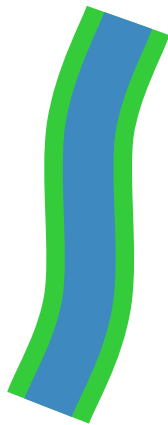


# Tapuata Stream Flood Assessment



Report prepared for Tararua District Council  
by

River Edge Consulting Limited

June 2024

|                            |                                                                                                               |                          |
|----------------------------|---------------------------------------------------------------------------------------------------------------|--------------------------|
| <b>Version:</b>            | Final                                                                                                         |                          |
| <b>Prepared for</b>        | Tararua District Council<br> |                          |
| <b>Report prepared by:</b> | Philip Wallace<br>River Edge Consulting Limited                                                               | <b>Date:</b> 3 June 2024 |



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## 1 Introduction

Tararua District Council (TDC) has identified a potential residential growth area for Dannevirke, on the true right bank of the Tapuata Stream (Figure 1-1). The area is currently zoned rural. The area on the true left bank is already zoned residential.

Little information on the flood hazard posed by the Tapuata Stream is available. TDC has engaged River Edge Consulting to carry out a flood assessment of the area and to produce floodmaps.



Figure 1-1 Tapuata Stream and proposed residential growth area, Dannevirke



## 2 Tapuata Stream and catchment

### 2.1 Location and extent

The Tapuata Stream is a tributary of the Mangatera Stream, itself a tributary of Manawatu River. The Tapuata Stream originates in low hill country to the east of the Ruahine Range before passing alongside the western boundary of Dannevirke and into the Mangatera Stream. Figure 2-1 shows the catchment of the Tapuata Stream. Upstream of the railway, the catchment area is approximately 12 km<sup>2</sup>.

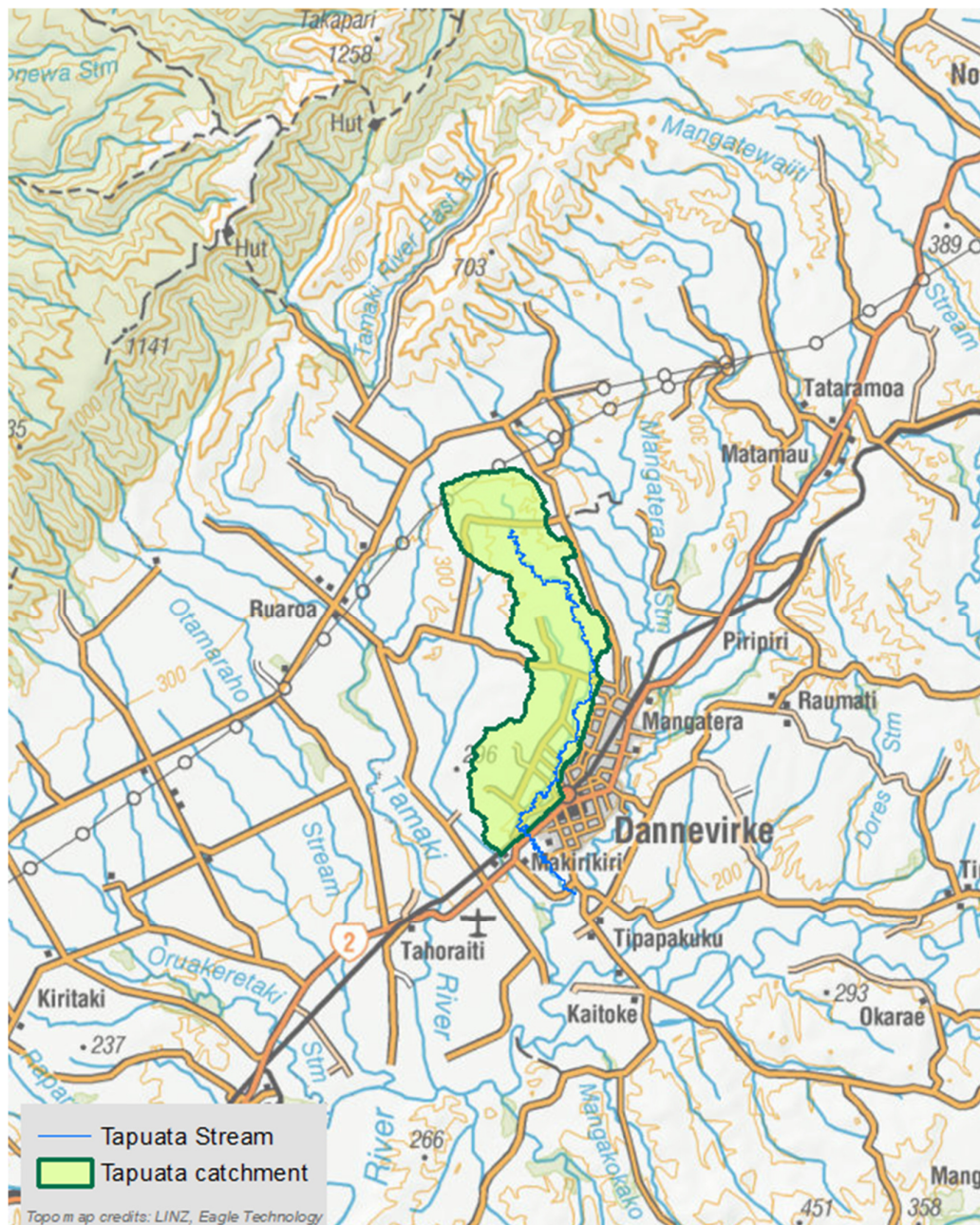


Figure 2-1 Tapuata Stream catchment



## 2.2 Stream flows and previous flooding

The stream carries only a small flow in normal conditions (e.g. as can be seen in Figure 2-2). Information on past flood events however is sparse. It is understood that the stream experienced some flooding in the February 2004 storm that hit the lower North Island, with small areas adjacent to the stream being inundated.<sup>1</sup> For reference, the nearby Tamaki River experienced a 10-year ARI<sup>2</sup> flood during that event (Horizons 2004). Press photos<sup>3</sup> show a small amount of flooding during a flood event in 2018 (Figure 2-3). During Cyclone Gabrielle (14 February 2023), the stream was reportedly relatively unaffected<sup>4</sup>. No other information on past flood events has come to hand during this study.



Figure 2-2 Tapuata Stream, 21 March 2024 (off end of Salisbury Street)

<sup>1</sup> Email from Daniel Batley (Evengreen Consulting) to Philip Wallace (River Edge Consulting), 27 February 2024

<sup>2</sup> Average recurrence interval

<sup>3</sup> <https://www.nzherald.co.nz/the-country/news/horizons-regional-council-proposes-radical-change-to-managing-rivers/6FLK3QEELRN3JAOSY333XYERPU/>

<sup>4</sup> Discussion with resident on Cole Street during site visit, 27 March 2024



Figure 2-3 Tapuata Stream, March 2018

## 2.3 Land use and soils

The landcover of the catchment is largely pasture. There are also small pockets of exotic forestry and, in the downstream reaches, the urban area of Dannevirke. Figure 2-4 shows the landcover according to the Landcover Database (LCDB 2018 v5) of Landcare Research.

Soils within the catchment are largely Orthic Allophanic or Firm Brown, with an area of Orthic Gley (Figure 2-5)<sup>5</sup>. (Urban soils are not classified.) Horizons Regional Council (“Horizons”) maps and datasheets<sup>6</sup> provide further detail (Figure 2-6). These suggest that around 30% of the rural catchment is well-drained (Orthic Allophanic, Dannevirke silt loam) and 70% is imperfectly or poorly drained (Firm Brown, Matamau silt loam and Orthic Gley, Raumati silt loam).

<sup>5</sup> <https://soils-maps.landcareresearch.co.nz/>

<sup>6</sup> <https://maps.horizons.govt.nz/Viewer/?map=fabf5ddf297242c8b4d76519e6b61f26> and <https://www.horizons.govt.nz/HRC/media/Media/Soil-Risk-list.pdf>



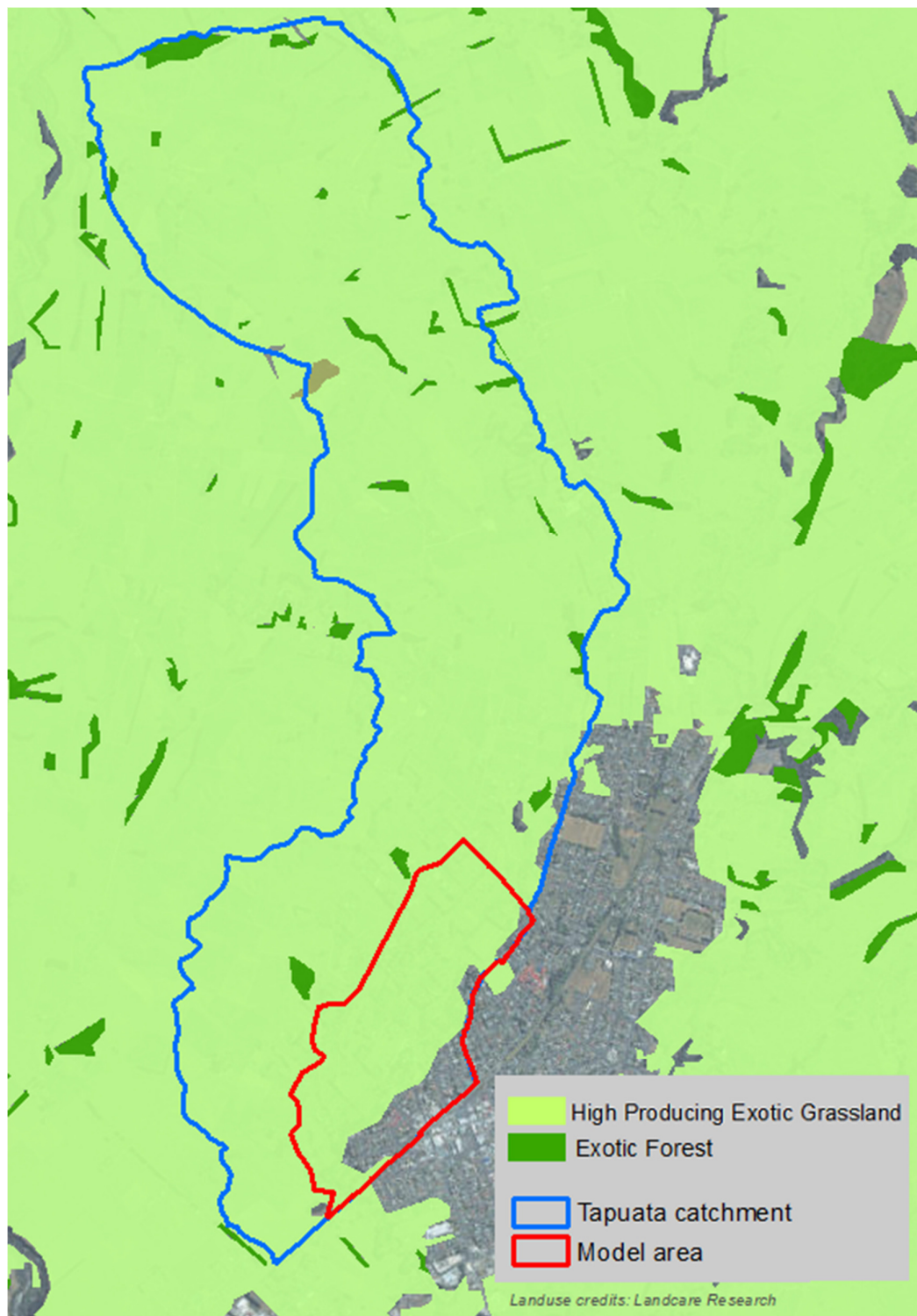


Figure 2-4 Landcover of Tapuata Stream (LCDB v5 2018)



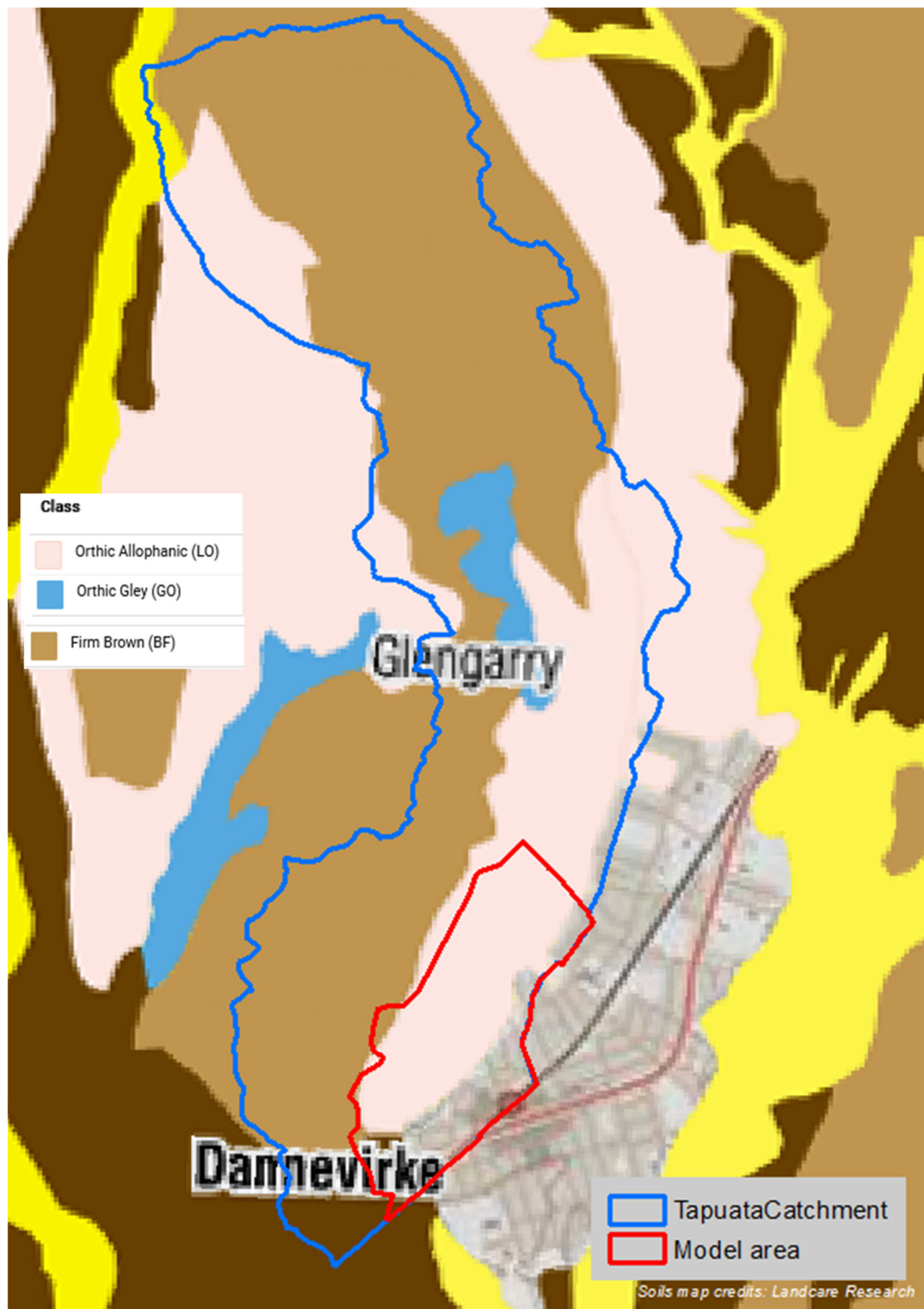


Figure 2-5 Soil classification of Tapuata Stream catchment

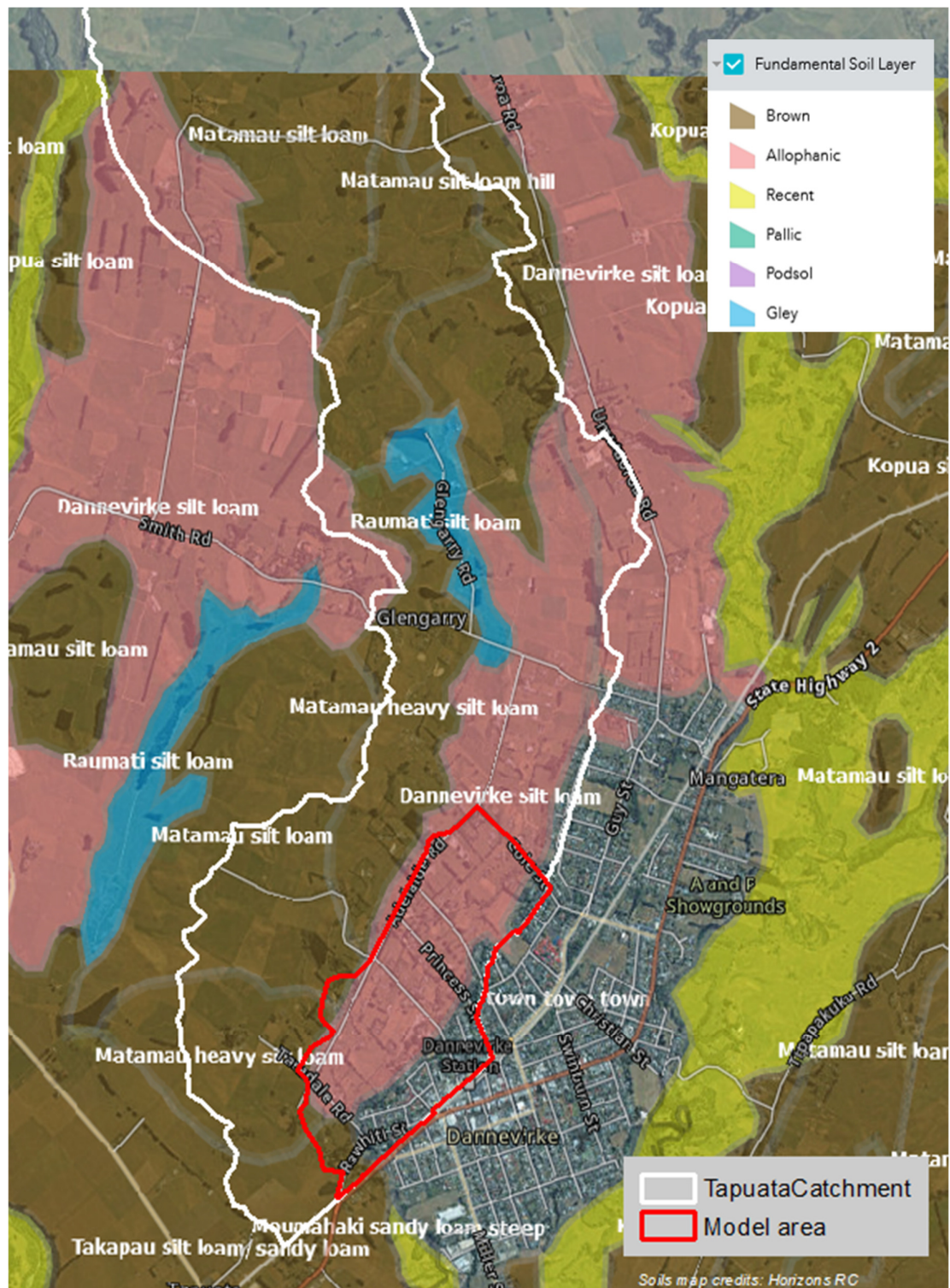


Figure 2-6 Soil of Tapuata Stream catchment

### 3 Design flood scenario

Policy 9-2 of the Horizons “One Plan” (Horizons, 2014) refers to a design flood standard of 0.5% AEP<sup>7</sup> (200-year ARI) in defining flood-prone areas and the level of protection required for occupied structures, an increase on an earlier 1% AEP standard to make allowance for climate change.

TDC has required that the flood assessment consider a 200-year ARI flood scenario, but with allowance for climate change. The particular climate change scenario required is RCP 8.5<sup>8</sup>, to the year 2090. TDC has also specifically requested that a 6-hour storm duration be assessed.

---

<sup>7</sup> Annual Exceedance Probability. The AEP is the inverse of the return period or average recurrence interval (ARI), so 0.5% AEP has the same meaning as a 200-year ARI event.

<sup>8</sup> Representative Concentration Pathway. RCPs denote particular greenhouse gas emission scenarios identified by the Intergovernmental Panel on Climate Change (IPCC). Under RCP 8.5, greenhouse gas emissions continue to rise throughout this century.



## 4 Hydraulic model

The flood assessment has been carried out with the aid of a computational hydraulic model.

The area of interest to TDC, i.e., the proposed residential growth area, lies between Victoria Avenue and Taradale Road, on the true right bank of the Tapuata Stream. The model area extends beyond these limits, to ensure that the choice of model boundaries does not affect results in the area of interest. Thus the model covers an area lying between Cole Street and the railway. The model also covers areas on the left bank of the stream, to capture any runoff that would contribute to the stream flow and flood extent. The left bank extent has been arrived at by considering the ground topography and the catchment boundary. Figure 4-1 shows the model extent.



Figure 4-1 Model extent

#### 4.1 Model software and configuration

The software used is the DHI product MIKE+ (v2024). The model provides a 2-dimensional (2-D) representation of the stream channel and floodplain via a flexible mesh of triangular elements. The mesh elements are a maximum of 0.5 m<sup>2</sup> within the stream channel and berms of the Tapuata Stream and minor watercourses, and maximum of 2.5 m<sup>2</sup> over the rest of the floodplain. In total, the model contains just under two million elements.

The model also includes a 1-dimensional (1-D) representation of a stormwater line from the corner of Princess Street and Queen Street, to take flow out of the model area to the south of the railway line. Other stormwater lines within the model area (of which there are only a few) capture runoff and pipe it towards the Tapuata Stream; these have not been included in the model. Runoff instead is allowed to travel overland as dictated by the surface topography, either north towards the stream or towards Queen Street and then southeast to the stream, parallel to the railway. It is also likely that stormwater inlets would get blocked with debris during a large flood event.

Figure 4-2 shows the model configuration.

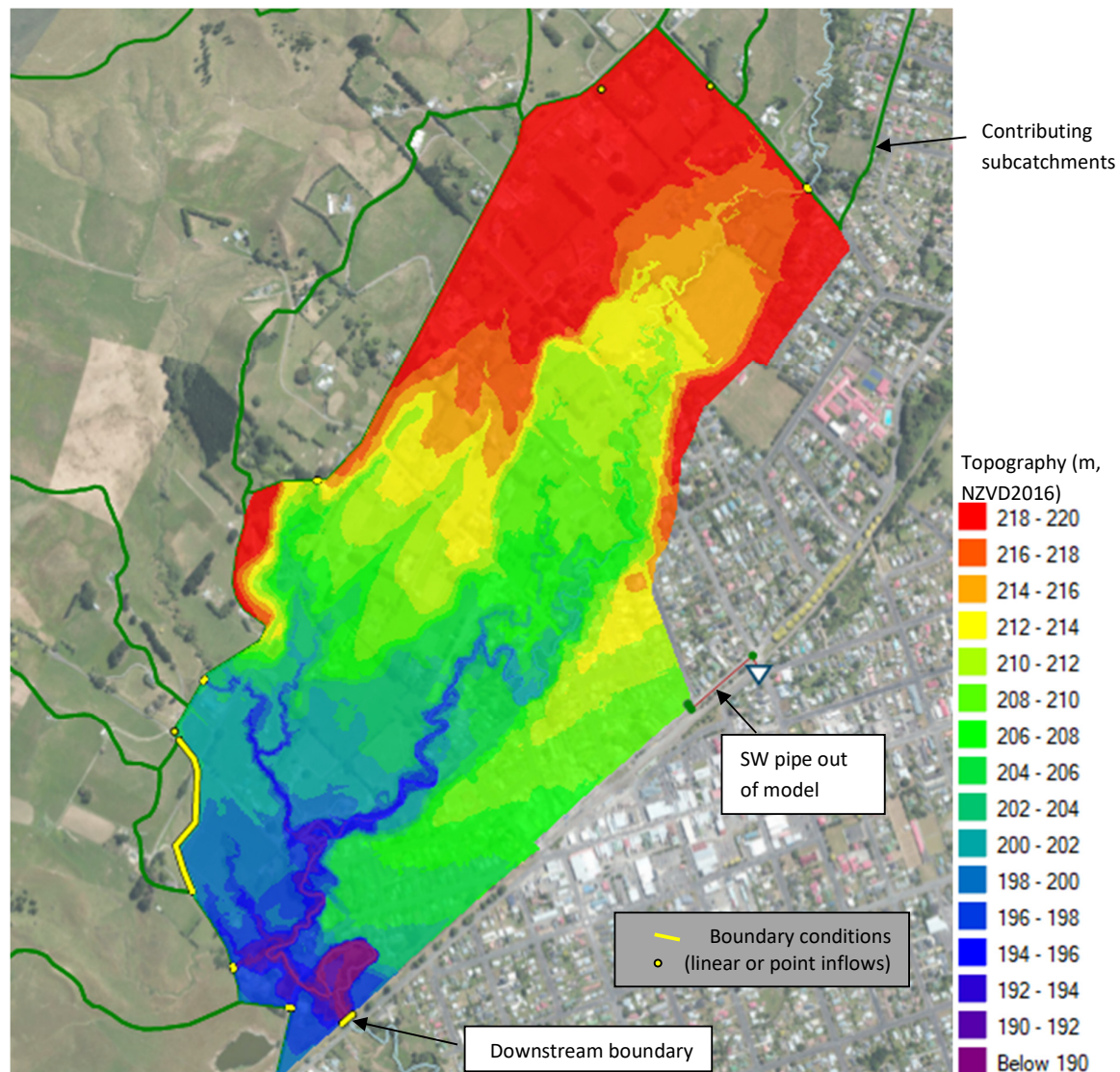


Figure 4-2 Hydraulic model configuration



## 4.2 Model topography

The model topography is based on recent aerial LiDAR surveys (2022-23) carried out by LandPro for Horizons Regional Council and TDC. The Horizons dataset covers just over half of the model area (on the western side) while the TDC dataset covers the entire model area.

Comparison of the two datasets in the area of overlap shows a small difference in the ground levels, of around 50 mm (for example, Figure 4-3), despite both LiDAR datasets being produced by the same company. Other than over a narrow buffer zone of around 5 m, where an average of the two datasets is used to smooth the discrepancy, the model uses the Horizons data in the area of overlap. The discrepancy is nonetheless small and within the expected vertical accuracy of LiDAR data.

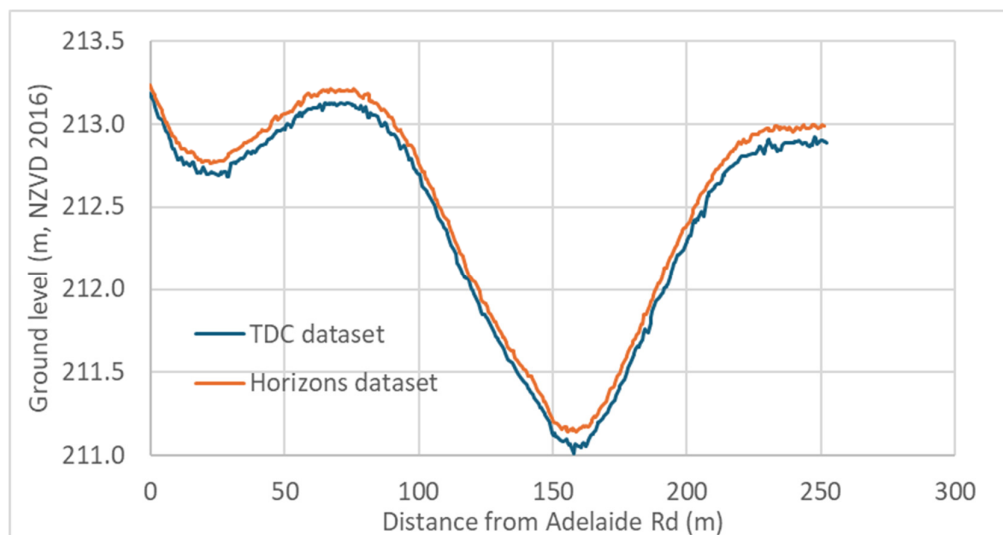


Figure 4-3 Comparison of levels along Cadman Road

Aerial LiDAR does not generally pick up stream bed levels, as it does not penetrate much below the water surface and in this case vegetation (and bridges) also obscures the bed in many stretches of the stream. Thus the true bed level is not necessarily represented in the model. However, there are some bed levels that have been picked up and depths are also generally shallow, so that the bed representation is adequate for the purposes of flood modelling.

## 4.3 Bridges and other structures

Five road bridges cross the stream within the model area: Victoria Avenue, Princess Street, Cadman Street, Taradale Road and Rawhiti Street (the model starts immediately downstream of Cole Street and ends at the upstream to the rail bridge). The only available data on the structure of these bridges is contained in original design drawings for the first three of these (dated between the 1940s and the 1970s). As the vertical datum of drawings is unknown, the bridge sections have been aligned vertically to approximately match at the road surface (for which LiDAR provides current levels). In this manner, the soffit levels of the bridges have been estimated. Within the model, the bridge sections have been represented with a depth-dependent roughness which steps up as the water level reaches the soffit.

No information on several culverts within the model area has been obtained. Two culverts with assumed dimensions are included in the model. The first is in the drainage channel parallel to Cole Street, under the driveway entrance to 109 and 111 Cole Street (Figure 4-4). The second is under Cadman Street, approximately 80 m north of the Tapuata Stream. Other culverts have not been modelled. Although information on them would be useful, it is also possible that they would be blocked in a major flood event.





Figure 4-4 Culvert in drain, 109-111 Cole Street

#### 4.4 Surface resistance

Floodplain and channel resistance (roughness) has been estimated following inspection of aerial photography as well as a site visit to the area. Typical values are as indicated in Table 4-1. Note that the extent of trees and vegetation has been obtained by a colour analysis of aerial photographs and is likely to overestimate the actual extent on the ground, due to tree canopies and shadows that show in the aerals. Model sensitivity to resistance values has also been tested (section 6.2.2).

Table 4-1 Floodplain resistance values

| Landuse type         | Manning's n |
|----------------------|-------------|
| Roads (sealed)       | 0.020       |
| Gravel driveways     | 0.025       |
| Stream bed           | 0.040       |
| Pasture              | 0.040       |
| Trees/vegetation     | 0.100       |
| Buildings            | 5           |
| Remaining urban area | 0.080       |

## 5 Model hydrology

The model boundary conditions are based on the following hydrological inputs:

- Subcatchment inflows from upstream of the model area
- Direct rainfall into the model area
- Rating curve at the railway bridge crossing of the Tapuata Stream

### 5.1 Subcatchment inflows

Subcatchments feeding the model area are shown in Figure 5-1.

No flow or water level recorders have ever been installed in the Tapuata Stream and hence there is no at-site flood frequency analysis that can be used to establish design flows.

The design 200-year flood flow estimate has therefore been arrived at after considering results from a range of methods for estimating flood flows. Estimates have been prepared for the main Tapuata Stream entering the model area, i.e. at Cole Street, the catchment area of which is 6 km<sup>2</sup>.

Applying the Regional Flood Estimation method, as outlined in McKerchar and Pearson (1989), and the contour maps within that report of  $q_{100}$  ( $= Q_{100}/Q_m$ ) and of  $Q_m/A^{0.8}$ , where  $Q_m$  = mean annual flood flow, gives 100-year and 200-year ARI flows of 20.9 m<sup>3</sup>/s and 23.1 m<sup>3</sup>/s, respectively. These estimates are without any climate change allowance.

An update of that method is available in a web-based map<sup>9</sup> published by NIWA. This gives a 100-year ARI flow of 14.8 m<sup>3</sup>/s, albeit with an assumed catchment area of 7 m<sup>3</sup>/s. Interpolating the flood frequency curve provided for the site gives a 200-year ARI flow of 16.3 m<sup>3</sup>/s.

Horizons maintains a nearby flow recorder at the Tamaki @ Stephenson's/Hartridge site<sup>10</sup>. (Figure 2-1 shows the Tamaki River). Assuming the relationship

$$Q \propto A^{0.8}, \text{ where } Q = \text{flow and } A = \text{catchment area,}$$

transposing the Tamaki flood frequency estimates (provided by Horizons) to the Tapuata at Cole Road site, gives a 200-year ARI of 38.8 m<sup>3</sup>/s (again, without climate change). However, the Tamaki catchment extends much higher into the Ruahine Range; it is much steeper in the upper reaches and while it is on the leeward side of the Range, it is likely to capture much more of the orographic rainfall.

The flood frequency analysis of the Manawatu River @ Weber Road site, around 1 km upstream of the Mangatera River confluence, has not been considered for a similar transposition analysis. The Manawatu catchment is much different and too big to be of relevance.

Horizons also maintains a flow recorder at the Kumeti @ Te Ruhunga, 6 km west of Dannevirke. This has over 30 years of record. Taking the results from the NIWA web-app and transposing them to the Tapuata at Cole Road site, gives a 200-year ARI of 11.7 m<sup>3</sup>/s (without climate change).

Other methods require time of concentration and design rainfall estimates. A time of concentration of 2 hours has been assumed (the Ramser-Kirpich method gives 108 minutes). Rainfall estimates have come from HIRDS v4 and are as given in

<sup>9</sup> <https://niwa.maps.arcgis.com/apps/webappviewer/index.html?id=933e8f24fe9140f99dfb57173087f27d>

<sup>10</sup> The Stephenson's site, about 600 m downstream of SH2, was used until 2016. Since then, the Hartridges site, 2 km downstream of SH2, has been used.

Table 5-1.

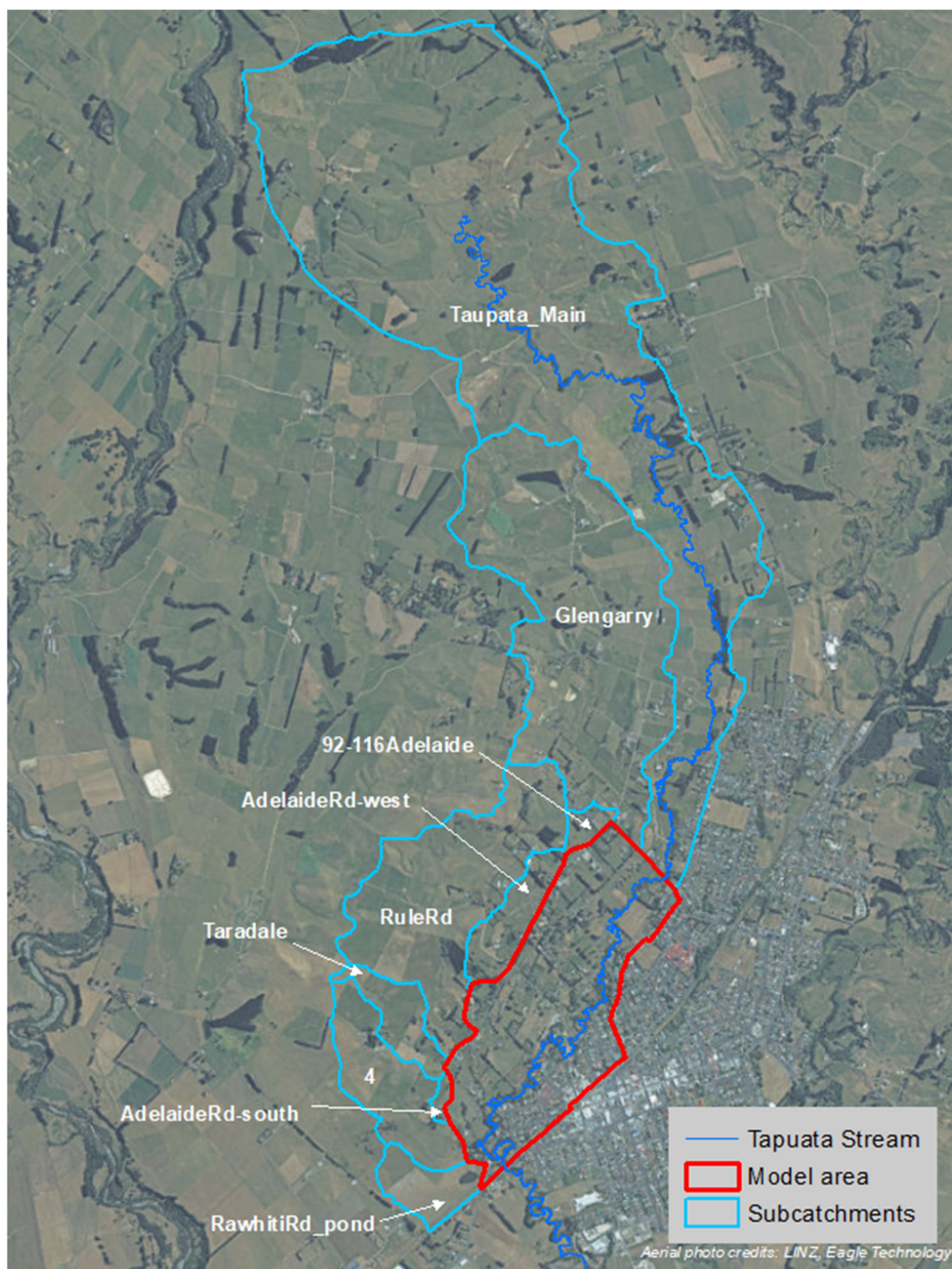


Figure 5-1 Catchments entering the model area



Table 5-1 Rainfall depths (mm) for given durations, from HIRDS v4

| Scenario                                      | 5 min | 10 min | 15 min | 20 min | 30 min | 1 hr  | 2 hr  | 3 hr   | 6 hr   | 12 hr  | 24 hr  |
|-----------------------------------------------|-------|--------|--------|--------|--------|-------|-------|--------|--------|--------|--------|
| 200-year, current climate, catchment centroid | 21.72 | 27.84  | 32.29  | 35.90  | 41.78  | 54.17 | 70.14 | 81.44  | 104.57 | 133.01 | 167.05 |
| 200-year, RCP 8.5 2090, catchment centroid    | 27.58 | 35.93  | 41.86  | 46.62  | 54.41  | 70.91 | 91.50 | 104.61 | 133.11 | 165.48 | 202.67 |
| 200-year, RCP 8.5 2090, model area            |       | 35.56  |        | 44.85  | 51.89  | 67.19 | 86.75 |        | 127.35 | 158.88 | 192.98 |

TM61 (MWD, 1980) gives 200-year ARI peak flows of 11.6 m<sup>3</sup>/s (no climate change) and 15.5 m<sup>3</sup>/s (RCP 8.5 2090).

The Rational Method gives peak flows of 20.4 m<sup>3</sup>/s (no climate change) and 26.6 m<sup>3</sup>/s (RCP 8.5 2090), assuming a runoff coefficient of 0.35. This method however is aimed at smaller catchments (< 80 ha) and so may not be appropriate for the main Tapuata subcatchment.

Finally, flow estimates were derived from the use of the rainfall-runoff software HEC-HMS<sup>11</sup>. Runoff losses were based on an SCS Curve Number (CN) approach. Assuming CN = 61 for the well-drained portion of the main Tapuata subcatchment and CN = 74 for the remainder, a weighted CN of 70 was adopted. A peak flow of 25.5 m<sup>3</sup>/s was obtained for a 6-hour duration 200-year ARI storm (RCP 8.5 2090).

The flow estimates have been summarised in Table 5-2. Where RCP 8.5 2090 values are not directly obtained, they have been estimated by increasing current climate values by 40% (an average of the increases derived directly) and shown in italics in Table 5-2.

Table 5-2 Peak flow estimates for Tapuata Stream at Cole Road

| Method                                         | 200-year | 200-year (RCP8.5, 2090) | Increase |
|------------------------------------------------|----------|-------------------------|----------|
| FFINZ <sup>12</sup>                            | 23.1     | 32.4                    |          |
| NIWA web (Taupata @ Cole St)                   | 16.3     | 22.9                    |          |
| NIWA web (transpose Kumeti)                    | 11.7     | 20.2                    |          |
| Transpose Tamaki @ Stephenson/Hartridge        | 38.8     | 54.4                    |          |
| TM61                                           | 11.6     | 15.5                    | 1.33     |
| Rational                                       | 20.4     | 26.6                    | 1.30     |
| HEC-HMS <sup>13</sup> (CN = 70, 6-hr duration) | 16.2     | 25.5                    | 1.58     |

Notwithstanding the limitations of some of the methods, a rounded average of the results is used, so that the adopted 200-year flow (RCP 8.5 2090) value for the Tapuata Stream at Cole Road is 30 m<sup>3</sup>/s. This is possibly conservative (especially given that the transposed Tamaki result is so high) but is considered prudent. A simulation with a larger flow of 35 m<sup>3</sup>/s has also been run, as a sensitivity test.

Note that the potential attenuation caused by the Smith Road and Cole Street bridges, both upstream of the model inflow, has not been considered. That will likely reduce the inflow, but any such reduction may be countered if the bridges are eventually upgraded.

<sup>11</sup> Hydrological modelling software, developed by US Army Corps of Engineers.

<sup>12</sup> Flood Frequency in New Zealand. McKerchar & Pearson (1989)

<sup>13</sup> Hydrological modelling software, developed by US Army Corps of Engineers. Rainfall hyetographs derived from HIRDS v4, losses based on a CN approach.

Peak flows for the remaining subcatchments are scaled from the main Tapuata subcatchment peak flow by the relationship  $Q \propto A^{0.8}$ . The areas and the resulting peak flows are listed in Table 5-2.

Table 5-3 Subcatchment peak inflows, 200-year ARI, RCP 8.5 2090

| Subcatchment     | Area (ha) | Peak flow |
|------------------|-----------|-----------|
| Taupata_Main     | 599.01    | 30.00     |
| Rawhiti-RailSH2  | 6.74      | 0.83      |
| RawhitiRd_pond   | 20.17     | 1.99      |
| central          | 155.27    | 10.19     |
| Glengarry        | 221.95    | 13.56     |
| 92-116Adelaide   | 5.97      | 0.75      |
| RuleRd           | 118.61    | 8.21      |
| Taradale         | 20.65     | 2.03      |
| AdelaideRd-south | 2.74      | 0.40      |
| 4                | 46.57     | 3.89      |
| 68Rawhiti        | 0.61      | 0.12      |
| AdelaideRd-west  | 22.95     | 2.21      |

The shape of the inflow hydrographs is derived from HEC-HMS outputs. For simplicity, the same shape and timing is used for each subcatchment inflow. Figure 5-2 shows the hydrograph shape (with the peak for the main Tapuata shown).

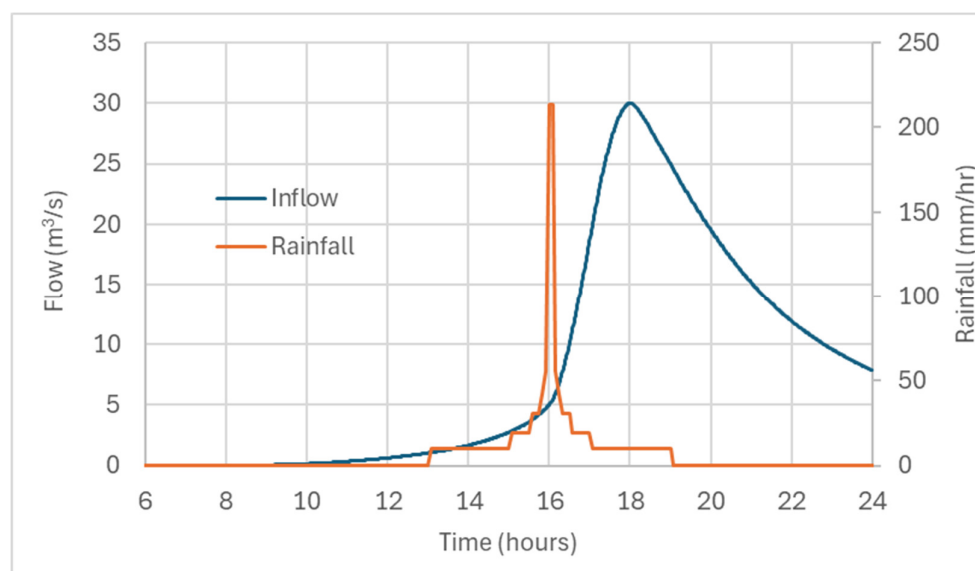


Figure 5-2 Inflow hydrograph shape and rainfall hyetograph applied to model area

## 5.2 Local rainfall

Over the model area, rainfall has been applied as “rain-on-grid”, i.e., direct to the model surface. A rainfall hyetograph for a nested 6-hour storm at the site has been derived from HIRDS data and is shown in Figure 5-2. The model area is small enough that it is reasonable for the rainfall to be spatially uniform.

Limited guidance is available on losses due to infiltration, but an initial loss of 20 mm and continuing losses of 8 mm/hour are assumed for the rural areas of Dannevirke silt loam. For the remaining

areas within the model extent (urban area and the small area of Matamau silt loam), an initial loss of 10 mm and continuing losses of 5 mm/hour are assumed.

### **5.3 Downstream water levels**

The downstream boundary condition is a rating curve derived from the Manning's equation, based on the cross-section surveyed downstream of the bridge, an estimated slope of 0.008 and assuming a Manning's  $n$  value of 0.045. In practice there might be some backwater effect from the SH2 road bridge, but the model boundary is far enough from the area of interest for this to be of no importance.



## 6 Model results and discussion

### 6.1 Flood depths and levels

Predicted 200-year ARI flood depths over the model area are shown in Figure 6-1. Larger scale maps are given in Figure 6-2 and Figure 6-3.

Several features of the maps and results should be mentioned.

The results show floodwaters collecting against Queen Street. As mentioned in section 4, that area would drain southwest towards SH2 and into the Tapuata Stream upstream of the SH2 bridge. However, if water levels are high enough, they could also flow across Queen Street and the railway line. The model does not allow that. Furthermore, the urban stormwater network is only partially modelled. For these reasons, the supplied flood depth files (in raster format) will clip out that part of the urban area and downstream of Rawhiti Street.

Flow from smaller upstream subcatchments and local runoff concentrate in several small low-lying drains and overflow paths, separate to the main Tapuata Stream overflows. In addition to the two modelled culverts identified in section 4, there are several other culverts under Adelaide Road, Cadman Street, Princess Street and Victoria Avenue that are unmodelled. Effectively, the model assumes that they are blocked, but if they were able to pass flow then depths would be less upstream and greater downstream. Flow across the roads would also be lower.

The soffit level at the Victoria Avenue bridge is particularly low and, as expected, flood levels reach above the soffit. Predicted flood levels at the other bridges are a little below the soffit levels, but the possibility of debris collecting on the bridge structures, and raising flood levels, cannot be discounted.

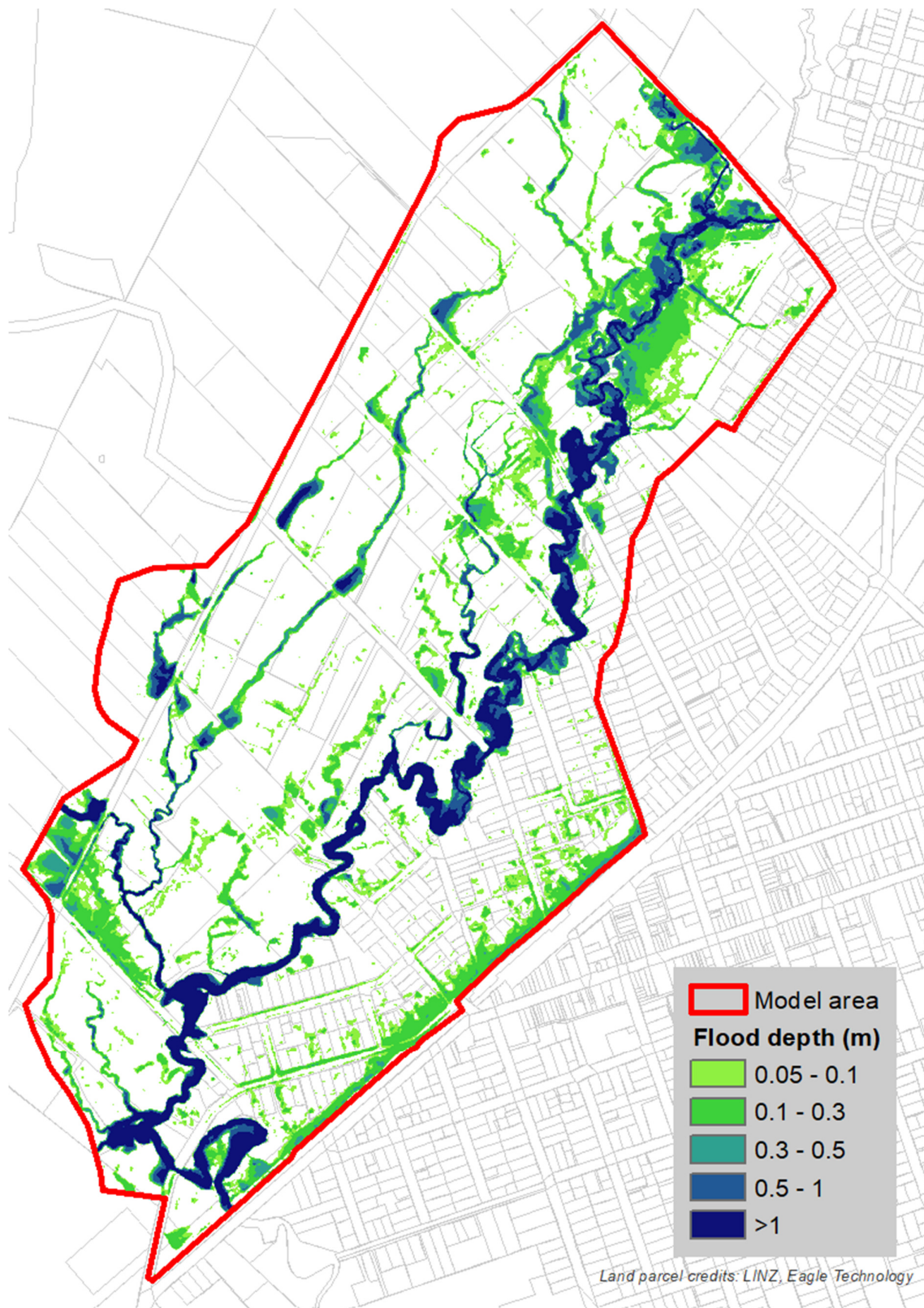


Figure 6-1 Peak flood depths, 200-year ARI flood, RCP 8.5 2090



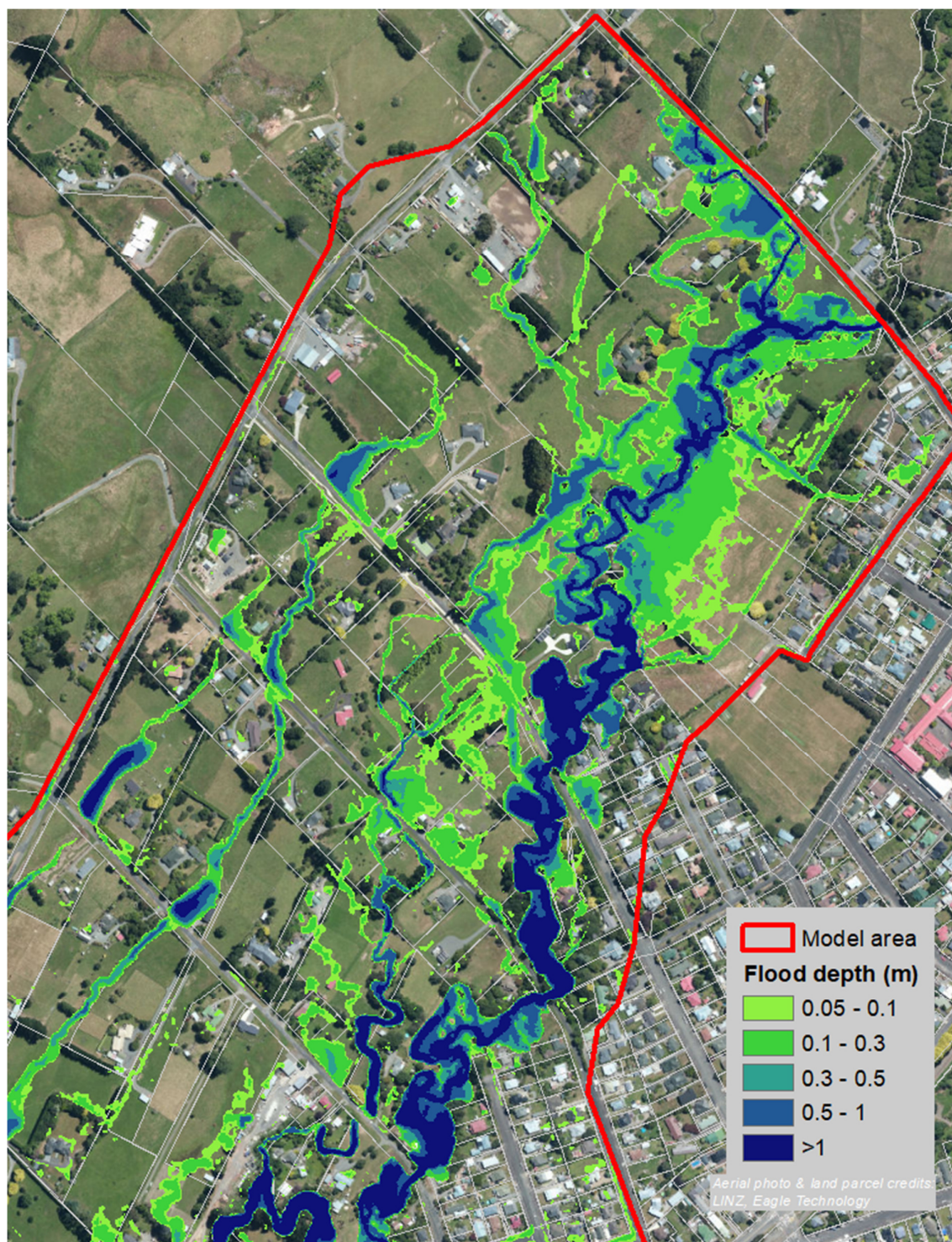


Figure 6-2 Peak flood depths, 200-year ARI flood, RCP 8.5 2090, northern portion



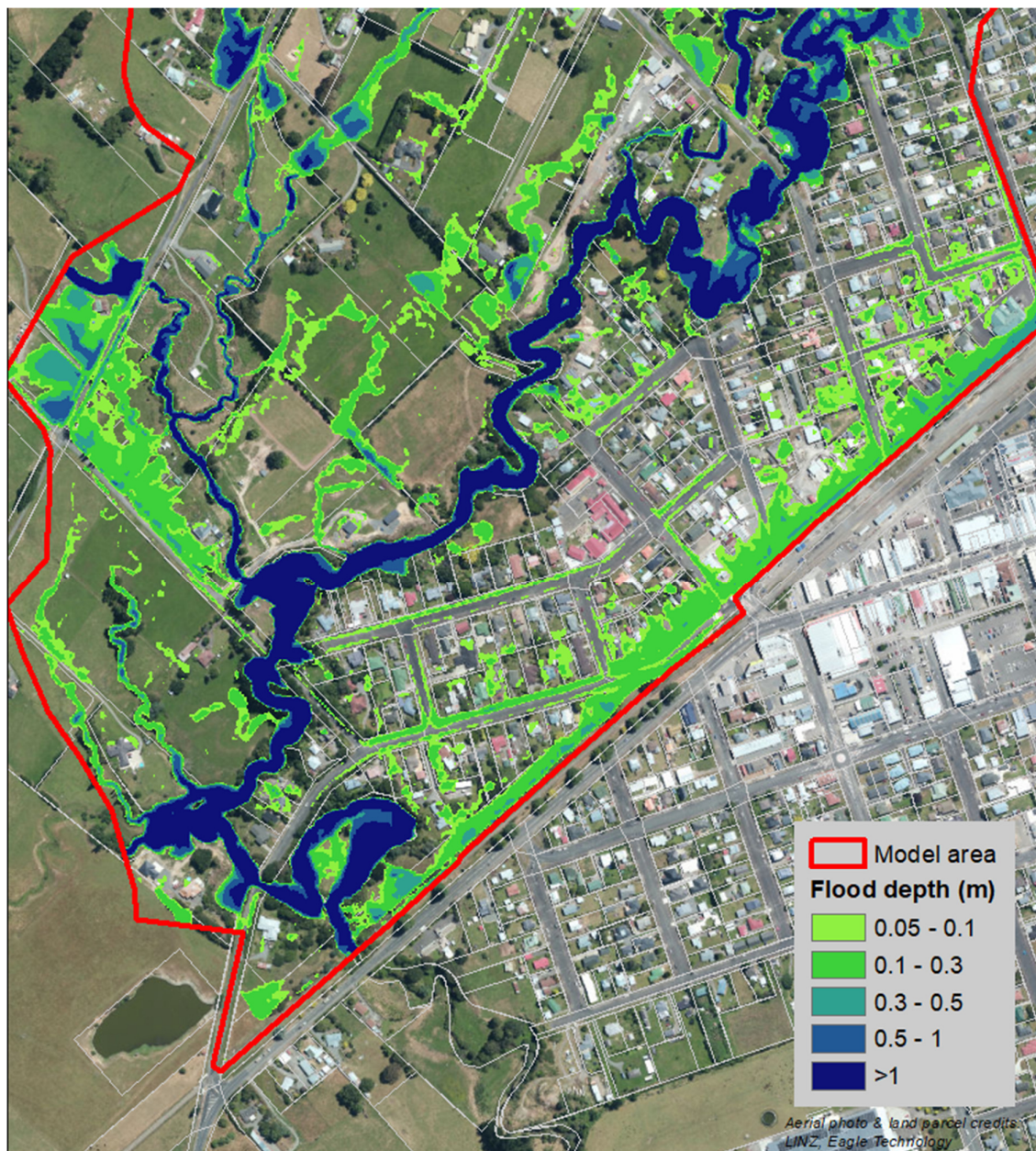


Figure 6-3 Peak flood depths, 200-year ARI flood, RCP 8.5 2090, southern portion

## 6.2 Sensitivity tests

Sensitivity tests are particularly important, given that the model is not calibrated and no flood flow records are available.

### 6.2.1 Model inflows

Two sensitivity tests on model inflows have been conducted. In the first, a peak inflow of  $35 \text{ m}^3/\text{s}$  from the main Tapuata subcatchment is assumed, with the other subcatchments scaled up by an equivalent amount. In this case, a 24-hour storm is assumed. While the scenario would seem to be a particularly severe one, based on the results given in Table 5-2, it is worth testing given climate change uncertainties in particular.

The extent of flooding is largely unchanged from that shown in Figure 6-1. However, flood depths in the main channel and immediate berms, and within the other drains and ephemeral overflow paths, increase by up to 400 mm within the area of interest (i.e., between Victoria Avenue and Taradale Road). Figure 6-4 shows peak flood depths for this scenario.

The second sensitivity test assumes a 24-hour storm but maintaining the 30 m<sup>3</sup>/s peak inflow from the main Tapuata subcatchment. The rainfall hyetograph applied to the model area itself is also changed to a 24-hour storm. The extent of flooding (Figure 6-5) is largely unchanged from that shown in Figure 6-1. Compared to the case with the 6-hour storm, the increase in flood depth within the main channel and immediate berms ranges from less than 10 mm at Victoria Avenue to around 50 mm at Taradale Road. Within the other drains and ephemeral flow paths, the increases range up to 300 mm, with the largest increases being confined to the channels flowing from Adelaide Road to the confluence with the Taupata Stream near Taradale Road.



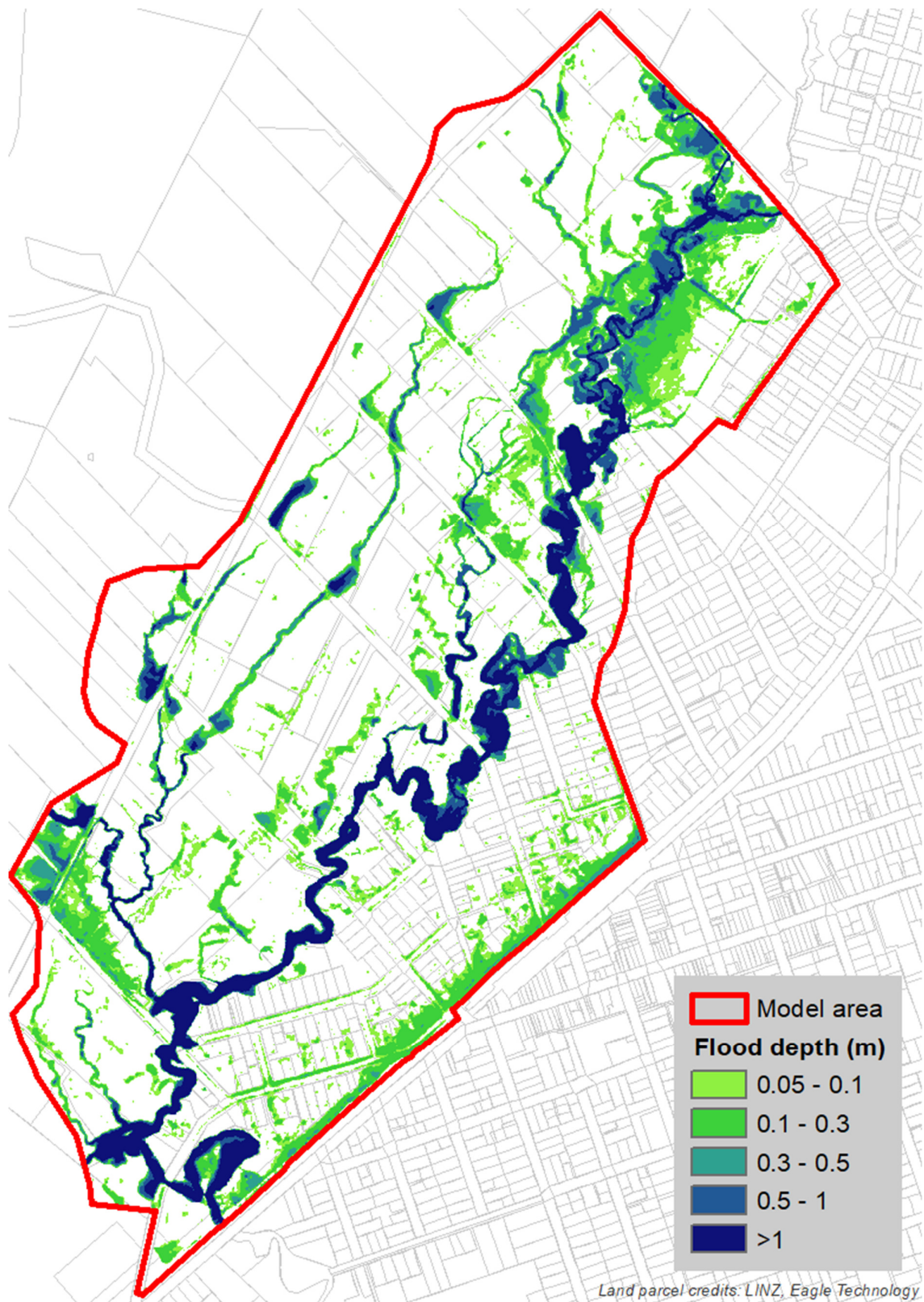


Figure 6-4 Sensitivity test: peak flood depths, 200-year ARI flood, RCP 8.5 2090, 24-hour storm, 35 m<sup>3</sup>/s peak inflow for main Tapuata branch



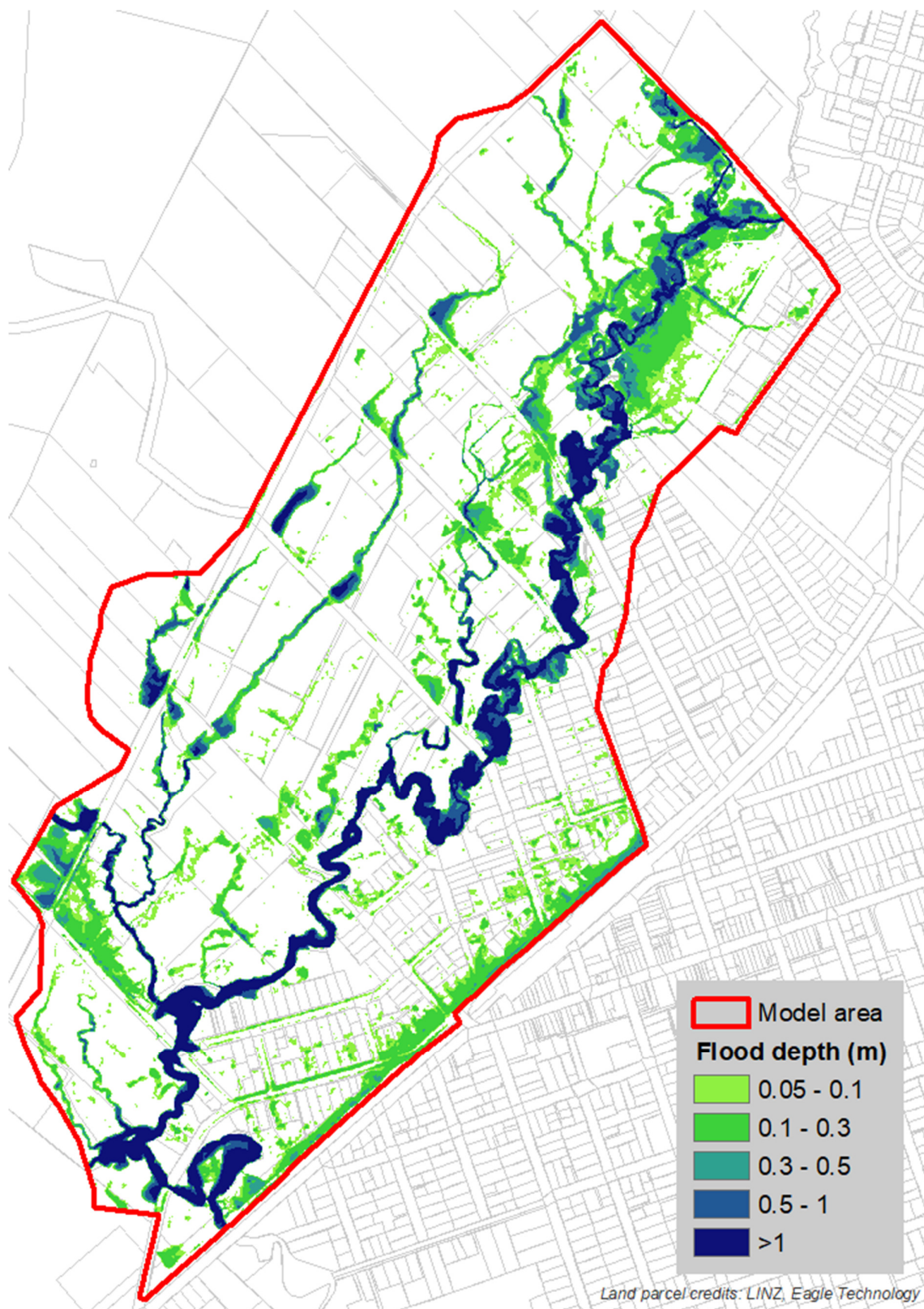


Figure 6-5 Sensitivity test: peak flood depths, 200-year ARI flood, RCP 8.5 2090, 24-hour storm, 30 m<sup>3</sup>/s peak inflow for main Tapuata branch

### **6.2.2 Channel resistance**

In this test, the channel resistance is increased to a Manning's n value of 0.0625 (Manning's M of 16) in areas of the stream where vegetation appears more dense and where other obstructions may be present.

Results indicate that flood levels typically only rise by no more than 4 cm, within the main stream corridor, while the extent of flooding is unchanged.

### **6.2.3 Infiltration**

In this sensitivity test, the initial loss for the rural areas of Dannevirke silt loam was lowered to 15 mm. Results show no difference in the flood extent and only a small increase (a few cm) within the drains and ephemeral overflow paths. A more useful test might be to lower the continuing losses, but results are also not expected to be significantly different.

## 7 Conclusions and recommendations

In normal circumstances the Tapuata Stream is a small placid stream, being fed by a small rural catchment. Nonetheless, runoff from the catchment, including from contributing subcatchments entering the proposed residential growth area, do pose a hazard to that area.

The meandering stream channel has over time entrenched itself, so that flood flows are mostly contained within an approximately 50 m width. Several smaller watercourses and narrow ephemeral channels also focus the runoff, but otherwise the predicted flooded areas are scattered and generally with shallow depths (less than 300 mm).

Flood depth and water level files have been electronically supplied to TDC, in the form of 1 m resolution rasters, suitable for use with GIS software. (Water level results are in terms of NZVD 2016.)

These results would need to have freeboard applied if they were to be used for design purposes or were to be used to set minimum floor levels of any proposed buildings.

Further model refinement would be possible with survey of key structures (bridges, culverts, stormwater infrastructure) and of stream bed levels.

It is also recommended that records be made of any future flood events, for instance survey of debris levels and collation of flood photographs. Ideally, flood flow gauging should also be carried out, although that would be a responsibility of Horizons and gauging of other streams may be prioritised during significant events.



## References

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- Horizons Regional Council (2004); *Storm: Civil Emergency – Storm and Flood Report, February 2004*.
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- Ministry of Works and Development (1980); *A method for estimating design peak discharge*. Technical Memorandum No. 61
- McKerchar A.I. and Pearson C.P. (1989); *Flood frequency in New Zealand*. Publication No. 20 of the Hydrology Centre. DSIR, Christchurch.
- Walter, K. (2000); *Index to hydrological recording sites in New Zealand flow sites*. NIWA Technical Report 73.

## Appendix A Site photographs

The following photographs were taken during a site visit on 21 March 2024. Weather conditions were fine.



Looking upstream from Rawhiti Road bridge



Looking downstream from Rawhiti Road bridge



Looking upstream from Taradale Road bridge



Looking upstream from Taradale Road bridge





Looking downstream from Taradale Road bridge



Looking towards stream crossing from Stairs Street



Looking downstream from Cadman Road



Looking upstream from under Cadman Road bridge

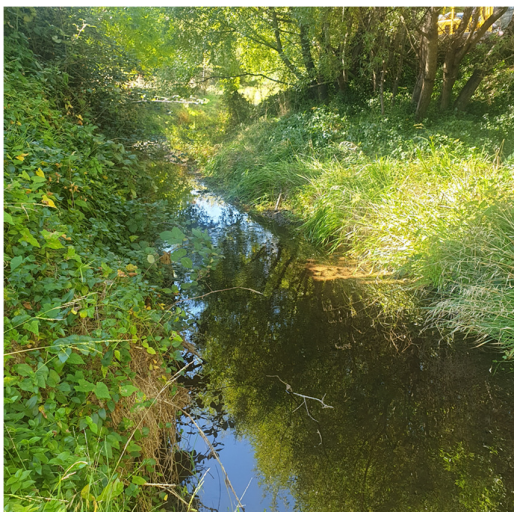


Looking upstream from under Cadman Road bridge

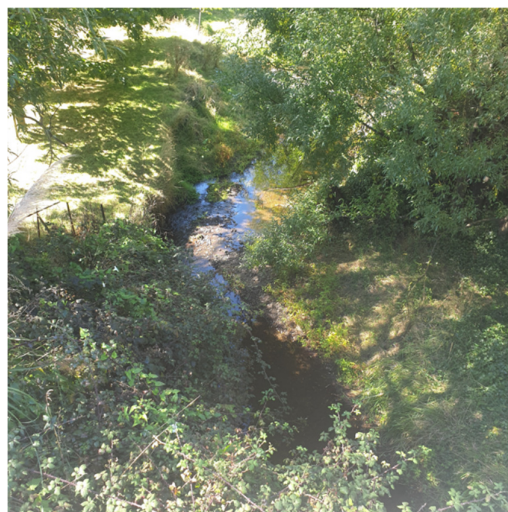


Under Cadman Road bridge, left bank





Looking upstream from under Cadman Road bridge



Looking upstream from Cadman Road bridge



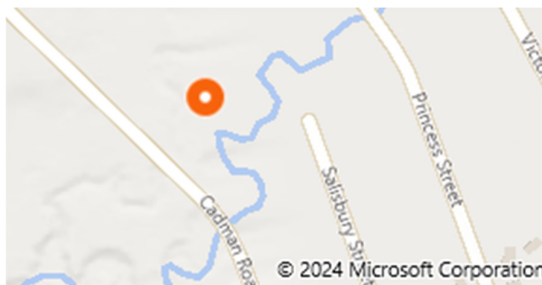
Looking downstream from Cadman Road bridge



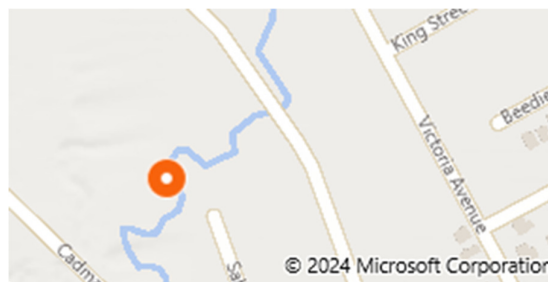
Looking upstream from Cadman Road bridge



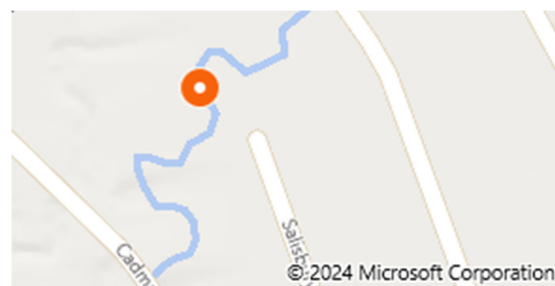
Between Cadman Road and Princess Street, access from Salisbury Street



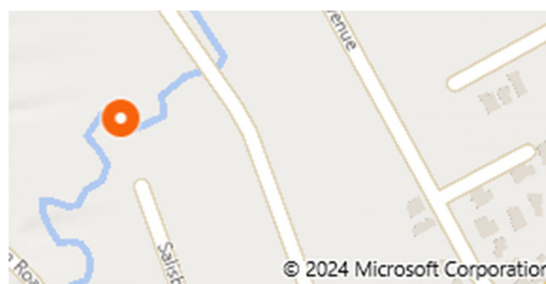




Between Cadman Road and Princess Street, access from Salisbury Street

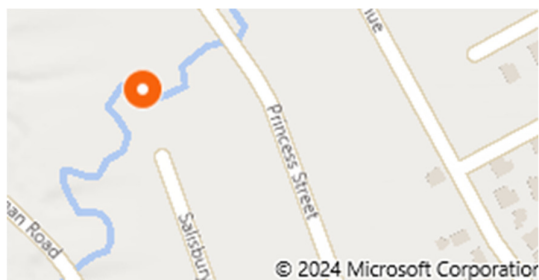


Between Cadman Road and Princess Street, access from Salisbury Street



Between Cadman Road and Princess Street, access from Salisbury Street





Between Cadman Road and Princess Street, access from Salisbury Street



Between Cadman Road and Princess Street, access from Salisbury Street



Looking upstream from Princess Street bridge



Looking downstream from under Princess Street bridge





Looking downstream from under Princess Street bridge



Stream bed under Princess Street bridge



Looking upstream from Victoria Avenue bridge



Looking downstream from Victoria Avenue bridge



Looking upstream from under Victoria Avenue bridge



Looking downstream from Victoria Avenue bridge





Looking downstream from under Victoria Avenue bridge



Looking downstream from Victoria Avenue bridge



Looking downstream from Cole Street (ephemeral meander in foreground)



Cole Street bridge (upstream side)



Looking upstream from Cole Street bridge





Floodplain upstream of Smith Road bridge



Smith Road bridge (upstream side)



Smith Road bridge (upstream side)



Smith Road bridge (downstream side)



Looking downstream from Smith Road (left floodplain)