APPENDIX 2

Te Hakapupu - Nature Based Solutions

Rapid Flood Hazard Model Build Report

Boffa Miskell

10 December 2024

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Executive Summary

GHD was engaged by Boffa Miskell on behalf of Otago Regional Council (ORC) to undertake Rapid Flood Hazard Mapping (RFHM) of the Te Hakapupu Pleasant River Catchment (Te Hakapupu) to understand the initial flood risk in the catchment.

The purpose of this report is to document the stormwater modelling methodology for the Te Hakapupu catchment and present high level RFHM results for the existing development (ED) with future rainfall and climate change to identify flood risks in the catchment. This report summarises the modelling methodology and the assessment of results. Flood maps for the 100-year ARI storm event with future climate changes allowances and existing land use flood extents, level, depth and speed in the catchment form part of this report.

The following conclusions can be derived from this flood assessment:

- The hydrology assessment was undertaken using HEC-HMS and the hydraulic modelling was undertaken using InfoWorks ICM.
- The upper catchment was divided into seven sub-catchments of various sizes to generate inflow boundary for the lower catchment.
- A minimum grid size of $9m^2$ was used for the 2D domain of the lower catchment in InfoWorks ICM.
- A constant downstream tidal boundary of 3.15mRL was used based on MHWS of 2.15mRL at Port Chalmers plus an additional metre to account for the sea level rise due to climate changes.
- The 2D InfoWorks ICM model has been set up for the 100-year ARI and 10-year ARI 24-hour storm duration events. Model has been simulated for the 100-year ARI 24-hour storm event at this stage.
- The maximum depth of flooding in the lower catchment was predicted to be about 5m mainly along the river system.

Contents

Table index

Figure index

1. Introduction

GHD was engaged by Boffa Miskell on behalf of Otago Regional Council (ORC) to undertake Rapid Flood Hazard Mapping (RFHM) of the Te Hakapupu Pleasant River Catchment (Te Hakapupu) to understand the initial flood risk in the catchment.

1.1 Purpose of this report

The purpose of this report is to document the stormwater modelling methodology for the Te Hakapupu catchment and present high level RFHM results for the existing development (ED) with future rainfall and climate change to identify flood risks in the catchment.

This report summarises the modelling methodology and presents the results. Flood maps showing the maximum flood level, depth, and speed in the catchment form part of this report.

1.2 Scope

The scope of work includes the following:

- Development of a simple HEC-HMS catchment-based model for the steep upper catchments to provide hydrological boundary conditions to the lower catchment.
- Develop a 2D hydraulic model for the lower downstream area using InfoWorks ICM with suitable mesh size to achieve a reasonable model run time.
- Determine rainfall profiles based on NIWA’s High Intensity Rainfall Design System (HIRDS) v4.0 and climate change RCP 8.5 scenarios and a future climate change adjusted tidal boundary using published data.
- Set up the 2D hydraulic model to simulate the 100-year ARI and 10-year ARI 24-hour duration storm events.
- Provide model outputs (floodplain extent) for the future climate change 100-year ARI 24-hour duration storm event with existing land use.
- Summarise the outcomes in a report.

1.3 Limitations

GHD has prepared this report on the basis of information provided by Boffa Miskell and others who provided information to GHD, which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

This report: has been prepared by GHD for Boffa Miskell and may only be used and relied on by Boffa Miskell for the purpose agreed between GHD and Boffa Miskell as set out section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Boffa Miskell arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this RFHM assessments for, and for the benefit and sole use of, Boffa Miskell to support their delivery of the Te Hakapupu Stage 1 Feasibility Study and must not be used for any other purpose or by any other person.

The information, data and assumptions ("Inputs") used as inputs into the Model are from publicly available sources or provided by or on behalf of the Boffa Miskell, (including possibly through stakeholder engagements). GHD has not independently verified or checked Inputs beyond its agreed scope of work. GHD's scope of work does not include review or update of the Model as further Inputs becomes available.

1.4 Assumptions

The following assumptions were made for this study:

- The RFHM assessment is based on the Te Hakapupu catchment topography only. The 1D pipe network, if any, has been excluded in this modelling assessment.
- All provided and sourced information (LiDAR data, catchment boundaries, GIS inputs) used for the development of the model have been assumed to be correct and accurate.
- The design storms and rainfall patterns have been generated using NIWA's HIRDS v4.0 and climate change RCP 8.5 scenarios for the future scenario (2081-2100).
- Upper catchments have been assumed to be completely pervious whereas the lower catchment has been assumed to have 1% imperviousness.
- No validation of the model results using historical data has been undertaken.

1.5 Background

ORC are currently partnering with Kāti Huirapa Rūnaka ki Puketeraki to deliver Toitū Te Hakapupu. Toitū Te Hakapupu for a multi-million-dollar catchment restoration project in the Te Hakapupu catchment, focusing on improvements to water quality and biodiversity. The project aims to improve the wider ecosystem, reduce sediment and nutrient inputs, and promote the use of modern-day knowledge to sustain current efforts. Completed and ongoing work on the Te Hakapupu catchment includes understanding water quality issues, developing environmental baselines, fence implementation and planting works.

The Te Hakapupu catchment is primarily rural covering approximately 12,800 hectares of land and is situated in East Otago at the immediate south of the Palmerston township (Figure 1).

Figure 1 Te Hakapupu | Pleasant River Catchment Boundary

The current study is one of two studies occurring in parallel and involves a feasibility study into flood mitigation opportunities for the Te Hakapupu catchment, with particular emphasis on nature-based interventions (restored and constructed wetlands). Intervention options that provide co-benefits for water quality and the environment are preferred. Nature-based flood hazard mitigation opportunities are to be investigated by are:

– Modelling the hydrology of the Te Hakapupu catchment under different rainfall events
– Developing key design criteria for nature-based flood mitigation opportunities
– Identifying suitable locations for intervention opportunities with respect to potential benefits, implementation costs, land ownership, and consenting requirements

The second study is an engagement study intended to complement the feasibility study and seeks to develop understanding of the opportunities and barriers to communities, particularly landowners for which the natured based intervention options will be adopted on their land. The two studies together aim to facilitate informed evidence-based decision making for mana whenua, ORC, and the East Otago community by providing an improved understanding of the potential natured-based interventions and perspectives of the community surrounding these interventions.

ORC currently requires technical advice about the implementation of nature-based flood hazard intervention opportunities in the Te Hakapupu catchment and has engaged Boffa Miskell to complete the stage 1 feasibility study.

Boffa Miskell have engaged GHD to support the hydrological modelling component of the above feasibility study. This entails the development of a rapid flood hazard model to identify initial flood risk.

2. Model Build

2.1 Modelling Software

HEC-HMS v4.10 was used to undertake hydrological analysis while InfoWorks ICM v2023.2 was used to complete a two-dimensional (2D) hydraulic assessment.

2.1.1 Topographical Data

Two Digital Elevation Models (DEMs) – 1m Otago DEM and 8m NZ DEM were downloaded from the freely available LINZ website and used in the model build process. To bypass software limitations, the 8m DEM was used to determine the boundary conditions from the upper catchment for the lower Te Hakapupu catchment. Differences between using the 8m and 1m DEMs for the upper catchment were considered negligible. Once the boundary conditions were identified, the 1m LiDAR DEM was used to develop the 2D model using InfoWorks ICM. The vertical datum of the 1m LiDAR DEM is NZVD2016 while horizontal projection is based on New Zealand Transverse Mercator 2000.

2.1.2 Catchment Delineation

The model has been structured based on considering potential flood risk. Additionally as per the scope of works, the Te Hakapupu catchment was divided into an upper catchment and lower catchment to achieve reasonable computation times for the lower 2D model domain. Due to the elevated topography in the west of the Te Hakapupu catchment, drainage channels were generally expected to drain from west to east towards the lower catchment and the ocean. Areas with the greatest risk of flooding would be expected to be at low elevation/flat land. The split between the upper catchment and lower catchment was therefore taken from the base of the hills.

The relevant upper catchment areas (west of the hills) were determined using the 8m DEM. The upper catchment within Te Hakapupu was divided into seven hydrologic catchments based on the topography and therefore drainage channels within the catchment (Figure 2). Catchments were delineated to estimate the incoming flows from the upper catchments into the lower half of the Te Hakapupu catchment. Each catchment represents the area that drains into the lower catchment. The longest flow path for each of the upper catchments were determined to estimate the time of concentration for the flows discharging into the lower catchment.

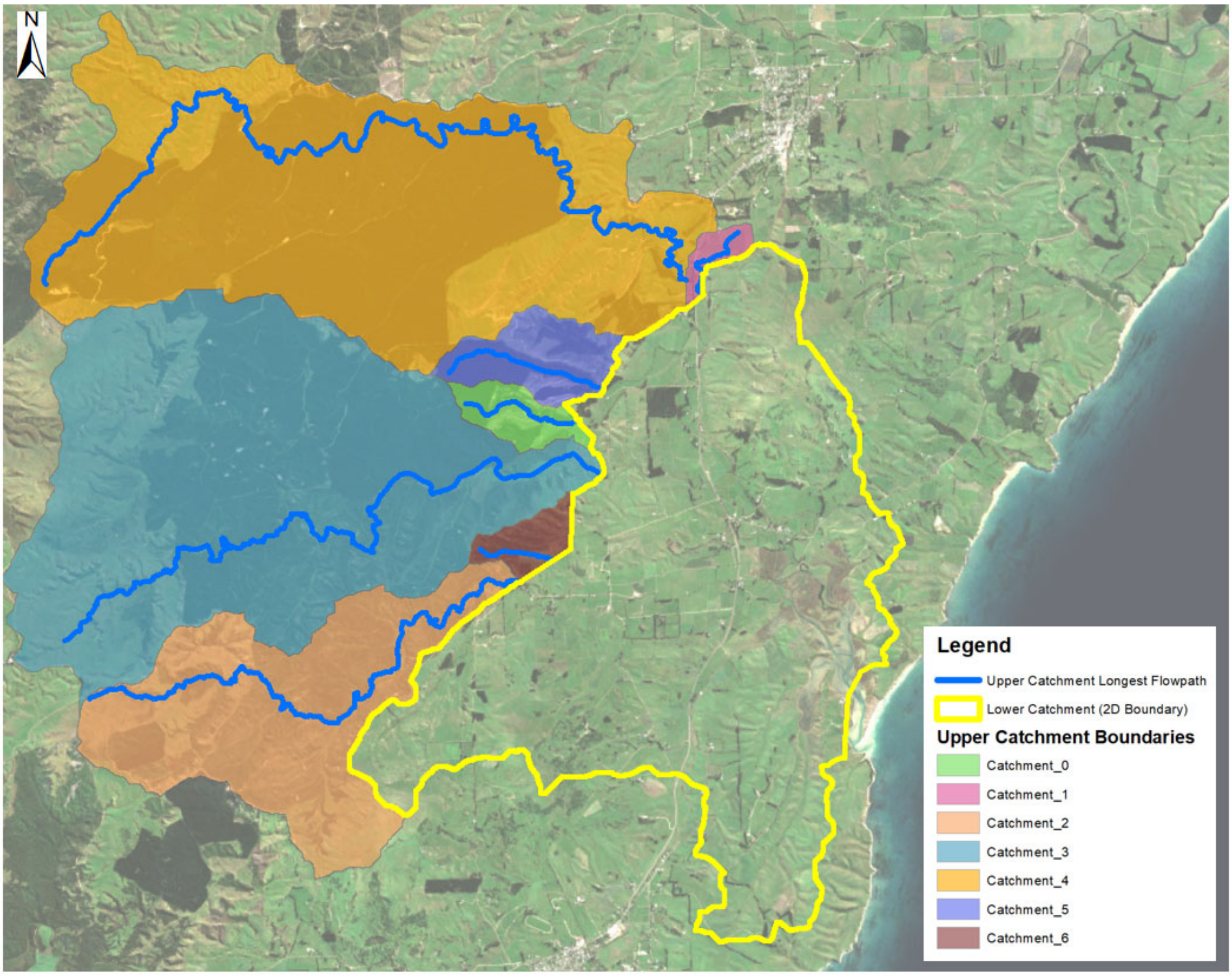

Figure 2 Delineated Upper Catchments and Lower 2D Model Boundary

2.2 HEC-HMS Model

HEC-HMS 4.10 was used to determine the boundary flow conditions from the upper catchment into the lower Te Hakapupu catchment.

2.2.1 Hydrological Parameters

A review of published geological map of the catchment (Institute of Geological and Nuclear Sciences, 1:250,000 Geological Maps, 2001) indicates that the Te Hakapupu catchment is made primarily of siltstone, sandstone, and schist, with smaller amounts of basalt, gravel, and sand (Figure 3).

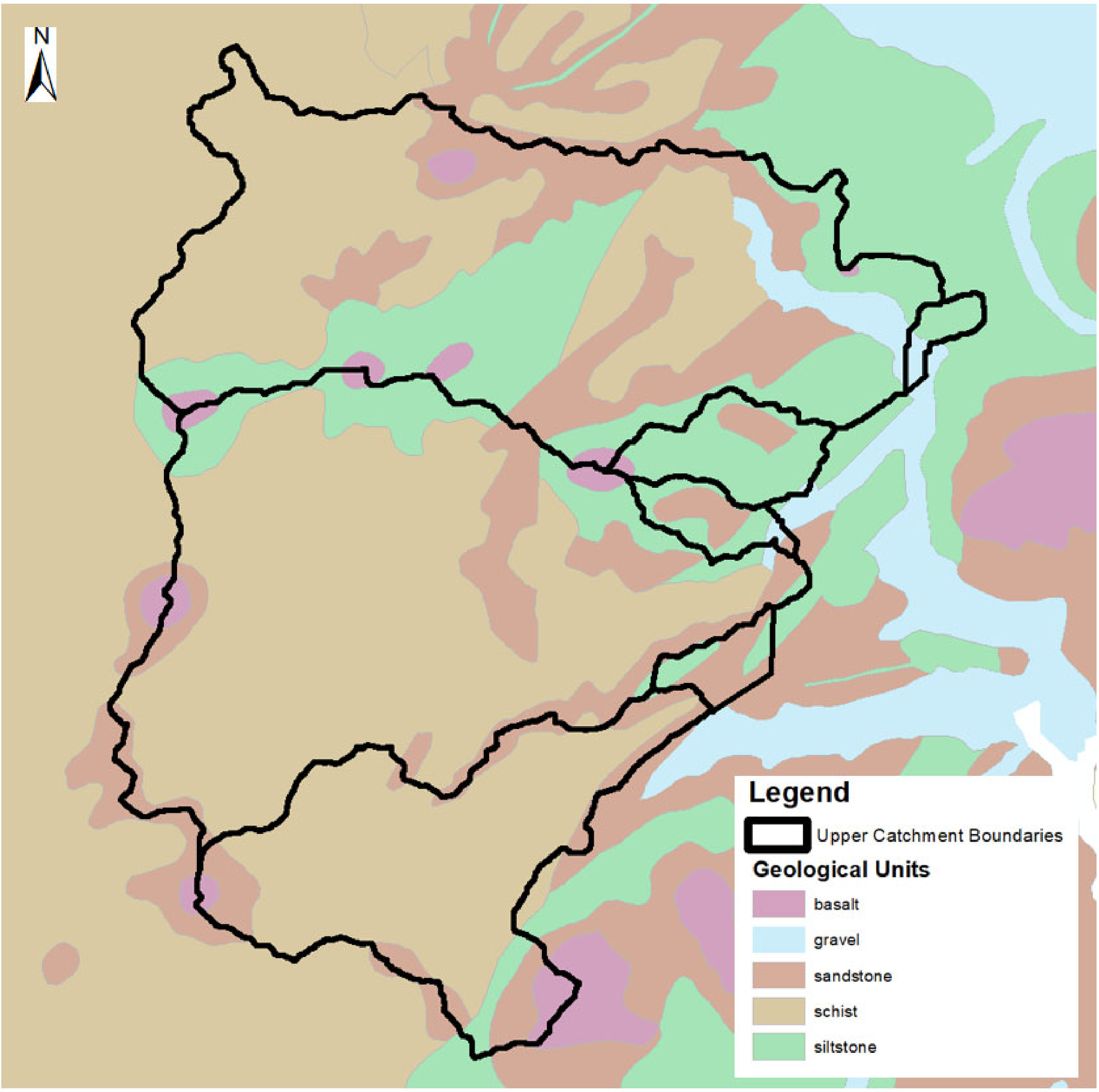

Figure 3 ***Geological Units within the Upper incoming Catchments of the Te Hakapupu Catchment***

Each geological unit was classified and assigned a curve number based on Auckland Council's "Guidelines for stormwater runoff modelling in the Auckland Region". This is summarised in Table 1.

Table 1 ***Te Hakapupu catchment geological classifications and curve numbers (Source: Guidelines for stormwater runoff modelling in the Auckland Region, Auckland Council April 1999)***

Geological Unit	Hydrological Soil Classification	Curve Number
Siltstone	Weathered mudstone and sandstone (Waitemata and Onerahi Series)	74
Sandstone	Weathered mudstone and sandstone (Waitemata and Onerahi Series)	74
Schist	Weathered mudstone and sandstone (Waitemata and Onerahi Series)	74
Basalt	Granular volcanic loam (ash, tuff, scoria)	39
Gravel	Granular volcanic loam (ash, tuff, scoria)	39

Geological Unit	Hydrological Soil Classification	Curve Number
Sand	Weathered mudstone and sandstone (Waitemata and Onerahi Series)	74
Unknown	-	74*

* A curve number of 74 was used for unidentified geological units as this was considered a more conservative value than 39.

The geological units of each upper catchment (Figure 2) were identified and their areas were calculated. The areas were then used to estimate a weighted average Curve Number (CN) for each upper catchment. The final weighted average CN numbers are provided below in Table 2.

Table 2 Weighted Average Curve Numbers for each Upper incoming Catchment

Catchment Number	Weighted Average Curve Number
Catchment_0	73
Catchment_1	64
Catchment_2	73
Catchment_3	74
Catchment_4	72
Catchment _5	73
Catchment _6	74

2.2.2 Elevation Profile of Flowpath

The elevation profile of each longest flow path was plotted out based on the river chainage across the 1m LiDAR DEM. In combination with the catchment area, the weighted CN as shown in Table 2, the elevation profile was used to estimate the time of concentration for each upper catchment.

2.2.3 Temporal Design Storm Pattern

The centre coordinates of the upper incoming catchment were calculated and input into NIWA's HIRDS v4.0 to determine rainfall depths for the 100-year ARI 24-hour storm duration. Together with NIWA's design parameters, the rainfall depths were used to generate the temporal storm pattern for each catchment for input into the HEC-HMS model for both upper and lower catchments.

2.2.3.1 Lower Catchment Rainfall Intensity Profile

The rainfall intensity profile applied was also developed in the HEC-HMS model, following a similar process as above using a time of concentration, initial losses and temporal design storm pattern specific to the lower catchment. The rainfall intensity profile represents the net rainfall (total rainfall minus losses) calculated in the HEC-HMS model. The net rainfall intensity profile of the lower catchment is illustrated in Figure 4 and was applied as rain-on-grid .into the entire 2D domain of the lower catchment.

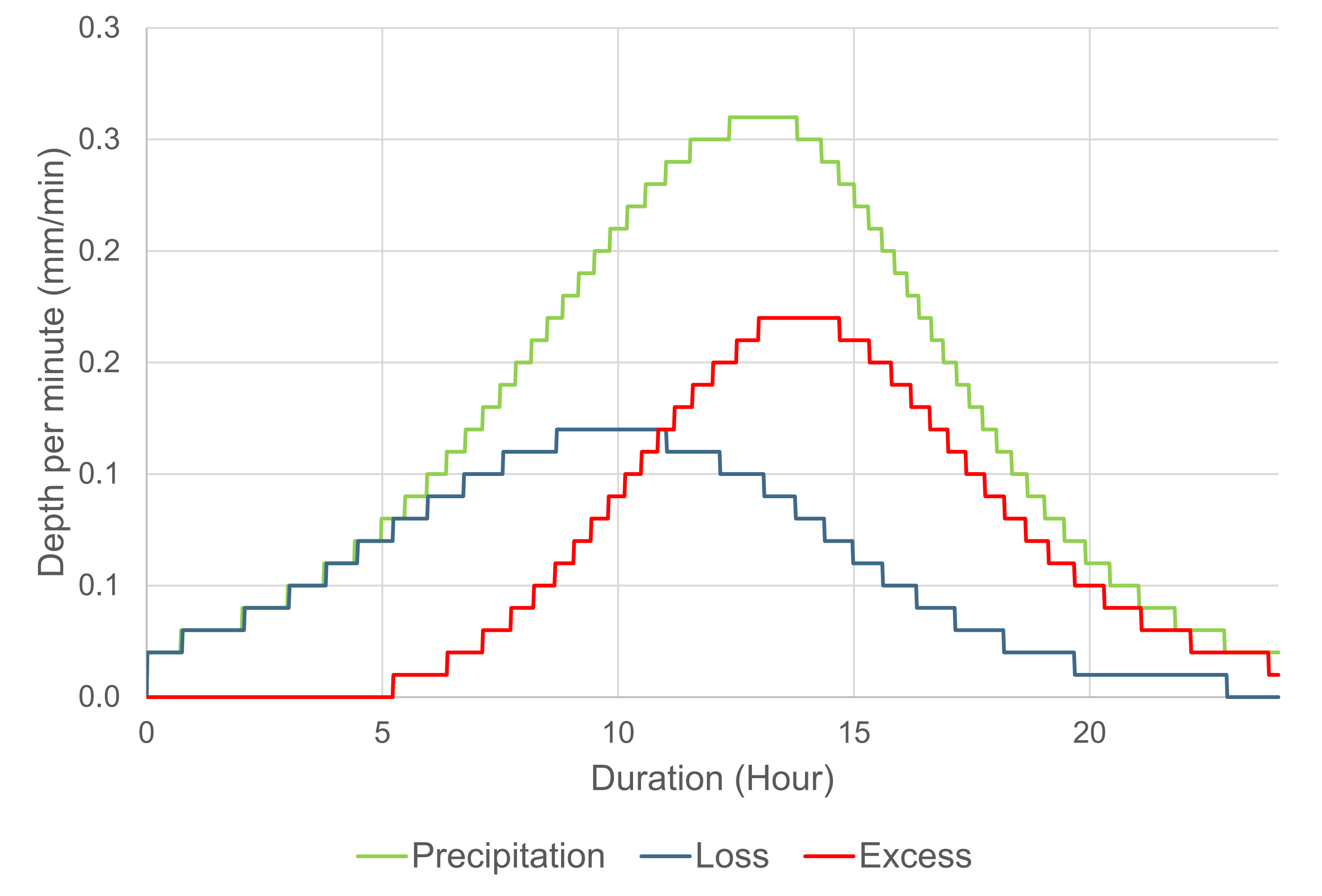

Figure 4 Lower Catchment Rainfall Intensity Profile showing Total, Loss and Excess Rainfall

2.2.4 Upper Catchment Inflows

Rainfall depths for the 100-year ARI 24 hour storm duration event with RCP 8.5 climate change were taken from HIRDS v4.0 at the centre of each of the seven upper catchments. This was used to determine the temporal design storm pattern for each upper catchment. The time of concentration and temporal design storm pattern for each upper catchment was then inputted into a rudimentary HEC-HMS model to simulate the incoming flows into the lower catchment. Upper catchment peak flows and rainfall are provided below in Table 3.

Table 3 Upper incoming catchment peak flows and rainfall for the 100-year ARI 24-hour storm duration event

Catchment Number	Total Rainfall (mm)	Total Loss (mm)	Total Excess (mm)	Peak Flow (m^3/S)
Catchment_0	180.93	70.47	110.38	4.50
Catchment_1	176.02	86.72	89.09	1.60
Catchment_2	190.02	71.41	118.02	48.10
Catchment_3	187.93	69.38	118.37	110.40
Catchment_4	190.02	73.06	116.23	107.50
Catchment_5	184.94	70.92	114.01	9.00
Catchment_6	176.02	67.97	108.14	3.60

The flow profile over the 24-hour duration for each upper catchment was extracted from HEC-HMS model and inputted as a boundary inflow to the InfoWorks ICM 2D model of lower catchment.

2.3 The 2D Hydraulic Model

The 2D hydraulic model was built in InfoWorks ICM v2023.2 after determining the boundary conditions in the HEC-HMS model. The 2D model boundary extends from the western hills within the Te Hakapupu catchment and covers the lower catchment area in the east up to the outfall of the river into the sea.

2.3.1 2D Surface Flow Model

The 2D model was developed and used to describe the overland flows within the 2D model domain. The ground surface within the 2D domain was represented by a minimum grid cell of 9 m^2 mesh generated in InfoWorks ICM using the 1m Otago DEM. A Manning's n-value of 0.06 was conservatively used for the entire 2D model domain.

2.3.2 Locations of Upper Catchment Inflows

The generated flow hydrographs as described in Section 2.2.4 above were loaded directly onto a node (Figure 5) near the downstream end of the upper catchment and the edge of the 2D model zone boundary, thus representing the discharge location of inflows into the lower catchment.

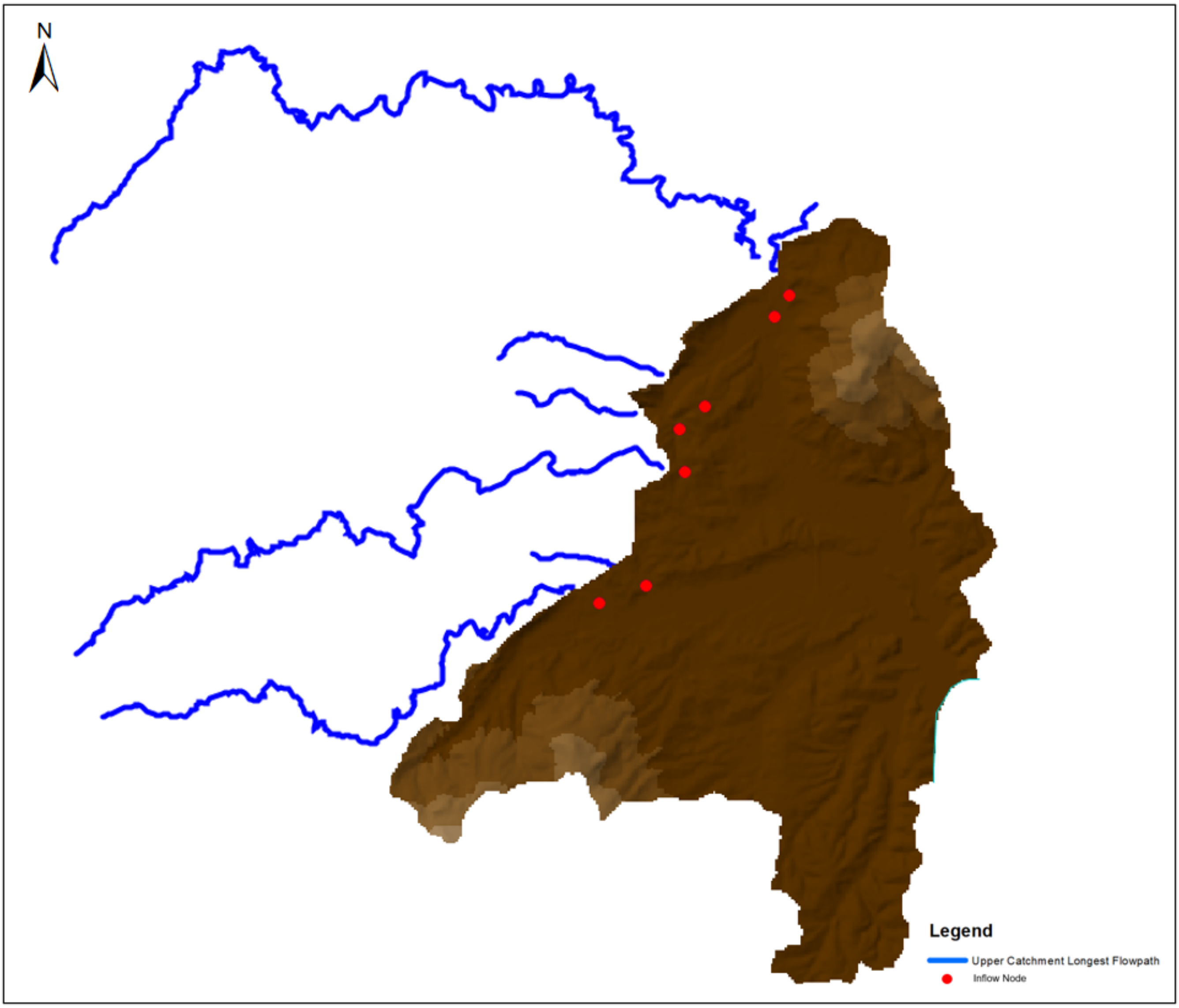

Figure 5 Location of incoming Flows into the Lower side of the Te Hakapupu Catchment

2.3.3 Tidal Boundary

The tidal boundary at the outfall of the Te Hakapupu River was derived from the nearest Port Chalmers tide data. The tidal boundary (see Figure 6) was set at 3.15 m based on the Mean High Water Spring (MHWS) level of 2.15mRL at Port Chalmers plus an additional one metre to account for future sea level rise due to climate changes.

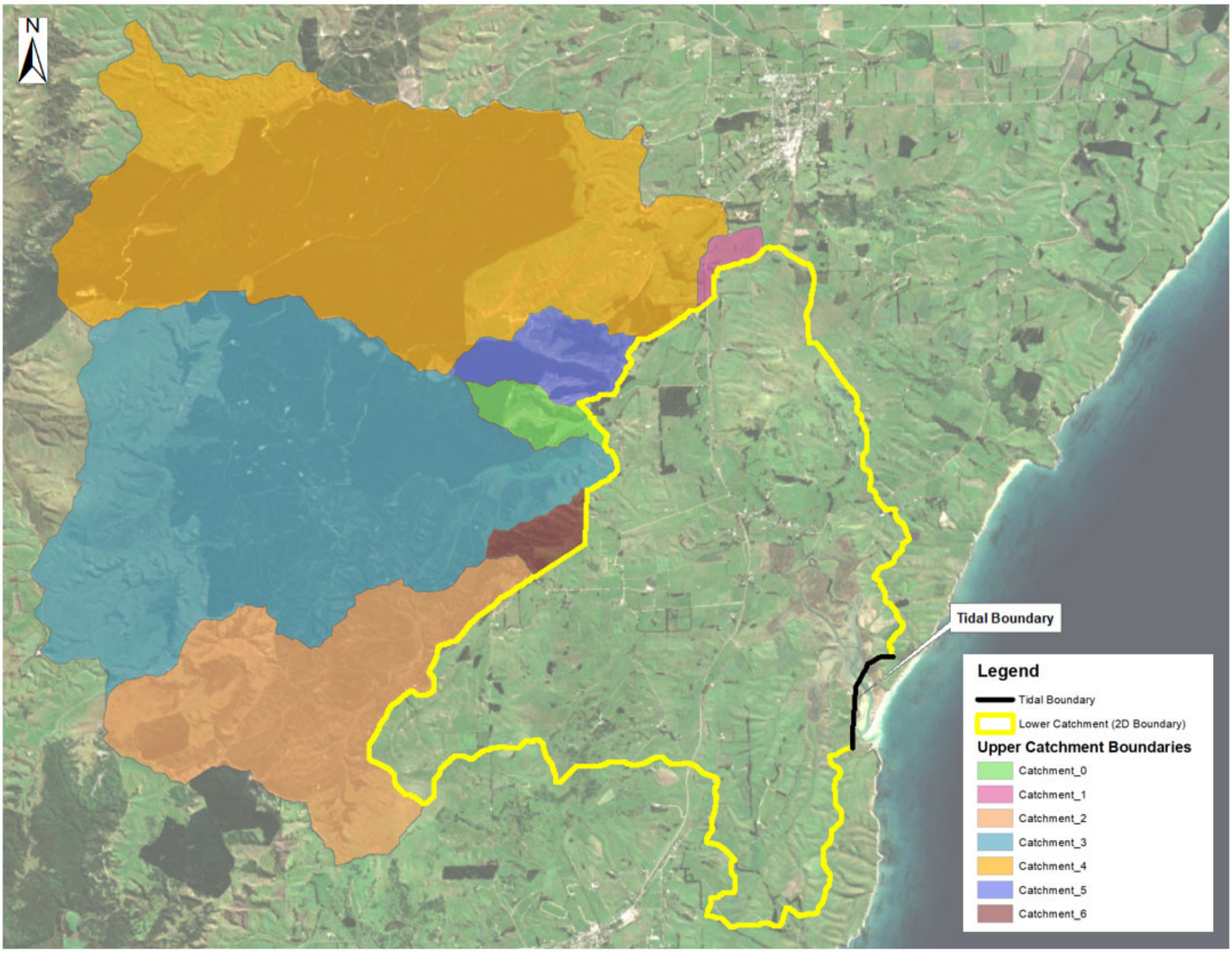

Figure 6 Location of the Tidal Boundary within the 2D Model

2.3.4 10-year ARI 24-hour Storm Duration

A scenario for the 10-year ARI 24-hour storm duration was set up following a similar process as the above. The HEC-HMS model was run using a temporal design storm pattern specific to the 10-year ARI 24-hour event. This enabled the HEC-HMS model to simulate peak flows and a rainfall intensity profile specific to the 10-year ARI 24-hour storm duration. The flow profiles and rainfall intensity profile were substituted in the 100-year ARI 24-hour scenario to set up the 10-year ARI 24-hour scenario. However, we haven't undertaken simulation of 10-year event at this stage.

3. Model Results

This section presents preliminary model results for the 100-year ARI 24-hour storm duration event prior to any model validation.

3.1 Existing Scenario

The predicted peak flood levels (Figure 7), peak depths (Figure 8) and peak speed (Figure 9) for the existing scenario 100-year ARI event are provided below for the lower catchment bounded in yellow. We have excluded 50mm depth from the predicted depth which is considered to be within the error margin of modelling software.

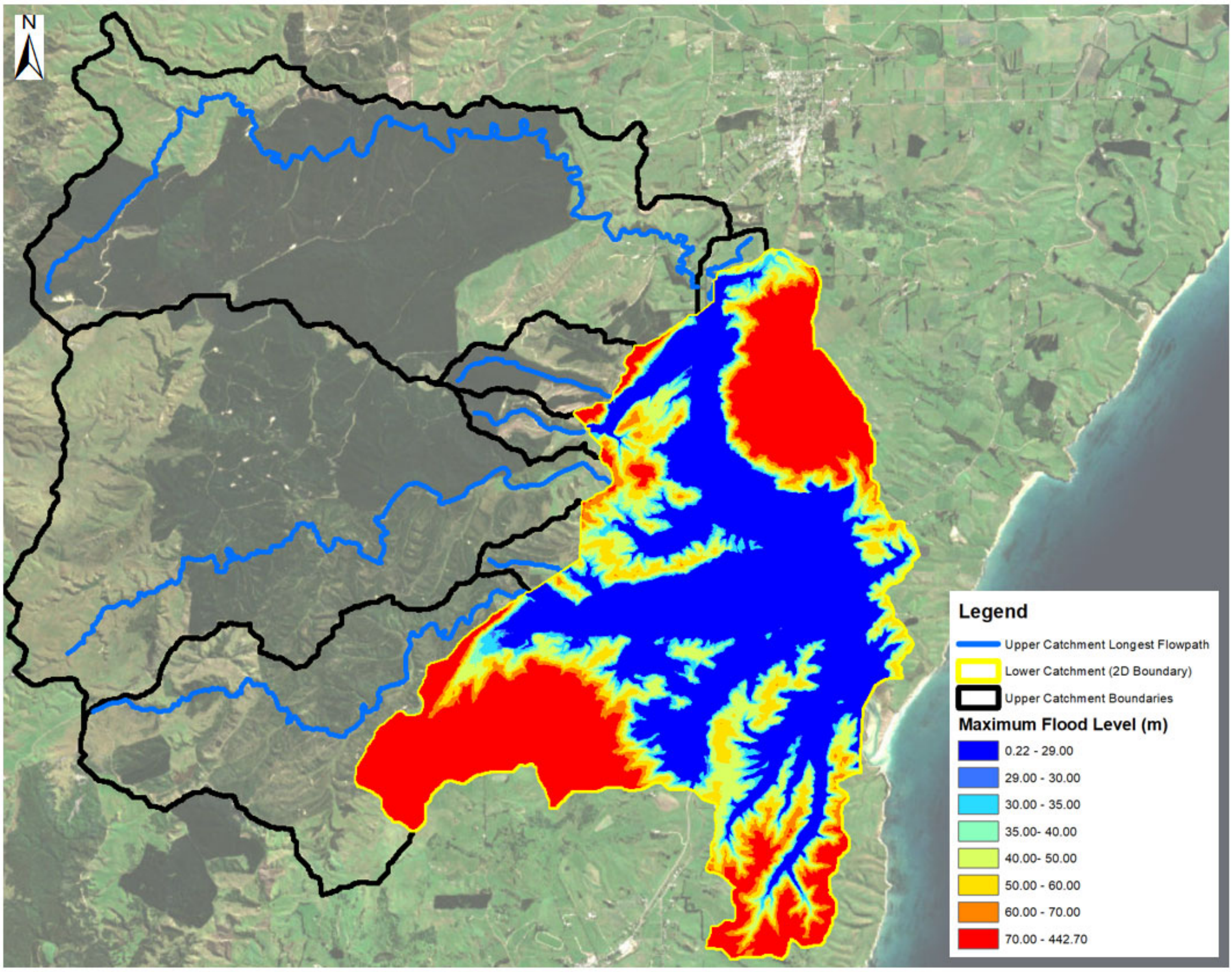

Figure 7 *Predicted Peak Flood level during 100-year ARI Event*

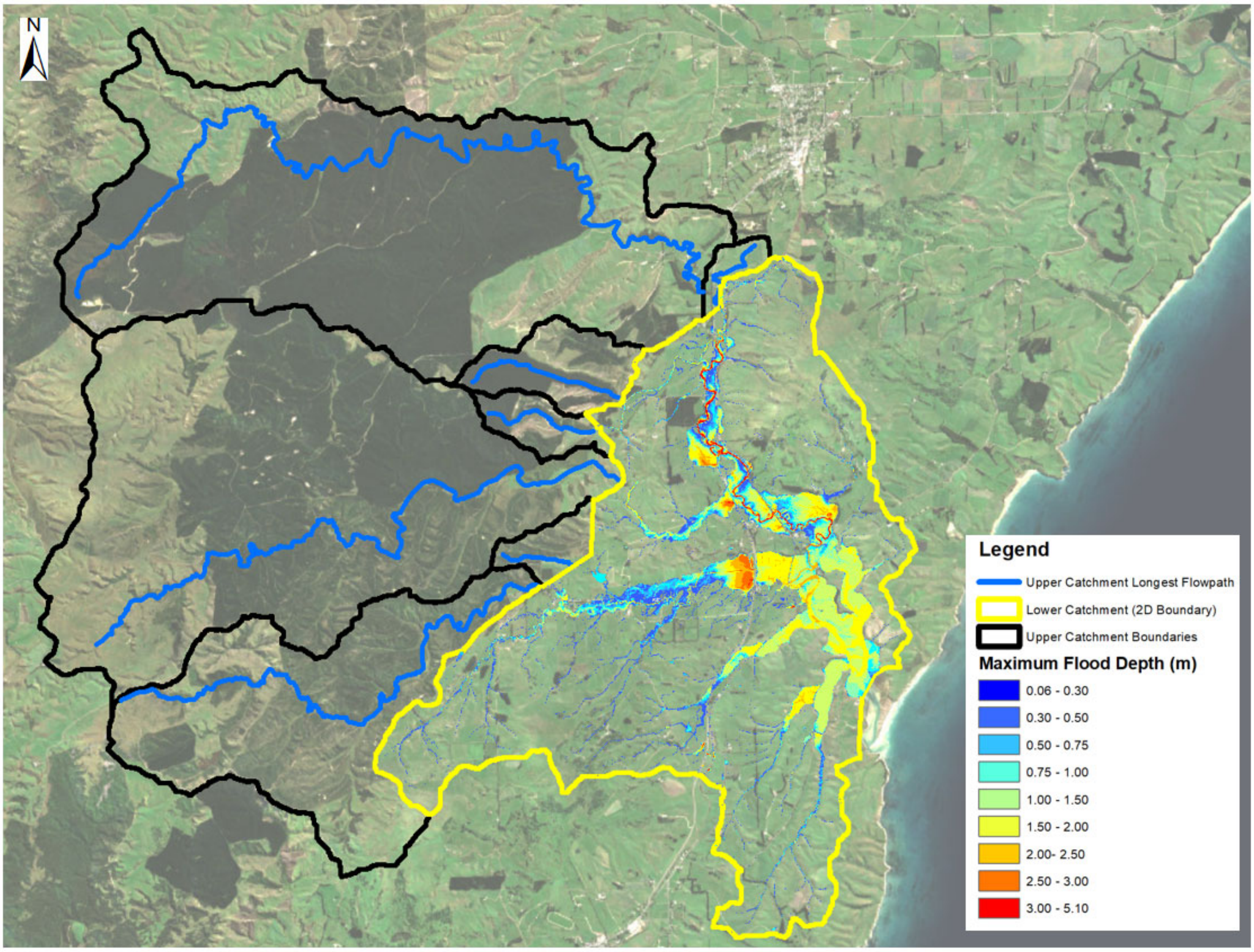

Figure 8 Predicted Peak Flood depth during 100-year ARI Event

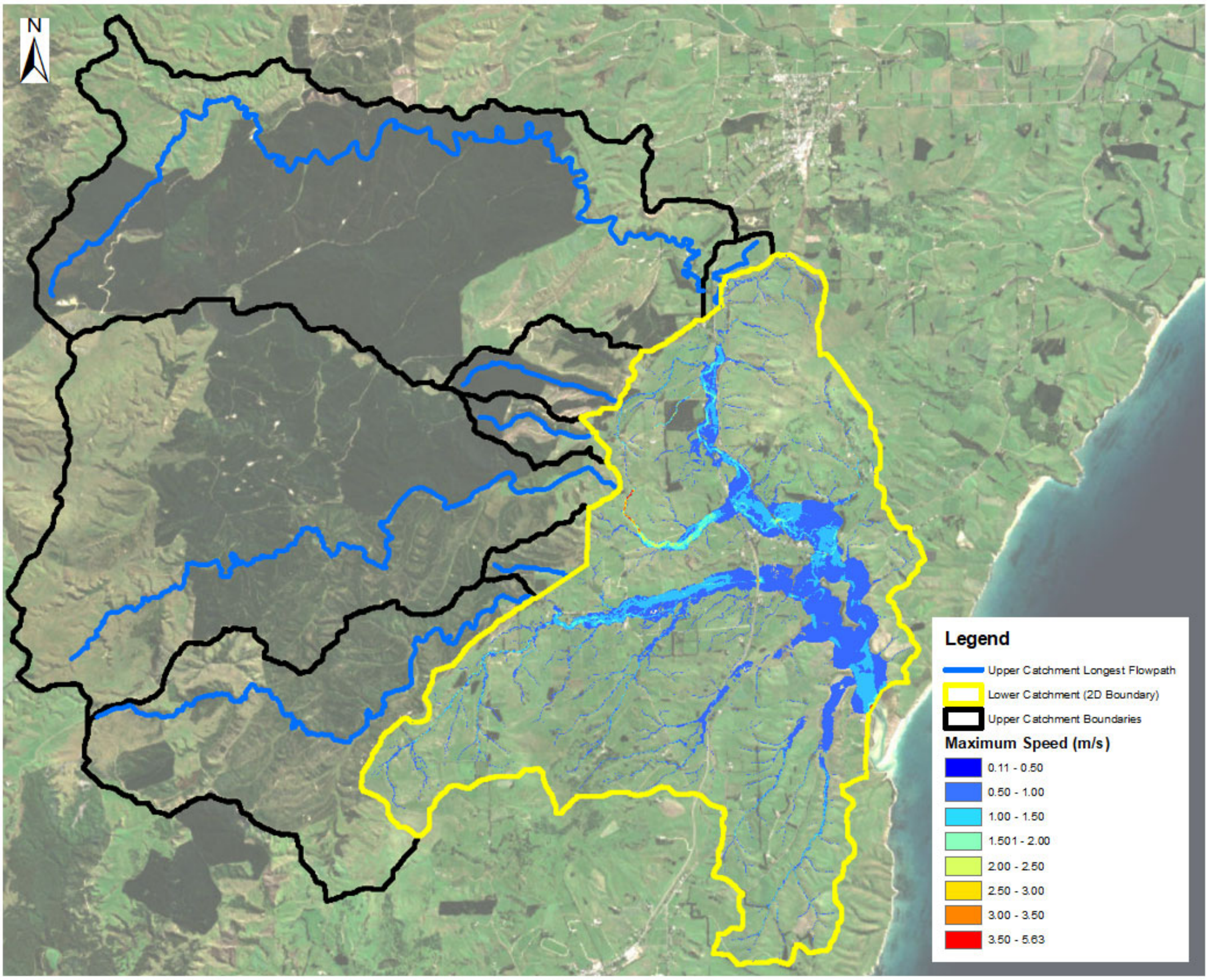

Figure 9 ***Predicted Peak Flow speed during 100-year ARI Event***

4. Integration with Nature Based Solutions

For the Te Hakapupu catchment, opportunities to implement nature-based solutions will depend on ORC priorities and the specific issues and locations of concern within the catchment. From discussions with ORC it is understood that concerns relate to:

- Sediment generation risk from harvesting in the upper catchment
- The ability to modify the current river channel to modify flood levels
- The ability to implement storage within the catchment (delivered in the form of wetland areas or similar)

4.1 Land Use

The model can be used to test some aspects of potential policy decisions within the catchment, such as land use / land coverage.

The upper catchments are largely covered by a mixture of forestry. The upper catchment models (HEC HMS components) were run with different runoff characteristics to frame out the relative change in outflow that could occur:

1. immediately following wide-spread harvest; or
2. with the land reverted to native forest.

The following changes were made to the CN values for the models:

1. Poor/bare coverage that would result immediately following forestry harvest

- CN 74 changed to CN **90** (residual crop cover, poor hydrologic condition, group C soils)
- CN 39 changed to **68** (grass, poor hydrologic condition, group A soils)

2. Improved coverage that would (eventually) result if the land was allowed to return to native forest

- CN 74 changed to CN **70** (woods, good hydrologic condition, group C soils)
- CN 39 changed to **30** (woods, good hydrologic condition, group A soils)

It should be noted that the CN values are impacted by the underlying soils as well as the type of vegetation and are empirical values.

The results have been compared to the original values (as provided in Table 3) and are summarised in Table 4 below.

Table 4 100-year ARI 24-hour storm duration (RCP 8.5 climate change) peak flows from the upper catchments under different land coverage scenarios

Catchment Number	Original Peak Flow (m^3/s)	Post Harvest Peak Flow (m^3/s)	Native Bush Peak Flow (m^3/s)
Catchment_0	4.5	5.6	4.2
Catchment_1	1.6	2.3	1.5
Catchment_2	48.1	60.2	45
Catchment_3	110.4	138.3	102.9
Catchment_4	107.5	138.5	99.9
Catchment_5	9	11.3	8.5
Catchment_6	3.6	4.5	3.4

Overall, in a 100-year ARI event with the post-harvest scenario, the model indicates that there could be increase in flow from the upper catchments in the order of 25% or more from the current forestry coverage. If the current forestry block was transitioned back to a full native bush coverage then a potential reduction in the order of 6-7% in 100-year ARI flows from these catchments could be possible compared to the current forestry coverage.

The values above are not absolute but instead provide an indication of the relative scale of change in flow (not flood extent) in the upper catchments, in a large event with future climate change projections included. Results in smaller events may be less pronounced. That said, the results indicate:

- A risk of increased rate of runoff post harvest
- Post-harvest sedimentation risk (resulting from increased runoff and potentially increased velocity and scour) in some catchments in the event of large rainfall events.

4.2 River Modification

In terms of flooding, the form of the river and the channel capacity will obviously impact flood depths as well as the frequency of spilling outside of the main channel and flood extents. In larger events, however, the capacity of the wider floodplain becomes more important.

One option considered was increasing naturalisation of the river channel and assessing how this could be beneficial in reducing flood risk. Options for naturalisation include channel modification (including reverting back to a more sinuous channel), increased planting and floodplain protection / modification.

At a high level, while there is evidence of channel modification through diverting and straightening through some properties, the channel itself is largely still that of a braided river system – so there would only be localised opportunities to implement changes. Compounding this, the flood extent shown in Figure 8 is significant. Naturalisation of these localised areas (through reinstating a more sinuous channel form and increasing floodplain storage) would be unlikely to be of a scale that would make a significant change in flood extent.

Vegetation measures may achieve benefits in terms of erosion management and protection of channel banks, but also may result in increased channel roughness and reduced channel capacity. The current model is not sufficiently detailed for assessment of erosion management options.

4.3 Additional Floodplain Storage

While additional floodplain storage was one of the options initially considered as an approach to manage flood extent, the scale and depth of flooding in the 100-year ARI event suggest that the results will depend on where this storage is provided (and what scale of flood reduction would be targeted). A large volume of storage would be necessary to achieve a material reduction, given that there are flood depths of more than 1.5m across most of the floodplain. In addition, flows are entering the main floodplain from a number of different reaches means that multiple basins could be necessary across the catchment.

It is important to note that flooding is a natural process and that it is not unexpected that there will be flooding in a widespread area in the event of a 100-year ARI event. There will be a need to consider the cost and trade-offs between the scale of purchase of land for provision of flood storage in upper branches compared to purchase of properties that might already be impacted by flooding in the first instance.

As some of the current flow depths and flood extent appear to be impacted by some of the current road levels then further survey is recommended to confirm road crest levels as well as identification of critical properties and location of dwellings to allow solutions to be considered in a more targeted manner. This particularly applies to State Highway 1 which is cutting across the floodplain in a number of areas.

4.4 Next Steps

While further information is necessary to enable the model to be used to develop possible nature-based solutions in more detail, including the size and location of possible options, in its current form the model gives an indication of the scale of solutions that would need to be developed to result in a reduction in floodplain level / extent.

It is recommended that the following steps be considered going forward:

- ORC consider assessment of smaller ARI flooding events as this may offer opportunities to manage flooding at a scale more frequently experienced by property owners.
- Consideration of development of the 1D component of the model to enable smaller scenario runs to be considered in future.
- Survey of road crest and culvert details around State Highway 1
- Dwelling extents may be worth incorporating into the flood maps for future assessment to support assessment of risk to people.
- Review specific areas around State Highway 1 and discuss with NZ Transport Agency Waka Kotahi future plans around road improvements.

5. Conclusions

The following conclusions can be derived from this flood assessment:

– The hydrology assessment was undertaken using HEC-HMS and the hydraulic modelling was undertaken using InfoWorks ICM.
– The upper catchment was divided into seven sub-catchments of various sizes to generate inflow boundary for the lower catchment.
– A minimum grid size of $9m^2$ was used for the 2D domain of the lower catchment in InfoWorks ICM.
– A constant downstream tidal boundary of 3.15mRL was used based on MHWS of 2.15mRL at Port Chalmers plus an additional metre to account for the sea level rise due to climate changes.
– The 2D InfoWorks ICM model has been set up for the 100-year ARI and 10-year ARI 24-hour storm duration events. Model has been simulated for the 100-year ARI 24-hour storm event at this stage.
– The maximum depth of flooding in the lower catchment was predicted to be about 5m mainly along the river system.

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