Western Hills Stormwater Catchment

Model Build Report

Our water, our future.

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1. Executive Summary

1.1. Introduction

This report has been prepared to detail the modelling analysis of the Western Hills stormwater catchment undertaken using InfoWorks Integrated Catchment Modelling (ICM) software.

This modelling study has been undertaken to assist Wellington Water Limited (WWL) with management of stormwater in the catchment. The model is to be used for the generation of District Plan flood hazard maps and may subsequently be used to assess options for upgrading the stormwater system to mitigate flooding in the catchment.

1.2. Study Objectives

The objective of this study is to provide WWL with an ICM stormwater/flooding model of the Western Hills catchment. The model is to include the stormwater reticulation dynamically linked to the ground surface.

The model is to be used to produce flood maps for various design storm events with the existing land use. The model should be suitable for use in detailed design of remedial options and for testing the impacts of increased rainfall intensity and sea level due to climate change.

1.3. Model Build Summary

A model of the Western Hills stormwater catchment was developed for this study using InfoWorks ICM software. The model was developed using:

- Network data (GIS shape files)
- LiDAR derived digital elevation model (DEM)
- Raster layers representing hydrology curve number, hydrology initial losses, and surface roughness
- As-constructed drawings of the network supplied by WWL.

This was supplemented with site inspections undertaken by GHD Ltd. staff and engineering judgement.

The model has been built to a high level of detail and includes all known sumps, manholes, pipes, inlets and outlets. Smaller open channels and the Hutt River have been modelled as one-dimensional river reaches and a fine mesh has been used in the two-dimensional model domain representing overland flow paths.

2. Catchment Description

2.1. Location

The Western Hills study area is in Greater Wellington suburb of Lower Hutt, north of Western Hutt Road. Figure 1 shows the location and boundary of the study area. The catchment is 3059 hectares in size and includes Belmont Regional Park and the suburbs on the northern side of the Western Hutt Road from Tirohanga to Haywards. The study area also includes the Belmont quarry. The Western Hills catchment straddles city boundaries and includes areas in Hutt City, Upper Hutt, and a small area in Porirua in the upper Belmont Regional Park.

Figure 2 shows the location of the Western Hills study area relative to adjacent stormwater modelling catchments. The downstream boundary of the catchment follows the Hutt River. Western Hills borders Upper Hutt Central catchment along the upstream boundary of the Hutt River and Petone catchment at the downstream Hutt River boundary. The Pauatahanui catchment borders Western Hills to the north along the ridge of hills in the Belmont Regional Park and drains back towards Porirua.

2.2. Topography

The Western Hills catchment is generally characterised by steep hills in the upper catchments draining toward the Hutt River along the south boundary of the catchment. The upper hills extend up to an elevation of 440 m RL at Boulder Hill and drain via streams including the Speedys and Korokoro Streams. These streams then drain through the residential areas in the lower catchment. State-Highway 2 (SH2) runs along the foothills. The strip of land between SH2 and the right bank of the Hutt River is relatively flat. The reach of the Hutt River in the model is approximately 8.7 km long and has upstream and downstream bed elevations of 28.9 m RL and 2.94 m RL respectively.

The topography of the catchment is shown in Figure 3.

2.3. Geology

The majority of the catchment is underlain with undifferentiated Rakaia Terrane Triassic sandstone and mudstone, with areas of Pleistocene - Holocene river deposits.[1] The basement rocks are comprised of greywacke. The valley lies adjacent to the Wellington Fault, which is a major contributor to the ongoing geological development of the Hutt Valley.

The permeability of the underlying geology has been used in the development of the hydrology layers used in the model. Most of the catchment is classified as either ‘well-drained’ or ‘moderately well-drained’, according to Landcare Research S-Map Online. Run-off from the developed areas will be largely determined by impervious surface cover.

[1] GNS Science Te Pū Ao, accessed November 2020, New Zealand Geology Web Map, https://data.gns.cri.nz/geology/

2.4. Land Use

Figure 4 shows the distribution of land use within the catchment based on district plan land use zones. Land use within the upper catchment is mostly vegetation in Belmont Regional Park. Areas of the lower catchment is residential and dominated by lots between 500m2 and 1000m2 in size. On these residential lots, buildings take up approximately between 22% and 30% of the lot area. The residential area in total covers approximately 10% of the Western Hills catchment[2]. The Belmont Quarry is in the east of the catchment and covers 52 ha ('extraction' land use in Figure 4).

2.5. Stormwater Drainage System

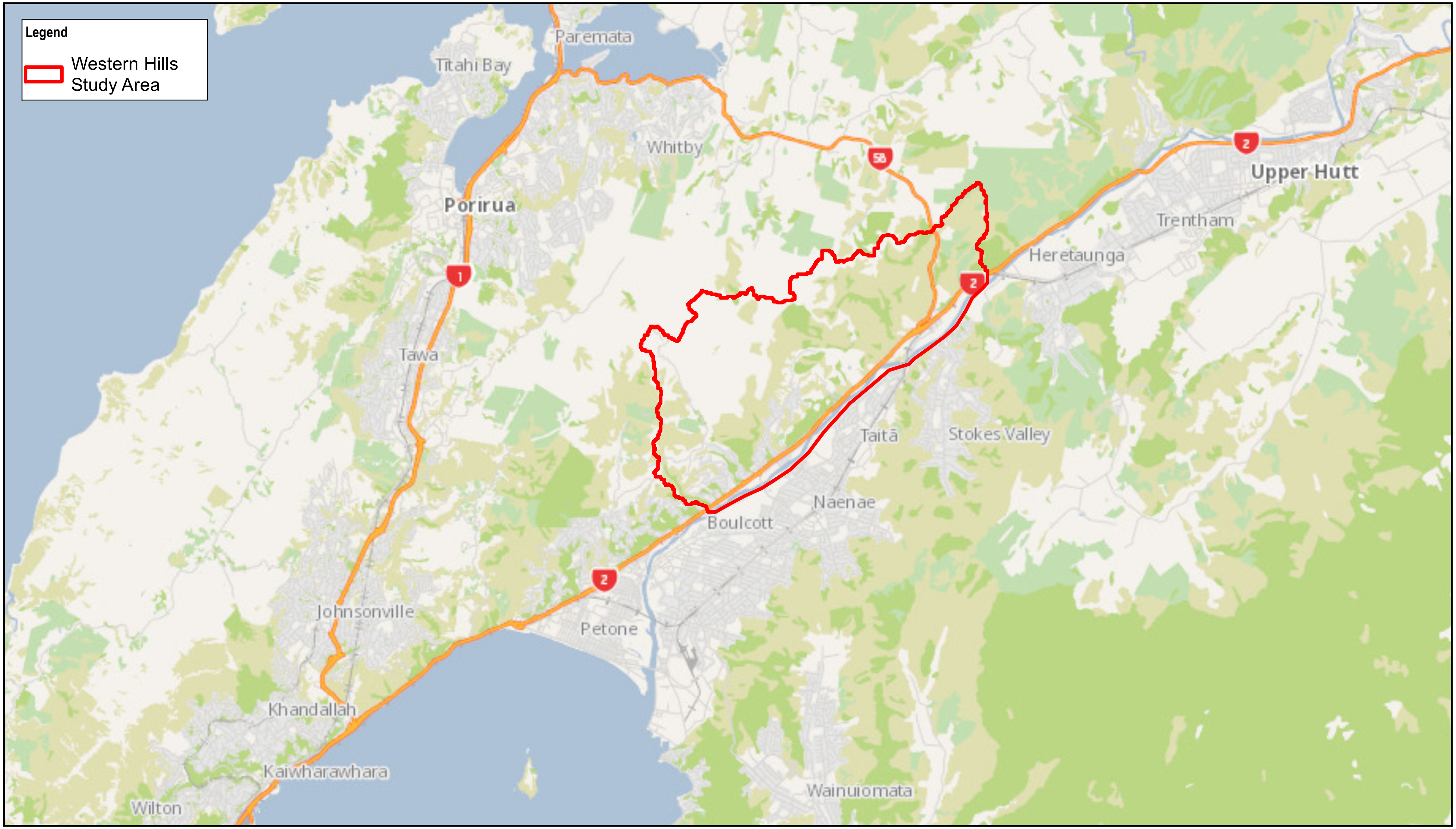
Figure 5 shows the stormwater drainage system in the study area. The stormwater network in the residential area generally consists of short discrete sections of pipework that discharge to open channels or streams. The catchment drains through several gullies and small streams, including Speedys Stream. Ultimately, these streams and all the run-off generated in the catchment drains to the Hutt River along the south boundary of the model.

Approximately 12% of houses and buildings in the Western Hills catchment have direct connections to the stormwater network.

2.6. Reported Flooding Issues

Limited flood record data is available for the Western Hills catchment. The available flood and inundation records are mainly located in the lower parts of the catchment, and near the Hutt River. Known areas of flooding are at the east end of Manor Park and around SH2 near the Kennedy-Good Bridge.

[2] GWRC, accessed November 2020, Resource Consent Applications, http://www.gw.govt.nz/assets/Our-Services/Flood-Protection/Hutt/Flood-Protection-in-the-Hutt-River.pdf



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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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Wellington Water
Western Hills Stormwater Catchment

Western Hills Catchment
Extent of Study Area

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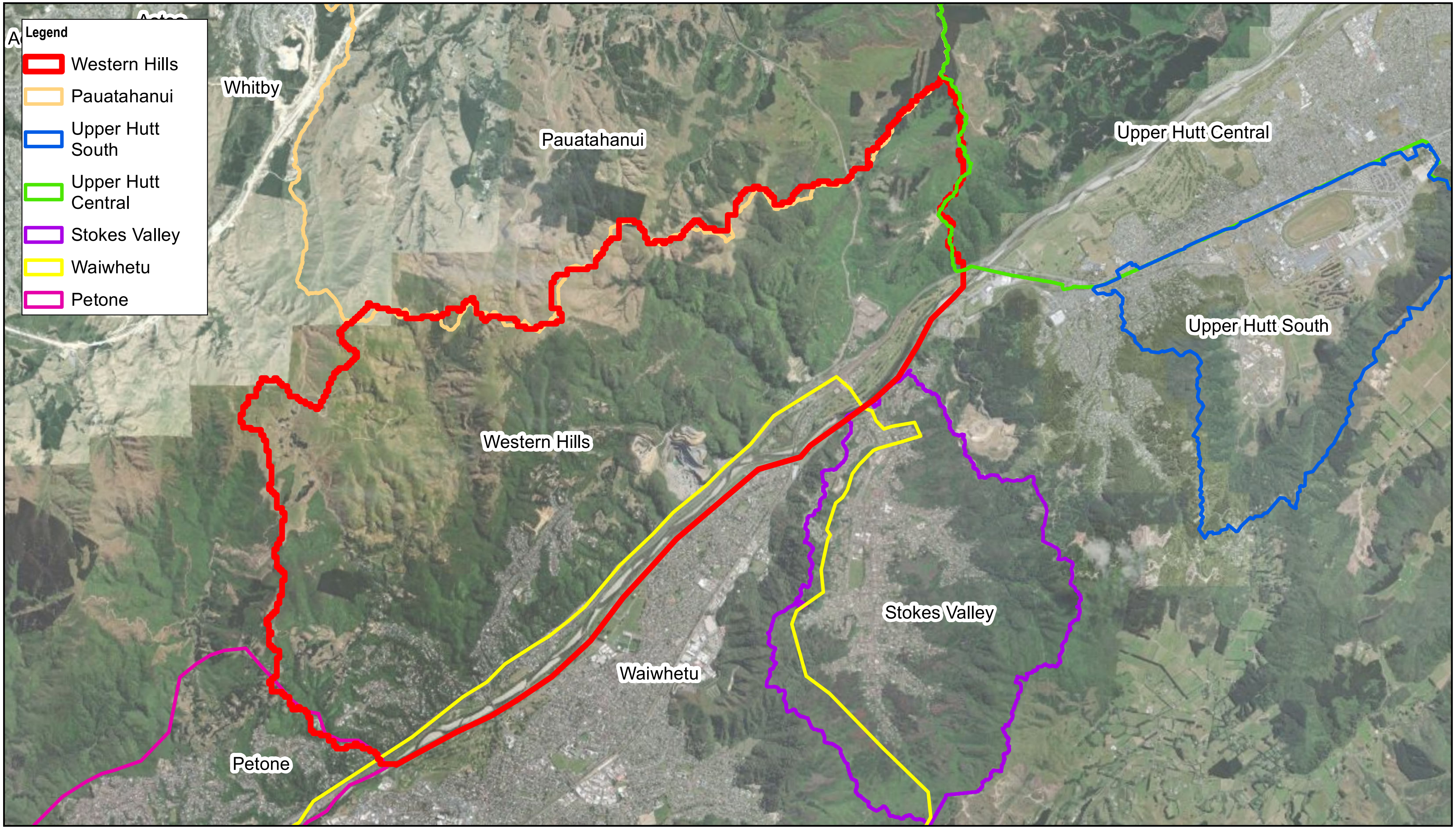
Revision No. **DRAFT A**
Date **01/11/2022**

FIGURE 1

N:\NZ\Wellington\Projects\51\12556744\GIS\Maps\Deliverables\Western Hills\Figure 1 - Study Area.mxd
Print date: 28 Oct 2022 - 11:28

Data source: Eagle Technology, Land Information New Zealand, Kiwi Rail, OpenStreetMap Community. Created by: cmurray2



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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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Wellington Water
Western Hills Stormwater Catchment

Western Hills Catchment and Adjacent Catchments

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FIGURE 2

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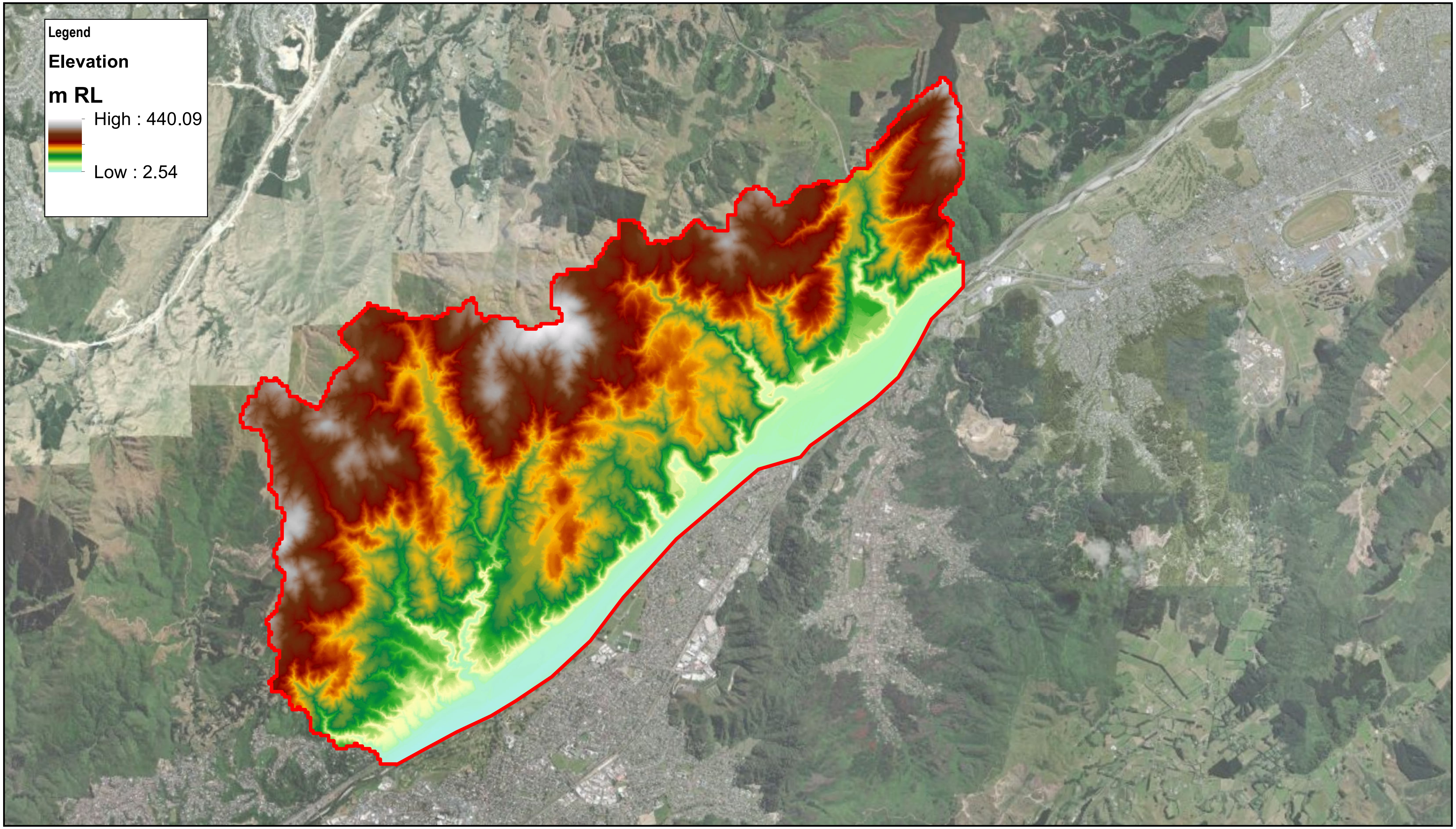
Data source: Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community. Created by: cmurray2



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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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Wellington Water
Western Hills Stormwater Catchment

Western Hills
General Topography

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Revision No. DRAFT A
Date 01/11/2022

FIGURE 3

\\ghdnet\ghd\NZ\Wellington\Projects\51\12556744\GIS\Maps\Deliverables\Western Hills\Figure 3 - General Topography.mxd
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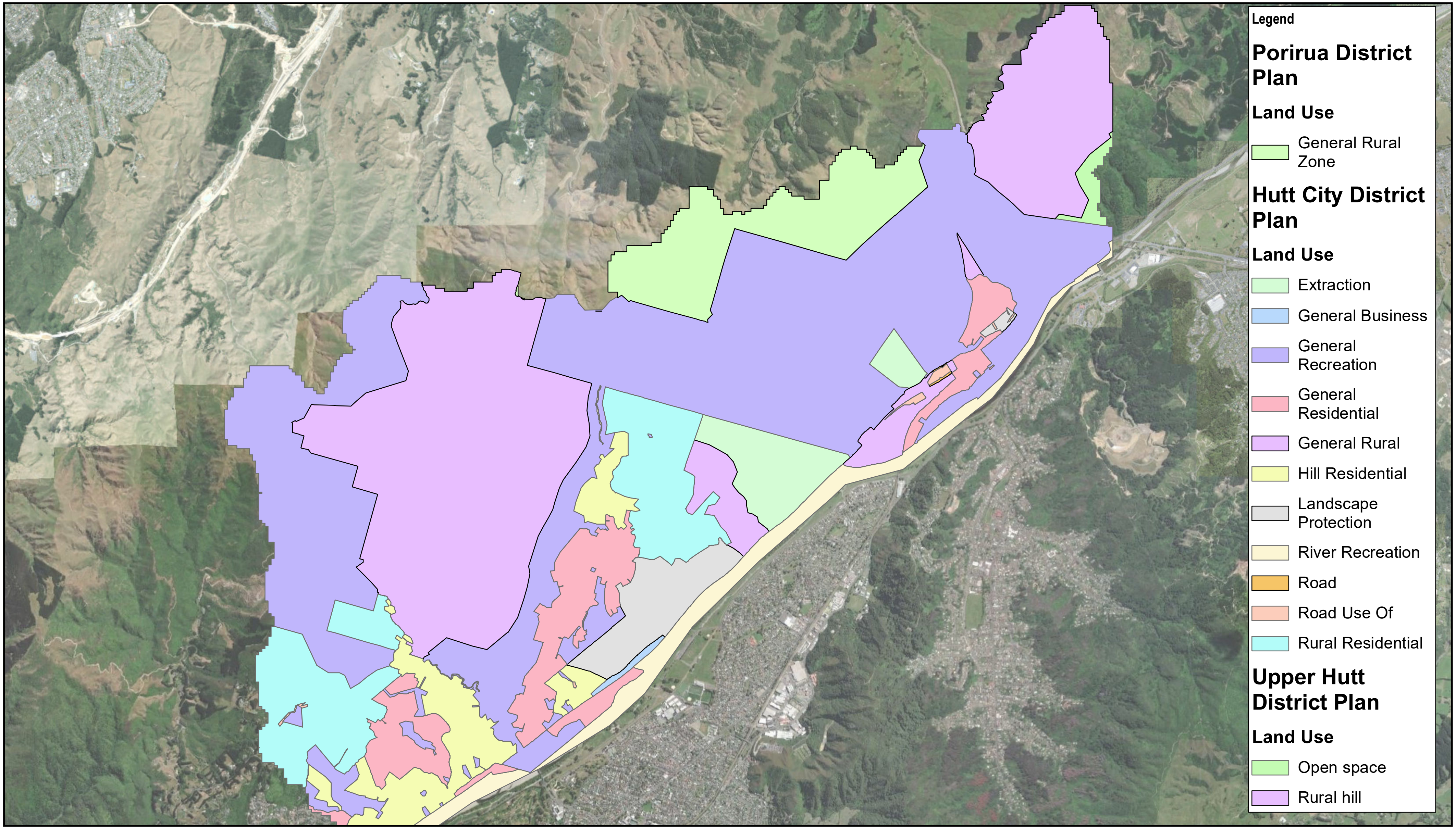

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Kilometers

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Map Projection: Transverse Mercator
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Grid: NZGD 2000 New Zealand Transverse Mercator

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Wellington Water
Western Hills Stormwater Catchment Model

Western Hills
Land Use

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FIGURE 4

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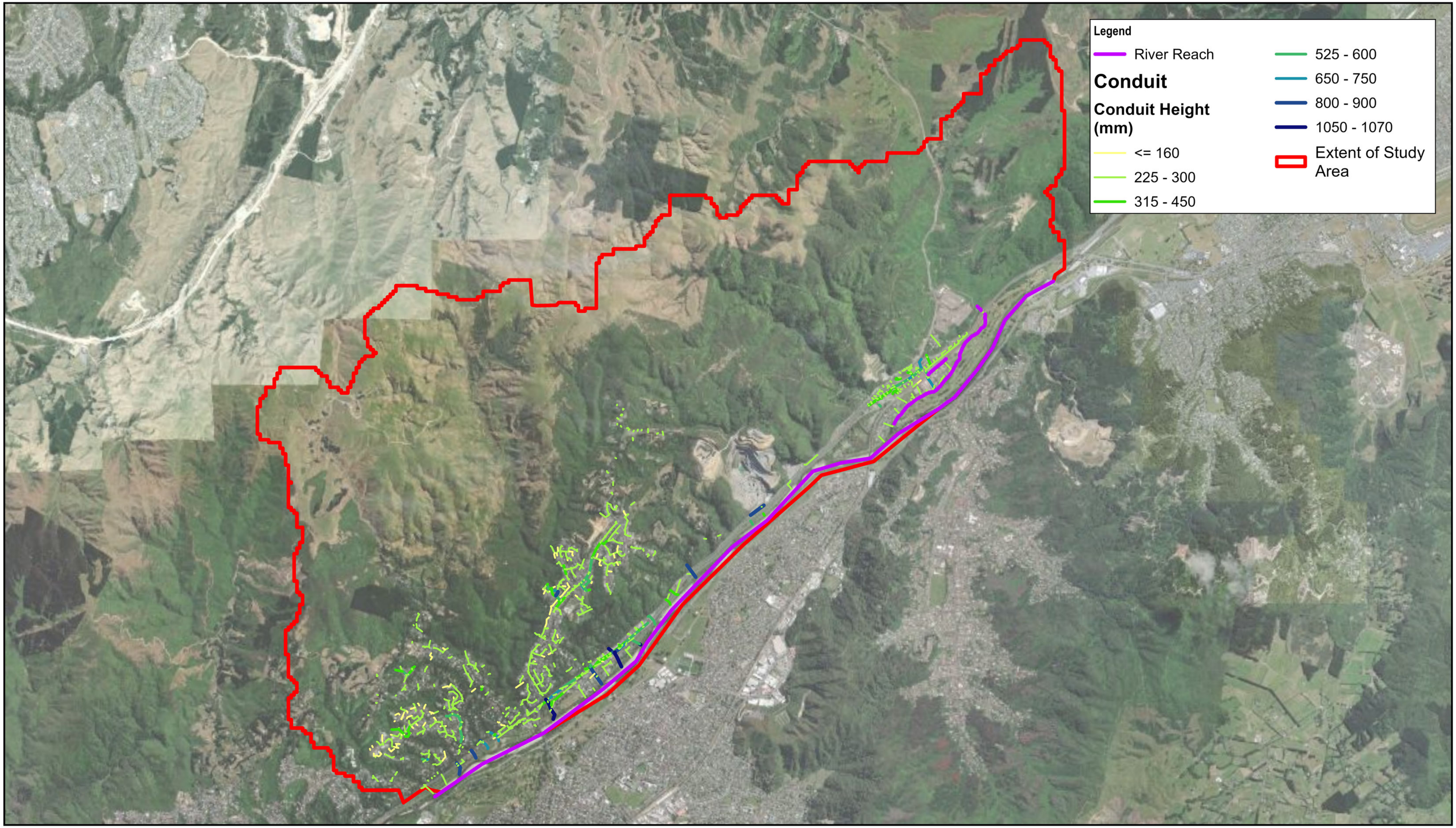

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Kilometers

Map Projection: Transverse Mercator
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Wellington Water
Western Hills Stormwater Catchment

Western Hills Modelled Streams and Stormwater Drainage System

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FIGURE 5

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Data source: World Imagery: Earthstar Geographics. Created by: cmurray2

3. Model Build

3.1. Modelling Software

The stormwater model has been developed using InfoWorks ICM v2021.6. This version was requested by WWL and differs from the version in the model build specifications.

3.2. Data

Key data sources used for the model build are listed below. Data flags from Appendix F of WWL's Regional Stormwater Hydraulic Modelling Specifications have been used in the Infoworks ICM model to track data sources for key parameters.

3.2.1. Asset Data

The 1D pipe network model is primarily based on GIS data supplied by WWL in September 2016. All stormwater network assets that could be identified from the supplied GIS data have been included in the model. The exception to this is some small diameter service lines that discharge to the kerb and channel, as well as private laterals.

3.2.2. As-Built Data

As-built plans for sections of the pipe network were supplied by WWL. The plans were reviewed to obtain additional asset information. The plans were predominantly used for invert levels of pipes and manholes and to confirm the connectivity of missing pipes. Assets or parameters updated based on as-built plans can be identified using the as-constructed flag 'ASCO' in the model.

3.2.3. Topographical Data

A 1 m by 1 m LiDAR derived digital elevation model (DEM) was provided by WWL for use in this study. The DEM is based on LiDAR collected in 2013. For further information refer to the Ground Model Assessment Summary Report submitted to WWL by MWH (now part of Stantec), in April 2016. An .asc file was created from the ground model to create the ground mesh for the Western Hills catchment. In some specific areas, adjustments were made to the ground model. These were generally sites of overland channels that, due to vegetation, were not depicted well within the ground model and alteration was required to ensure water drained to the correct location.

3.2.4. Site-specific Data

Field inspections were undertaken by GHD Ltd staff to resolve errors, anomalies, and omissions in the stormwater network data. Data collected included the approximate locations of sumps, inlet and outlet structures, and the approximate direction of sump leads.

3.2.5. Hydrologic / Hydrometric Data

Land use designation, curve numbers and surface roughness layers were supplied by WWL for use in the model. Some editing of the roughness layer was undertaken to resolve anomalies and conflict with aerial photography and to remove small objects which increased the mesh generation processing time.

3.2.6. Google Streetview

Google Streetview was used to identify sumps not captured in the WWL asset data. Missing sumps were added to the model and either connected to the nearby pipe network or discharged to the nearest gully or stream.

3.3. Hydrological Model

3.3.1. Methodology

Catchment based hydrological models were developed in accordance with the Quick Reference Guide for Design Storm Hydrology, February 2016. This requires the use of the Soil Conservation Services (SCS) unit hydrograph method.

3.3.2. Sub-catchment Delineation

Hydrologic sub-catchments have been delineated using the catchment delineation tool in UMM, which identifies the watershed draining to specific locations using a ground model. Sub-catchments were delineated for each sump, inlet and open channel and also for each building with a direct connection to the stormwater network. This approach allows the discharges from the hydrological model to be widely distributed across the hydraulic model. Sub-catchments range and are smaller in the urban area and range in size up to 62 ha in the hills of the upper catchment.

The Western Hills model contains 1448 sub-catchments, shown in Figure 6. Of the delineated sub-catchments, 213 connect directly to streams or the 2D zone and 802 connect to sumps. The remaining sub-catchments (439) were for buildings with a direct connection to the network.

3.3.3. Rainfall – Runoff Model Parameters

The Soil Conservation Service (SCS) unit hydrograph methodology was applied in accordance with the Quick Reference Guide for Design Storm Hydrology, February 2016. The parameters for this method were calibrated for the Wellington Region during the development of the guide.

Key parameters of this approach are:

- Sub-catchment area
- Initial Abstraction (represents the depth of rainfall that falls before runoff occurs, i.e. surface wetting and depression storage)
- Antecedent Moisture Conditions
- Curve Number
- Time of Concentration.

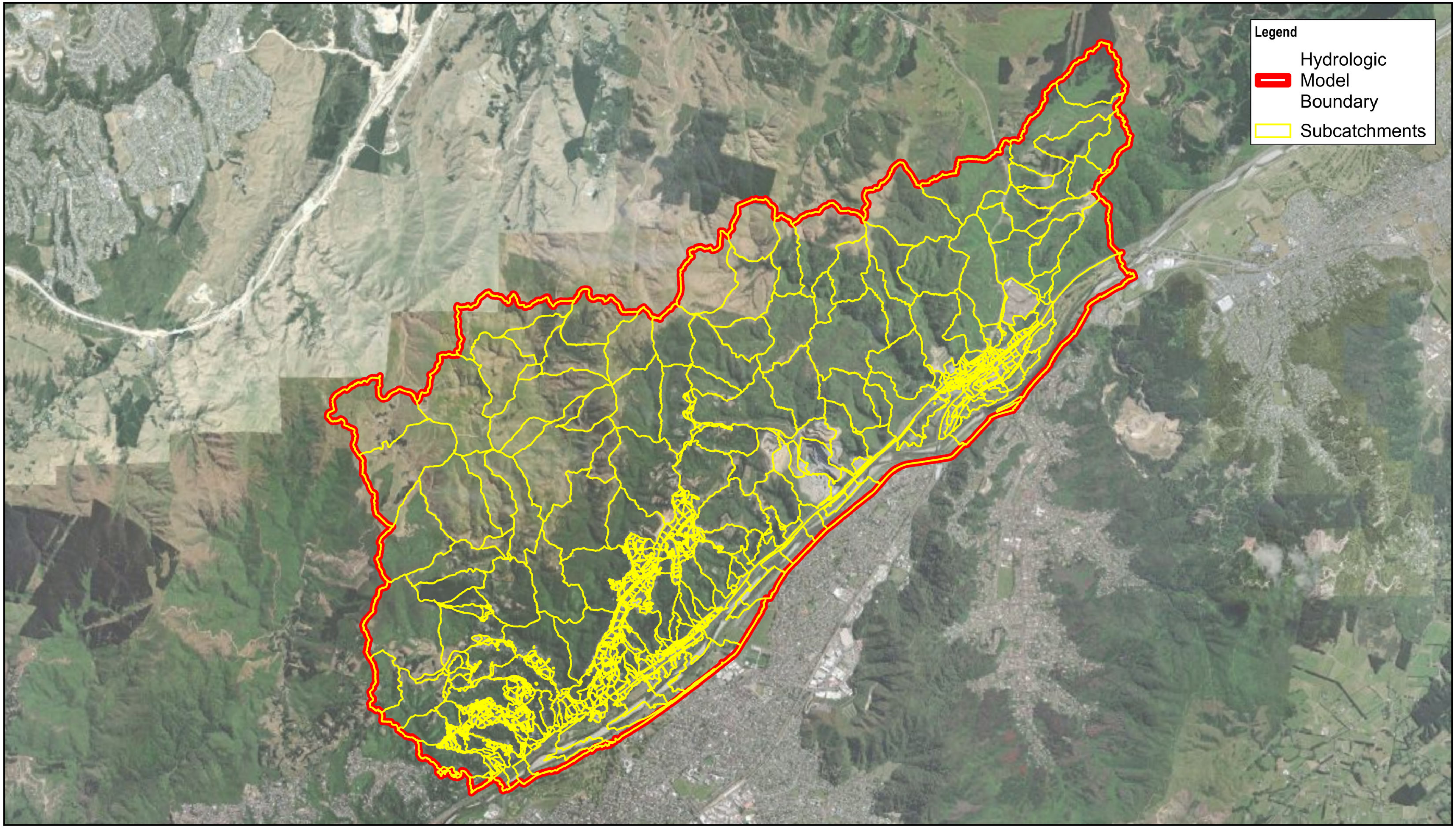
The sub-catchment parameterisation used an area weighted mean of the curve number and initial abstraction. The curve number and initial abstraction layers are shown in Figure 7 and Figure 8, respectively.

The Quick Reference Guide for Design Storm Hydrology, February 2016 provides the equations for calculating the time of concentration for use in the UHM model. The time of overland flow has been applied over a maximum distance of 50 m. The shallow concentrated flow equation has been applied over a maximum distance of 100 m starting from the end of the overland flow component.

The kerb flow equation has been applied from the point where the flow path enters the road as identified from the roughness layer or from the end of the shallow concentrated flow component. A minimum time of concentration of 5 minutes has been applied.

As the pipe networks and open channels have been included in the hydraulic model it was not necessary to utilise the time of open channel flow and time of pipe flow equations.

For building sub-catchments, the Time of Concentration has been set to 5 minutes, as per WWL Regional Stormwater Hydraulic Modelling Specifications.



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Kilometers

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Grid: NZGD 2000 New Zealand Transverse Mercator

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Wellington Water
Western Hills Stormwater Catchment

Hydrologic Model Boundary and Subcatchments

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Date **22/11/2022**

FIGURE 6

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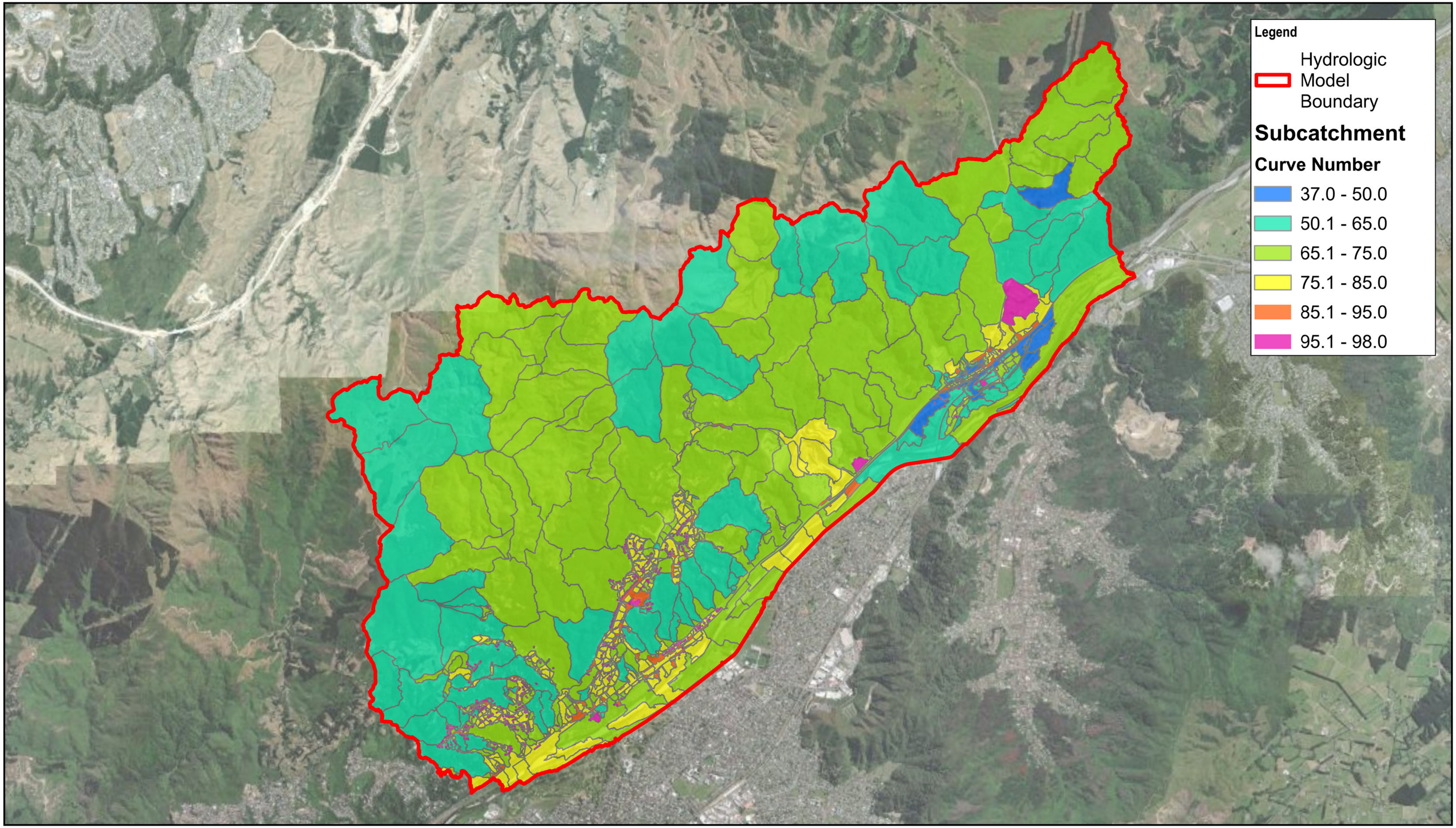

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Kilometers

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Map Projection: Transverse Mercator
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Grid: NZGD 2000 New Zealand Transverse Mercator

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Wellington Water
Western Hills Stormwater Catchment

Western Hills CN Curve Numbers

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FIGURE 7

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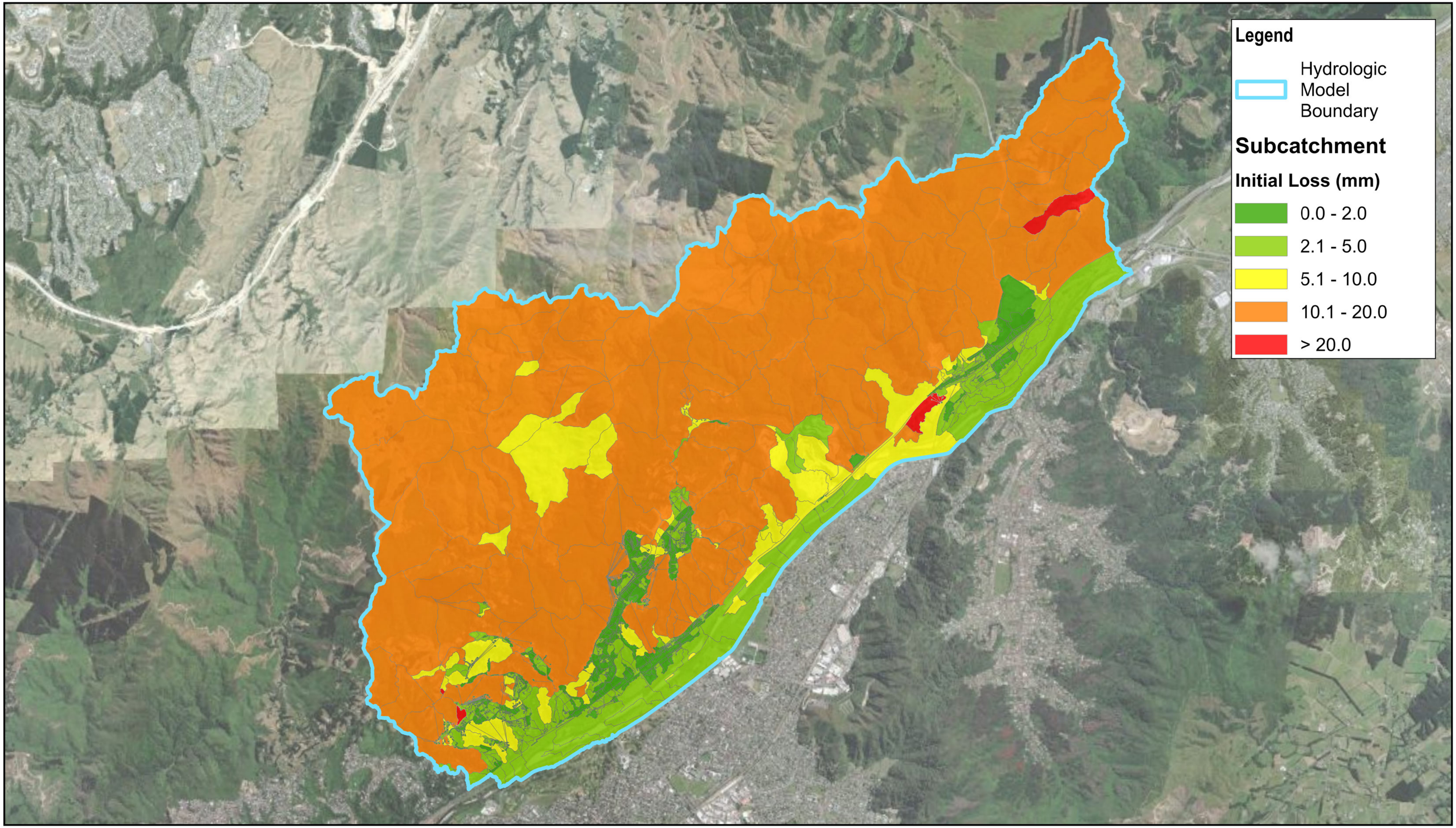

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Kilometers

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Grid: NZGD 2000 New Zealand Transverse Mercator

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Wellington Water
Western Hills Stormwater Catchment

Western Hills
Initial Abstraction

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FIGURE 8

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Data source: World Imagery: Earthstar Geographics. Created by: cmurray2

3.4. Hydraulic Model

A coupled 1D and 2D hydraulic model has been developed in InfoWorks ICM to represent flow interchanges between the 1D pipe network, 1D open channels and the 2D surface. The hydraulic model is to be shown in Figure 9.

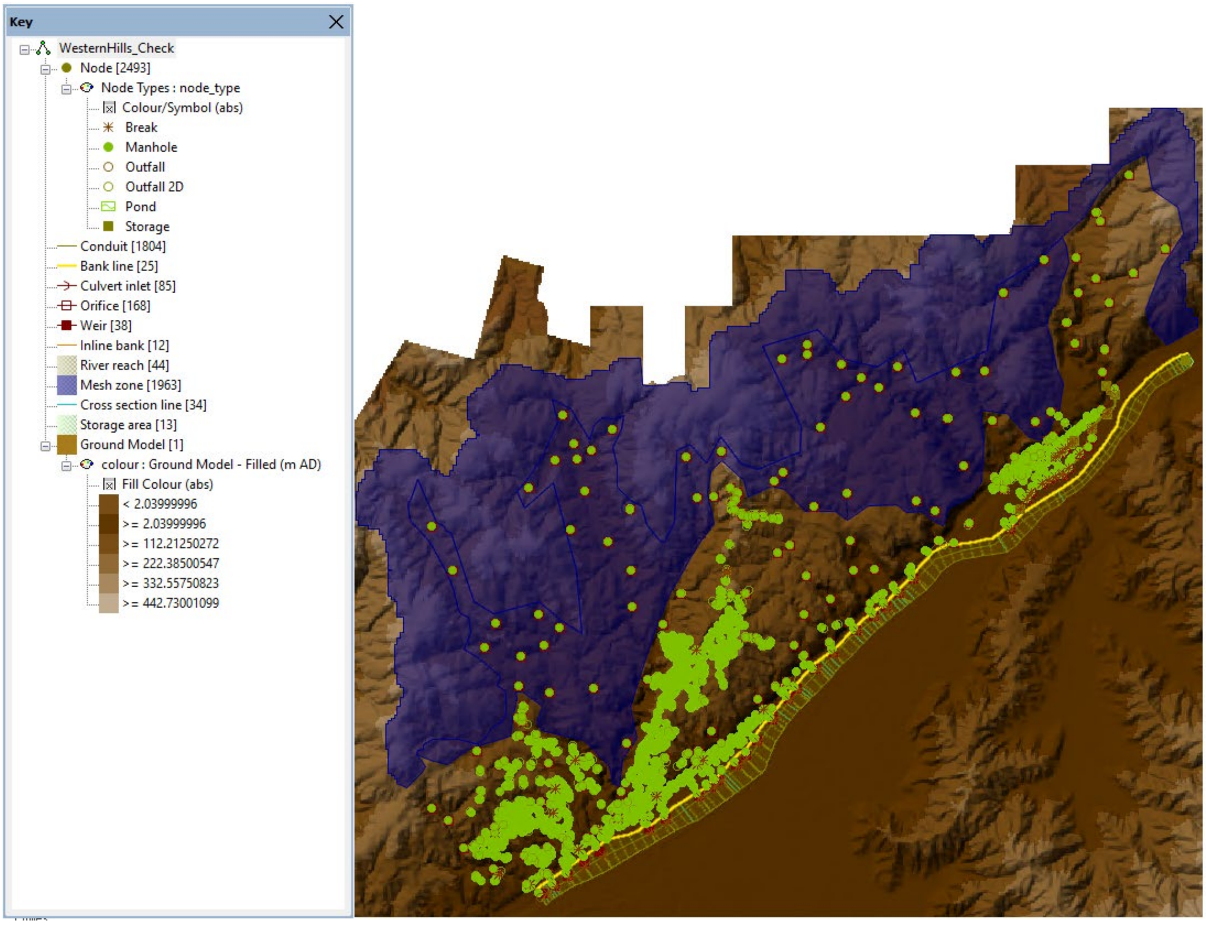


Figure 9 Final extent of the hydraulic model

3.4.1. 2D Model

The 2D model is used to describe overland flow within the catchment and streams not included in the 1D model.

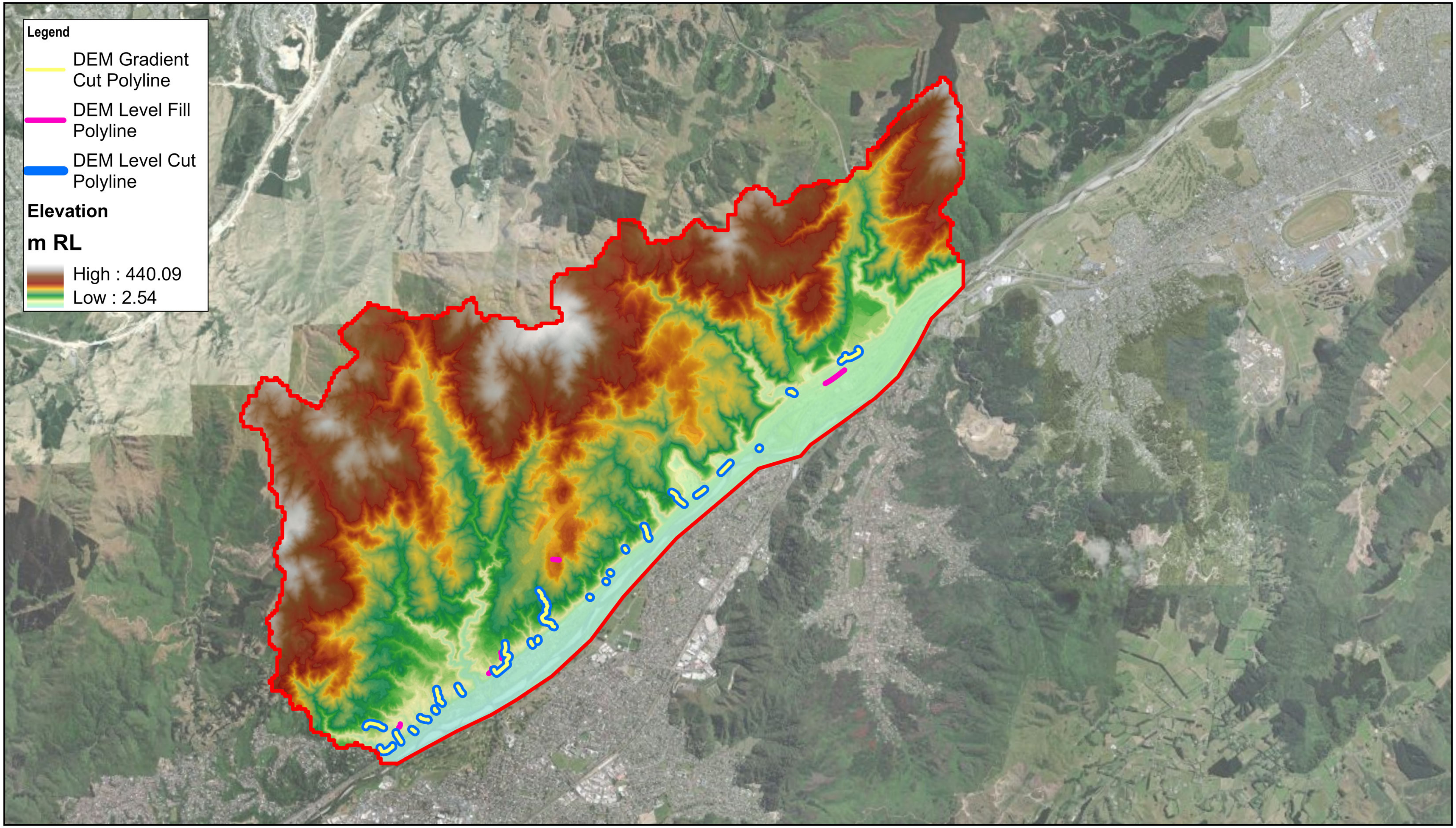
The 1m x 1m DEM provided by WWL was processed using the UMM sub-catchment delineation tool to develop watershed boundaries. The resulting watershed boundaries were used to determine the extent of the model and minimise overlap with adjacent catchments. The hydraulic model includes all pipework within the hydrological model extent. A small section of network, outside the hydrological model extent, at the west end of the model has been included. The network is located Catherine Grove and Pomare Road and was included because the network drains into the Western Hills catchment.

3.4.1.1. DEM Adjustment

Due to the presence of vegetation, many of the open channels and drainage gullies were not well represented in the DEM, particularly around inlet and outlet structures. In many cases, the ground and invert levels for inlets and outlets in the model were not available from WWL GIS data and were sampled from the terrain.

Terrain adjustment was required so that the flow paths modelled were consistent with grades and flow paths observed during the site visit. Adjustments were also made to ensure water flows away from outlets and toward inlets. Terrain processing was not carried out in the undeveloped steep hills in the upper catchment since this is considered to have a minimal impact on the downstream private property flood results and there are no significant inlets and outlets. The terrain edited was focused on the lower catchment where the terrain representation will have a more notable impact on property flooding.

The locations of the DEM adjustments are shown in Figure 10.



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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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Wellington Water
Western Hills Stormwater Catchment

Western Hills
Locations of Open Channel
DEM Adjustments

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Date **01/11/2022**

FIGURE 10

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Print date: 09 Jun 2023 - 12:04

Data source: World Imagery: Earthstar Geographics. Created by: cmurray2

3.4.1.2. 2D Mesh

The ground surface within the 2D zone is represented using a triangular mesh, created in ICM using the adjusted DEM. This has a maximum triangle area of 4 m^2, with a minimum element area of 2 m^2.

Mesh zones, specifying a larger element area, were created for the rural area in the upper catchment to improve model stability and runtime. The upper hills mesh zone includes the upper catchments and has a minimum and maximum element area of 50 and 100 m^2, respectively. The lower hills mesh zone covers the gullies draining towards the urban area and lower rural area closer to the urban area. The minimum and maximum element areas for this area were set to 10 to 25 m^2, respectively.

Mesh zones specifying a larger mesh size were also created around 2D inlets and 2D outlets. The mesh zones around the inlets and outlets also have a level modification to match the pipe invert level. 1 m^2 mesh zones were also included around all sumps and manholes and the level of the mesh zone was set to the rim level of the node. The default mesh zone sizes around some manholes, inlets and outlets were enlarged slightly where required for model stability and to resolve flow limiting.

The mesh zones used in the Western Hills mesh generation are shown in Figure 11 and the parameters of the mesh zones used are summarised in Table 1. These mesh zone element sizes will be updated as required during model validation and system performance to improve model results and minimise instability.

Table 1: Mesh Zone Parameters

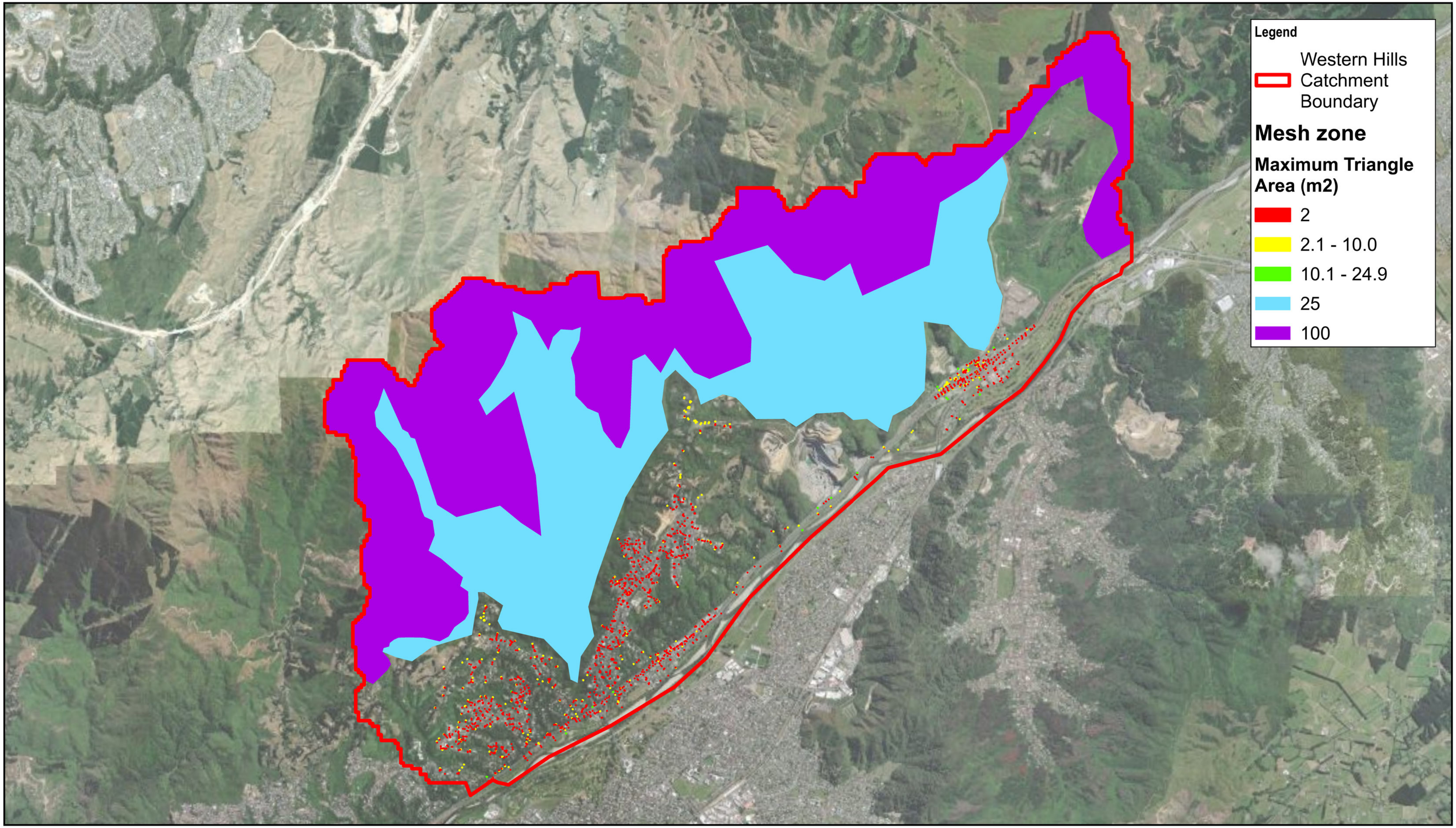
Mesh Zone	Minimum Element Area (m^2)	Maximum Element Area (m^2)
Sumps and Manholes	1	2
2D Inlets and Outlets	9	10
Lower Hills	10	25
Upper Hills	50	100

3.4.1.3. Building Void Mesh Zone

Large commercial building footprints were voided from the 2D mesh to ensure surface flow could not pass through. This is due to larger buildings generally being a barrier to overland flow paths. Twenty (20) buildings were included as voids in the Western Hills mesh. Figure 12 shows the location of these building voids.

3.4.1.4. 2D Streams and River Reaches

Most streams were modelled on the 2D surface except for channels running through residential areas in the lower catchment and the Hutt River. A couple of channels were also moved from a 1D channel representation to the 2D grid to resolve runtime instabilities in the model. In general, all streams and gullies in the lower catchment were modelled on the 2D grid using a minimum element area of 2 m^2 and a maximum element area of 4 m^2. Larger triangles were used for gullies and overland flow paths in the upper catchment in hilly areas, according to the parameters in Table 1.



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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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Wellington Water
Western Hills Stormwater Catchment

Western Hills Modelled Mesh Zones

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FIGURE 11

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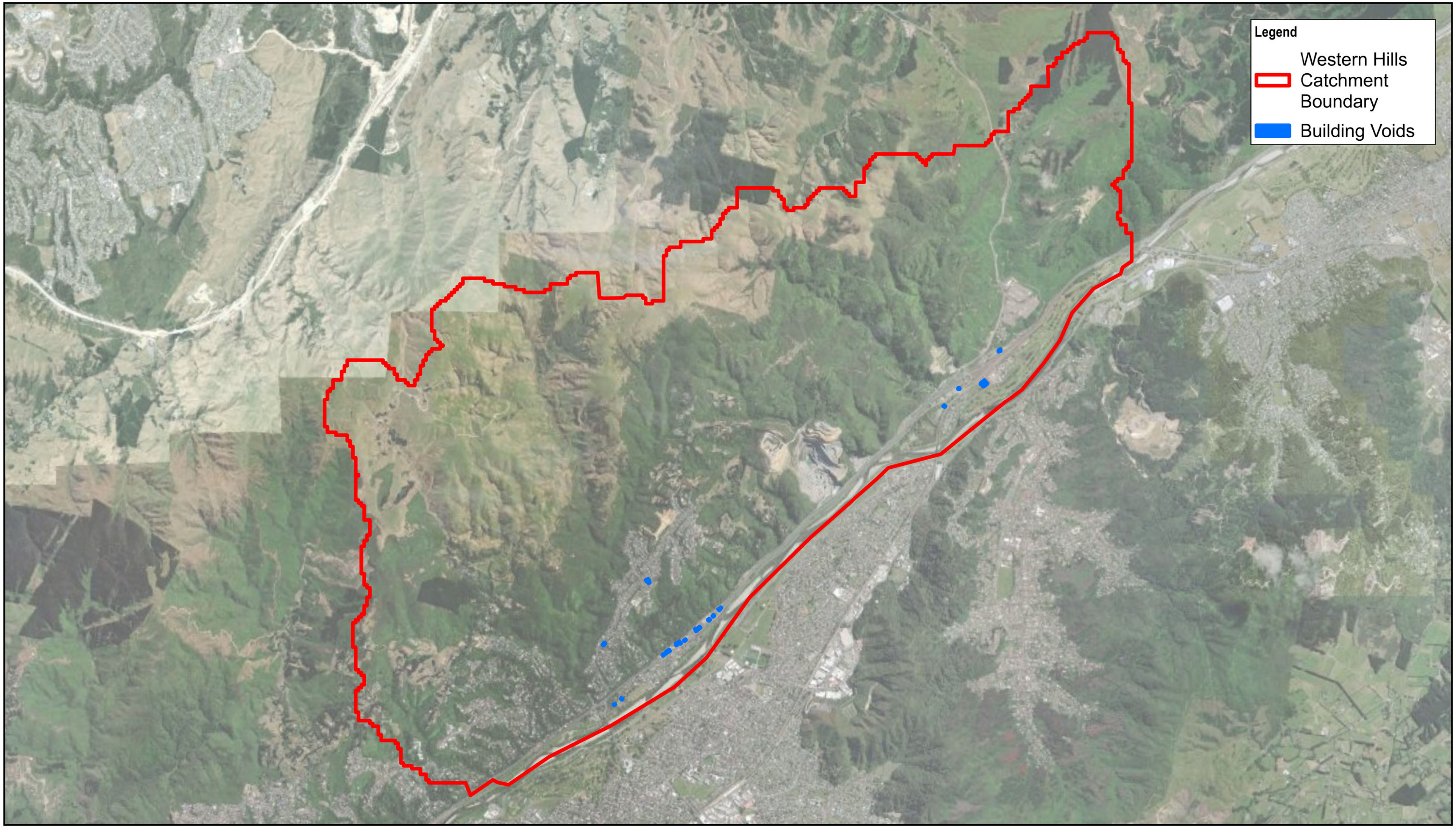

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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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Wellington Water
Western Hills Stormwater Catchment

Western Hills
Modelled Building Voids

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FIGURE 12

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Data source: World Imagery: Earthstar Geographics. Created by: cmurray2

3.4.2. 1D Pipe Network Model

The 1D pipe network model represents flows through the pipework beneath the 2D surface. All stormwater pipes, manholes and sumps contained within the provided GIS data, aside from those small diameter private pipes and kerb connections, have been included in the 1D model.

Missing or anomalous data was added or updated where necessary based on as-built information, surrounding pipework, ortho-photos and site survey undertaken by GHD staff. Where sumps have been identified from ortho-photography, they have been added to the model with the ID "WH_StreetView_Sump" suffixed with an integer. Connections to the pipe network or discharges to nearby gullies or streams from these sumps have been added to the model based on engineering judgement.

3.4.2.1. Culvert Inlets

Culvert inlets have been modelled in ICM as square edged headwalls using the following parameters:

For circular conduits:

- K 0.0098
- M 2.0
- C 0.0398
- Y 0.67
- Ki 0.5.

For rectangular conduits:

- K 0.026
- M 1.0
- C 0.0385
- Y 0.81
- Ki 0.3.

There is an existing culvert at the southern end of Major Drive (refer Figure 13), crossing Western Hutt Road. This culvert is understood to be a double culvert with the same invert levels. A weir allows spilling between the two culverts.

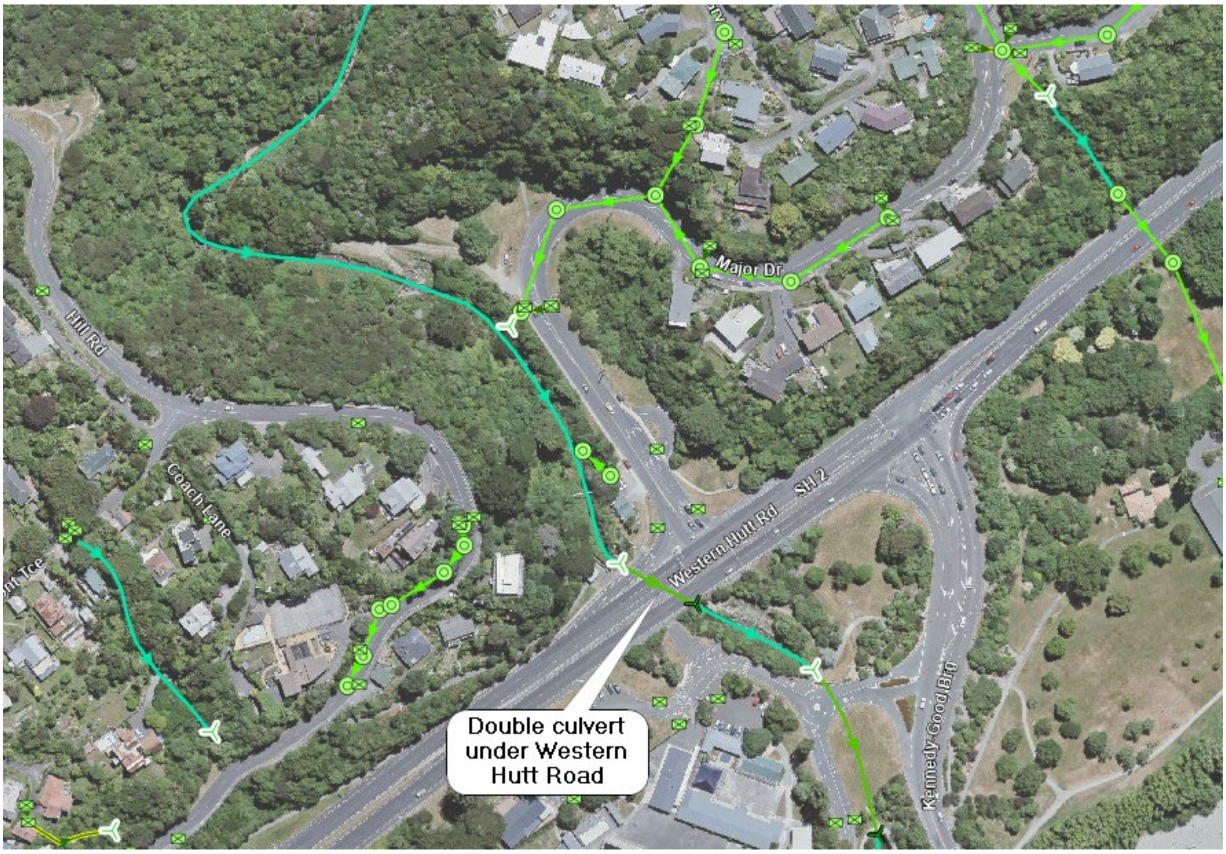


Figure 13: Culvert at Major Drive

3.4.2.2. Screens

No screens were observed by GHD staff during the site visit. No screens were included within the model setup.

3.4.3. 1D Open Channels

The Hutt River and two small streams have been modelled as one-dimensional open channels based on the stream lines layer supplied by WWL. In most cases the open channels required some editing with centrelines adjusted to align with low cells in the DEM and any visual representation of the stream from ortho photography.

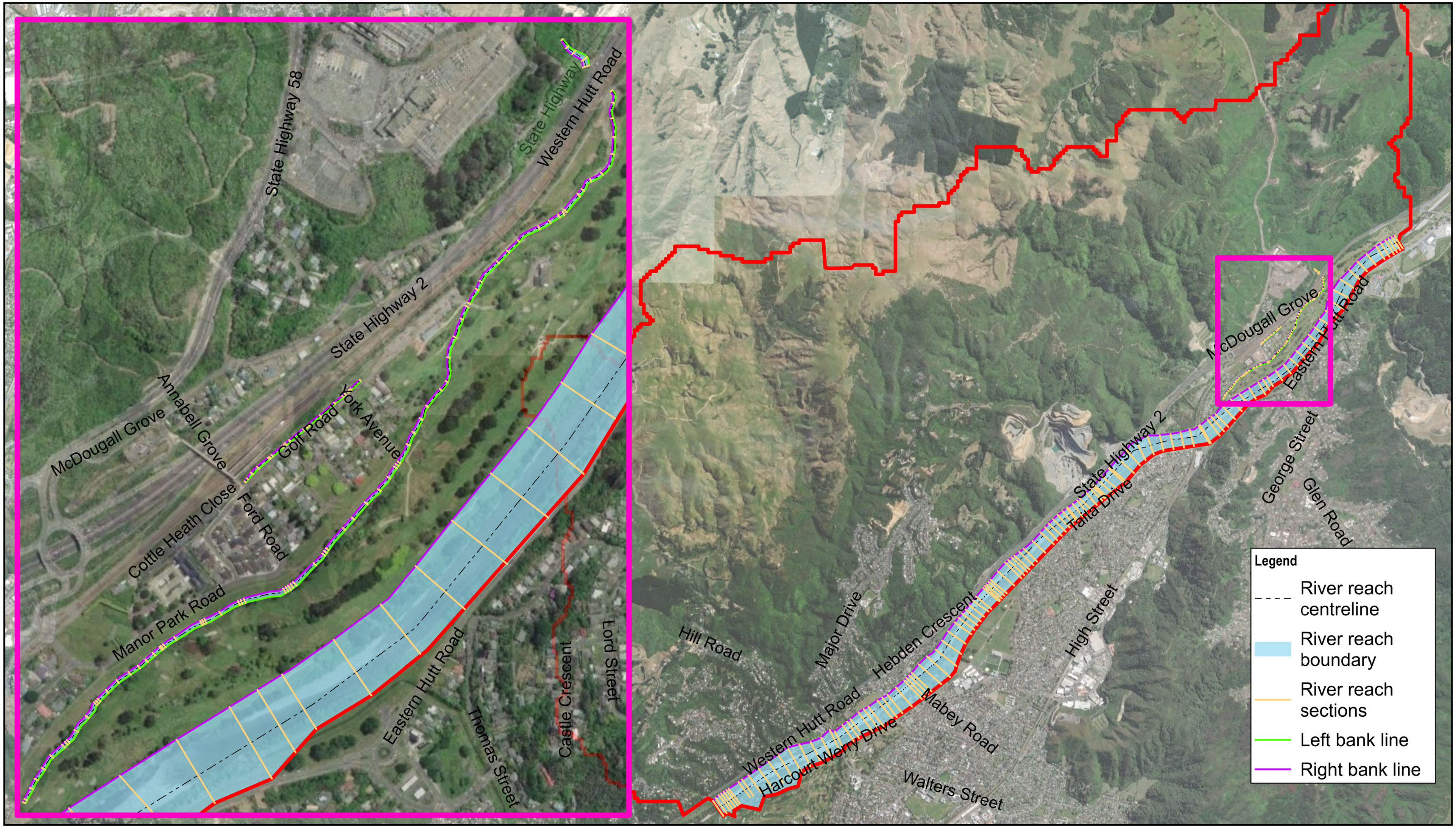
Cross-sections for the Hutt River are from cross-sections provided by Greater Wellington Regional Council (GWRC) in 2020. These cross-sections are in the same locations as the 2009 cross-sections but are based on bathymetry collected in the Hutt River in 2019. Note that these cross-sections differ from the cross-sections in GWRC's Hutt River model (DHI 2018) which were based on a 1998 bed survey and a 1987-1989 berm survey.

A cross section survey has not been undertaken for any of the other open channels as they are considered minor channels. Consideration of cross section surveys should be made if the model is to be used for options analysis or detailed design in the vicinity of the modelled open channels.

Cross sections were extracted from the DEM approximately every 10 to 20 metres along the open channels, or at any significant change in channel gradient or cross section shape. Most cross sections were taken at locations where the DEM has been edited to better represent the open channel. Cross-sections at the upstream and downstream ends of the open channels were created as a regular trapezoidal shape with dimensions based on the inlet or outlet pipe size.

The length of each 'River Reach' has been defined by the location of inlet and outlet structures, or pipe inlets and outlets to the channels. Break nodes have been placed at the upstream and downstream sections of the river reaches to allow for the connection of weirs from the pipe network outlets, lateral inflows from sub-catchments not included in the pipe network, or to mark the start or end of a structure. At inlet and outlet structures, storage nodes with associated storage areas have been used.

Locations of the 1D open channels are shown in Figure 14.



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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

N

GHD

Wellington Water
Western Hills Stormwater Catchment

Western Hills
Streams modelled as 1D Open Channels

Project No. **12556744**
Revision No. **DRAFT A**
Date **24/01/2023**

FIGURE 14

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Data source: World Imagery: Porirua City Council, Maxar
World Imagery: Maxar. Created by: cmurray2

3.4.4. Model Domain Linkages

There are three model domains in the Western Hills stormwater model: the 1D pipe network, the 1D river reach network and the 2D surface. Flow is transferred between the three domains.

There are two types of links between the 1D pipe network and the 2D surface. The first is at manholes and sumps in the network. These have been modelled with a Flood Type attribute of “Gully 2D” which allows the transfer of water from and to the node to the 2D mesh element the node is located in. For these nodes, transferred flow is calculated using a head discharge table. The head discharge table applied to nodes restricts flow entering the network while allowing free flow out of the network. Where a node is located beneath a building footprint, the Flood Type is set to “Sealed”, preventing the exchange of flow between the 2D model and the 1D pipe network.

The second type of link is where a pipe network outlet discharges directly onto the 2D surface. At these locations an “Outfall 2D” node has been used, where flow transferred is calculated as a vortex control with a nominal head discharge relationship. To address instabilities in the initial model testing, some of these nodes were changed to manhole types with a “2D” flood type. This was found to reduce flow limiting and volume balance at some nodes.

The third type of link is between river reaches and the 2D zone. Each river reach uses two bank lines to connect to the adjacent 2D zone. The bank lines have been generated from the ground model. The alignment of the bank lines has been digitised to represent an appropriate top-of-bank location. The discharge coefficient values for the bank lines have been set at 0.8 and the modular limits for the bank lines have been set at 0.7. At network inlet locations the overtopping of the inlet has been modelled using ‘Inline Bank’ elements.

The left bank of the Hutt River reach is not linked to the 2D surface. Therefore, the left banks of the Hutt River cross sections were extended to ensure the highest elevation in the cross section is greater than the predicted maximum water levels in the channel.

3.4.5. Energy Losses

3.4.5.1. 1D Pipe Network

Energy losses in the 1D pipe network due to surface friction have been accounted for using the pipe material information in the WWL GIS data for pipes. All pipes in the Western Hills catchment had a pipe material attribute in the GIS data. Table 2 summarises the pipe roughness values used in the model.

Table 2: Pipe Materials and Manning's n

Pipe Material	Model Conduit Material Name	Manning’s ‘n’
Asbestos cement	Abs	0.013
Ceramic	Cerm	0.014
Concrete	Conc	0.013
Iron	Iron	0.014
PVC	PVC	0.012
Unknown	UNKN	0.013

Discrete energy losses were applied to each node dependent on the node type and angle of attached pipework. The method for calculating the discrete losses is outlined in Table 3.

Table 3: Summary of node head loss parameters used in the model

Link Type	Node Head Loss Parameter
'Normal' Manhole Nodes	'Mean Energy Approach' with Ku inferred using InfoWorks ICM. As there is limited information regarding the network in general, the 'Normal' head loss type was used for all manholes and the coefficient calculated based on the angle of the outgoing pipe in relation to the incoming pipe. Where the outgoing pipe gradient was greater than 0.1 the headloss type was set to 'None'. This was to improve model stability.
Open Channel Nodes and Dummy / Saddled Manholes	'No Headlosses'

3.4.5.2. 1D Channel Network

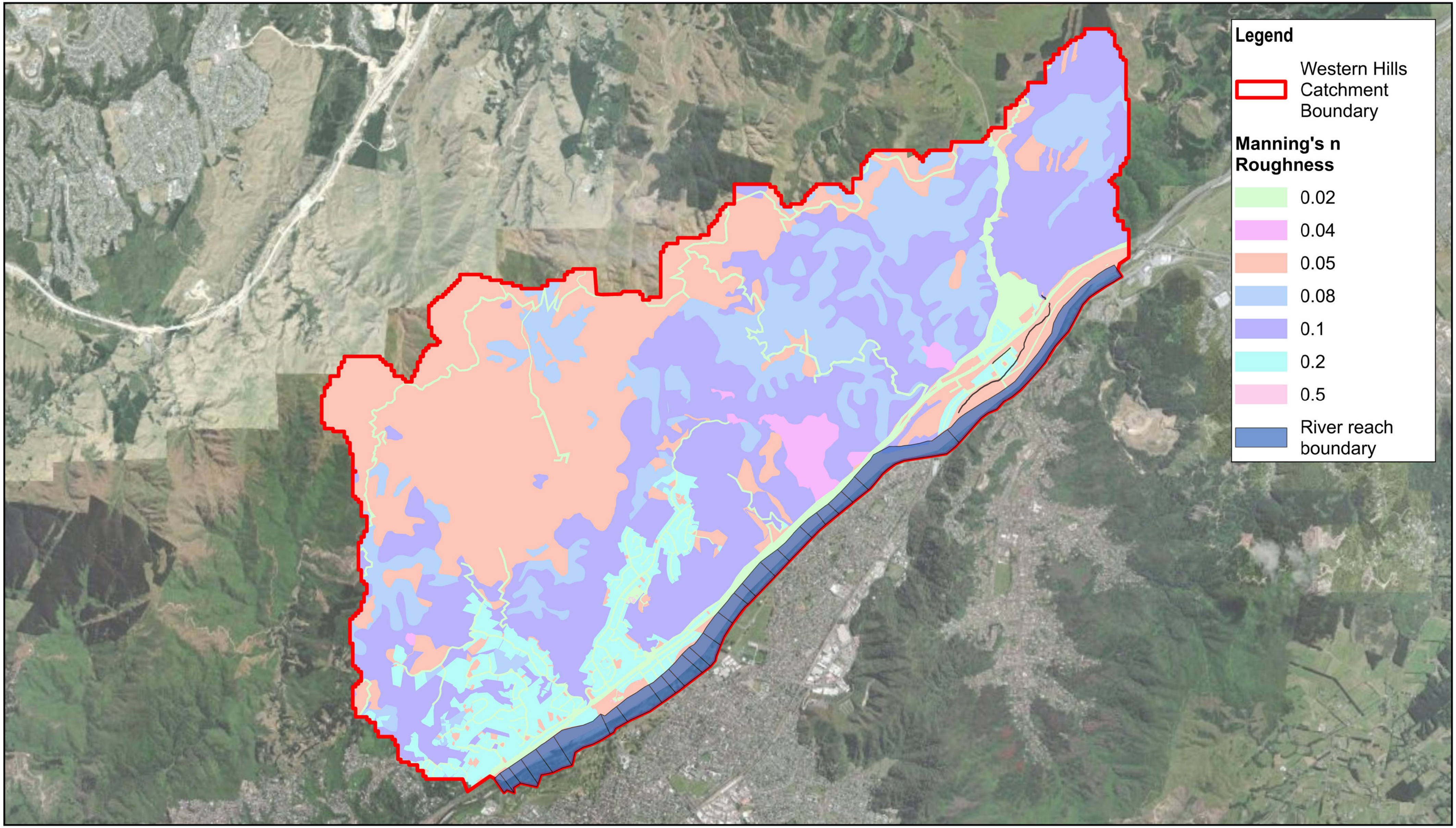
Energy losses in the 1D channel network due to surface friction have been accounted for using Manning's n values. The values of Manning's n have been taken from the Regional Stormwater Hydraulic Modelling Specification (WWL, version 5 December 2017) and assigned based on channel type. All modelled channels, including the Hutt River, have been assigned a Manning's n value of 0.03, based on site observations of the stream conditions.

3.4.5.3. 2D Network

Energy losses in the 2D network due to surface friction have been accounted for using Roughness Zones set to Manning's n roughness values across the 2D Zone. The Roughness Zones have been adopted from the Regional Ground Roughness Coefficient, MWH 2016. Some edits were made to the roughness zones to resolve anomalies and conflict with the aerial photography and to remove very small roughness zones (less than 8 m^2). Table 4 shows the roughness values used in the Western Hills model and the corresponding ground cover type. Roughness zones applied in the model are shown in Figure 15.

Table 4: Ground Roughness Coefficients

Ground cover	Manning's roughness coefficient 'n'
Roads and footpaths / non-residential and residential properties: pavement	0.02
Vegetation: bare / residential properties: grass	0.04
River / recreational area, playing field / vegetation: alpine, impervious, pasture, urban open space	0.05
Vegetation: scrub/flax	0.08
Vegetation: forests / residential properties: small fenced backyards	0.1
Residential properties: trees	0.2
Non-residential and residential properties: buildings	0.5



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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

N

GHD

Wellington Water
Western Hills Stormwater Catchment

Western Hills
Roughness Zones

Project No. **12556744**
Revision No. **DRAFT A**
Date **23/11/2022**

FIGURE 15

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Data source: World Imagery: Maxar. Created by: cmurray2

3.5. Boundary Conditions

3.5.1. Rainfall Data

Rainfall inputs for design events were derived using the methodology outlined in SCS Rainfall Runoff Model Calibration: Standardised Parameters for Hydrological Modelling (March 2017). The design rainfall was collected from the HIRDSv4 website for the Western Hills catchment for the point with the following NZTM2000 coordinates:

- Northing: 5441304.4
- Easting: 1762848.8.

This corresponds to the following WGS84 Coordinates:

- Longitude: 174.941
- Latitude: 41.163.

The depth-duration data is provided in Table 5 for the historical data.

Table 5 Design rainfall depth used for the Western Hills catchment

ARI (y)	AEP	10m	20m	30m	60m	2h	6h	12h
1.58	0.633	7.38	10.2	12.3	17.2	24	39.9	53.7
2	0.5	8.1	11.2	13.5	18.8	26.2	43.5	58.5
5	0.2	10.6	14.5	17.6	24.4	33.9	56	75
10	0.1	12.5	17.1	20.7	28.7	39.7	65.2	87.2
20	0.05	14.5	19.8	23.9	33	45.7	74.8	99.8
30	0.033	15.7	21.4	25.8	35.7	49.3	80.6	107
40	0.025	16.6	22.6	27.2	37.6	51.9	84.7	113
50	0.02	17.3	23.5	28.4	39.1	54	88	117
60	0.017	17.9	24.3	29.3	40.4	55.7	90.7	121
80	0.012	18.8	25.6	30.8	42.4	58.4	95	126
100	0.01	19.5	26.5	31.9	44	60.5	98.4	131

For the future conditions climate change scenarios the rainfall depths have been increased by 20% to account for a 2.5˚C temperate increase by 2090. The depth-duration data for future conditions climate change scenarios is provided in Table 6.

Table 6 Design rainfall depths for Pukerua Bay catchment with a climate change (20% increase)

ARI (y)	AEP	10m	20m	30m	60m	2h	6h	12h
1.58	0.633	8.9	12.2	14.8	20.6	28.8	47.9	64.4
2	0.5	9.7	13.4	16.2	22.6	31.4	52.2	70.2
5	0.2	12.7	17.4	21.1	29.3	40.7	67.2	90.0
10	0.1	15.0	20.5	24.8	34.4	47.6	78.2	104.6
20	0.05	17.4	23.8	28.7	39.6	54.8	89.8	119.8
30	0.033	18.8	25.7	31.0	42.8	59.2	96.7	128.4
40	0.025	19.9	27.1	32.6	45.1	62.3	101.6	135.6
50	0.02	20.8	28.2	34.1	46.9	64.8	105.6	140.4
60	0.017	21.5	29.2	35.2	48.5	66.8	108.8	145.2
80	0.012	22.6	30.7	37.0	50.9	70.1	114.0	151.2
100	0.01	23.4	31.8	38.3	52.8	72.6	118.1	157.2

3.5.2. Hutt River Inflow and Water Level

The only inflow boundary condition into the catchment is to the Hutt River along the south boundary of the model. The Hutt River was represented in the model as a 1D channel and essentially provides a downstream level condition for the local drainage in the Western Hills catchment. In consultation with WWL, the 10-year ARI event was selected for the Hutt River to use as the boundary condition for both the 10- and 100-year ARI rainfall events in the Western Hills catchment. This is justified by different time of concentrations for the Western Hills catchment compared to the Hutt River; peak discharge in the Hutt River typically occurs several hours after peak runoff in Western Hills.

The 1D channel was modelled with an inflow at the upstream extent and a level boundary at the downstream extent of the river reach. The initial inflow was obtained from the Hutt River MIKE model built by DHI for GWRC and applied at the inflow location identified in Figure 16. The MIKEmodel was run with 10-year ARI historical rainfall and the model predicts a peak discharge of 1,244 m^3/s near this location in the Hutt River. The MIKE model was based on gauge data at the Hutt River at Taita Gorge site and boundary conditions supplied by GWRC. This discharge was applied in the Western Hills model as a short ramp up period followed by constant inflow. This was found to improve model stability. An additional inflow of 0.5 m^3/s was added at five Hutt River cross-sections at the upstream end of the Hutt River model. This was found to improve model stability and is expected to have a very minor impact on predicted flood levels since the total additional flow (2.5 m^3/s) is very small compared to the 1,244 m^3/s base flow.

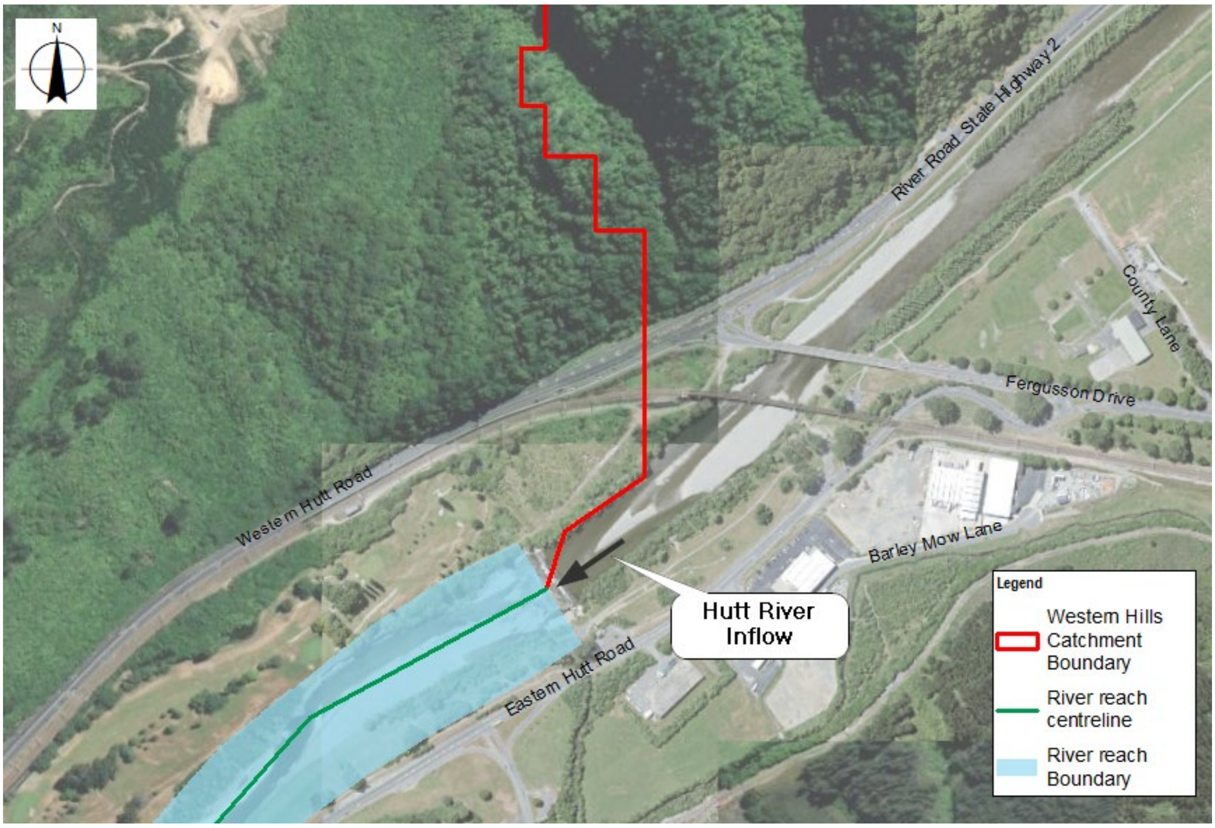


Figure 16: Location of Hutt River Inflow Boundary Condition

A 10-year ARI level boundary obtained from the GWRC Hutt River MIKE model was applied at the downstream end of the Hutt River 1D channel in the model. As with the inflow, a short ramp up period followed by a constant level was applied, and this was found to improve model stability. The water level applied at the downstream end was 7 m RL.

The model was run with the initial inflow and level boundaries described. The Hutt River water levels in the Western Hills InfoWorks model was then compared to water levels in the GWRC Hutt River MIKE model, with a focus on areas where flooding of properties was predicted because of the Hutt River levels. This comparison was focused on two key areas where preliminary results predicted flooding between State-Highway 2 and the Hutt River. This was the Manor Park suburb, and the vicinity of Owen and Norfolk Streets (refer to locations in Figure 17).

There was a large disagreement in peak water levels predicted by the two models especially around Manor Park (refer to Table 7). The differences between the two models were found to be due to differences in cross-sections. The cross-sections in the GWRC Hutt River model are derived from a 1998 bed survey and berms surveyed between 1987-1989 (DHI, 2018), whereas the cross-sections in the InfoWorks ICM model are based on Hutt River cross-sections provided by GWRC in 2020 and derived from bathymetry collected by GWRC in 2019. The more recent 2020 cross-sections were kept in the InfoWorks ICM model, but the Hutt River water levels in the model could not be validated against the GWRC MIKE model due to the cross-section differences.

Table 7 Comparison between Hutt River levels in InfoWorks Western Hills model and GWRC Hutt River model

Location	Difference in 10 year ARI water level	Difference in Cross-section
Manor Park	Water level is generally about 600 mm lower in Western Hills model	Channel invert is about 400-600 mm lower in Western Hills model cross-sections
Owen and Norfolk Streets	Water level is generally about 200 mm higher in Western Hills model	Differences in channel invert is less than 200 mm on average

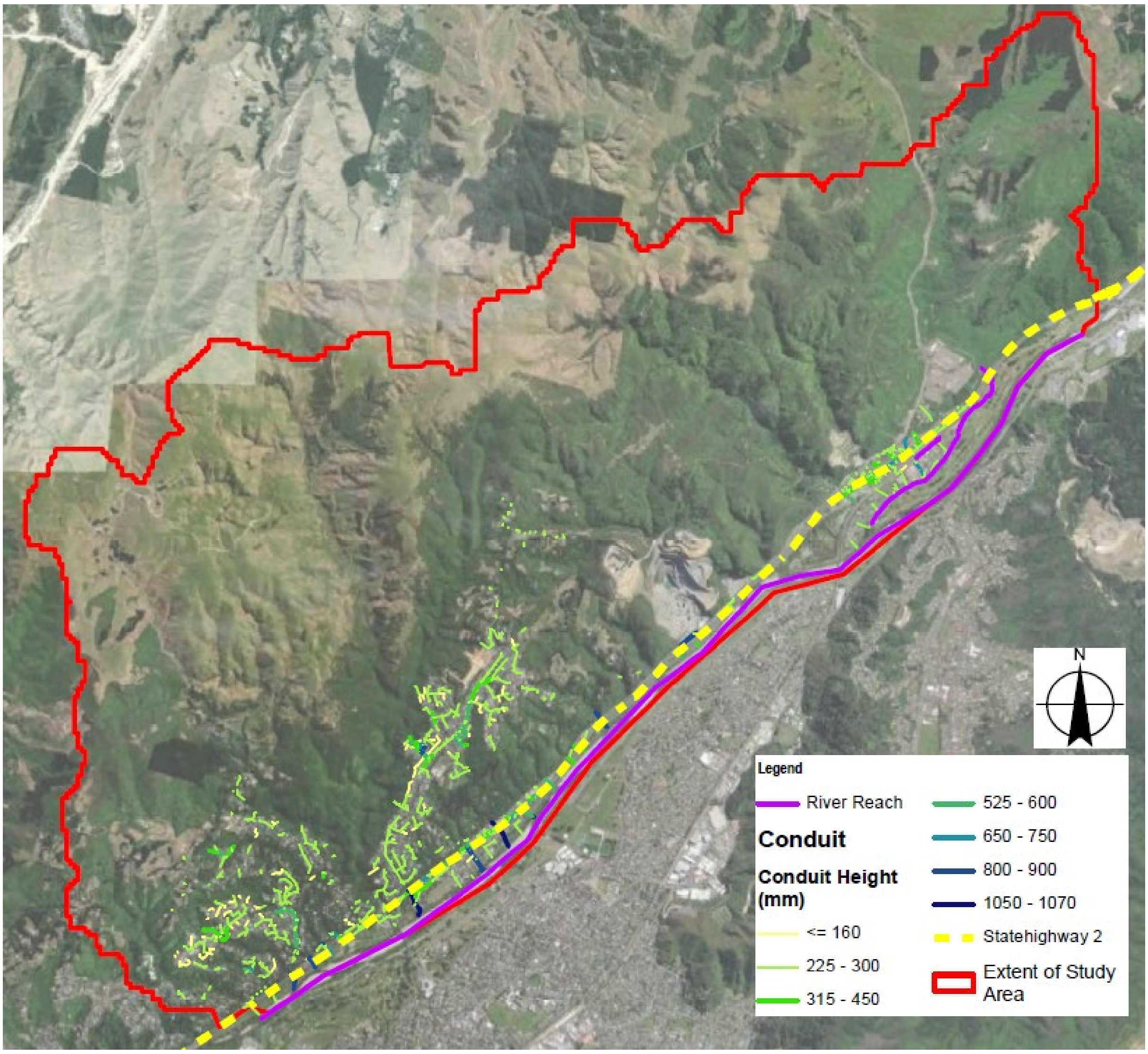


Figure 17: Areas affected from Hutt River water levels

3.5.3. 2D Zone

A ‘normal condition’ has been applied to the boundary of the 2D Zone. The 2D Zone extent has been developed so overland flow is unlikely to reach the boundary of the zone except at the downstream end of the catchment at the Hutt River.

3.6. Model Limitations and Assumptions

Computational models are only as accurate as the information input to them and the data available to verify their accuracy. The primary sources of information for this investigation were available GIS asset data, LiDAR and scanned as-built plans all provided by WWL, and site visit information collected by GHD staff.

The constraints and limitations of the stormwater flood model are as follows:

- Manhole and pipe levels for some of the network have been interpolated from available data.
- Large parts of the model are based on LiDAR. Where the quality of the LiDAR is suspect or there have been changes made since the collection of LiDAR, the model may not represent the real-life situation. Further information on the quality of LiDAR can be referred to in Ground Model Assessment Summary Report, April 2016.
- The open channel cross sections represented in the 2D surface model or in 1D channels are largely based on the LiDAR. These cross sections may underrepresent channel volume due to vegetation cover.
- Building floor levels are not applied.
- Fences and walls that may constrict flow paths are not represented in the model.
- Predicted flood depths at the downstream end of the model (near 2 Pomare Rd) may have inaccuracies due to the proximity to the downstream boundary on the Hutt River and due to the missing section on the Hutt River.

3.6.1. Hydrological Model Assumptions

The following assumptions have been applied in the development of the hydrological model:

- The hydrological method specified by WWL for use in the catchment is appropriate.
- The sub-catchments delineated are appropriate and have been correctly parameterised.

3.6.2. Hydraulic Model Assumptions

The following assumptions have been applied in the development of the hydraulic model:

- The LiDAR generated ground model is an accurate representation of catchment topography.
- Manhole lid levels are adequately represented in the ground model.
- Pipes are sediment free.
- Inlets, outlets and sumps are sediment free.
- The network asset data is of a suitable standard for use in the model without additional survey.

3.7. Initial Model Testing

3.7.1. Layout Checks

The model has been built using aerial photography, topographic information, and GIS layers provided by WWL. The stormwater network has been based on a combination of WCC GIS layers of the network assets and available as-built information. The extent of the 2D simulation polygon (2D Zone) was defined based on the topography of the Western Hills catchment and the reticulated stormwater network, ensuring that it covers all low-lying areas and high points, and extends upstream of all branches of the pipe network.

The Western Hills network extent is adequately represented in the model.

3.7.2. Instability Tests

Initial model testing was carried out using a 10-year ARI nested design storm event and a 100-year ARI nested design storm event under existing climate conditions. The option to link 1D and 2D calculations at minor timestep was applied to these scenarios to reduce volume balance errors. There were found to be no nodes within the PRN result file where the Volume Balance (%) was above 5%. This Volume Balance calculates the total flow entering the node, minus the total flow leaving it, including the transition between the 1D and 2D zones. Large values are a sign of instability.

3.7.3. Sensibility Check

Sensibility checks were carried out for the model. These included:

- Inspecting pipe grade and soffit levels
- Inspecting the total head of pipes
- Inspecting the total flow in pipes and open channels
- Inspecting velocity in pipes
- Inspecting locations and depths of ponding.

There were no obvious issues found in the model from these sensibility checks.

3.7.4. Mass Balance Checks

By default, the ICM simulation engine undertakes mass balance checks at every simulation time step. If the cumulative Mass Balance error exceeds 0.01 m^3 at any individual time step the simulation is automatically terminated. This implies that any simulation that is completed is considered to have passed this check.

The mass and volume balances for the 10 year ARI and 100 year ARI simulations under existing climate conditions are provided in Table 8, below.

Table 8 Volume Balance Summary for Initial Simulations

Design Storm Event	2D Total Mass Error	Volume Error
10 year ARI	0.1021 m^3	37,597 m^3 (0.28%)
100 year ARI	0.0951 m^3	51,375 m^3 (0.23%)

4. Model Confidence

4.1. Model Validation

The following section details the steps taken to assess simulation results and provide confidence in the Western Hills model. Confidence in the model has been achieved by validating against a measured rainfall event and general patterns of flooding and assessing model predictions for a range of sensitivity scenarios.

4.1.1. Data

4.1.1.1. Flood Record Data

The following recent rainfall events were considered significant for the Western Hills catchment:

- 14 May 2015
- 15 November 2016 (immediately after the earthquake)
- April 2019 (two events during this month).

Wellington Water provided flood information for the Western Hills area. This included historic photos at street level combined for several events between 2004 and 2008, an extract of flood records for the 14 May 2015 event, and mapping indicating the general areas of inundation ("Flood data - Inundation Areas Under Investigation, Hutt City", Flood Maps HCC Stage 2 Feb 2008.pdf). This mapping is based on various sources, including the Engineers Map from the August 2004 flood. Several GHD reports were provided for specific properties, but these were located outside of the Western Hills catchment boundary.

The 14 May 2015 event was selected for validation since flood records were available for this event. In addition, the general patterns of flooding noted in the inundation mapping was compared to the 10 year ARI design event.

The historic photos between 2004 and 2008 have not been used for the validation. Some photos have timestamps from various flood events between 2004 and 2008; other photos do not have timestamps and it is not clear which event they are from. Additionally, infrastructure changes or upgrades may have occurred since these events. The comparison to the Inundation areas mapping is considered sufficient to capture the general patterns of flooding in the catchment during these events.

4.1.1.2. Rainfall Data

The closest station to the Western Hills catchment is the Hutt River at Haywards Hill Reservoir gauge, which is located within the Western Hills catchment boundary. However, data is only available at this station from 2019 and therefore does not cover any of the large rainfall events identified. There are four other stations located near the Western Hills catchment. These stations are listed below and their location in relation to the Western Hills catchment are shown in Figure 18.

- Hutt River at Haywards Hill Reservoir (data available from June 2019)
- Hutt River at Mabey Road Depot (data available November 1995 to February 2003, and then April 2008 onwards)

- Pinehaven Stream at Pinehaven Reservoir (data availability unknown)
- Korokoro Stream at Belmont Trig (data available from June 2017)
- Hutt River at Birch Lane (data available from July 2001).

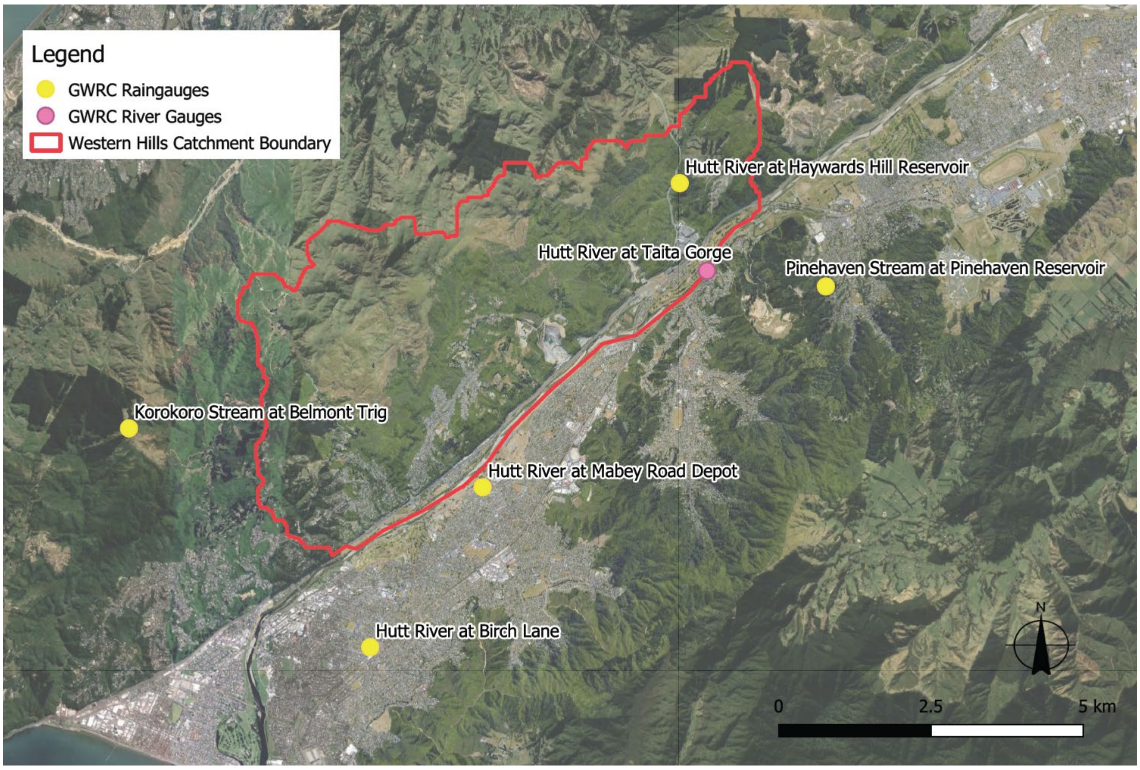


Figure 18: Location of GWRC Raingauges relative to Western Hills catchment

Rainfall for the 14 May 2015 event is only available at the Pinehaven Stream at Pinehaven Reservoir and Hutt River at Birch Lane stations. Figure 19 shows the cumulative rainfall at the two rainfall gauges. The cumulative rainfall depth at the Birch Lane gauge is about 14% higher than the Pinehaven gauge. Peak rainfall intensity was also much higher at the Birch Lane gauge. The average return period for each duration was estimated at the two rain gauges for the 14 May 2015 event and is summarised in Table 9.

Table 9: 14 May 2015 Rainfall Return Period (ARI) for Selected Rain Gauges

Duration	10min	20min	30min	1hr	2hr	6hr	12hr	12 hr
Pinehaven Stream at Pinehaven Reservoir	< 1 year	< 1 year	< 1 year	< 1 year	< 1 year	< 1 year	< 2 year	2-5 year
Hutt River at Birch Lane	5 year	10-20 year	30-40 year	60-80 year	30 year	5-10 year	5-10 year	2-10 year

The Thiessen Polygon Method was used to determine which rain gauge data was applied to each subcatchment. The locations of the rain gauges and polygons derived using this method for the 14 May 2015 event are shown in Figure 20. A limitation of the Thiessen Polygon method is that it doesn't consider the topography of the catchment and how this can influence the spatial variance of rainfall. The Wellington Region is very hilly and is known to have quite spatially varying and localised rainfall.

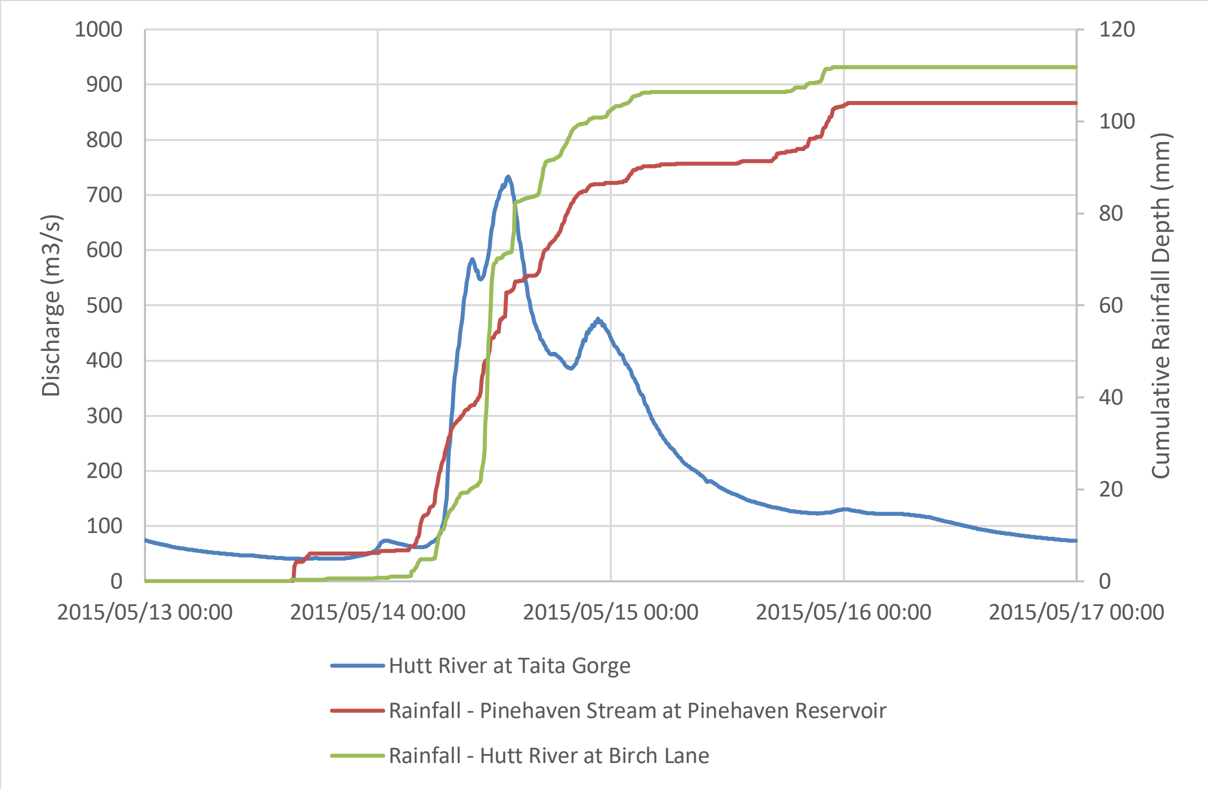


Figure 19: Cumulative Rainfall and Hutt River Inflow for 14 May 2015 Event

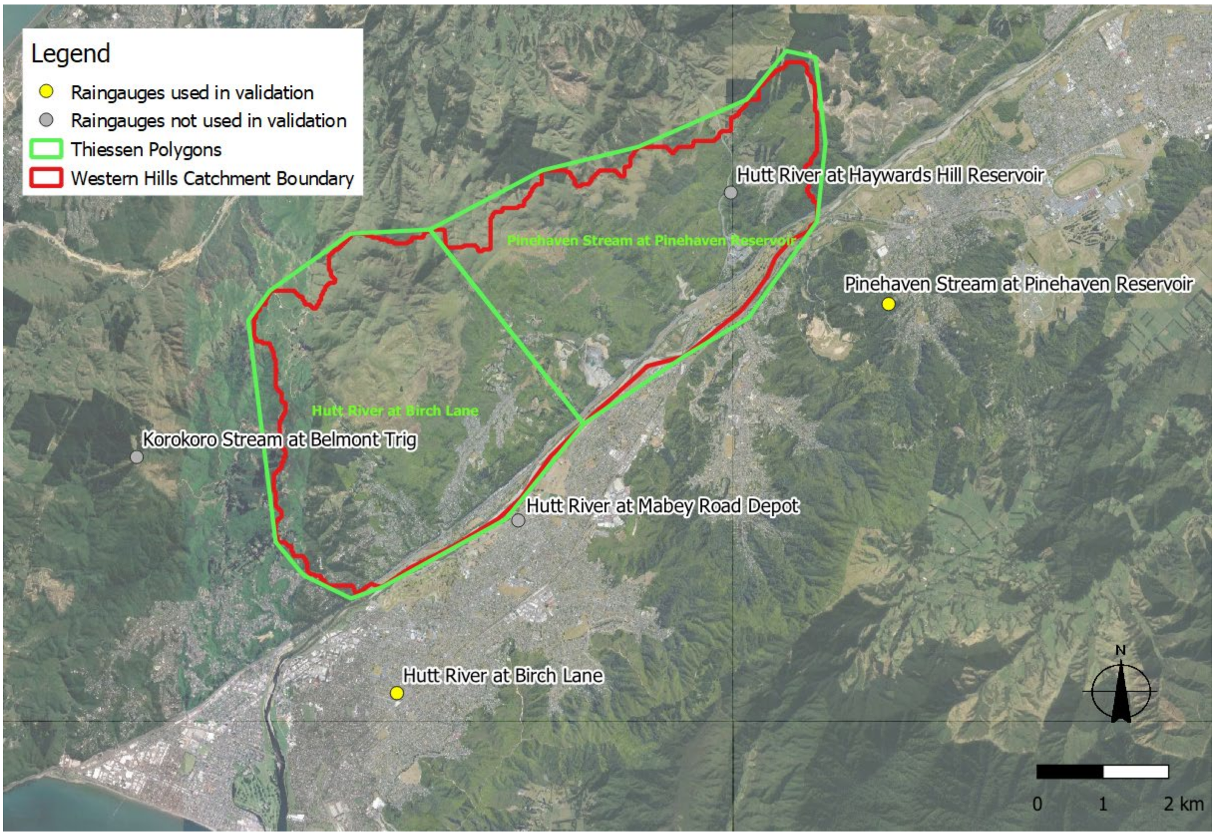


Figure 20 Thiessen Polygons for 14 May 2015 event

4.1.1.3. Hutt River Inflow and Water Level

Hutt River inflow near the upstream boundary of the catchment is available at the GWRC Hutt River at Taita Gorge station. The Hutt River at Taita Gorge station is located opposite Stokes Valley (refer to location in Figure 18) and has been operating since March 1979. For this validation, the discharge measured at the Taita Gorge station was applied at the upstream boundary of the catchment. For model stability, the inflow was applied as a linear ramp-up and then constant at the peak discharge recorded at the Taita Gorge gauge of 733 m^3/s for the event. Figure 21 shows the Hutt River discharge at Taita Gorge, and rainfall recorded at the Pinehaven gauge.

The Hutt River 10-year ARI water level boundary obtained from the GWRC Hutt River Mike model was applied at the downstream end of the Hutt River 1D channel in the model for the 14 May 2015 event. A short ramp up period followed by a constant level of 7 m RL was applied.

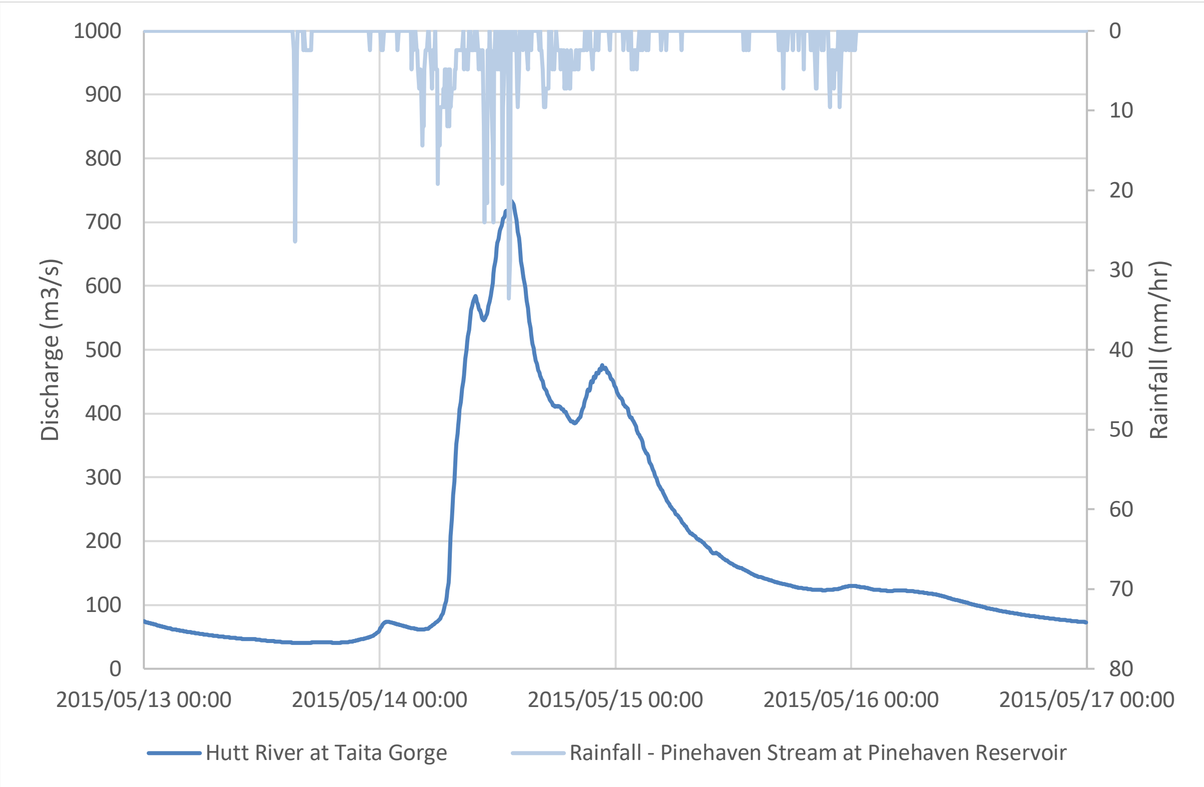


Figure 21: Rainfall and Hutt River Inflow for 14 May 2015 Event

4.1.2. Results

4.1.2.1. 14 May 2015

The model was run with the measured rainfall at the two gauges and constant Hutt River inflow at the upstream end of the model. There were three reports of flooding in the Western Hills catchment in extract of flood complaints received for the 14 May 2015 event. A comparison between the model results and flood complaints is summarised in Table 10 and detailed in Appendix A.

The model predicted flooding at the three properties which had flood complaints in the flood complaints extract provided. The model also predicted flooding in a number of locations in the Western Hills catchment, particularly in the west, where no flood complaints were received. This may be due to the following reasons:

- In the west part of the catchment, the rainfall from the Hutt River at Birch Lane was applied and the peak intensities measured at this gauge are much higher than at the Pinehaven gauge. This indicates large spatial variation in the rainfall, and the applied rainfall may be an overestimate of actual rainfall.
- The estimated return periods for the Birch Lane gauge for the durations relevant to the stormwater network exceed the likely design capacity of the stormwater network (refer to Table 9). In some locations, the model is predicting surcharging of the network and overland flow paths, which would be expected for a larger event. Some properties that are predicted to flood during the 14 May 2015 event with Birch Lane gauge rainfall, are not predicted to flood during the synthetic 10 year ARI design event.
- Peak rainfall occurred in the middle of a weekday. This is a mainly residential catchment so property flooding may not have been noticed or reported.
- Although some flood complaints were not recorded during this event, some of the areas overlap the general areas of inundation identified in the 2008 inundation mapping.

In the east part of the catchment, where the Pinehaven gauge rainfall was applied, there were no flood complaints received nor locations where flooding was predicted in the model.

During the validation, it was noted that some predicted ponding was occurring near inlets or pipes with assumed diameters (300 mm default conduit size). Online WWL GIS was reviewed, and it was found that some of these pipes now have diameters available. Pipes with default diameters, and where ponding was predicted, were checked against the WWL GIS. The pipe diameters in the model were updated where diameters where available in the GIS. Additionally, during these checks it was noted that upgrades have been carried out in some areas (e.g. on Kelso Grove) since the GIS data was originally provided by WWL for the catchment model build. These were not updated and the model reflects the SW network at the time the GIS data was provided.

Table 10: 14 May 2015 Event – Comparison of Modelled and Reported Flooding

	Location	Comment
Reported flooding reproduced in the model	280 Major Drive, Kelson	“Flooding within property” recorded in flood complaints extract. Model predicts flood depths of up to 0.25 m near house on the property.
	12 Gainsborough Grove	“Flooding inside garage/basement” recorded in flood complaints extract. Model predicts manhole to rear of #12 is surcharged and spilling. Ponding up to 0.15 m predicted near rear right side of the house.
	273 Grounsell Crescent	“Flooding within property” recorded in flood complaints extract. Inlet pipe near north boundary of #273 is surcharged and generating overland flow path over #273. Flood depths up to 0.8 m predicted near the right side and rear of the property.

Modelled flooding not reported	282-284 Grounsell Crescent	Flooding up to 0.3 m predicted and related to the overland flow path generated from #273 Grounsell Crescent (for which there was a flood complaint).
	2 Pomare Road	Flood depths up to 0.4 m on property, but confined to the gully adjacent to the house and likely not reported.
	249 Grounsell Crescent	Flood depths up to 0.9 m recorded adjacent to the house upstream of the 900 mm diameter inlet in the channel through the property. Flooding may not have reached house. The 900 mm inlet is not running full, however model updates were made to increase flow entering pipe as much as possible including removing culvert inlet (so no losses were modelled) and increasing the 2D element size at the inlet, and reducing upstream headlosses on the downstream pipe.
	259, 261, 250 and 258 Grounsell Crecent	Overland flow path from the gully upstream predicted to result in flood depths up to 0.6 m on properties on Grounsell Crescent. The predicted overland flow path does not intersect the inlet connected to the 900 mm diameter pipe. WWL to confirm the stormwater network layout and pipe sizes on site. This area was included in the 2008 inundation mapping.
	78 Owen Street	Model predicts surcharged pipe network on Owen Street, ponding in the carriageway and overland flow path across #78 Owen street. Ponding up to 0.8 m predicted in the rear yard of the property. Note that during the 10 year ARI event, there is only isolated ponding predicted at the back yard of the property.
	Properties on West side of Park Road, between Natusch Road and Redvers Drive	Model predicts 600 mm inlet on north side of Redvers Drive is surcharged and generating overland flow path down Park Road properties. Predicted flood depths are up to 0.2 m and larger flood depths in isolated locations due to low points in topography. Flooding may not have been significant enough to report.
	709-711 Western Hutt Road (Belmont School)	Model predicts extensive ponding on the school grounds for 14 May 2015 event due to surcharging of the network. Note there is no ponding on school grounds predicted during the 10 year ARI design event.
	Norfolk Street, Owen Street	Ponding up to 0.6 m predicted on properties and carriageway at the west end of Norfolk Street and to properties on the north side of Owen Street. This area was included in the 2008 inundation mapping.
	334-364 Hebden Crescent	Flood depths up to 0.3 m predicted in isolated locations in industrial yards. This area was included in the 2008 inundation mapping.

4.1.2.2. Overview of Flooding

As only three properties from the 14 May 2015 flood event fell in the catchment area, other data was used to further validate the model. An extract from the 2008 inundation map, overlapping the Western Hills catchment is shown in Figure 22 and Table 11. There are four areas within the Western Hills catchment as labelled in the figure.

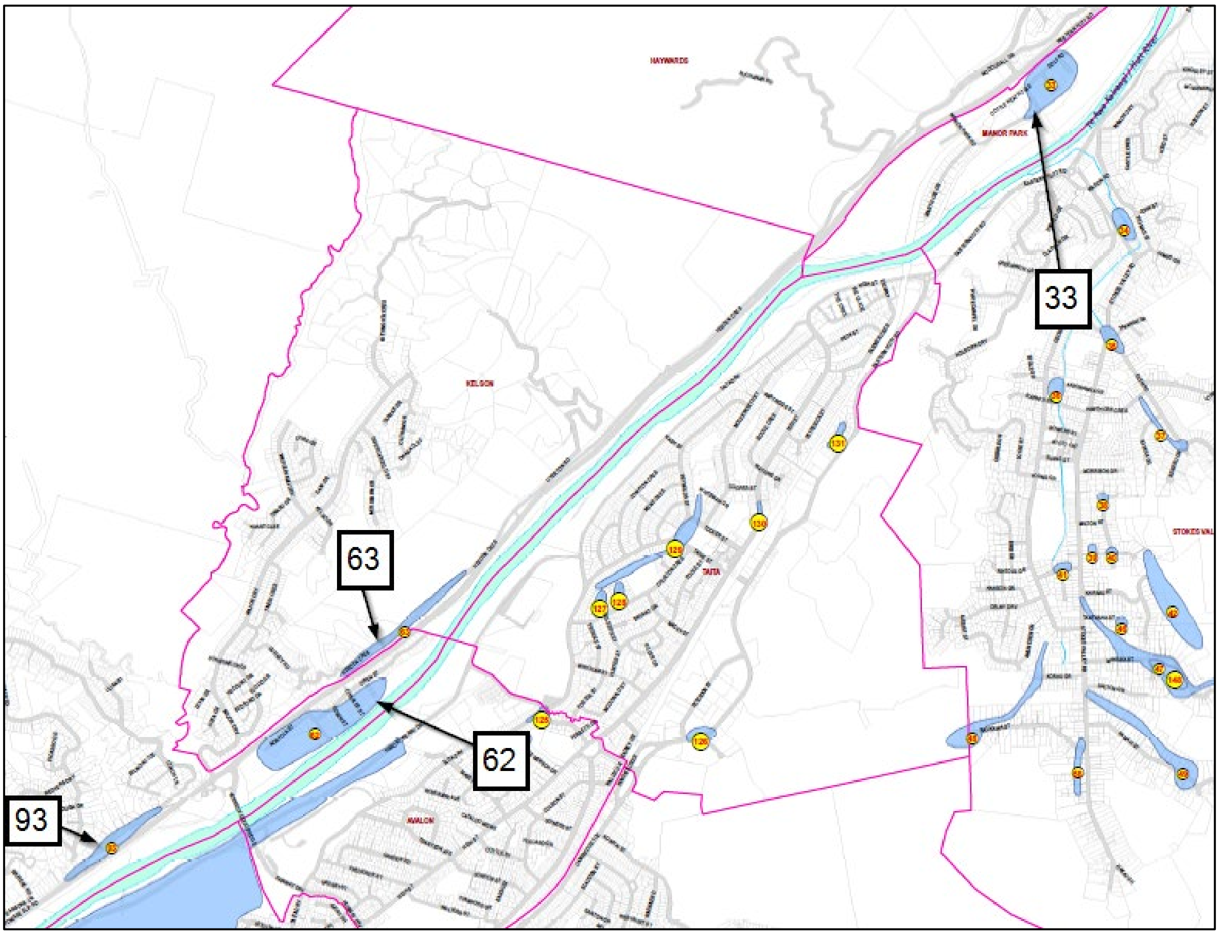


Figure 22 Extract from "Flood data – Inundation Areas Under Investigation, Hutt City" (Flood Maps HCC Stage 2 Feb 2008.pdf)

A comparison between the areas of inundation and the 10 year (historical rainfall) design event is summarised in Table 11 and detailed in Appendix A. In general, the areas of inundation mapped are consistent with model predictions, with isolated areas of flooding predicted in all four areas. More extensive flooding may have been due to blockage of large diameter inlets, or a higher Hutt River elevation.

Table 11: Comparison between 10 year ARI flood model results and Inundation mapping (Flood data – Inundation Areas Under Investigation, Hutt City" (Flood Maps HCC Stage 2 Feb 2008.pdf))

2008 Map Inundation Area	10 year ARI Flood Results Comments
93 – Grounsell Crescent	Flood depths up to 0.4 m predicted in isolated locations on properties between Grounsell Crecent and Western Hutt Road/SH2.
62 – Belmont Flat, Owen Street, Norfolk Street, Edwin & Charles Street	Ponding up to 0.4 m predicted on properties in Norfolk Street and Owen Street. No ponding predicted on Edwin Street, Charles Street and Richard Street. Observed inundations may have been due to higher Hutt River levels.
63 – Hebden Crescent	Isolated areas of minor ponding predicted on Hebden Crescent. More widespread observed flooding may have been due to blockage of 1050 mm diameter culvert inlet.
33 – Manor Park	Isolated areas of ponding up to 0.3 m predicted on properties and carriageways on Golf Road and York Avenue. More extensive inundation may have been due to a higher bed level or water level in the Hutt River.

4.1.3. Summary

The validation showed that predicted flooding in the Western Hills catchment can generally be explained by either flood complaints or past records of historical flooding (2008 inundation mapping). The rainfall used in the model for some areas for the validation event may be overestimating the actual rainfall because there is a large spatial rainfall variation between the two rain gauges used. This supports the over prediction of flooding in some areas. Minor differences in predicted and observed flood inundation is likely due to flood incidents not being reported, blockage in the pipe network or differences in Hutt River levels. The model is considered acceptable for use for the generation of District Plan flood hazard maps and may subsequently be used to assess options for upgrading the stormwater system to mitigate flooding in the catchment.

4.2. Sensitivity Analysis

To provide further confidence in the model, sensitivity runs were carried out to understand how the model predictions are affected by changes in model parameters and assumptions. The sensitivity scenarios were discussed and agreed with WWL. The scenarios have been chosen to test key model parameter and assumptions that may affect the predicted flood risk.

Five sensitivity scenarios completed are as follows:

- Sensitivity Scenario 1 - Extreme rainfall scenario
- Sensitivity Scenario 2 - Inlet blockage scenario
- Sensitivity Scenario 3 - Outlet blockage scenario
- Sensitivity Scenario 4 - Extreme Hutt River flow scenario
- Sensitivity Scenario 5 - Mean annual flow in Hutt River scenario

The 100 year ARI plus climate change rainfall event was used as the base case for comparison in the sensitivity analysis, and this rainfall event was used in all scenarios (except for the extreme rainfall scenario).

4.2.1. Sensitivity Scenario 1 - Extreme Rainfall Scenario

The rainfall intensity for the 100 year ARI plus climate change event was increased by 50% and the model run with this rainfall data. This is to test the response of the catchment in an extreme rainfall event and identify any new areas of flooding or overland flow paths. The results of this scenario were compared against the 100 year ARI plus climate change model run.

The difference in predicted flood depths between the extreme rainfall scenario and base 100 year ARI plus climate change event is shown in Figure B-1, Appendix B.

The results from the extreme rainfall event show a general increase in flood depths throughout the catchment and particularly along main drainage paths. Properties affected by increased flood depths are mainly those close to main drainage or overland flow paths and in the lower part of the catchment near the Hutt River. Increased flood risk locations and affected properties where flood depths are increased by more than 0.2 metres are listed below:

- Flood depths increased by up to 0.3 metres at 2 Pomare Street due to increased flow in the gully (refer Figure B-1, dark blue view).
- Flood depths increased by up to 1.1 metres at 2 Corrondella Grove due to increased flow in gully (refer Figure B-1, dark blue view). The predicted flooding appears to be confined to the gully and is not affecting the house.
- Isolated locations of increased flood depth to properties on Park Road, particularly to properties on the west side of the street and near the intersection with Redvers Drive. This also results in an increase in flood depth on properties on Grounsell Crescent (#259, #250, #258) where the overland flow path meets Western Hutt Road (refer Figure B-1, light blue view).
- Increased flow in the gully between Park Road and Hill Road results in up to 0.4 metre increase in flood depths at properties on Grounsell Crescent (#276, 282 and 284) (refer Figure B-1, light blue view).
- Increased flow in the overland flow path between Major Drive and Hill road results in increase in flood depths up to 0.5 metres to properties between Western Hutt Road and the Hutt River. This includes Belmont School, properties on Norfolk Street, and west end of Owen Street (refer Figure B-1, green view).
- Up to 0.6 metres increase in flood depths to industrial properties on the south side of Hebden Crecent (#300-330) and properties at the corner of Charles and Owen Streets (1 & 2 Charles Street, 34 Owen Street) (refer Figure B-1, pink view).
- Increased run-off in the east part of the catchment results in flood depth increases of up to 0.5 metres in the Manor Park suburb, particularly in the east including properties on Ford Road and Manor Park Private Hospital (refer Figure B-1, orange view).

4.2.2. Sensitivity Scenario 2 – Inlet Blockage Scenario

In this scenario, all inlets with a downstream pipe diameter of 450 mm or greater were blocked with a sediment depth of 80% of the conduit height. This 450 mm threshold resulted in 37 inlets being blocked.

The difference in predicted flood depths between the blocked inlet scenario and base 100 year ARI plus climate change event is shown in Figure B-2, Appendix B.

In general, this scenario resulted in isolated areas of increased flood depths near the blocked inlets. The following increases in predicted flood depths affected properties:

- Up to 0.2 metres at 2 Pomare Street (refer Figure B-2, dark blue view).
- Up to 1.1 metres at 2 Corrondella Grove (refer Figure B-2, dark blue view). The predicted flooding appears to be confined to the gully and not affecting the house.
- Up to 0.3 metres at corner of Western Hutt Road and Major Drive, including Belmont School (refer Figure B-2, green view).
- Up to 0.5 metres to industrial properties on the south side of Hebden Crecent (#300-322) (refer Figure B-2, pink view).
- Up to 0.4 metres to properties near the corner of Charles Street and Owen Street (1 & 2 Charles Street and 34 Owen Street) (refer Figure B-2, pink view).
- Up to 0.3 metres at 23 and 24 Owen Street (refer Figure B-2, pink view).
- Up to 0.1 metres on the north side of Owen Street (#1-15) (refer Figure B-2, pink view).
- Up to 0.1 metres on Norfolk Street, particularly properties on north and west sides (refer Figure B-2, green view).
- Up to 0.1 metres to properties near the intersection of Redvers Drive and Park Road (8 Redvers Drive, 1 Palm Grove and 72 Park Road) (refer Figure B-2, light blue view).

Flood risk in the Manor Park suburb is reduced due to reduced flows in the stormwater network as a result of upstream inlet blockages.

4.2.3. Sensitivity Scenario 3 – Outlet Blockage Scenario

In this scenario, all outlets with an upstream pipe diameter of 600 mm or greater were blocked with a sediment depth of 50% of the conduit height. The 600 mm threshold resulted in 27 outlets being blocked. 16 of these outlets discharge to the Hutt River.

The majority of the blocked outlets didn't significantly affect predicted flood depths upstream of the outlets, outside of the +/- 0.05 m tolerance. There are some isolated areas with predicted increases in peak flood depths. The increase in flood depths is generally less than 0.2 metres, with the exception of an area near 320 Hebden Crescent where predicted flood depths are about 0.3 metres greater. Part of the Manor Park suburb, between Manor Park Road and Cottle Heath Close / Golf Road has predicted flood depths up to 0.3 metres greater in the blocked outlet scenario. This was due to the blockage of the 1350 mm outfall to the Cottle Crescent / Manor Park Road open drain.

The difference in predicted flood depths between the blocked outlet scenario and base 100 year ARI plus climate change event is shown in Figure B-3, Appendix B.

4.2.4. Sensitivity Scenario 4 – Extreme Hutt River Scenario

In this scenario, the inflow in the Hutt River was increased to test the effect of Hutt River flow in predicted flooding in the catchment. For this scenario, an inflow of 1950 m^3/s was applied. This discharge was provided by WWL and corresponds to a 25 year ARI event with climate change at Taita Gorge. The inflow was applied in the model using a short ramp up, followed by a constant inflow.

The purpose of this sensitivity scenario is essentially to assess the level of increase in peak flood depths in the catchment if the Hutt River water levels are elevated. Note that water levels in the Hutt River were higher than the left bank elevation at some cross-sections in the downstream reaches.

This means flow was artificially contained within the Hutt River rather than spilling from the left bank and may result in slightly more conservative flood depths in the Western Hills catchment.

Increases in peak flood depths, outside the +/- 0.05 metres threshold are largely in isolated locations along the right bank of the Hutt River. There are only two locations where flood depths on properties are affected. Around 320 Hebden Crescent peak flood depths are predicted to increase by up to 0.12 metres, and at 2 Charles Street and 34 Owen Street peak flood depths are predicted to increase by up to 0.2 metres. Both increased flood depths are due to surcharge and spilling occurring in the local network. This means, the stormwater network is sensitive to the backwater elevation (water level in the Hutt River) and a cautionary approach should be applied.

The difference in predicted flood depths between the extreme Hutt River flow scenario and base 100 year ARI plus climate change event is shown in Figure B-4, Appendix B.

4.2.5. Sensitivity Scenario 5 – Mean Annual Flow in Hutt River

In this scenario, the mean annual flow in the Hutt River was applied as an inflow into the Hutt River. A discharge of 850 m^3/s was applied as an inflow in the model. This discharge was provided by WWL and corresponds to a 2 year ARI event at Taita Gorge. The inflow was applied in the model using a short ramp up, followed by a constant inflow.

The lower Hutt River flow didn't significantly affect predicted flood depths, outside of the +/- 0.05 metres tolerance. There are several locations along the right bank of the Hutt River where predicted flood depths have reduced by more than 0.05 metres. There are only two locations where predicted flood depths are higher in this scenario. At #320-322 Hebden Crescent flood depths are 0.2 metres higher, and at #77-79 Owen Street flood depths are up to 0.1 metres higher in the sensitivity scenario. The change in Hutt River levels appears to be changing the distribution of flow to different outfalls. This is resulting in a different split in overland flow which is causing more ponding at the two locations identified.

The difference in predicted flood depths between the mean annual flow scenario and base 100 year ARI plus climate change event is shown in Figure B-5, Appendix B.

4.2.6. Sensitivity Summary

The sensitivity analysis has confirmed that, except for specific localised areas in particular along main drainage channels, much of the peak flood levels predicted in the catchment are not significantly impacted by variations in the assumptions used in the base model. The sensitivity scenarios show that the catchment is most sensitive to rainfall intensity, while inlet blockages cause localised increases in flood depths only.

The sensitivity testing has identified some specific areas where a cautionary approach to managing the flood risk should be taken. These are mainly areas in the lower part of the catchment, on the right bank of the Hutt River and near inlets or outlets. Flood risk in the upper parts of the catchment was not found to be sensitive to assumptions in the model.

4.3. Validation and Sensitivity Summary

The Western Hills catchment stormwater model has been constructed to identify flood hazard zones for the Western Hills catchment. An important assumption in the model is that the network is fully operational. Operational issues such as blocked sumps and culverts, cracked pipes and obstructed outlets could increase flooding.

Limited information and data were available for the validation. The 14 May 2015 event was selected for the validation since there were some flood complaints received in the Western Hills catchment during this rainfall event. The model predicted flooding at all three properties where flood complaints were received. However, flooding was also predicted in additional areas and to properties which did not have recorded flood complaints. These may be due the significant spatial variation in rainfall seen in gauges used for this event.

The general patterns of inundation predicted by the model for the 10 year ARI design event was compared to an engineer's map showing inundation areas in the catchment. The general patterns of inundation predicted by the model agreed with the map.

Five sensitivity scenarios were run to check the sensitivity of the predicted flood depths to model inputs, assumptions in the model and operational issues such as blockages. The sensitivity testing showed that the assumptions in the model do not significantly affect the predicted flood risk. Areas which showed some sensitivity were concentrated in the lower part of the catchment closer to the banks of the Hutt River. In these areas, a cautionary approach is recommended in managing flood risk. The model is considered fit for its intended purpose.

5. Conclusion

The Western Hills stormwater catchment model build has been completed. All efforts have been made to ensure the model provides a good representation of the stormwater network, the ground model and hydraulic / hydrologic parameters.

The Western Hills stormwater model is considered fit for its intended purpose, which is to identify, map and manage flood hazards in the Western Hills catchment area. The model provides a detailed analysis of locations where surface flooding is a risk and a detailed understanding on the causes of this flooding in relation to network capacity and overland flow paths.

Where the model is to be used for detailed design of upgrades to the stormwater network, it is recommended that further site survey is undertaken around the area of interest. Such survey information will confirm any assumptions made in the stormwater network model and resolve any anomalies.

Appendices

Appendix A

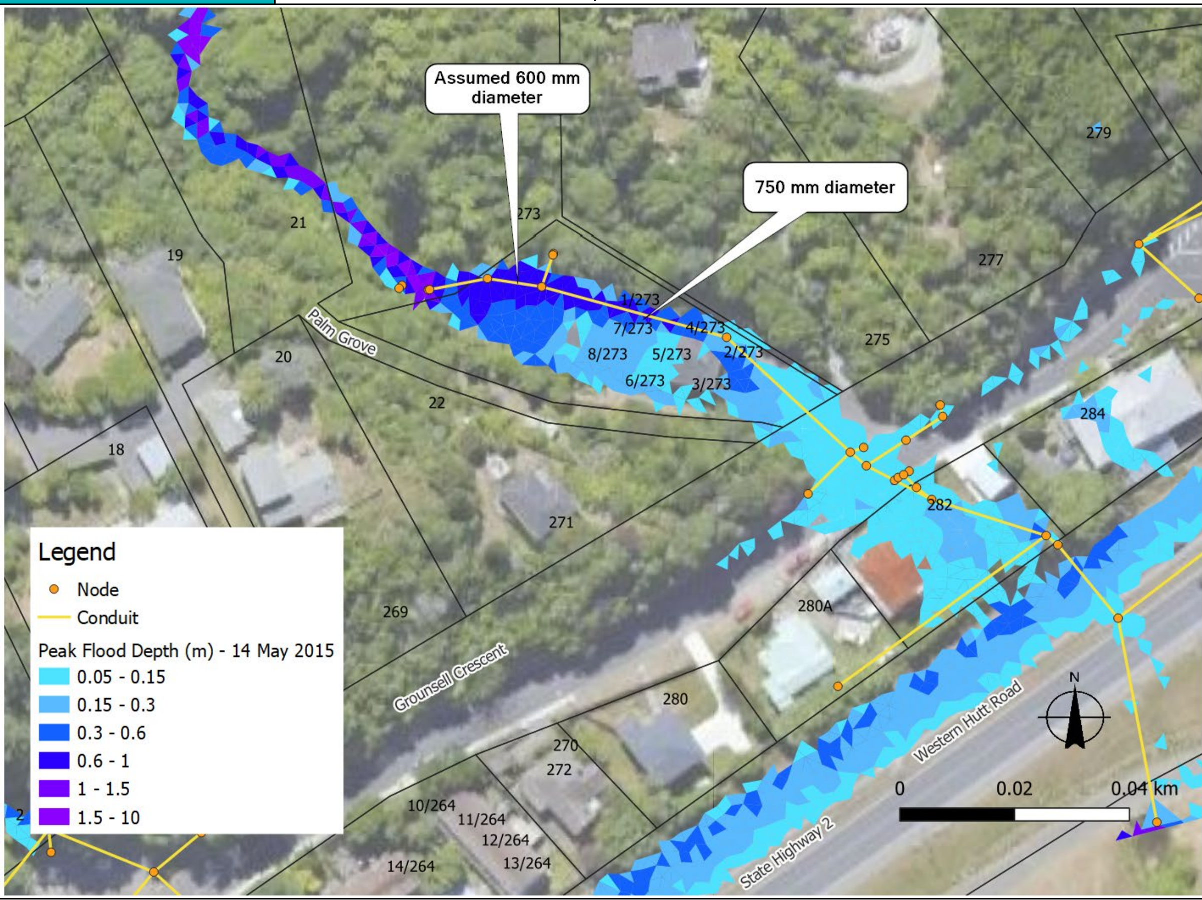
Validation Results

14 May 2015 Results

Reported Flooding that was reproduced in the model	
Affected properties	280 Major Drive, Kelson
Description of flooding from HCC Extract	Flooding within property
Description of flooding from model	Model predicts overland flow path through property to the north end of Major Drive. Flood depths of up to 0.3 m predicted near the house on the property.

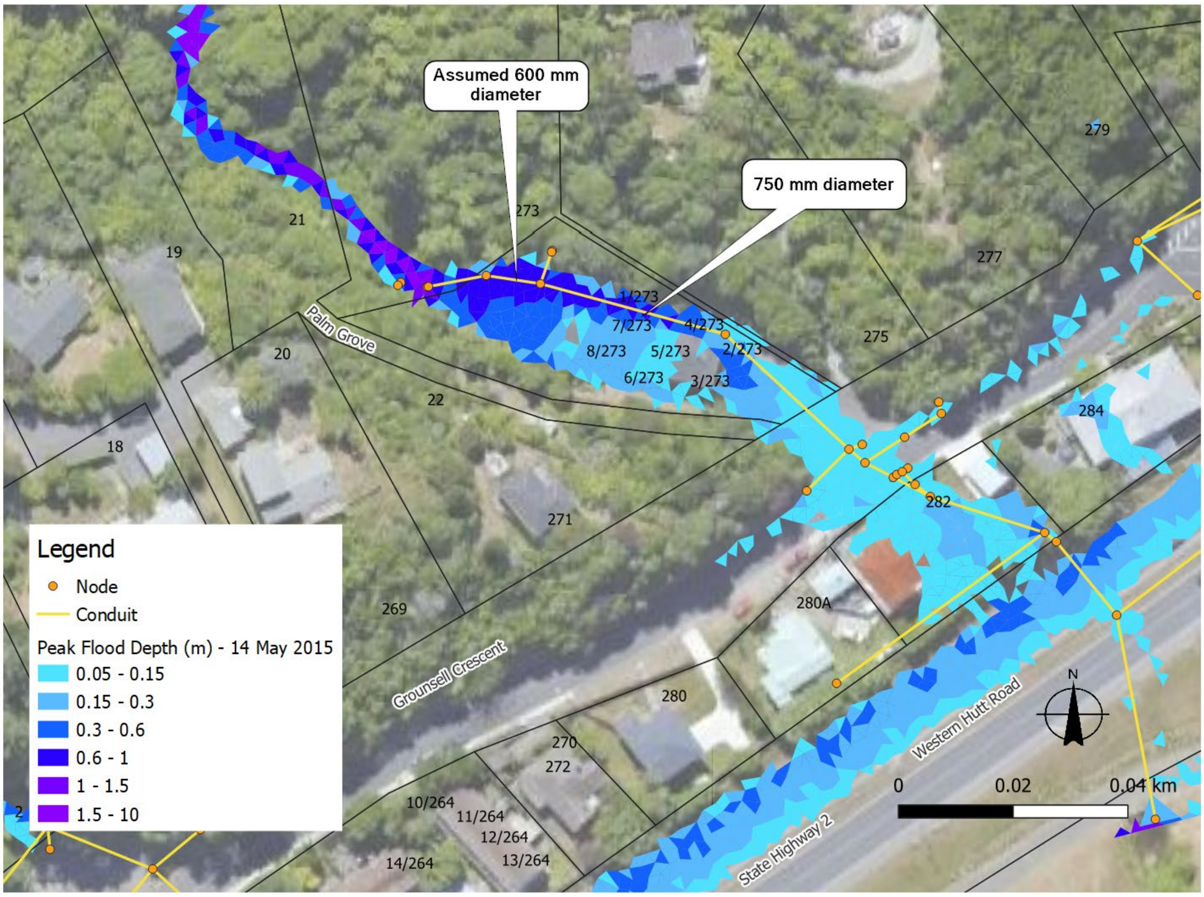
Reported Flooding that was reproduced in the model	
Affected properties	12 Gainsborough Grove
Description of flooding from HCC Extract	Flooding inside garage / basement
Description of flooding from model	Model predicts 225 mm diameter main from Redvers Drive to Gainsborough Grove is surcharged and spilling from the manhole to the rear of #12 Gainsborough Grove. Ponding up to 0.15 m predicted to rear right side of the house.

Reported Flooding that was reproduced in the model	
Affected properties	273 Grounsell Crescent
Description of flooding from HCC Extract	Flooding within property
Description of flooding from model	The 600 mm diameter inlet pipe is surcharged, and an overland flow path is predicted through the property to Grounsell Crescent. Flooding up to 0.8 m predicted on property, with peak depths occurring toward the right side and rear of the property. Note that the inlet pipe diameter was not available in the GIS and has been assumed to be 600 mm diameter (the *chamber dimension* on the inlet node is 600 mm in the GIS data).

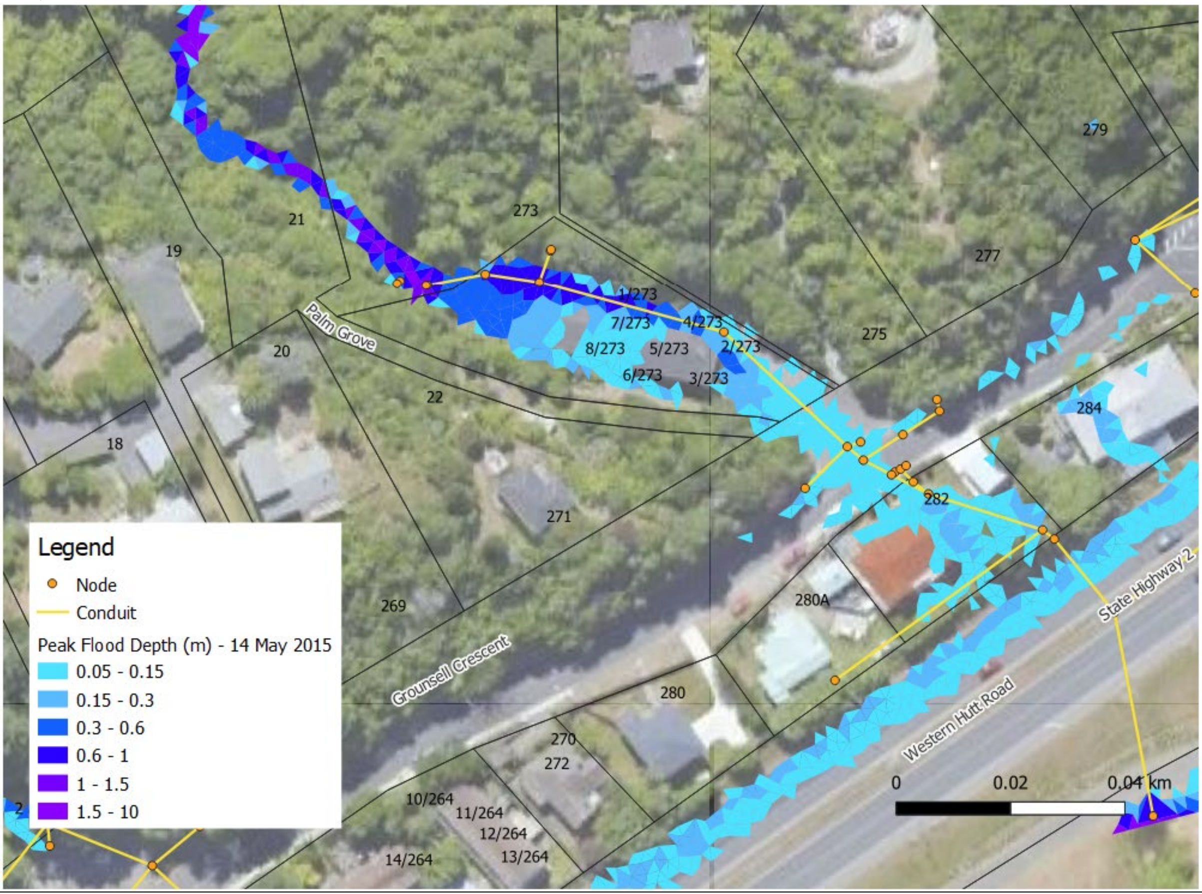


Flooding not reported but produced in the model	
Affected properties	282-284 Grounsell Crescent
Description of flooding from model	Flooding up to 0.3 m is predicted on #282, and isolated area of flooding up to 0.2 m on #284. The flooding is from the overland flow path from 273 Grounsell Crescent (for which there was a flood complaint). Birch Lane rainfall was applied in this area and may be overestimating actual rainfall (see section 4.1.1.2 in report). For comparison, in the 10 year ARI design event the model predicts only isolated spots of flooding up to 0.2 m and may not have been reported.

Peak flood depths for 14 May 2015 event using Birch Lane gauge rainfall



10 year ARI Design Event

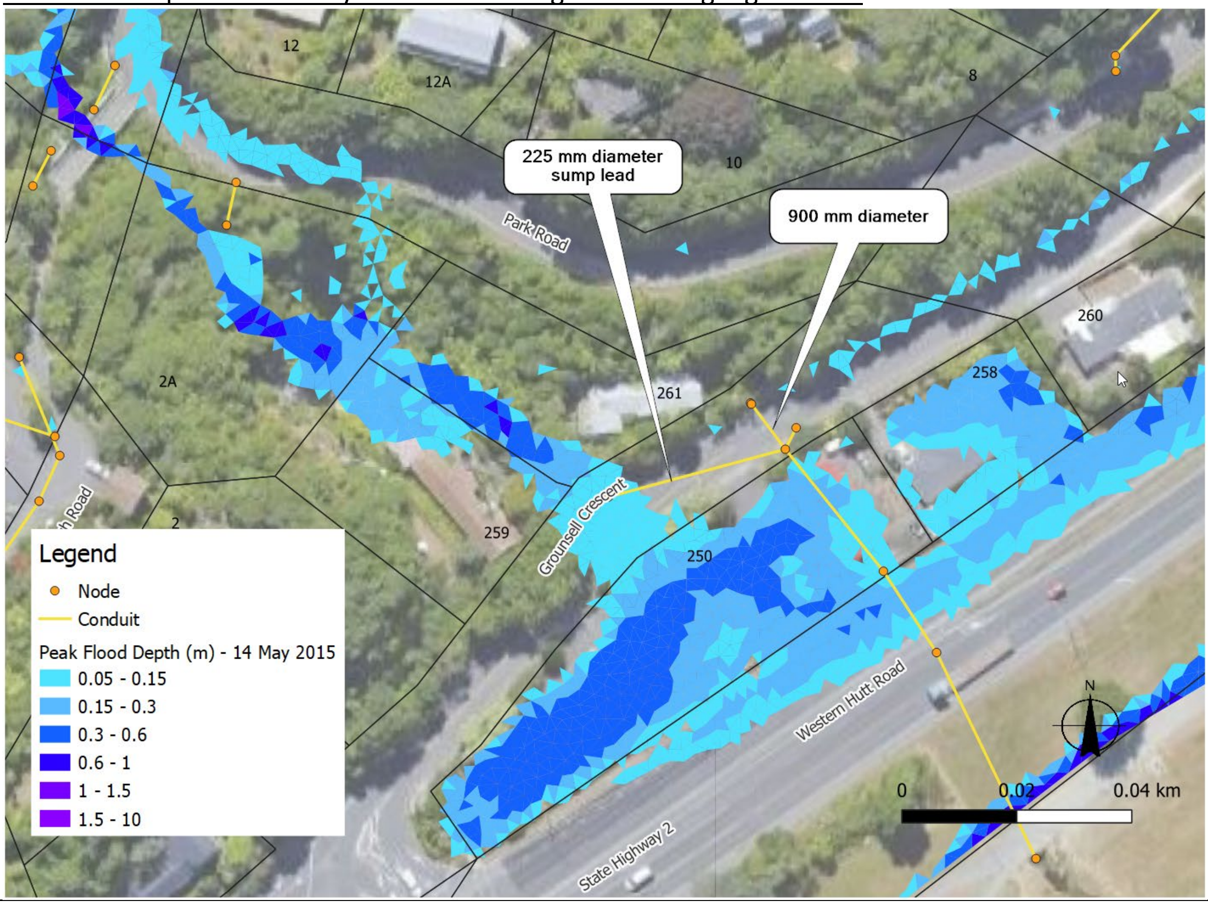


Flooding not reported but produced in the model	
Affected properties	2 Pomare Road
Description of flooding from model	Flood depths up to 0.4 m predicted along the left side of the house. The flooding is confined to the gully and does not appear to have reached the house and the size of the gully in the model may also be underestimated in the LiDAR due to vegetation. Flooding may not have been reported if the house was not affected.

Flooding not reported but produced in the model	
Affected properties	249 Grounsell Crescent
Description of flooding from model	Flood depths up to 0.9 m recorded adjacent to the house upstream of the 900 mm diameter inlet in the channel through the property. The 900 mm diameter pipe is not flowing full. Edits were made to reduce ponding and increase flow in the pipe. This included removing the culvert inlet to reduce headlosses and increasing the size of both the mesh zone for the inlet node and the shaft area of the node to increase flow from the 2D zone. Only minor flow limiting is predicted at the node and this is not expected to be the cause of the predicted ponding on the property. The flooding may not have been reported if the house was not affected. Birch Lane rainfall was also applied at this location and may have been an overestimate of actual rainfall at the site. This area is also heavily vegetated and there may be some inaccuracies in the LiDAR and where the flow paths are predicted to the inlet.

Flooding not reported but produced in the model	
Affected properties	259, 261, 250 and 258 Grounsell Crecent
Description of flooding from model	Overland flow path from the gully upstream predicted to result in flood depths up to 0.6 m on properties on Grounsell Crescent. The GIS shows a 900 mm diameter with an inlet in the kerb line on the north side of Grounsell Crecent. This does not intersect the predicted overland path at the site. The overland flow path is intercepted only by the 225 mm sump lead which is surcharged in the model. WWL to confirm the stormwater network layout and pipe sizes on site. This area was included in Area 93 – Grounsell Crescent in the 2008 inundation mapping.

Peak flood depths for 14 May 2015 event using Birch Lane gauge rainfall



Flooding not reported but produced in the model	
Affected properties	78 Owen Street
Description of flooding from model	Sump leads and outfall pipe from Owen Street are surcharged, causing ponding on the carriageway and then triggering an overland flowpath through 78 Owen Street to the Hutt River. Flood depths up to 0.8 m are predicted on the property to the rear of the house. Rainfall from the Birch Lane gauge was applied in this area and peak rainfall intensities for the 10-20 min duration were estimated to correspond to a 5-20 year ARI event, which likely exceeds the design capacity of the pipe network. The large spatial variation in rainfall during this event mean rainfall from the Birch Lane gauge may be overestimating actual rainfall for this catchment (see section 4.1.1.2 in report). Only one isolated location of ponding up to 0.3 m predicted at the rear of the property during the 10 year ARI design event and the flooding may not have been reported.

Peak flood depths for 14 May 2015 event using Birch Lane gauge rainfall

10 year ARI Design event

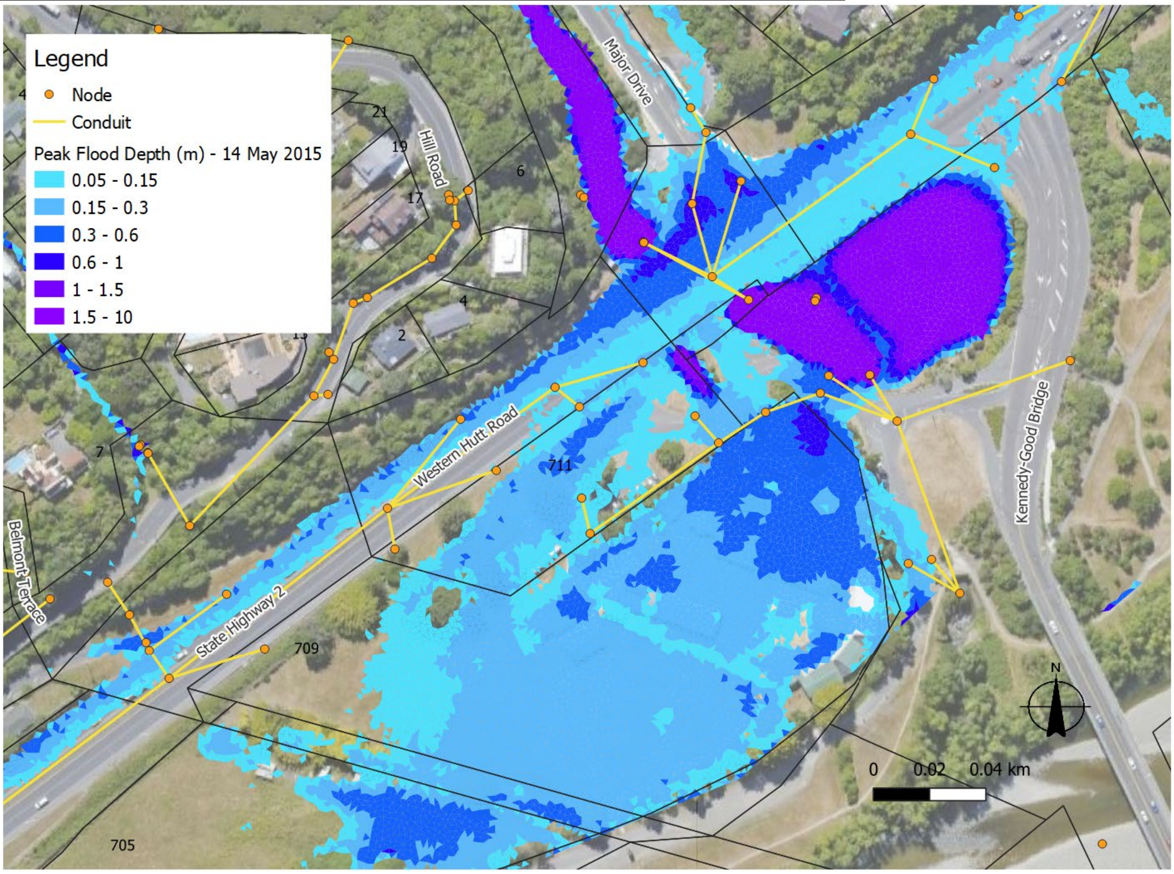
Flooding not reported but produced in the model	
Affected properties	Properties on West side of Park Road, between Natusch Road and Redvers Drive
Description of flooding from model	600 mm inlet is surcharged and the model predicts an overland flow path down Park Road. Properties on the west side of the street are lower than the carriageway elevation and flooding on these properties is predicted. Predicted flood depths are up to 0.2 m and larger isolated flood depths are predicted on #15 and #17 Park Road, and #2 and #4 Redvers Drive due to low points in the topography. This area is mainly residential and the peak rainfall occurred in the middle of a weekday. Therefore flooding may not have been reported. Measured rainfall from the Birch Lane gauge was applied here. The large spatial variation in rainfall during this event mean rainfall from the Birch Lane gauge may be overestimating actual rainfall (see section 4.1.1.2 in report). Comparison with the 10 year ARI event peak flood depths is also shown. During the 10 year ARI event, only isolated locations of flooding exceeding 0.15 m are predicteddue to low points in the topography.

Peak flood depths for 14 May 2015 event using Birch Lane gauge rainfall

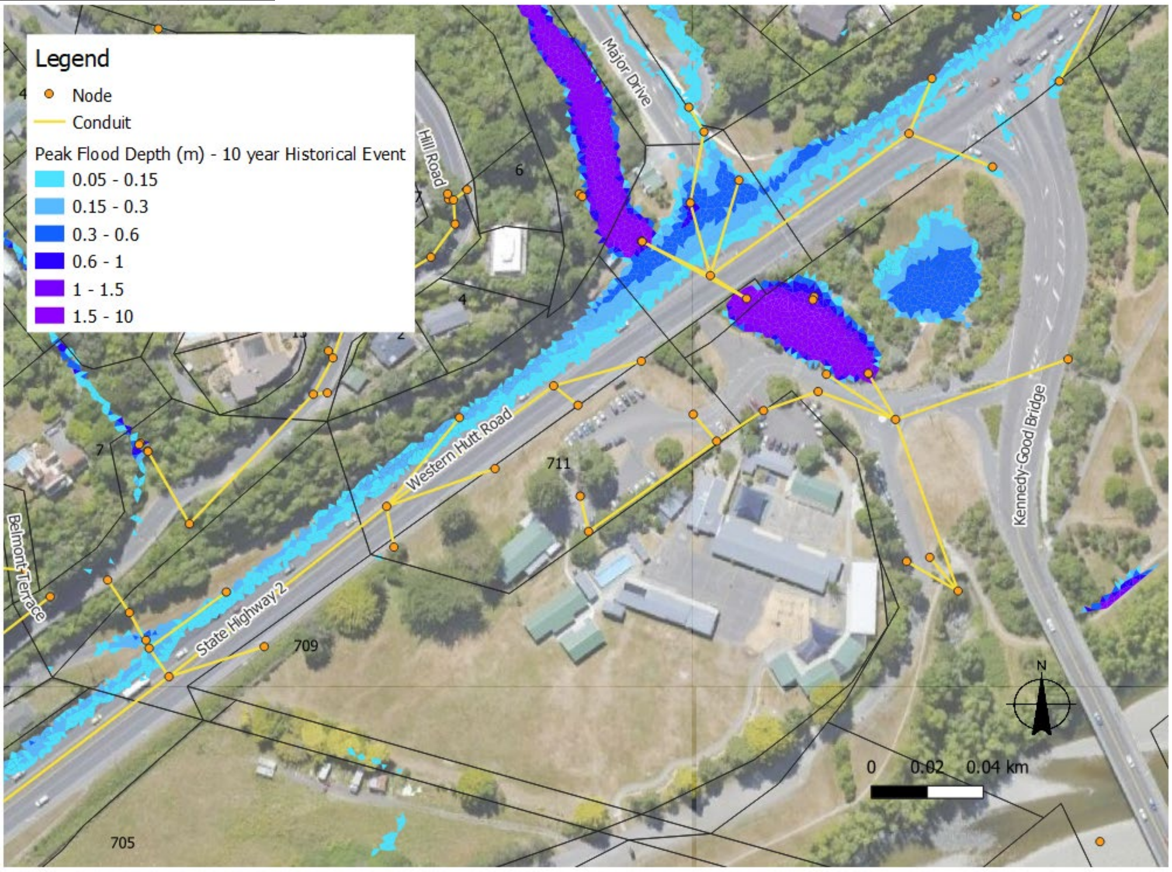
10 year ARI Design Event

Flooding not reported but produced in the model	
Affected properties	709-711 Western Hutt Road (Belmont School)
Description of flooding from model	Extensive ponding on the school grounds is predicted due to surcharging of the network. No flooding at the school is predicted during the 10 year ARI design event. This suggests the Birch Lane gauge rainfall is an overestimate of actual rainfall for this area. See comparison below.

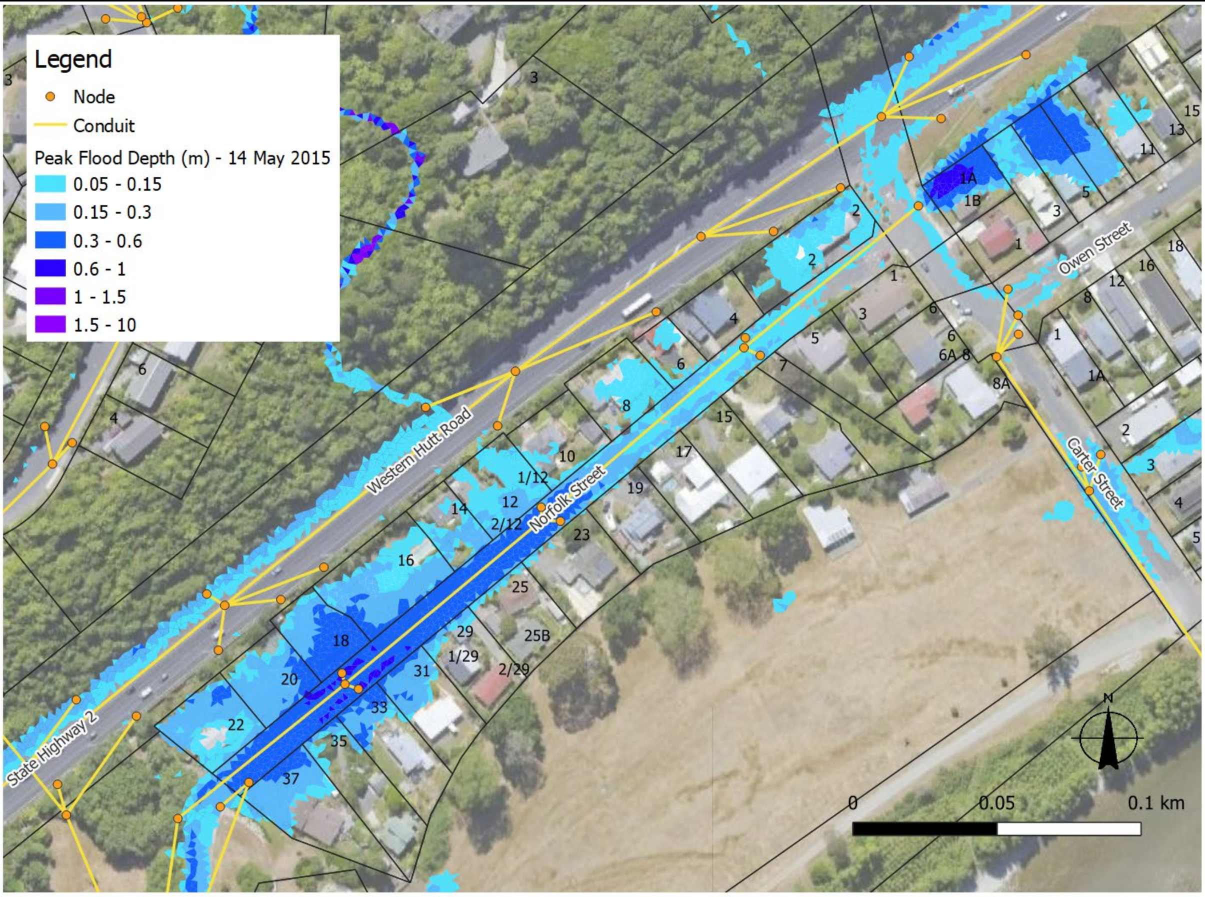
Peak flood depths for 14 May 2015 event using Birch Lane gauge rainfall



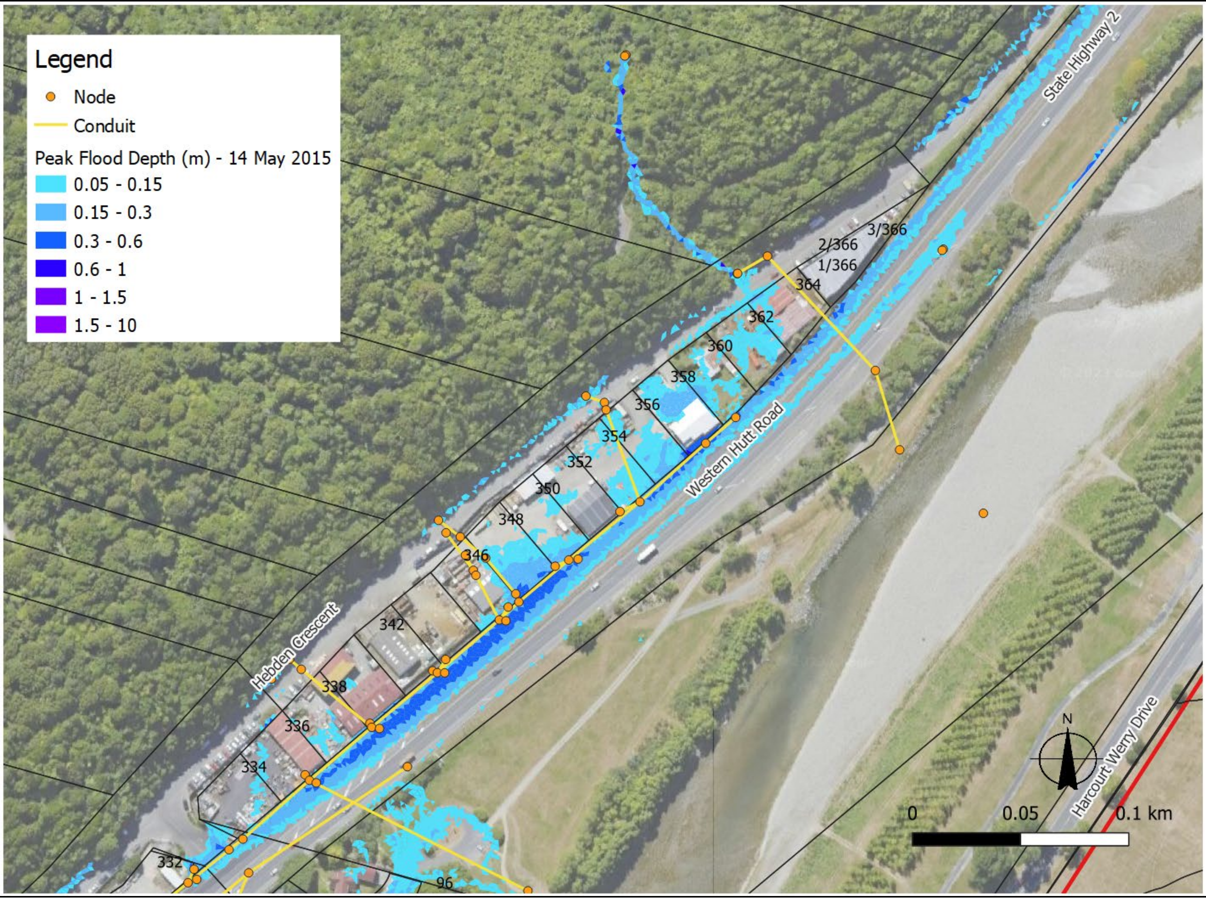
10 year ARI design event



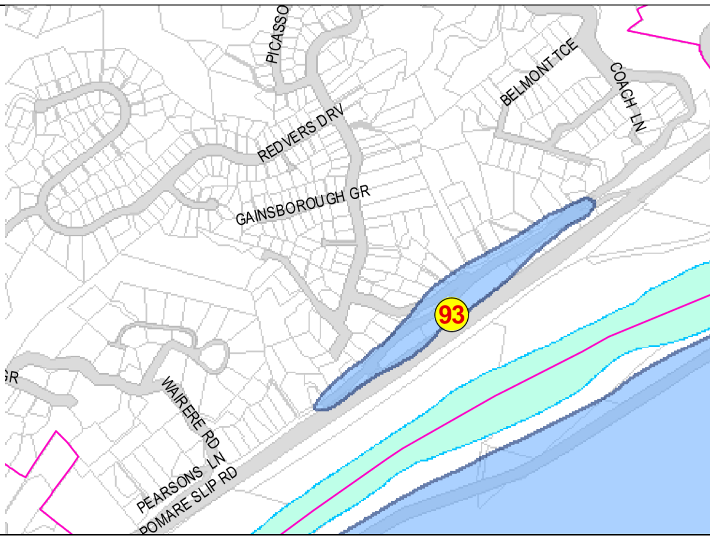
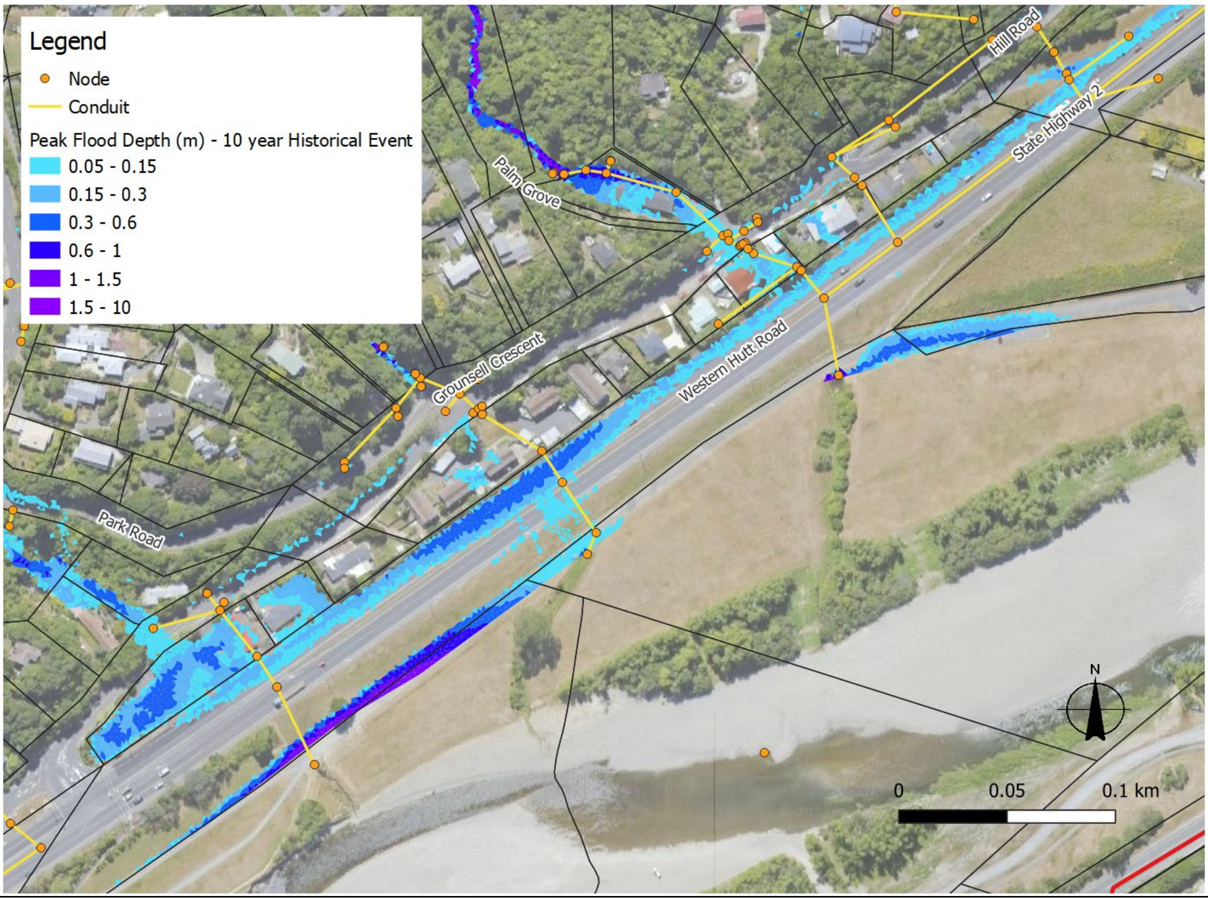
Flooding not reported but produced in the model	
Affected properties	Norfolk Street, Owen Street
Description of flooding from model	Ponding up to 0.6 m predicted on properties and carriageway at the west end of Norfolk Street and to properties on the north side of Owen Street. Although there were no property-specific flood complaints during this event, this area is included in the 2008 inundation mapping (area 62- Belmont Flat, Owen Street, Edwin & Charles Street).



Flooding not reported but produced in the model	
Affected properties	334-364 Hebden Crescent
Description of flooding from model	Flood depths up to 0.3 m predicted in isolated locations in industrial yards. The flooding appears to be confined to the yards and therefore may not have been reported. Note also that this area was included in Area 63 – Hebden Crescent in the 2008 inundation mapping.



10 year ARI Results – Comparison to 2008 Inundation map

<table>
<tr><th colspan="2">Historic Flooding and 10 year ARI Results</th></tr>
<tr><td>Area</td><td>93 – Grounsell Crescent</td></tr>
<tr><td>Summary of Inundation area</td><td>
</td></tr>
<tr><td>Description of flooding from model for 10 year ARI event</td><td>Flood depths up to 0.4 m predicted by the model on properties between Grounsell Crecent and Western Hutt Road/SH2. Flooding due to surcharging of inlets and generation of overland flow paths.
WWL to confirm the stormwater network layout and pipe sizes adjacent to 250 Grounsell Crescent.</td></tr>
<tr><td colspan="2">
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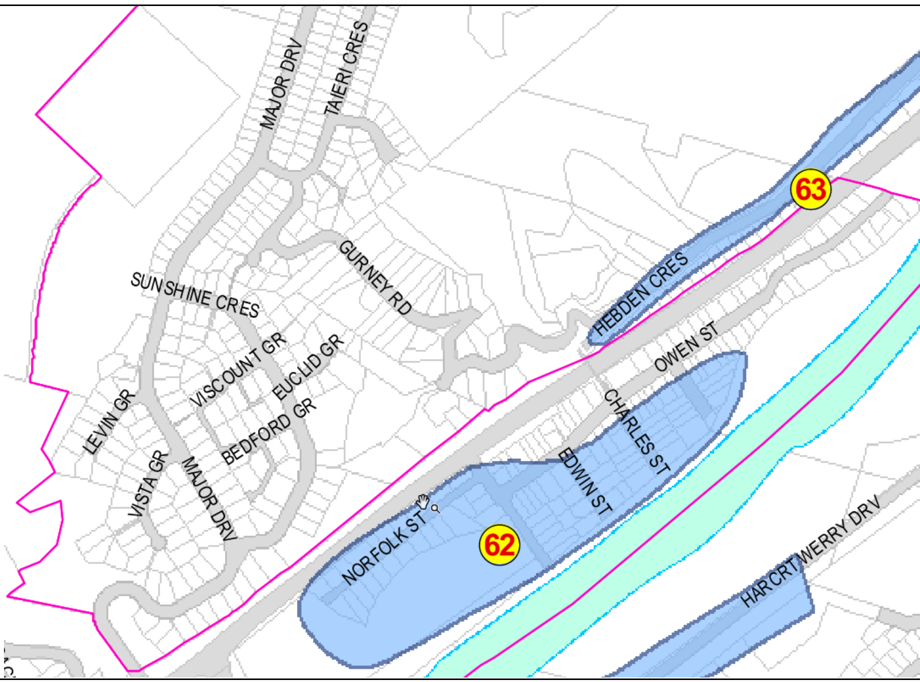
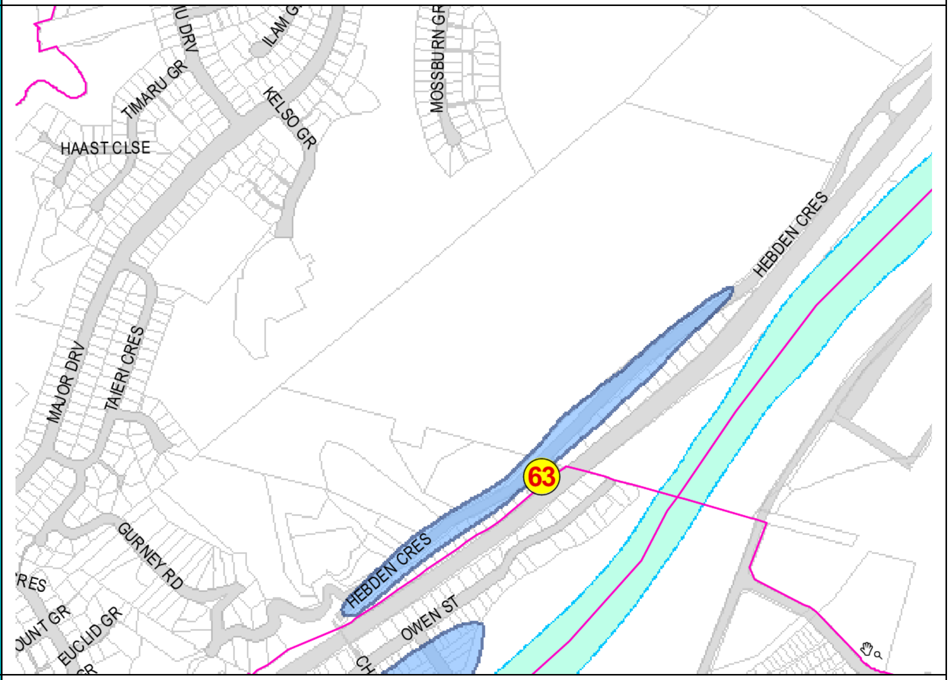
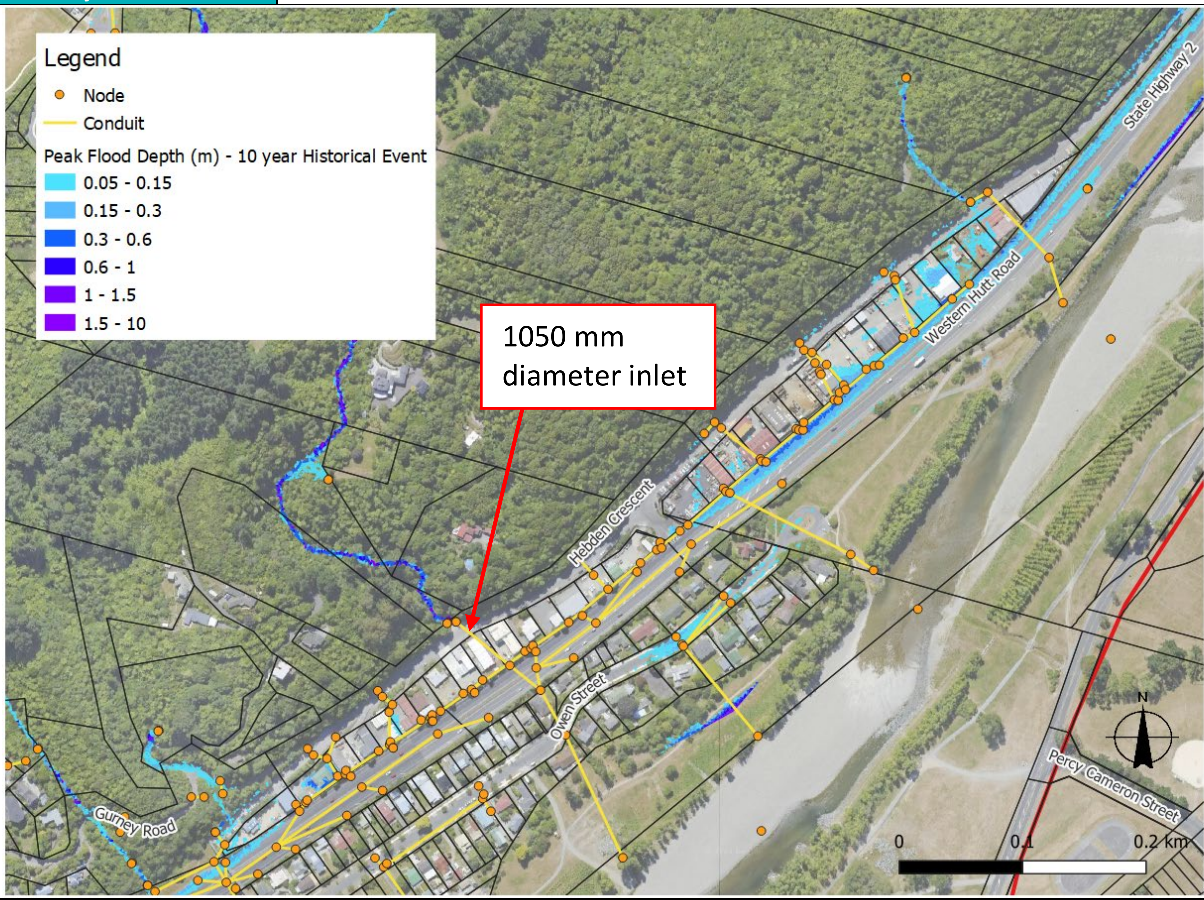
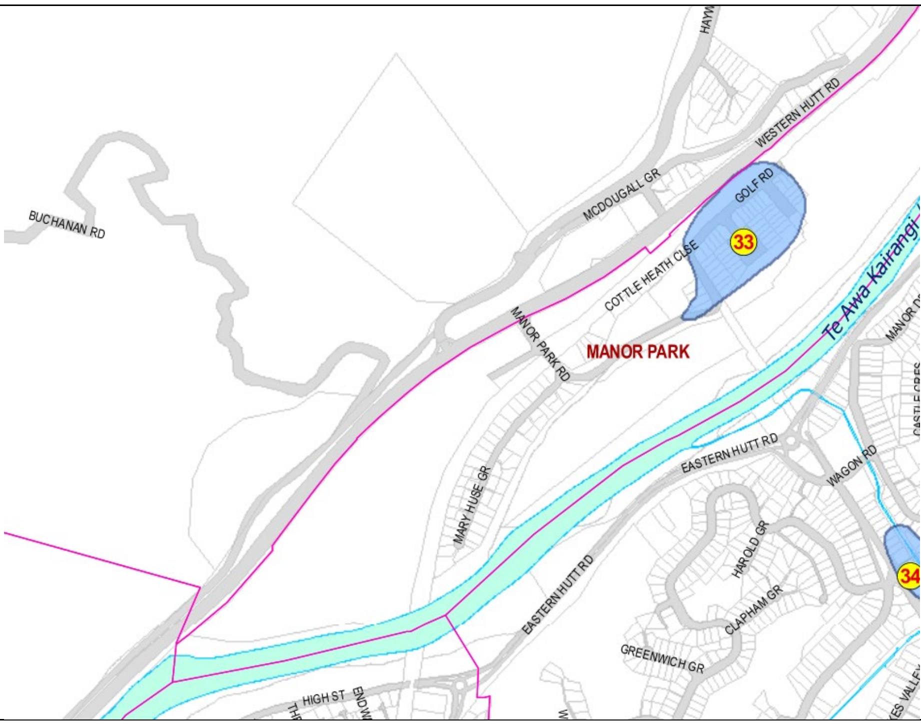
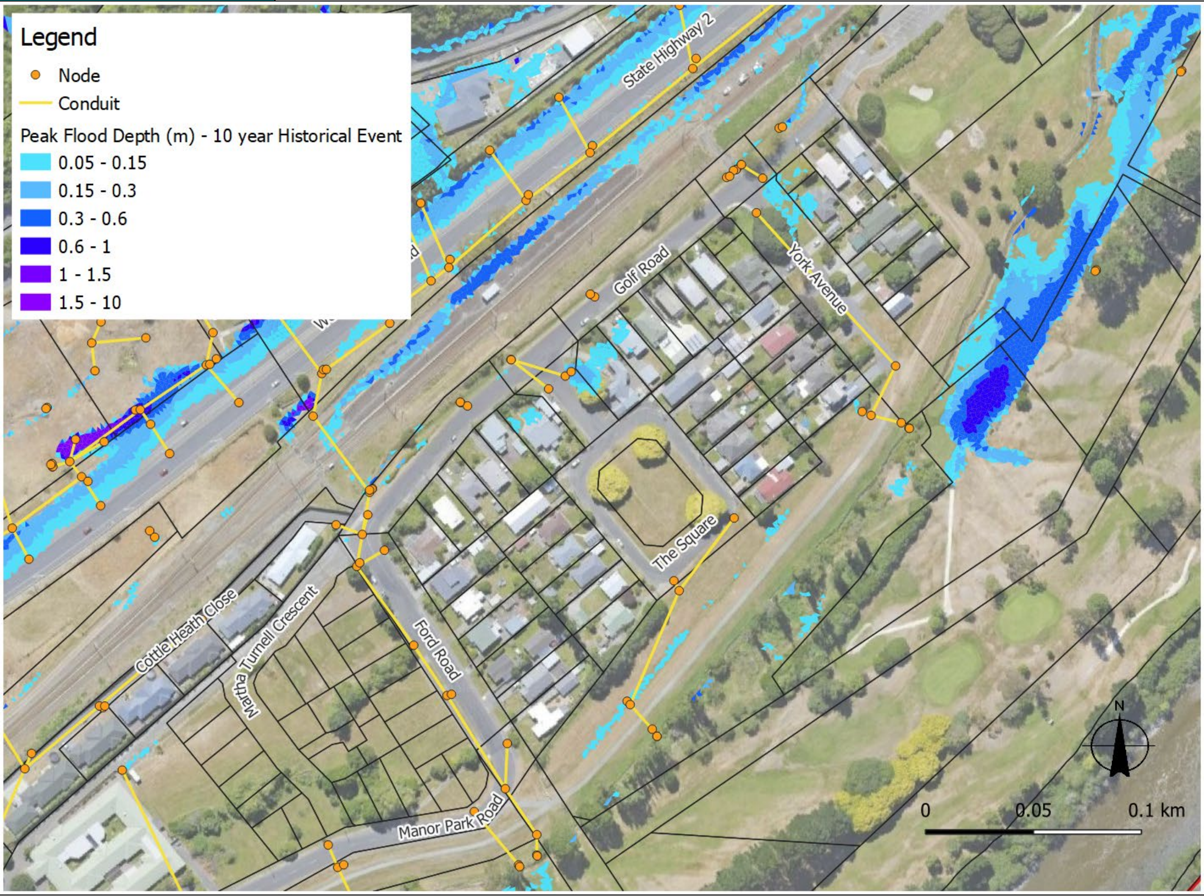
<table>
<tr><th colspan="2">Historic Flooding and 10 year ARI Results</th></tr>
<tr><td>Area</td><td>62 – Belmont Flat, Owen Street, Norfolk Street, Edwin & Charles Street</td></tr>
<tr><td>Summary of Inundation area</td><td>
</td></tr>
<tr><td>Description of flooding from model for 10 year ARI event</td><td>Ponding up to 0.4 m predicted on properties in Norfolk Street and Owen Street. No ponding predicted on Edwin Street, Charles Street and Richard Street. Observed inundations may have been due to higher Hutt River Levels.</td></tr>
<tr><td colspan="2">
</td></tr>
</table>

Historic Flooding and 10 year ARI Results	
Area	63 – Hebden Crescent
Summary of Inundation area	
Description of flooding from model for 10 year ARI event	Isolated areas of minor ponding predicted on Hebden Crescent. Recorded flooding may be due to blockage of 1050 mm diameter culvert inlet.

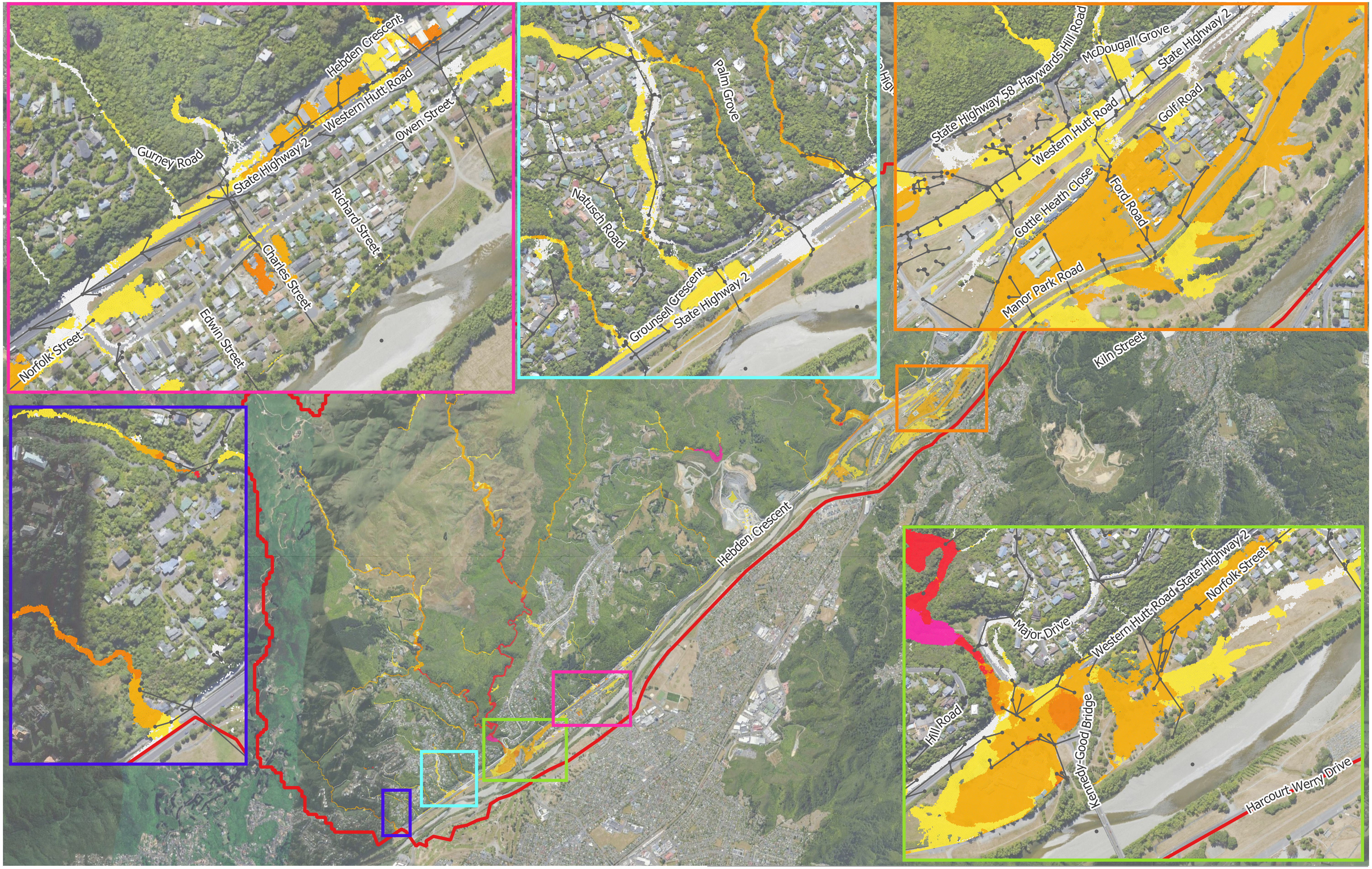


Historic Flooding and 10 year ARI Results	
Area	33 – Manor Park
Summary of Inundation area	
Description of flooding from model for 10 year ARI event	Areas of ponding up to 0.3 m predicted on properties and carriageways on Golf Road and York Avenue. More extensive inundation may have been due to a higher bed level or higher water levels in the Hutt River.



Appendix B

Sensitivity Analysis Results



Legend

Difference in Peak Flood Depth (m) (Scenario - Base)

- < -0.05
- -0.05 - 0.05
- 0.05 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0
- Western Hills Catchment Boundary
- Conduit
- Node

Paper Size ISO A3

Map Projection: Mercator Auxiliary Sphere
Horizontal Datum: WGS 1984
Grid: WGS 1984 Web Mercator Auxillary Sphere

N

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Wellington Water Limited
Western Hills Stormwater Catchment Modelling

Sensitivity Scenario 1
Extreme Rainfall Scenario
Difference in Flood Depth

Project No. **12556744**
Revision No. **A**
Date. **15/06/2023**

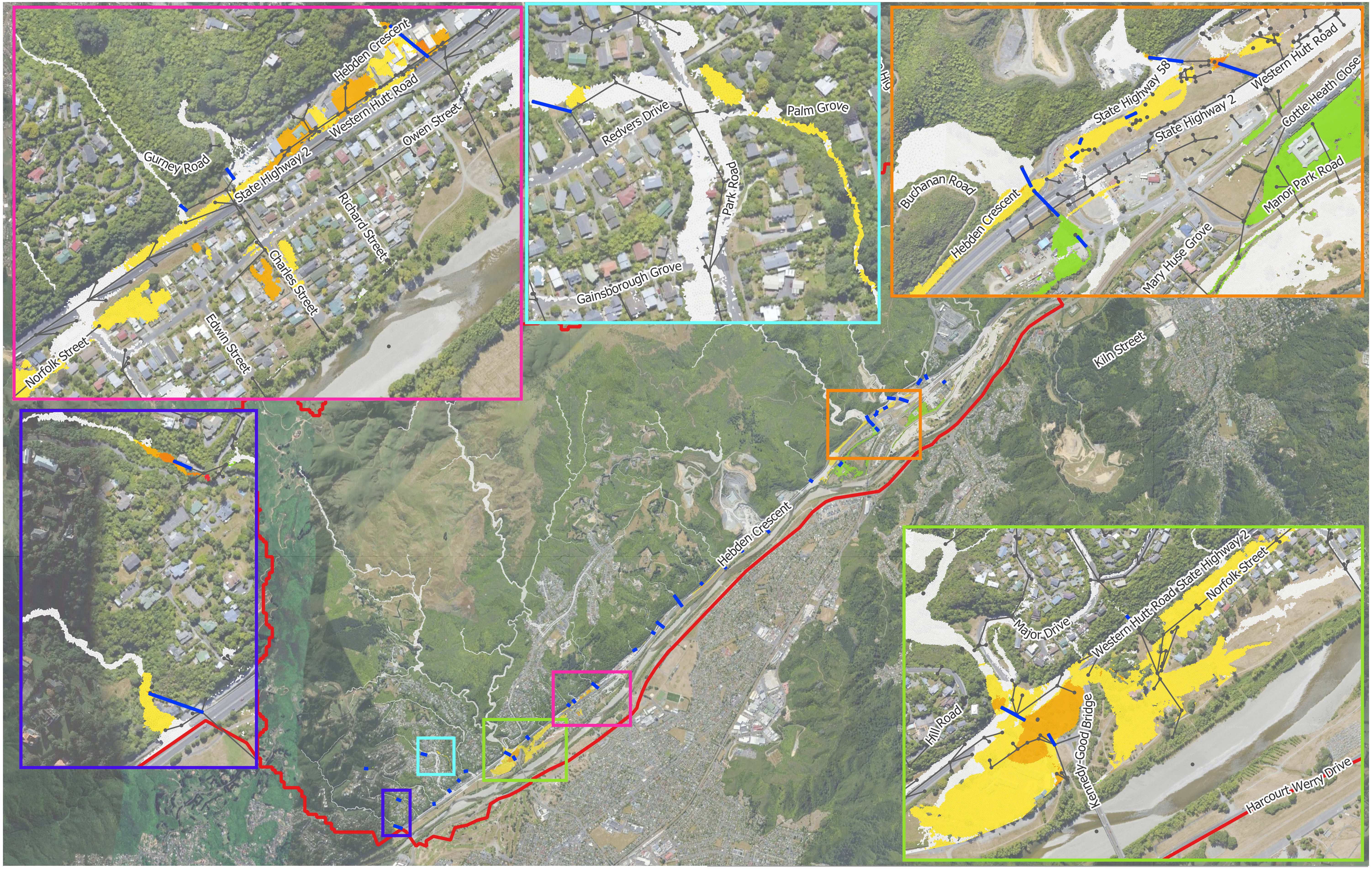
FIGURE B-1

Data Source:

Document Path: \\ghdnet\ghd\NZ\Wellington\Projects\51\12556744\GIS\Maps\Deliverables\Western Hills\AppendixB-Sensitivity\FIGB1_SensitivityScen1_ExtremeRainfall.qgz

Print Date: 2023-06-16

Created By: Claire Murray



Legend

Western Hills Catchment Boundary
Conduit
Node

Blocked Inlet
Blocked Inlet

Difference in Peak Flood Depth (m) (Scenario - Base)
<-0.05
-0.05 - 0.05
0.05 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0

Paper Size ISO A3

Map Projection: Mercator Auxiliary Sphere
Horizontal Datum: WGS 1984
Grid: WGS 1984 Web Mercator Auxillary Sphere

N

GHD

Wellington Water Limited
Western Hills Stormwater Catchment Modelling

Sensitivity Scenario 2
Inlet Blockage Scenario
Difference in Flood Depth

Project No. **12556744**
Revision No. **A**
Date. **15/06/2023**

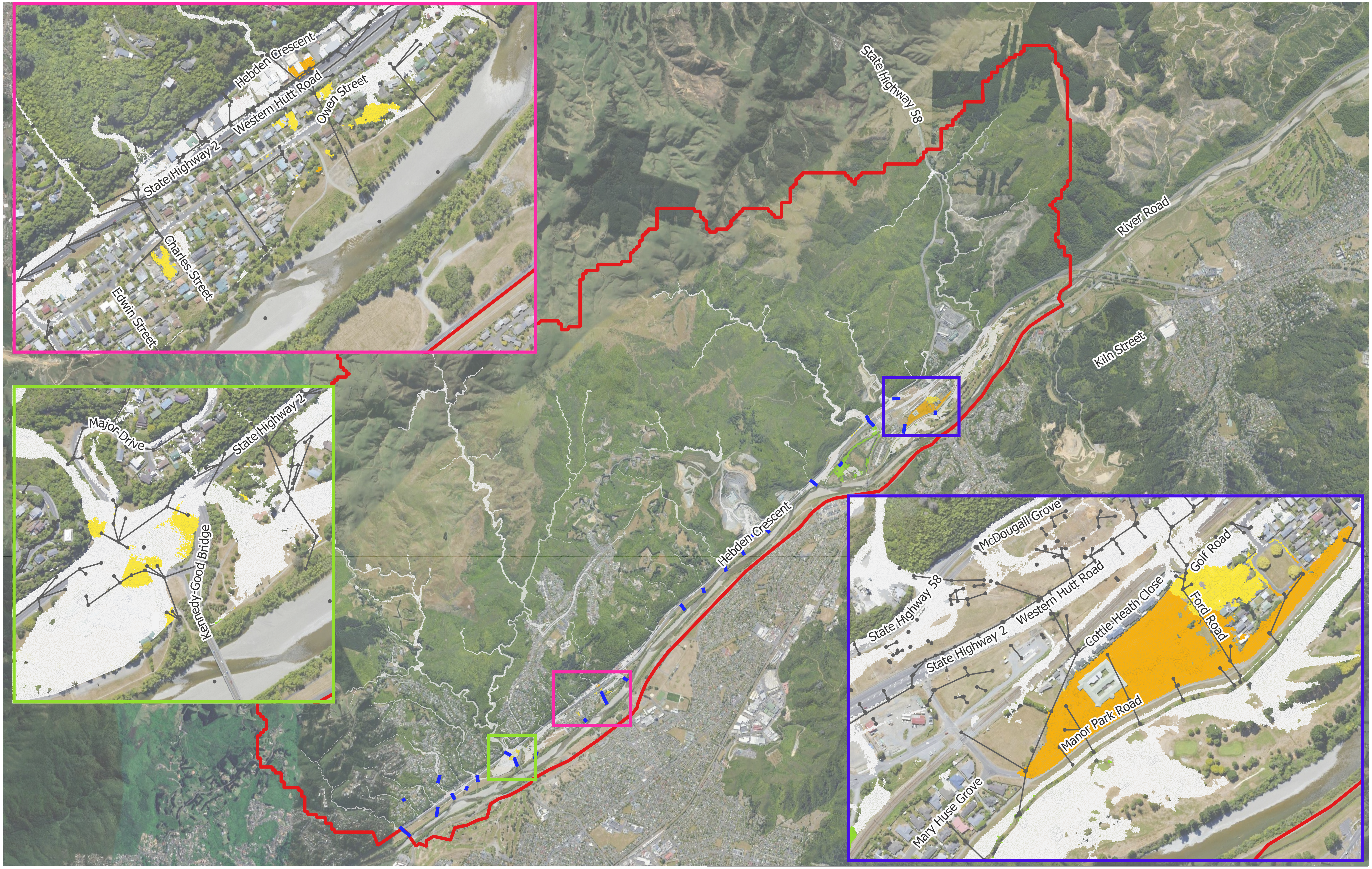
FIGURE B-2

Document Path: \\ghdnet\ghd\NZ\Wellington\Projects\51\12556744\GIS\Maps\Deliverables\Western Hills\AppendixB-Sensitivity\FIGB2_SensitivityScen2_BlockedCulverts.qgz

Print Date: 2023-06-28

Data Source:

Created By: Claire Murray



Legend

- Western Hills Catchment Boundary
- Conduit
- Node

Blocked Outlets

- Blocked Outlet

Difference in Peak Flood Depth (m) (Scenario - Base)

- <-0.05
- -0.05 - 0.05
- 0.05 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Paper Size ISO A3

Map Projection: Mercator Auxiliary Sphere
Horizontal Datum: WGS 1984
Grid: WGS 1984 Web Mercator Auxillary Sphere

N

Wellington Water Limited
Western Hills Stormwater Catchment Modelling

Sensitivity Scenario 3
Outlet Blockage Scenario
Difference in Flood Depth

Project No. **12556744**
Revision No. **A**
Date. **15/06/2023**

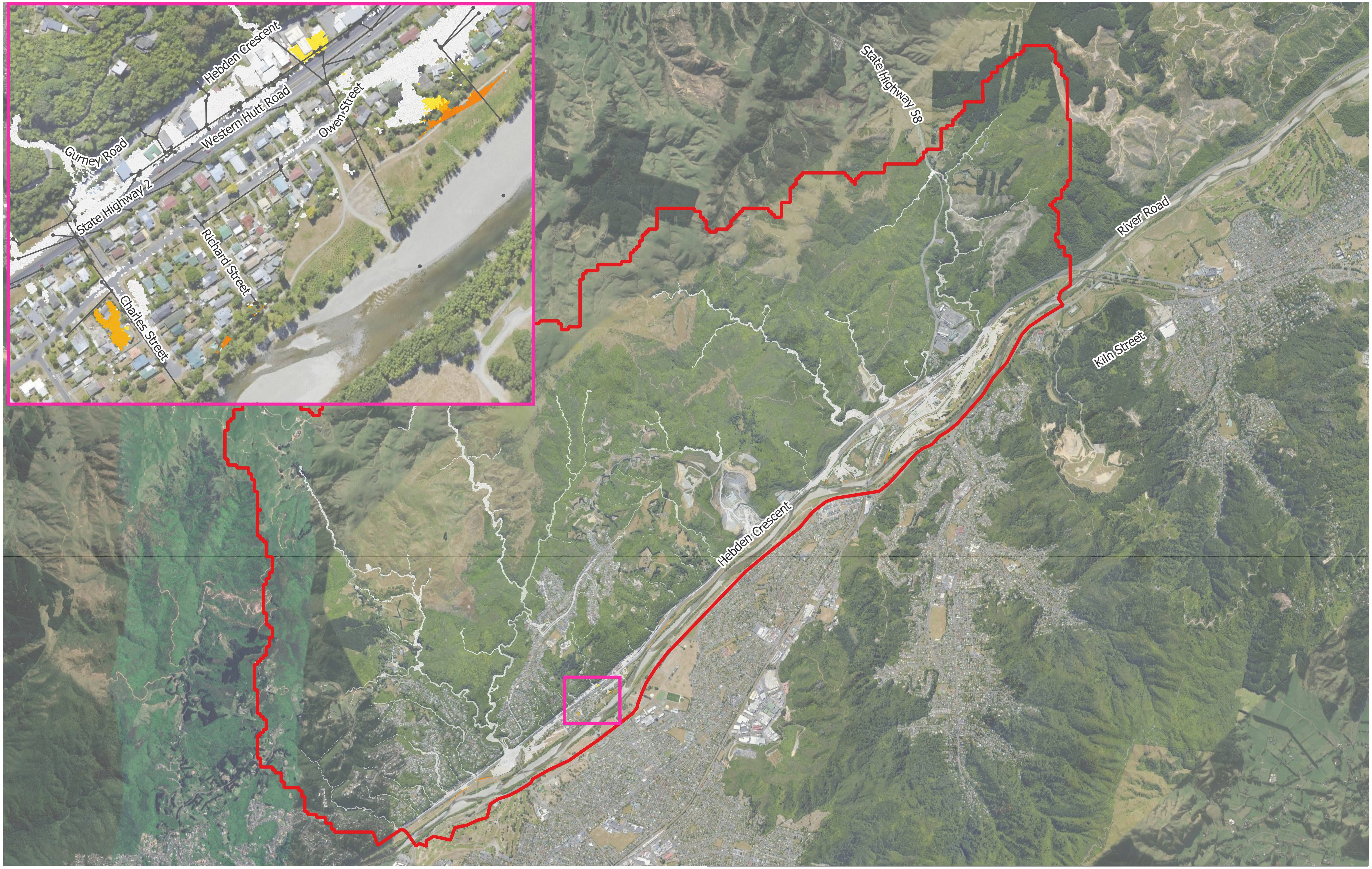
FIGURE B-3

Data Source:

Created By: Claire Murray

Document Path: \\ghdnet\ghd\NZ\Wellington\Projects\51\12556744\GIS\Maps\Deliverables\Western Hills\AppendixB-Sensitivity\FIGB3_SensitivityScen3_BlockedOutlets.qgz

Print Date: 2023-06-28



Legend

Difference in Peak Flood Depth (m) (Scenario - Base)

- <-0.05
- -0.05 - 0.05
- 0.05 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0
- Western Hills Catchment Boundary
- Conduit
- Node

Paper Size ISO A3

Map Projection: Mercator Auxiliary Sphere
Horizontal Datum: WGS 1984
Grid: WGS 1984 Web Mercator Auxillary Sphere

Wellington Water Limited
Western Hills Stormwater Catchment Modelling

Sensitivity Scenario 4
Extreme Hutt River Flow
Difference in Flood Depth

Project No. 12556744
Revision No. A
Date. 15/06/2023

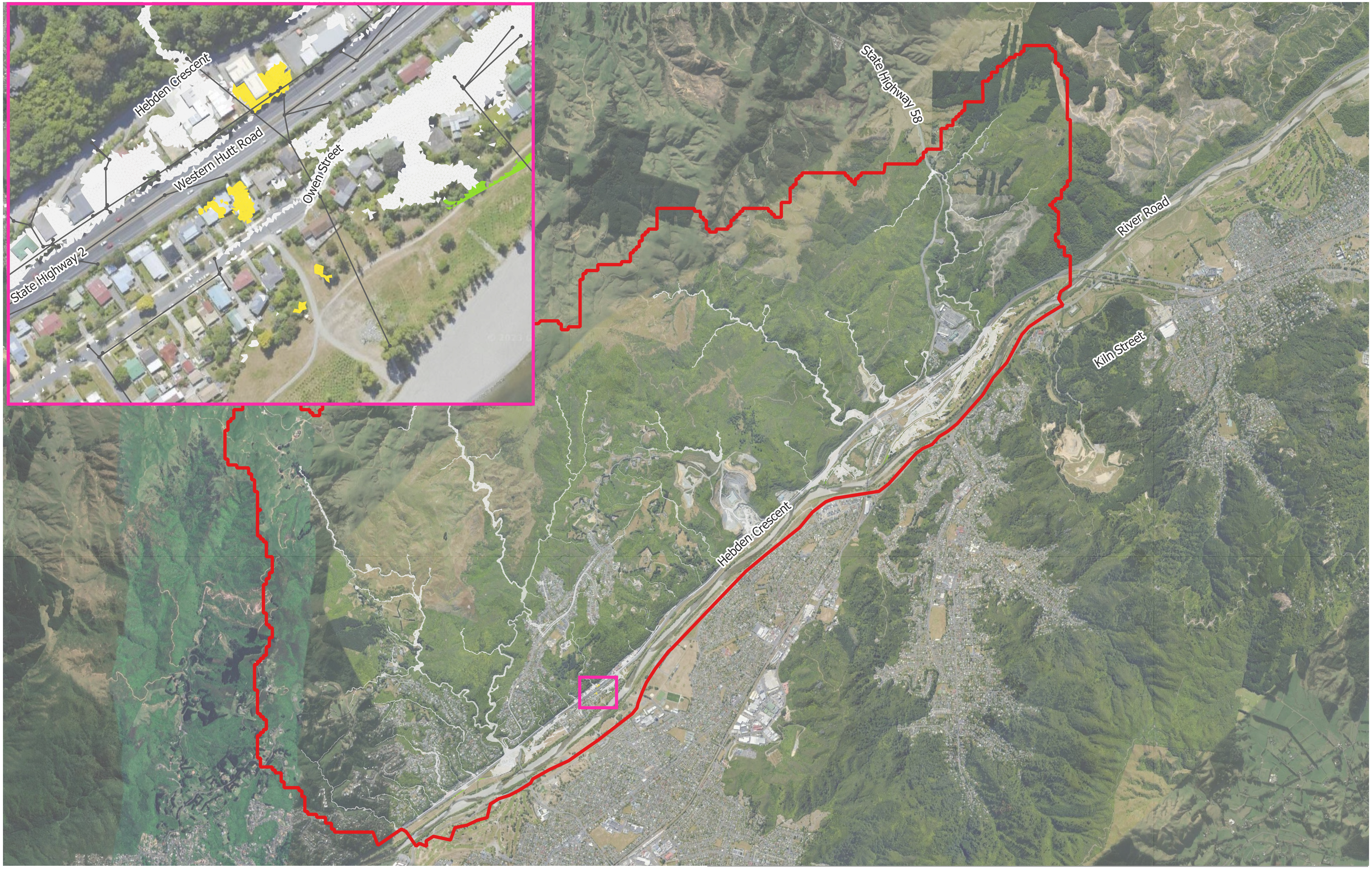
FIGURE B-4

Document Path: \\ghdnet\ghd\NZ\Wellington\Projects\51\12556744\GIS\Maps\Deliverables\Western Hills\AppendixB-Sensitivity\FIGB4_SensitivityScen4_ExtremeHuttRiverFlow.qgz

Print Date: 2023-06-15

Data Source:

Created By: Claire Murray



Legend

Difference in Peak Flood Depth (m) (Scenario - Base)

- < -0.05
- -0.05 - 0.05
- 0.05 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0
- Western Hills Catchment Boundary
- Conduit
- Node

Paper Size ISO A3

Map Projection: Mercator Auxiliary Sphere
Horizontal Datum: WGS 1984
Grid: WGS 1984 Web Mercator Auxillary Sphere

N

Wellington Water Limited
Western Hills Stormwater Catchment Modelling

Sensitivity Scenario 5
Mean Annual Hutt River Flow
Difference in Flood Depth

Project No. **12556744**
Revision No. **A**
Date. **15/06/2023**

FIGURE B-5

Document Path: \\ghdnet\ghd\NZ\Wellington\Projects\51\12556744\GIS\Maps\Deliverables\Western Hills\AppendixB-Sensitivity\FIGB5_SensitivityScen5_MeanAnnualHuttRiverFlow.qgz

Print Date: 2023-06-16

Data Source:

Created By: Claire Murray

This document was prepared by GHD Ltd.

On behalf of WWL.

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https://projectsportal.ghd.com/sites/pp02_04/wwlwesternhillsstorm/ProjectDocs/12556744-REP-Western Hills SW Model Build Report_Formatted.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
0	Claire Murray	Chamila Haegoda	C. Haegoda	Scott Wilkinson		2023-12-20