 2021 event:

- There is evidence March Creek overflowed its banks upstream of the State Highway 87 crossing, with flood debris seen on the fence line approaching the level of the highway (see Figure 3-12 and Figure 3-13). Debris accumulation was also observed on a fence line downstream of the highway (see Figure 3-14).
- Sediment was observed on the Tawe Street bridge, indicating the roadway was overtopped (see Figure 3-15).
- Sediment was observed in the swale between the Tawe Street crossing and Rail Bridge (see Figure 3-16), indicating back up from the railway culvert constraint or overland (from the upstream breakout) re-entering the main channel.
- Flood debris were observed accumulated on the railway culvert fence, indicating overtopping (see Figure 3-17).

Figure 3-12: Standing Water in Paddock Upstream of State Highway 87 Crossing (Photo Provided by ORC)

Figure 3-13: Flood Debris on Fenceline Upstream of State Highway 87 Crossing (Photo Provided by ORC)

Figure 3-14: Debris on Fenceline Downstream of State Highway 87 Crossing (Photo Provided by ORC)

Figure 3-15: Sediment on Top of Tawe Street Crossing, Indicating Overtopping (Photo Provided by ORC)

Figure 3-16: Sediment in Swale Between Tawe Street Crossing and Rail Bridge (Photo Provided by ORC)

Figure 3-17: Flood Debris Accumulation on Railway Culvert (Photo Provided by ORC)

Model results for the 9 March 2021 event for March Creek through Middlemarch are shown on Figure 3-18.

Figure 3-18: Validation Event 2 Model Results from State Highway 87 to Railway Culvert

The following is noted for the 9 March 2021 validation event:

— Upstream of State Highway 87, the model does not predict either of March Creek or Dewar Creek overtop their banks. This is consistent with ORC observations during this event.

— During peak flow in the creek, the model predicts the railway culvert is under capacity, resulting flow in the creek overtopping its banks between Tawe Street and the railway culvert (reach MC_04). It is believed these results correspond to actual conditions, as flood debris was observed to have accumulated along the railway culvert fence line.

— Ponded water due to the limited creek capacity below the rail bridge is predicted by the model, which has confirmed by sediment accumulation seen in photos.

3.3.3 28 MAY 2021 (WWF3)

For the 28 May 2021 event no overtopping of March Creek was observed from Gladbrook Road to Cemetery Road. ORC staff provided marked up pictures showing the maximum water level between Tawe Street and the railway culvert (see Figure 3-19 and Figure 3-20). There were no reports of flooding adjacent to March Creek through Middlemarch.

Debris was observed accumulated on the Gladbrook Road crossing of Dewer Creek (see Figure 3-21) however this debris may have been from events earlier in the year.

Figure 3-19: Maximum Creek Water Level (Red) Tawe Street Bridge to Railway Culvert (Photo Provided by ORC)

Figure 3-20: Maximum Creek Water Level (Red) at Tawe Street Bridge (Photo Provided by ORC)

Figure 3-21: Flood Debris Accumulation on Dewar Creek Culvert at Gladbrook Road (Photo Provided by ORC)

Model results for the 28 May 2021 event for March Creek through Middlemarch are shown on Figure 3-22.

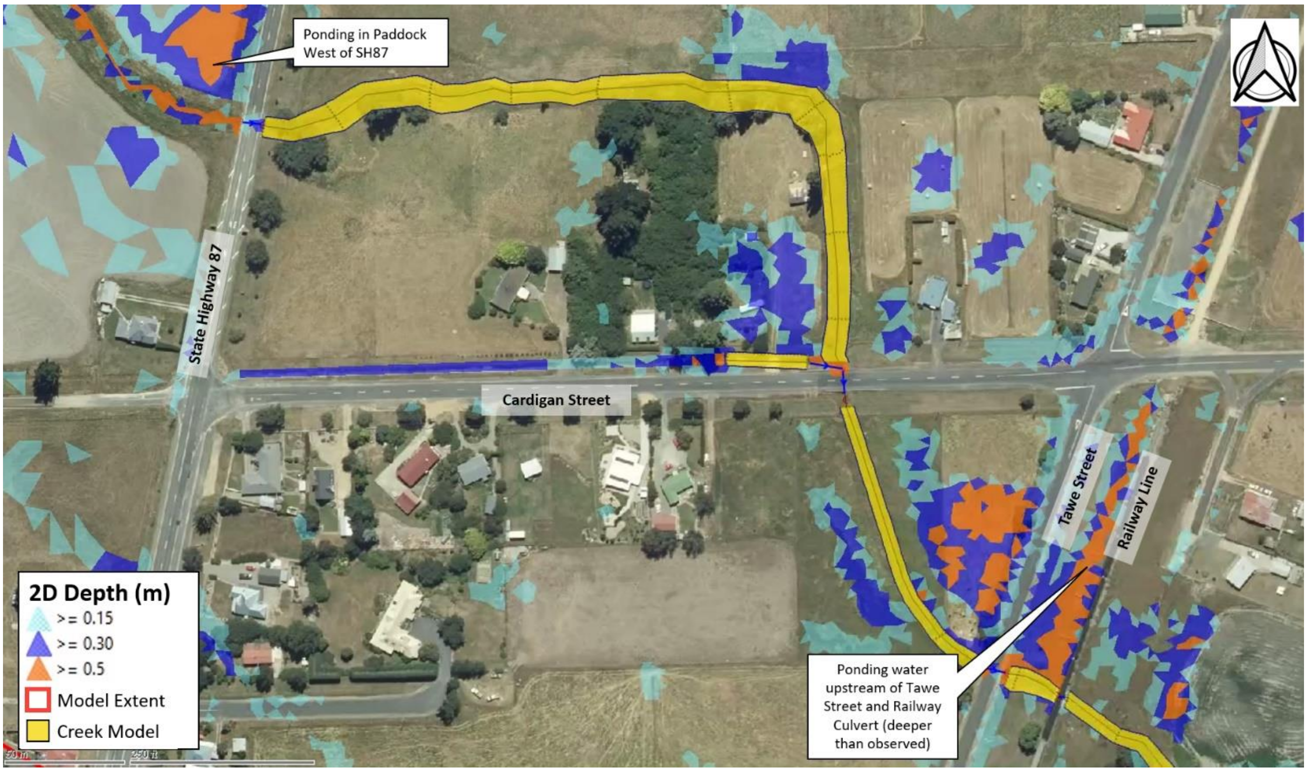

Figure 3-22: Validation Event 3 Model Results from State Highway 87 to Railway Culvert

The following is noted for the 28 May 2021 validation event:

- This rainfall event has an estimated ARI of 2 - 5 years in the upper catchment and 2 years in Middlemarch, being larger than the March 2021 event at both locations. However, the extent of observed flooding for this event was less than was observed during the March 2021 event. The model predicts a greater extent of flooding in Middlemarch for this event than the March 2021 event.
- Upstream of State Highway 87, the model does not predict either of March Creek or Dewar Creek overtop their banks. This is consistent with ORC observations during this event.
- During peak flow in the creek, the model predicts the railway culvert is under capacity, resulting in the creek overtopping its banks between Tawe Street and the railway culvert (reach MC_04) and Cardigan Street and Tawe Street (reach MC_03). The predicted peak water level is greater than indicated on marked up photos provided by ORC.

3.4 VALIDATION DISCUSSION

For all validation events the model accurately represents observations in the catchment upstream of Middlemarch, predicting March Creek and Dewar Creek only overtopped their banks for the January 2021 event.

In Middlemarch, the model accurately represents observed conditions for the January and March 2021 events. The model overpredicts flooding for the May 2021 event, predicting that the creek overtopped its banks between Cardigan Street and the railway culvert which was not observed.

An extended climate dataset was reviewed to better understand the catchment's antecedent conditions at the time of the validation events. Table 3-2 presents the monthly number of wet days versus the historical average leading up to the validation events. Table 3-3 presents observed versus historical monthly precipitation for the same period.

The two months leading up to the January event and one month leading up to the March event were drier than the historical average, with both a lower number of wet days and total rainfall recorded. In contrast, for the May event, the preceding month was slightly wetter than the historical average, having more wet days and total rainfall volume. This analysis shows the model likely better represents actual conditions for dry catchment conditions. When investigating flooding issues in the wider Middlemarch catchment in future stages of this project, hydrological parameters in the model could be refined to better representant observations during the May validation event. Additionally, the model predictions could be validated for further rainfall events when they occur and flooding observations are available.

Table 3-2: 2021 Monthly Number of Wet Days Versus Historical Average

MONTH	2021 NUMBER OF WET DAYS	HISTORICAL NUMBER OF WET DAYS	PERCENT ABOVE AVERAGE IN 2021	NOTES
November	4	5.2	-23%	
December	4	5.5	-28%	
January	9	4.7	91%	WWF1 on January 1 (Good validation)

MONTH	2021 NUMBER OF WET DAYS	HISTORICAL NUMBER OF WET DAYS	PERCENT ABOVE AVERAGE IN 2021	NOTES
February	2	4.4	-54%	
March	2	3.5	-42%	WWF2 on March 9 with no wet days recoded earlier in the month (Good validation)
April	1	3.5	-72%	
May	5	4.5	12%	WWF3 on May 28 (Model overpredicts flows)

Table 3-3: 2021 Monthly Total Precipitation Versus Historical Average

MONTH	2021 TOTAL PRECIPITATION (MM)	HISTORICAL AVERAGE PRECIPITATION (MM)	PERCENT ABOVE AVERAGE IN 2021	NOTES
November	42.6	49.6	-14%	
December	44.8	54.1	-17%	
January	148.8	48.7	206%	WWF1 on January 1 (Good validation)
February	16	46.7	-66%	
March	17.8	32.3	-45%	WWF2 on March 9 with no wet days recoded earlier in the month (Good validation)
April	15.8	33.6	-53%	
May	45.4	37.1	22%	WWF3 on May 28 (Model overpredicts flows)

Data in the above tables was sourced from the Middlemarch Electronic Weather Station (Cliflo Agent Number 18437) with historical averages based on the precipitation record for the years 2000 to 2024.

4 SYSTEM PERFORMANCE ASSESSMENT

4.1 DESIGN RAINFALL

The capacity of March Creek was assessed for the 2 and 20 year ARI design storms and the wider catchment was assessed for the 2 and 50 year ARI events.

Rainfall data was sourced from HIRDS ver4.0 (for historical climate conditions) at the location Middlemarch EWS and Rock and Pillar rain gauges. The Middlemarch EWS design rainfall was applied across the plains, and Rock and Pillar design rainfall was applied to the upper catchment.

A nested storm profile was applied to all rainfall data.

4.2 MARCH CREEK CAPACITY ASSESSMENT

4.2.1 EXISTING CONDITIONS

The maximum predicted water level for the 2 and 20 year ARI events relative to the creek banks with the downstream boundary condition is shown on Figure 4-1 and Figure 4-2.

For the 2 year ARI event, the railway culvert restricts flow, resulting in water backing up to the Cardigan Street bridge. Due to this constraint the maximum water level exceeds the creek banks from the Cardigan Street bridge to the railway culvert.

For the 20 year ARI event, railway culvert restricts flow in the Creek, with the maximum water level exceeding the creek banks for all modelled sections of Creek upstream (to State Highway 87).

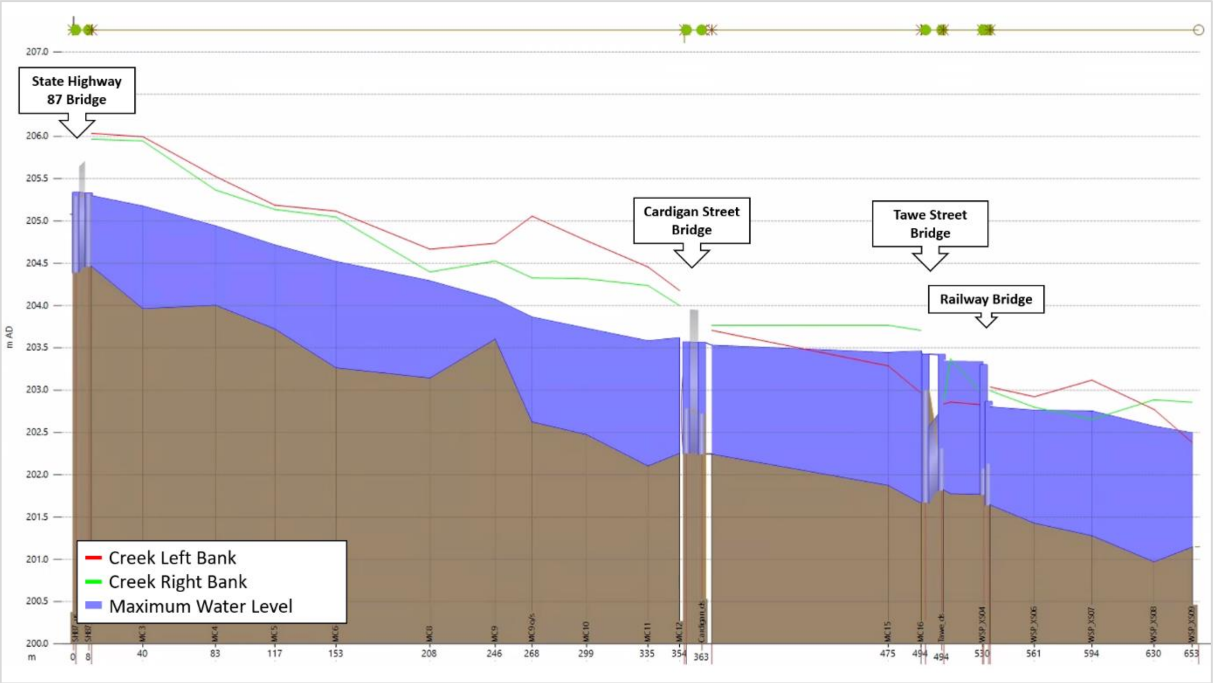

Figure 4-1: 2 Year ARI Design Storm Maximum Water Level Relative to March Creek Banks

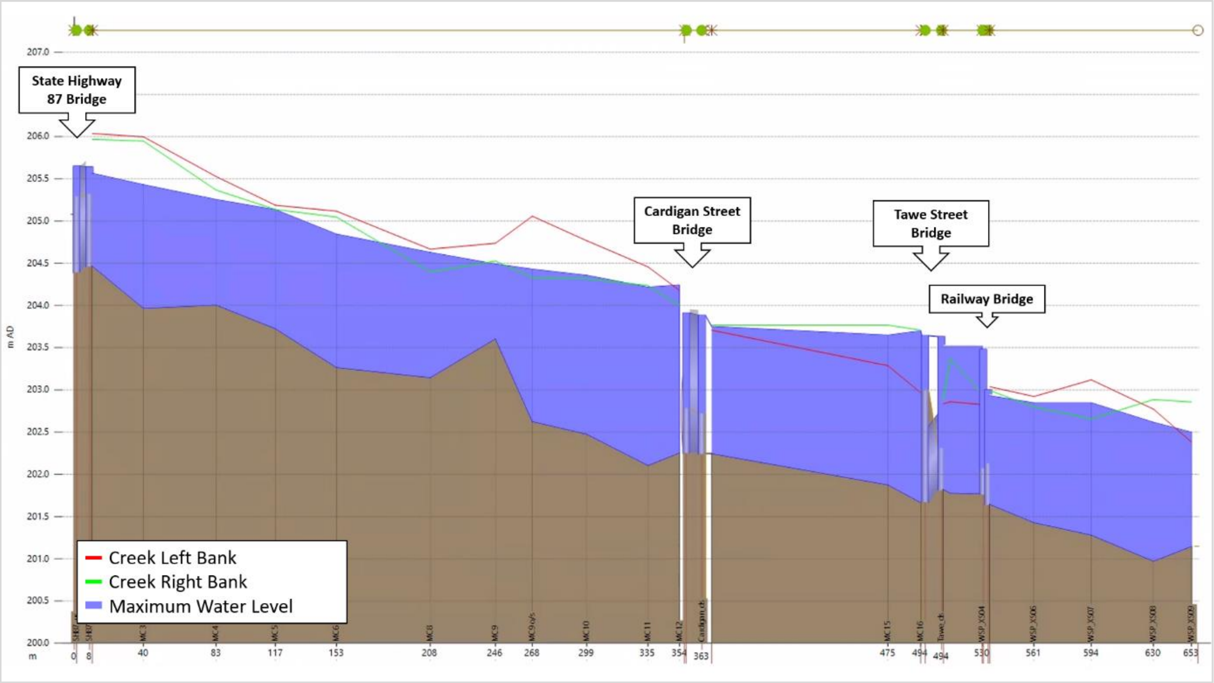

Figure 4-2: 20 Year ARI Design Storm Maximum Water Level Relative to March Creek Banks

4.2.2 INFLUENCE OF DOWNSTREAM WATER LEVEL

The influence of the water level in the creek downstream of the railway culvert was assessed by running a model scenario without the downstream boundary condition applied. The maximum predicted water level for the two design storms relative to the creek banks is shown on Figure 4-3 and Figure 4-4. For reference, the maximum predicted water level for the existing system is shown on both figures.

For both design storms, removing the downstream boundary condition does not reduce the maximum predicted water level in the creek upstream of the railway culvert. This indicates that the water level in the creek downstream of the railway is not the main cause of flooding in Middlemarch, but rather capacity of the railway culvert.

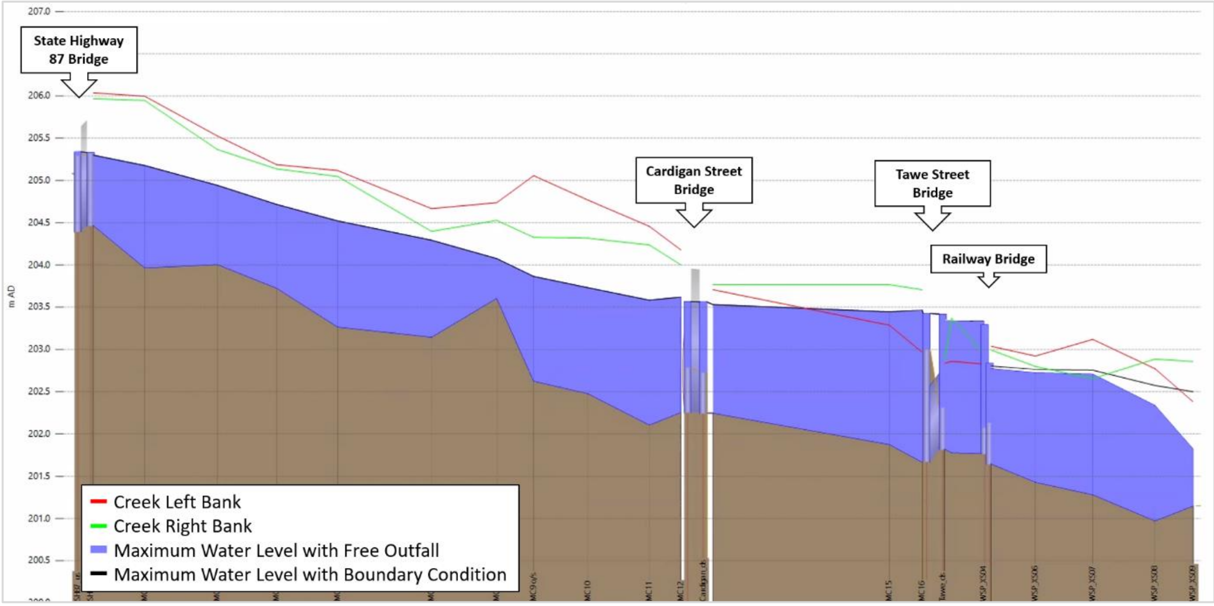

Figure 4-3: 2 Year ARI Design Storm Maximum Water Level Relative to March Creek Banks with and without Downstream Boundary Condition

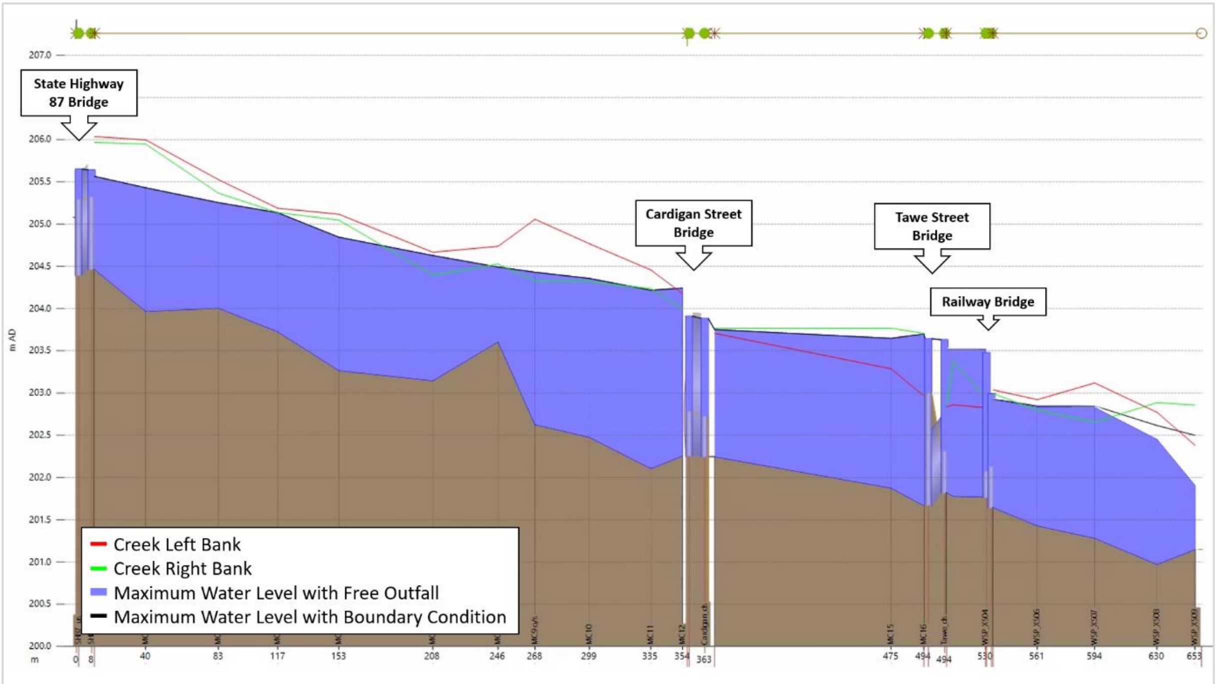

Figure 4-4: 20 Year ARI Design Storm Maximum Water Level Relative to March Creek Banks with and without Downstream Boundary Condition

4.2.3 CREEK CAPACITY WITH RAILWAY CULVERT REMOVED

The Tawe Street bridge is the second smallest structure in March Creek through Middlemarch and was also assessed for the two design storms. The capacity of this bridge was assessed by removing the downstream capacity constraint at the railway culvert from the model and replacing it with an open channel. The maximum predicted water levels for this scenario relative to the creek banks is shown on Figure 4-5 and Figure 4-6.

For the 2 year ARI event, the Tawe Street bridge restricts flow, resulting in the creek overtopping it's banks between Tawe Street and Cardigan Street. Removing the railway culvert has resulted in a decrease in creek water levels from Cardigan Street to the railway culvert. These is also a minor reduction in the predicted creek depth upstream of Cardigan Street bridge. The State Highway 87 and Cardigan Street bridges are not predicted to be a constraint for this event.

For the 20 year ARI event, both the Tawe Street bridge and Cardigan Street bridges restrict flow in the Creek with the maximum water level exceeding the creek banks for all modelled sections of the creek. Removing the railway culvert only results in a minor decrease in the creek water level for the between Cardigan Street and Tawe Street and no decrease in water level upstream of Cardigan Street.

For both design storms, removing the railway culvert results in an increase to the predicted water level in the receiving creek.

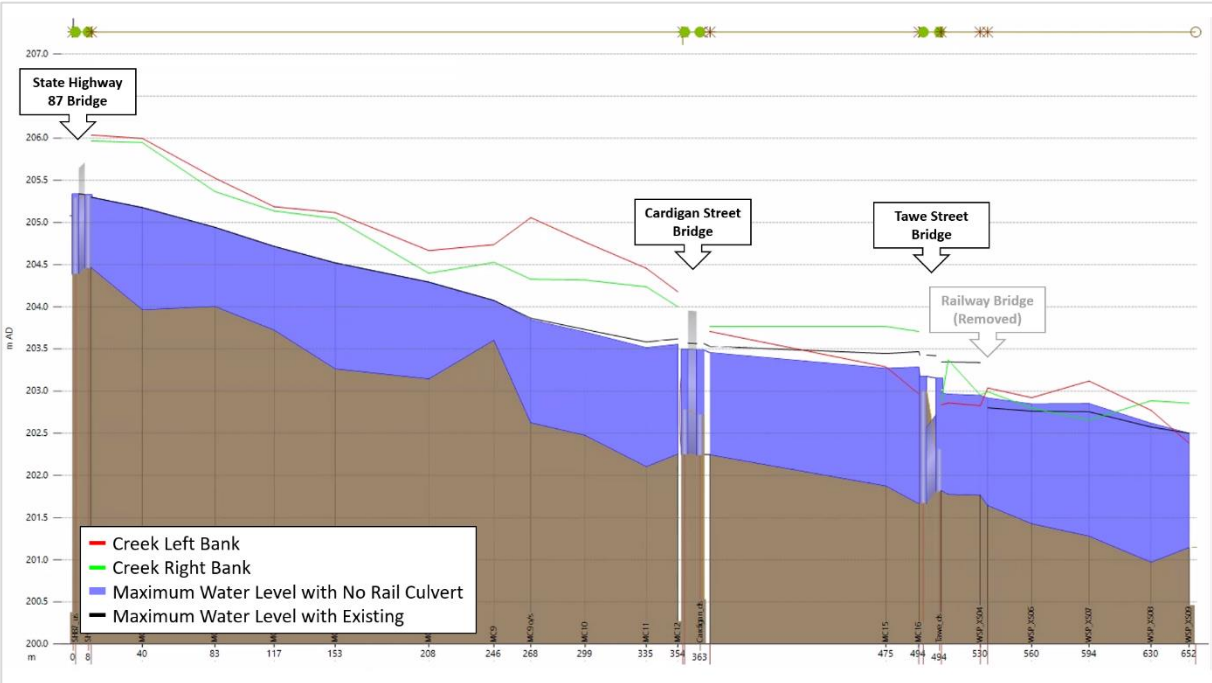

Figure 4-5: 2 Year ARI Design Storm Maximum Water Level Relative to March Creek Banks with Railway Culvert Removed

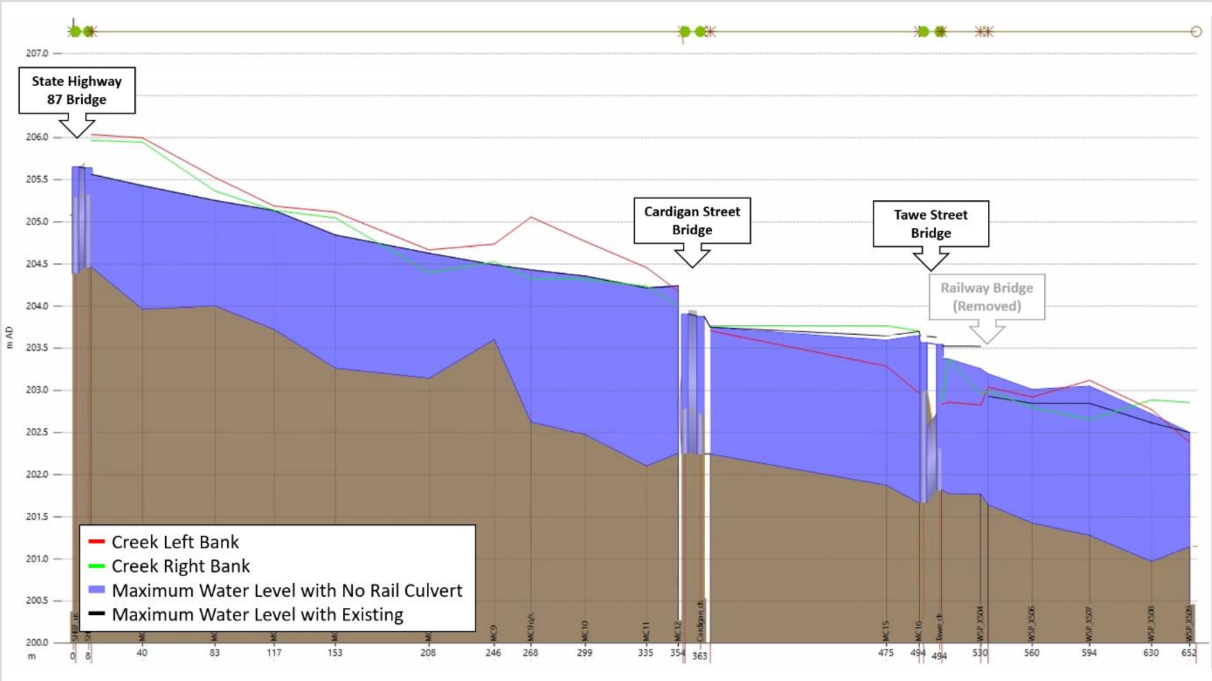

Figure 4-6: 20 Year ARI Design Storm Maximum Water Level Relative to March Creek Banks with Railway Culvert Removed

4.2.4 CREEK CAPACITY WITH RAILWAY CULVERT AND TAWE STREET BRIDGE REMOVED

The capacity of March Creek through Middlemarch was also assessed with both the railway culvert and Tawe Street Bridge removed. The maximum predicted water level for the two design storms for this scenario relative to the creek banks is shown on Figure 4-7 and Figure 4-8.

For the 2 year ARI event, removing both structures results in a further decrease in the creek water level from the previous scenario (only railway culvert removed). The reduction in water level is predicted from the railway culvert to upstream of the Cardigan Street bridge.

For the 20 year ARI event, removing both structures results in a decrease in the maximum predicted water level for sections of creek between Cardigan Street bridge and the railway culvert. The Cardigan Street bridge is predicted to be under capacity, and therefore removing downstream structures does not result in a decrease in the upstream water level.

As was noted for the previous scenario, removing the railway culvert and Tawe Street bridge results in an increase to the predicted water level in the receiving creek.

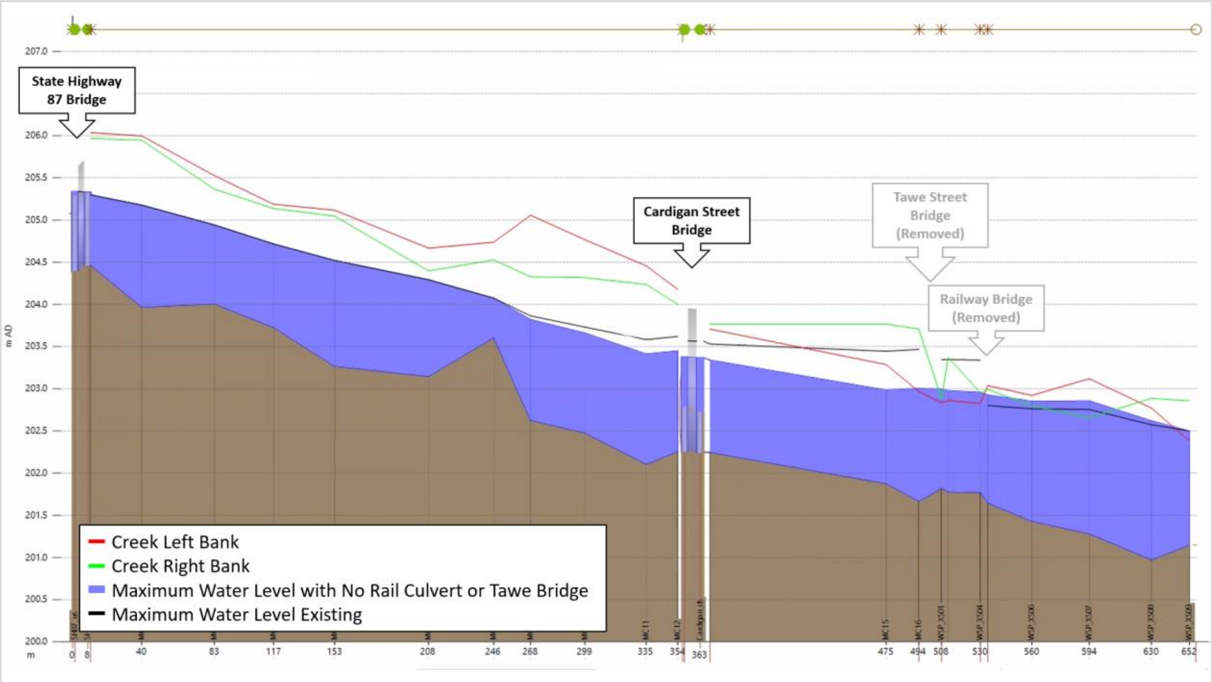

Figure 4-7: 2 Year ARI Design Storm Maximum Water Level Relative to March Creek Banks with Railway Culvert and Tawe Street Bridge Removed

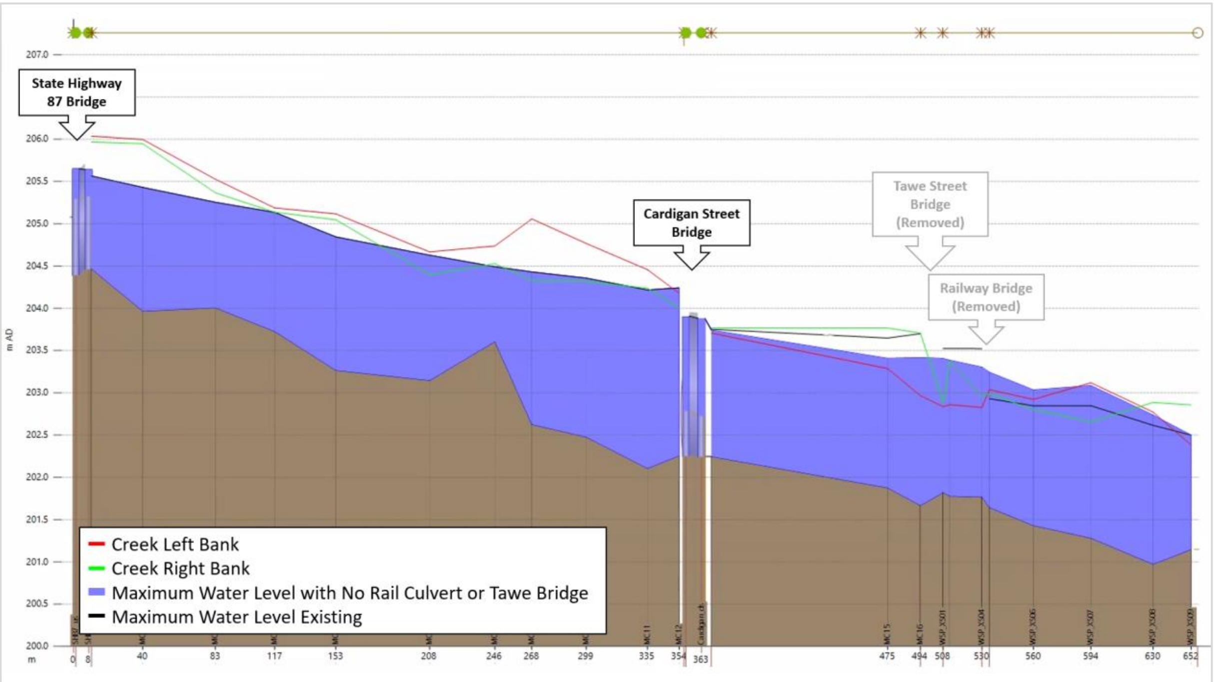

Figure 4-8: 20 Year ARI Design Storm Maximum Water Level Relative to March Creek Banks with Railway Culvert and Tawe Street Bridge Removed

4.3 CATCHMENT ASSESSMENT

4.3.1 FLOOD MAPPING

Figure 4-9 and Figure 4-10 show the maximum predicted water depth for the wider catchment for the 2 and 50 ARI events.

The following is noted for the 2 year ARI event:

- Dewar Creek and March Creek are not predicted to overtop upstream of Gladbrook Road or between Gladbrook Road and State Highway 87.
- In Middlemarch, the capacity constraints caused by the railway culvert and Tawe Street bridge results in March Creek overtopping its banks upstream of the Tawe Street bridge and railway culvert (as described in Section 4.2) resulting in flooding greater than 0.5 m.
- Flooding greater than 0.5 m is predicted northwest of the March Creek crossing of State Highway 87. This flooding is a result of other overland flow routes contributing to a low point, and not capacity constraints structures or March Creek through Middlemarch.

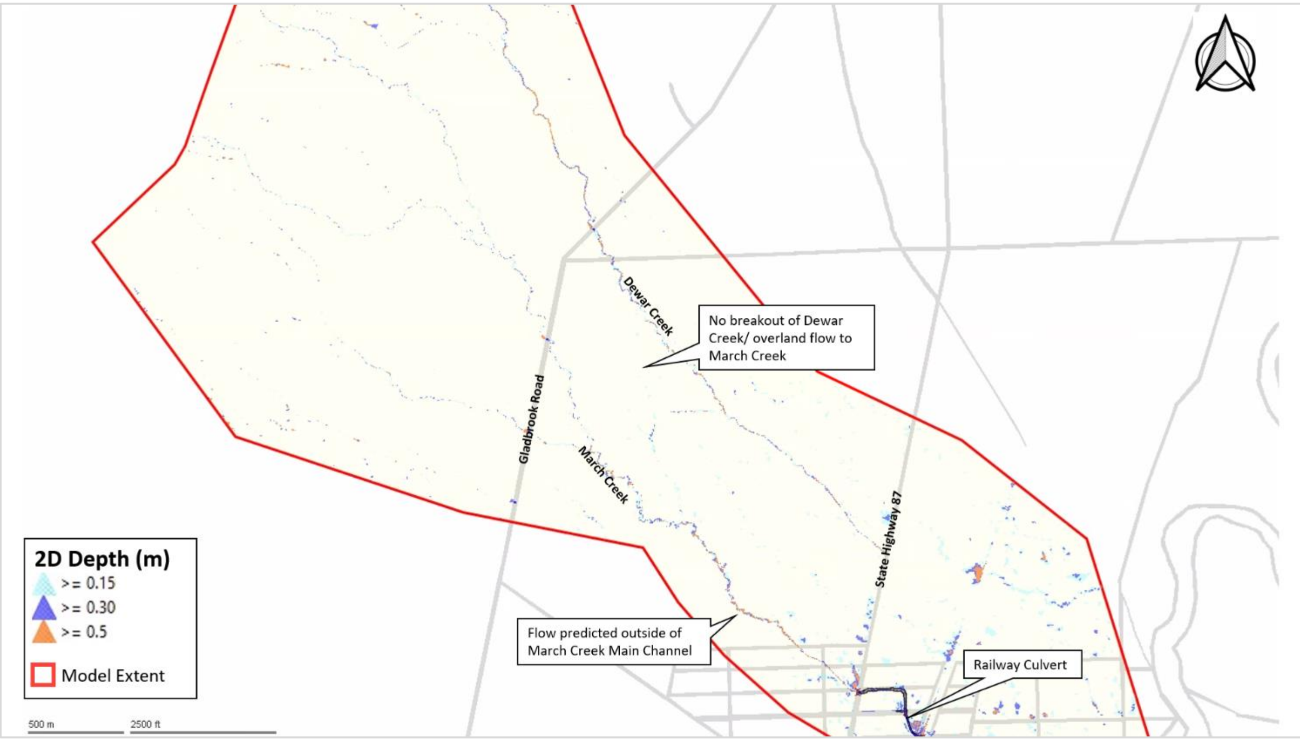

Figure 4-9: 2 Year ARI Design Storm Maximum Flood Depth

The following is noted for the 50 year ARI event:

- March Creek and Dewar Creek are predicted to overtop their banks upstream of the Gladbrook Road crossings.
- Dewar Creek is predicted to overtop its banks at Gladbrook Road, with a portion of flows flowing overland and contributing to March Creek upstream of Middlemarch.
- March Creek is predicted to overtop it's banks upstream of the State Highway 87 crossing, with flow outside of the main channel towards Middlemarch.

- There is substantial flooding though Middlemarch, with the maximum depth exceeding 0.5 m at several locations along the creek.

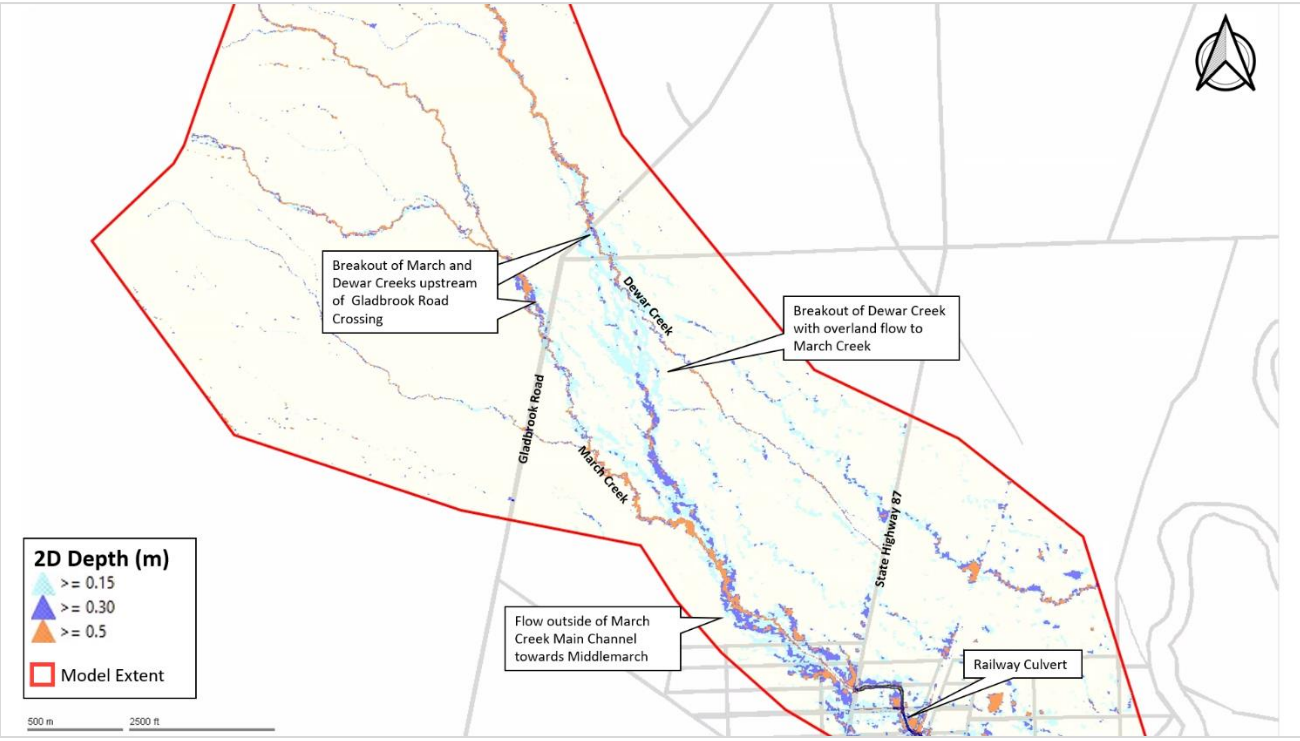

Figure 4-10: 50 Year ARI Design Storm Maximum Flood Depth

4.3.2 VELOCITY MAPS

Figure 4-11 and Figure 4-12 show the maximum predicted water velocity for the 2 and 50 year ARI events. High velocities predicted by the model can identify areas in the catchment where overland flow may be strong enough to cause erosion, transport sediment, damage infrastructure (roads and fence lines) and cause safety risks.

For the 2 year ARI event, velocities exceeding 2 m/s are predicted in the upper gullies of both March and Dewar Creeks. These areas may be prone to erosion during this event. On the plains, areas of high velocity are mostly contained within the banks of the creeks.

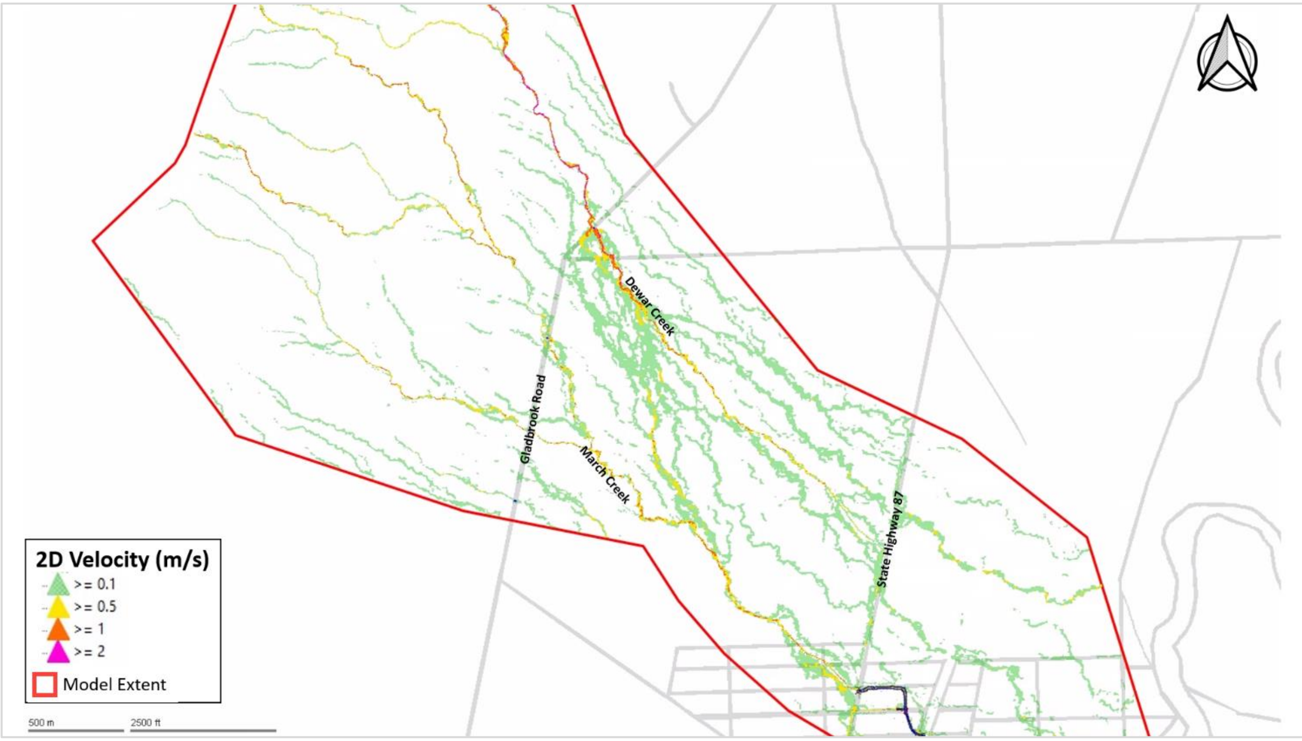

Figure 4-11: 2 Year ARI Design Storm Maximum Velocity

For the 50 year ARI event, velocities are predicted to increase across the upper catchment. Velocities now exceed 2 m/s in the upper gullies of both creeks, within the creeks along the plains and in the overflow from Dewar Creek to March Creek.

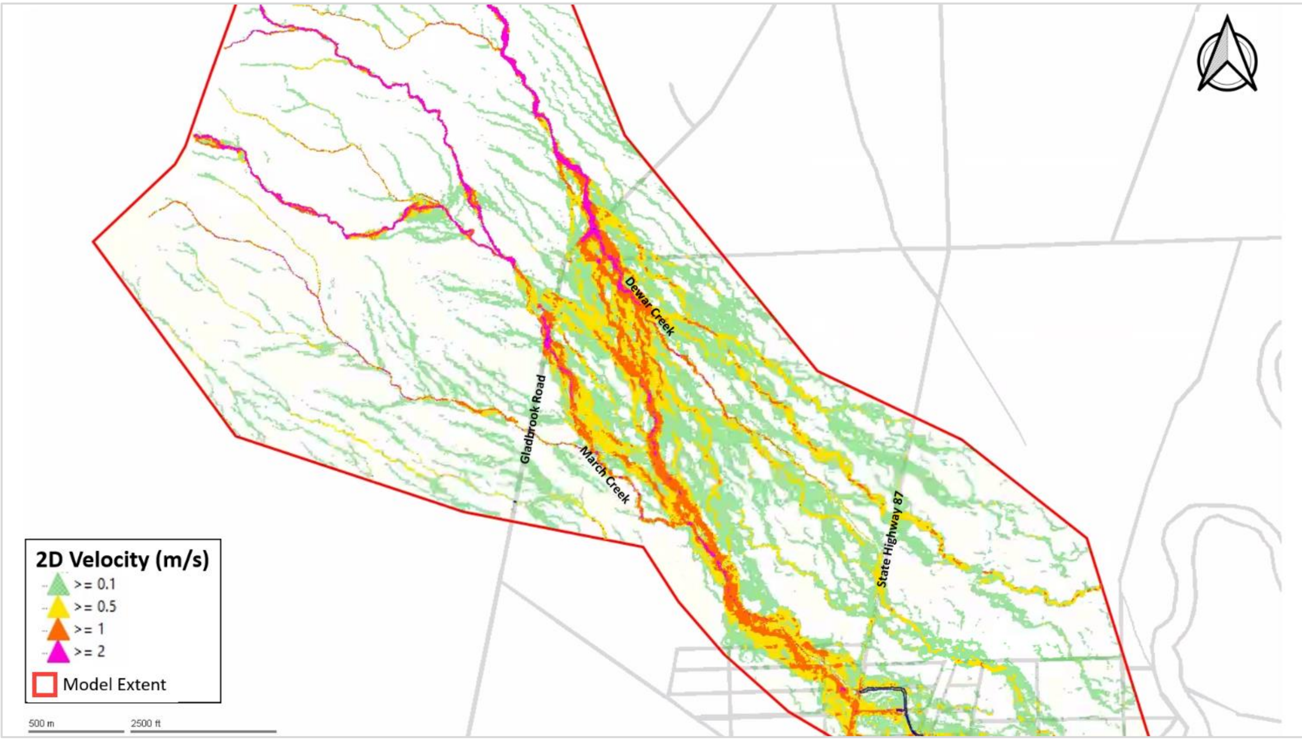

Figure 4-12: 50 Year ARI Design Storm Maximum Velocity

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The following conclusions are made from above assessment:

- The railway culvert has been identified as a constraint in March Creek, affecting floodwater conveyance through Middlemarch for the 2 year ARI event. The Tawe Street bridge directly upstream also presents a constraint for this event.
- Testing boundary conditions (water levels) downstream of the railway culvert in the hydraulic model has shown that the water level in the receiving stream is not the primary cause of historical flooding through Middlemarch, but rather the capacity constraints caused by bridges or creek through Middlemarch. This is confirmed for the 2 year ARI event.
- For larger rainfall events, such as the 20 year ARI event, floodwater conveyance of March Creek through Middlemarch is limited by capacity of the creek and other structures in the creek. This has been confirmed by running model scenarios with the railway culvert and Tawe Street bridge removed.
- An analysis of radar-derived rainfall data indicates there is a substantial variation in precipitation across the March Creek and Dewar Creek catchments. The most intense rainfall occurs in the upper catchment, within the Rock and Pillar range. This area contributes a substantial floodwater through Middlemarch.
- The catchment model has confirmed observations of Dewar Creek overtopping its banks and contributing to March Creek during large rainfall events. This was predicted by the model for the historical January 2021 event and the 50 year ARI design event.
- The catchment model has confirmed observations of a March Creek overtopping its banks upstream of the State Highway 87 bridge during large rainfall events (downstream of the inflow from Dewar Creek). This flow runs overland across properties before re-entering March Creek downstream of the Tawe Street bridge.

5.2 RECOMMENDATIONS

The following recommendations are made for the next stages of this project to address flooding issues along March Creek:

- Further modelling should be completed to assess if increases to structure capacity (railway culvert and Tawe Street bridge) are feasible and provide a substantial reduction in flood risk in Middlemarch.
- The assessment of increasing structure capacity should consider the downstream implications of increased flows. It is recommended further survey of the downstream creek and bridges is undertaken so they can be accurately represented in the model for this assessment.

The following recommendations are made for the next stages of this project to investigate flooding in the wider catchment surrounding Middlemarch:

- Further survey should be undertaken to improve the model's representation of the capacity of March Creek and Dewar Creek upstream of Middlemarch, with a particular focus on the locations where they are predicted to overtop their banks during large rainfall events.
- Hydrological inputs to the model should be refined to better represent the observed variation in rainfall across the catchment and runoff during wetter periods (ex: validation event 3). When developing flooding mitigation options, the effects of climate change should be incorporated into these inputs.
- Opportunities attenuating runoff in the upper catchment should be investigated (such as reforestation, check dams and contour trenching).
- When refining the catchment model, the model should be expanded to include all creeks that may contribute overland flow through Middlemarch (ex: Browns Creek catchment).

6 LIMITATIONS

This report ('Report') has been prepared by WSP New Zealand Limited ('WSP') exclusively for Otago Regional Council ('Client') in relation to the investigation of the floodwater conveyance of March Creek through Middlemarch ('Purpose') and in accordance with the Short Form Agreement dated 18 October 2023 ('Agreement'). The findings in this Report are based on and are subject to the assumptions specified in the Report. WSP accepts no liability whatsoever for any use or reliance on this Report, in whole or in part, for any purpose other than the Purpose or for any use or reliance on this Report by any third party.

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APPENDIX A

RADAR RAINFALL MAPS

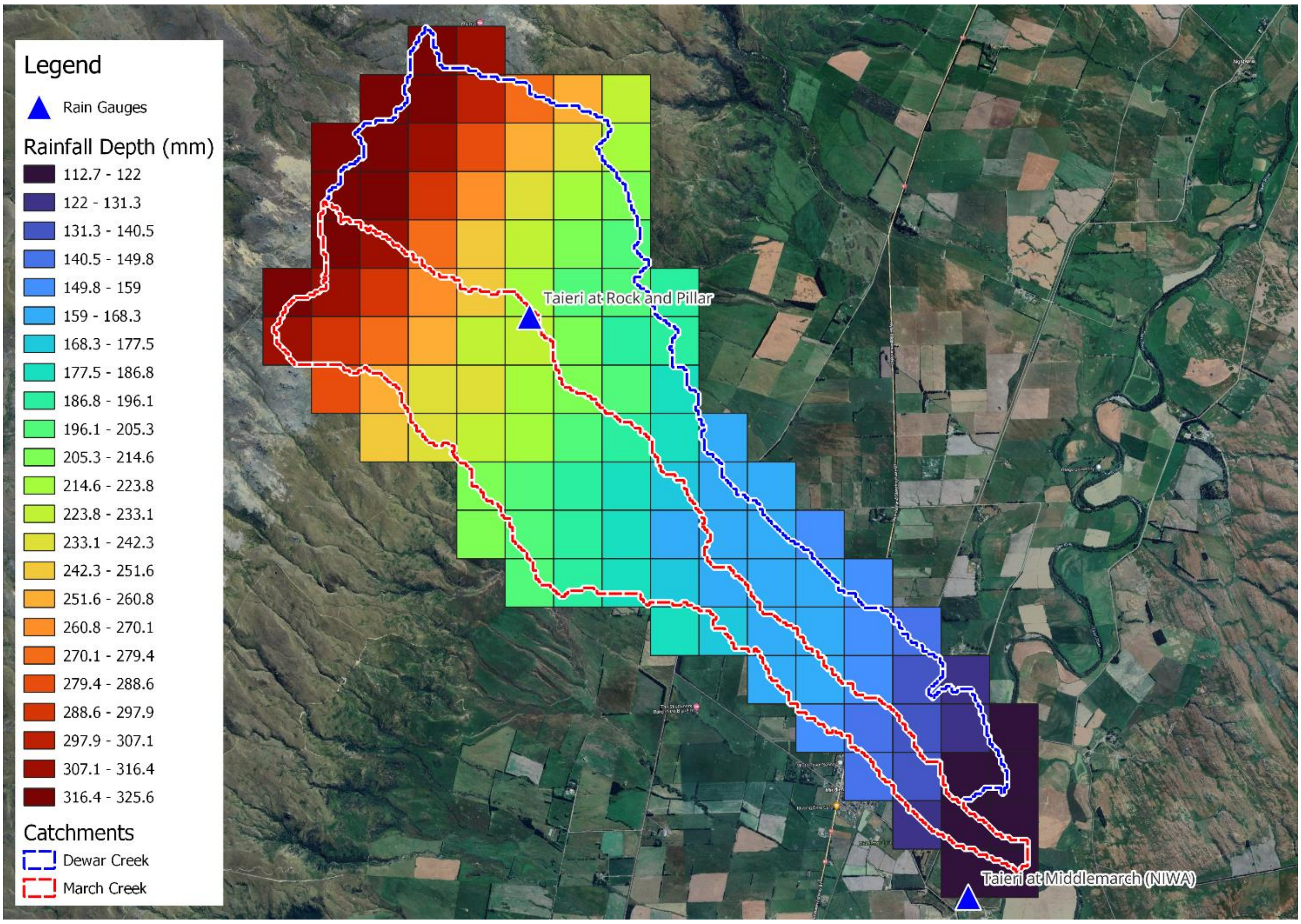

Figure 0-1: Validation Event 1 Cumulative Rainfall (21 December 2020 to 11 January 2021)

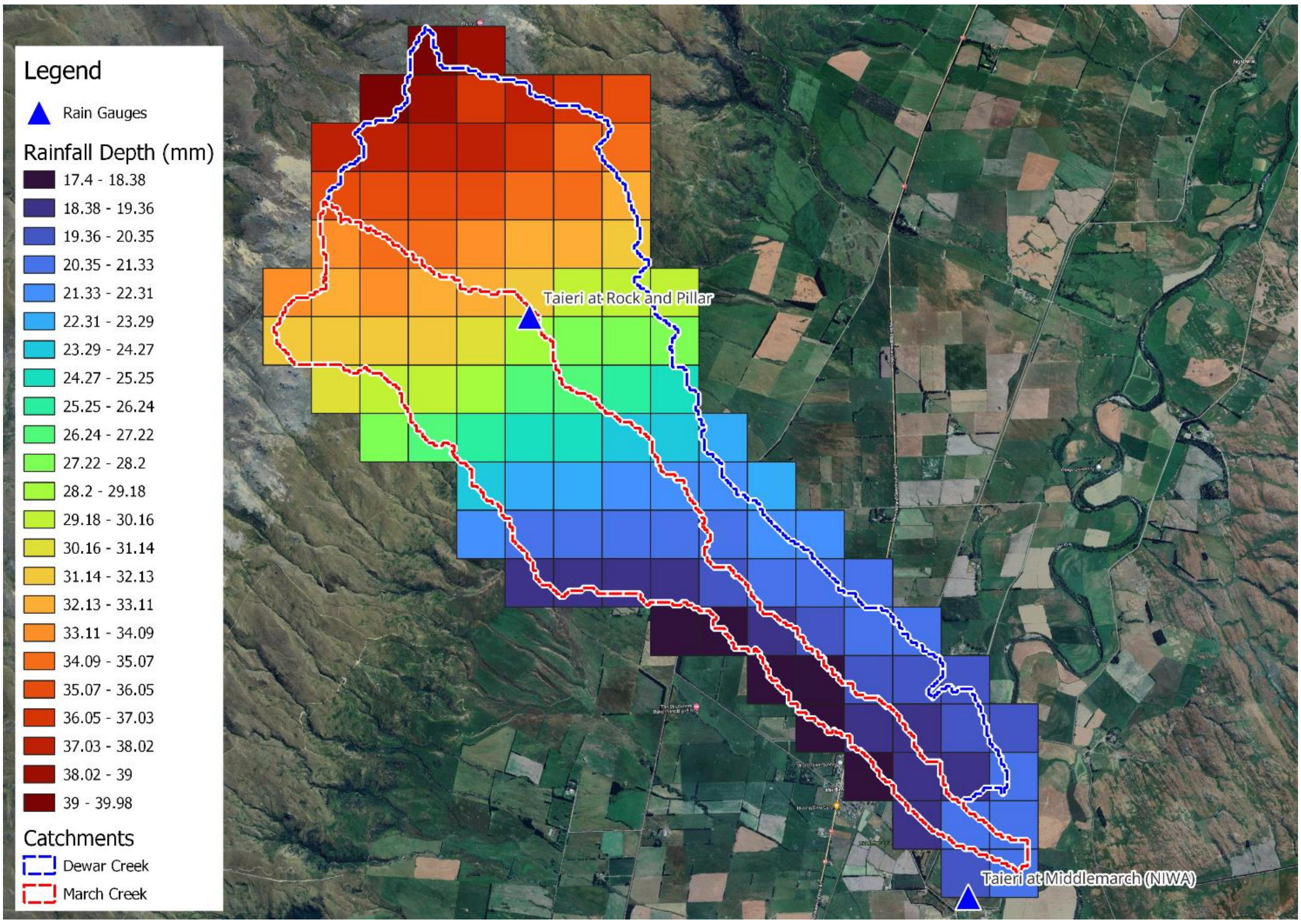

Figure 0-2: Validation Event 2 Cumulative Rainfall (19 February to 12 March 2021)

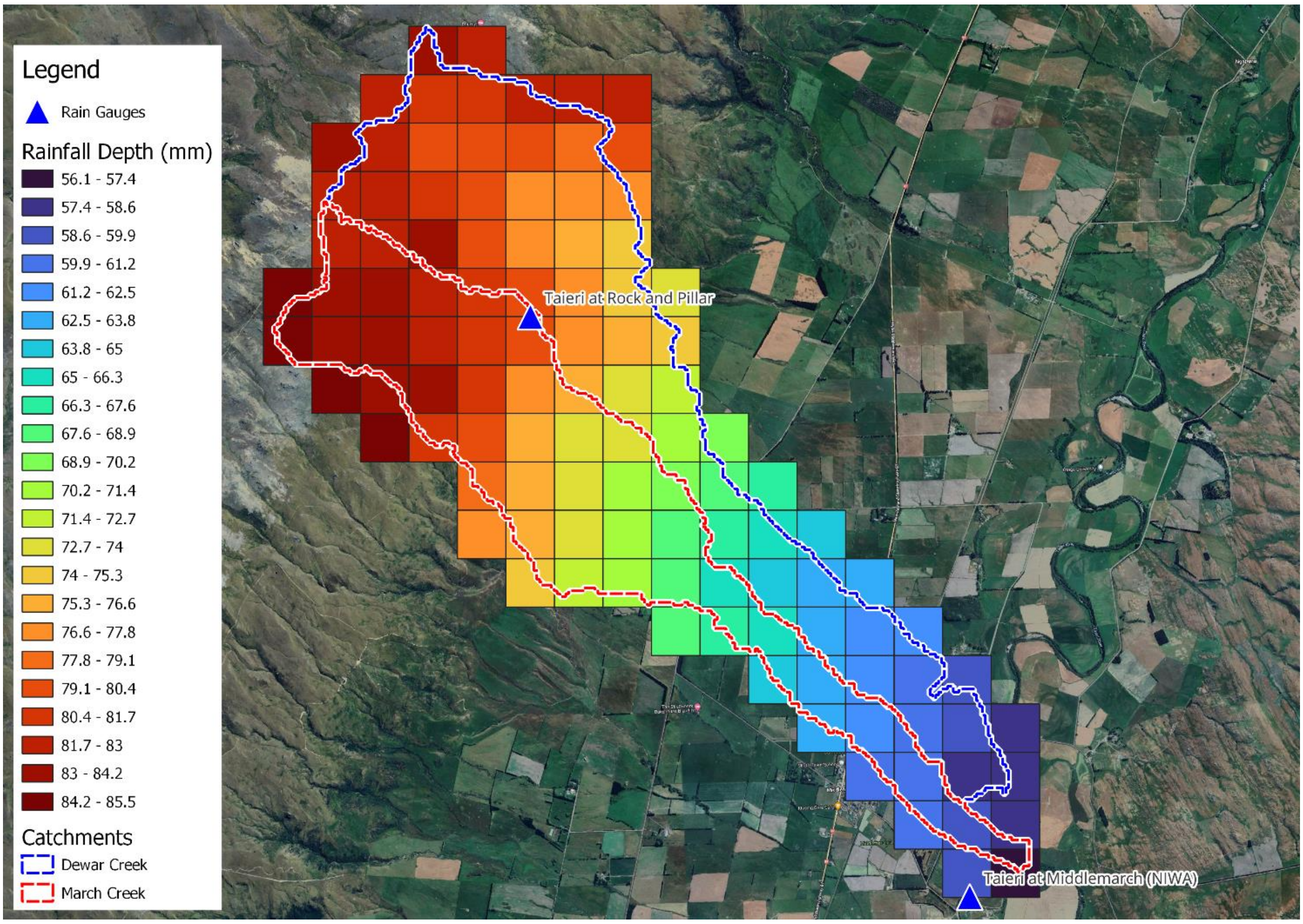

Figure 0-3: Validation Event 3 Cumulative Rainfall (18 May to 7 June 2023)

7 REFERENCES

Akan, O. A. (1993). *Urban Stormwater Hydrology: A Guide to Engineering Calculations.* CRC Press.

Chow, V. T. (1959). *Open Channel Hydraulics.* New York: McGraw-Hill.

CIRIA. (2019). *Culvert, Screen and Outfall Manual.* London: CIRIA.

8 GEOSPATIAL DATA SOURCES

FSL New Zealand Soil Classification
https://lris.scinfo.org.nz/layer/48079-fsl-new-zealand-soil-classification-v10/

NZ 8m Digital Elevation Model (2012)
https://data.linz.govt.nz/layer/51768-nz-8m-digital-elevation-model-2012/

Otago LiDAR 1m DEM (2016)
https://data.linz.govt.nz/layer/99123-otago-lidar-1m-dem-2016/

NZ River Centrelines
https://data.linz.govt.nz/layer/50327-nz-river-centrelines-topo-150k/

NZ Building Outlines
https://data.linz.govt.nz/layer/101290-nz-building-outlines/

NZ Primary Road Parcels
https://data.linz.govt.nz/layer/50796-nz-primary-road-parcels/

LCDB v5.0 - Land Cover Database version 5.0, Mainland New Zealand
https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/