Official Height Standard Change

From 1 July 2024, Auckland Council adopts the official height standard for New Zealand called New Zealand Vertical Datum 2016 (NZVD2016).

This model was carried out prior to the height standard change.

All levels included in this modelling report are in Auckland Vertical Datum 1946 (AUK1946/AVD1946).

Levels in this report can be transformed from Auckland Vertical Datum 1946 into New Zealand Vertical Datum 2016 by applying an offset value of 0.283 m.

For example:

$$H_{NZVD2016} = H_{AVD1946} - \text{Offset Value}$$

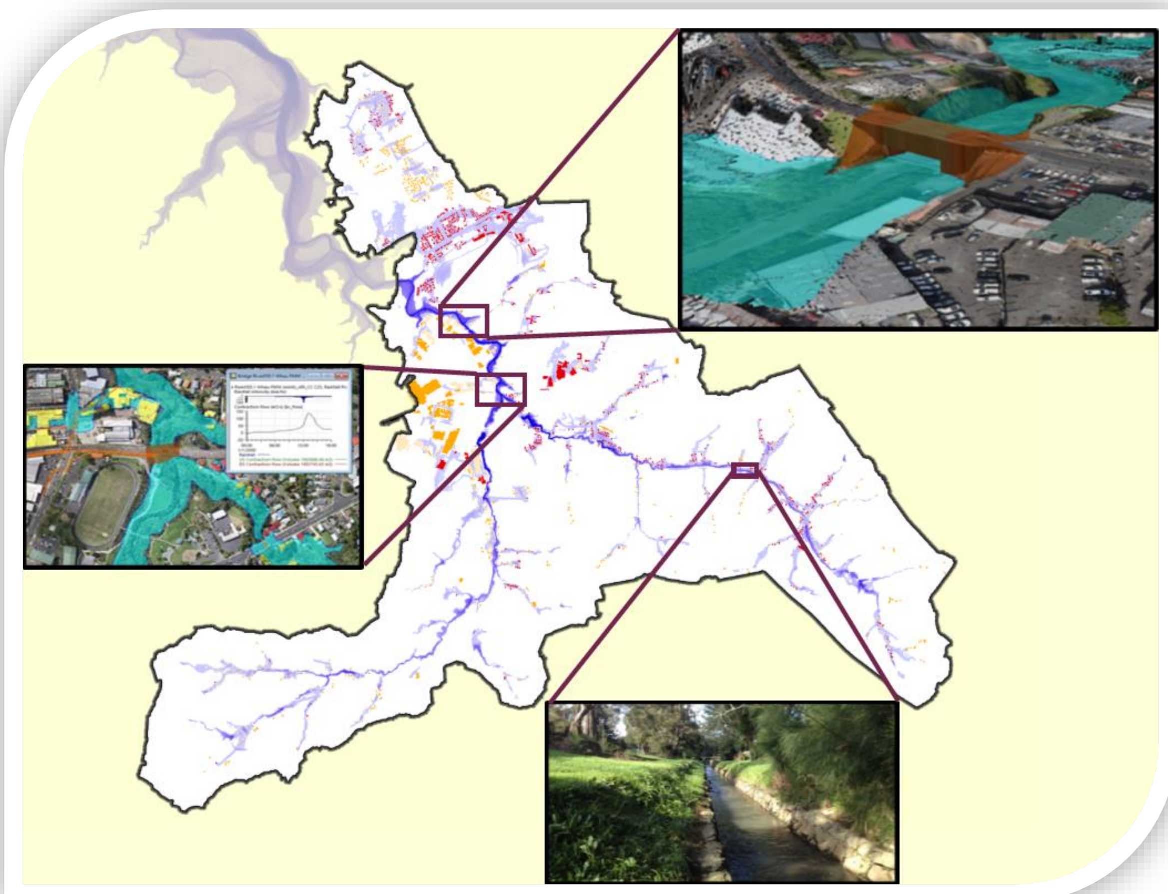
A single offset value for the catchment has been taken from the Land Information New Zealand (LINZ) Auckland 1946 to NZVD2016 Conversion Raster therefore this offset should be taken as an approximation only for the catchment.

A more accurate height transformation value can be derived by downloading the conversion raster available on the LINZ website below:

https://data.linz.govt.nz/layer/103953-auckland-1946-to-nzvd2016-conversion-raster/

WHAU FRAMEWORK MODEL

Ewaters New Zealand Limited



Whau Framework Model

1620004_3

Ewaters New Zealand Ltd

Twelfth April 2018

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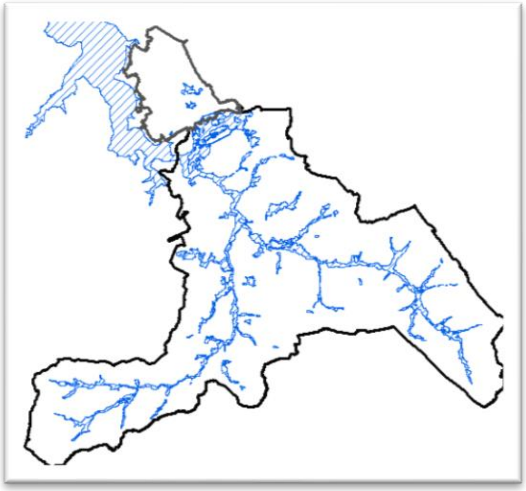
Client	Client's representative
Auckland Council Healthy Waters	Cheryl Bai

Project Whau Framework Model					Project No 1620004
Authors Jess Wallace Principal Water Resources Engineer Jorge Astudillo Principal Hydraulic Engineer					Date 12 April 2018 Approved by Jess Wallace

Revision	Description	By	Checked	Approved	Date
00	Draft	JAC	JSW	JSW	20/11/17
01	Final	JAC	JSW	JSW	06/03/18
002	Issued	JAC	JSW	JSW	12/04/2018

Key words	Status
	☐ Draft ☐ Final ■ Issued

EXECUTIVE SUMMARY



Ewaters was engaged to create a Framework Model for the Eastern portion of the Whau Catchment. The framework model considers the major streams and culverts of the catchment. As a rule, pipes over 550 mm and relevant streams are included. This covers the main flood extent defined by the Rapid Flood Hazard Model (RFHM). Project objectives include:

- Provide a framework model of the eastern side of the Whau Catchment, specifically the Avondale Stream and Whau River, with its outlet at the Rata Street Bridge (approx. 1625ha) which is fit to be used for options testing and business case production.
- Validate the framework model based on the survey and records available for the event of March 2017 (variation scope).
- Provide an update to the Flood Plain extent based on the framework model outputs and provide an economical pathway to development of a full FHM.

Most of the model was built from the Auckland Council GIS Asset Database, the survey data collected during 2013/2014, and 2016/2017 site visits and the flood surveys after the March 2017 event. The 1D/2D coupled Framework model was built in Innovyze ICM version 7.5. The model builds upon the experience and understanding of the rapid flood model built in 2016 by Ewaters for Auckland Council. The main river channels and associated culverts/pipes are included as the 1D portion of the model. Overland flow paths identified by the RFHA model that fall outside the 1D extent are covered by the 2D portion of the model. This approach provides a stable model that runs efficiently.

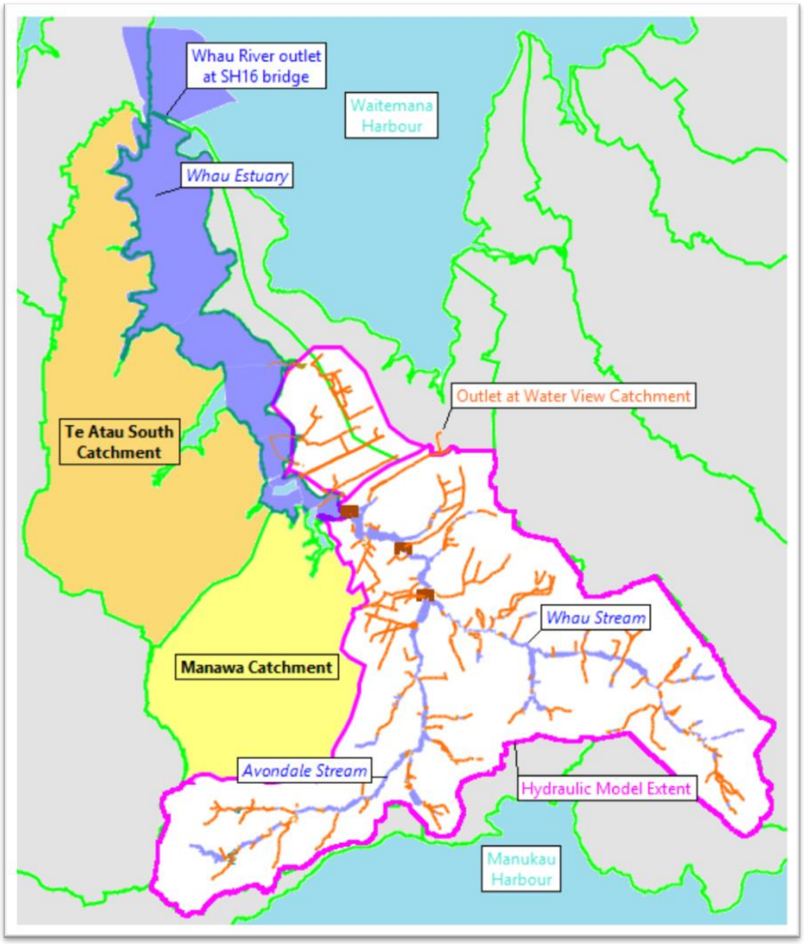
The design rainfall storm profile has been developed in accordance with the Auckland Council TP108 methodology and Stormwater Flood Modelling Specifications (Auckland Council, November 2011) for the 2, 5, 10, 20, 50 and 100-year design events with and without climate change. The tidal boundary condition is set to 2.57mRL at the outlet of the Whau Rive at State Highway 16 bridge.

A validation event was requested for the 12th March 2017 and considers 4 rain gauges, 1 tidal gauge, and several flood levels, mainly from flood debris surveyed after the event. The sensitivity analysis comparisons are analyzed at the Ash St Bridge the actual Whau catchment outlet as defined by Auckland Council.

It is recommended to utilize the Whau Framework Model (FWM) to set targets by determining suitable and reasonable flow capacity of the system and plan and test comprehensive stormwater management for the catchment The model is suited to provide the necessary assessment, set targets and design options to fit the growing demand of urban stormwater services

CONTENTS

1. INTRODUCTION



Ewaters NZ was engaged by Auckland Council (AC) to undertake the development of a framework model for a portion of the Whau catchment, specifically the Avondale Stream and Whau River, with its outlet at the Rata Street Bridge. The catchment that has been mapped is approximately 1625 ha, including a portion of Rosebank plains which drains into the Whau River. The catchment extent that has been included in the hydrological model is modelling extent that has been mapped was determined from the necessity to provide an updated flood map for the area and known high risk areas to be targeted. Additional sub-catchments (Te Atatu South and Manawa sub-catchments were added to improve the models representation of the downstream conditions specifically the estuary flooding. These areas were not included in the flood mapping.

1.1. BACKGROUND

The Whau catchment has had many previous studies performed in the past. Several ICS studies were performed for over the past decade for the catchment. The previous models of the Whau catchment were determined to not be of sufficient reliability to confidently provide comprehensive stormwater management of the catchment. The catchment itself was split and managed by Waitakere City Council and Metro Water. The dual management led to many legacy data challenges and differing catchment management approaches. Additionally, a 2012-2014 modelling project was abandoned due to not meeting Council specifications. The framework model considers the major streams and culverts of the catchment. As a rule, pipes over 550 mm and relevant streams are included. This definition is intended to cover the main flood extent defined by the RFHM and the main flooding risk in the catchment. The development of a framework model was a logical step in the modelling process. It is intended to provide the necessary accuracy for flood mapping whilst also being a base model for detailed sub-catchment analysis.

A preliminary model extent was defined during the proposal stage and was agreed with the AC manager, As stated in the introduction during the modelling stage it was found that Te Atatu South and Manawa sub-catchments did influence the flooding due to the estuary. These were included in the final model as large sub-catchments.

The original corporate GIS was delivered in November 2016 and used for model set up. It was discovered in February 2017 the Corporate AC GIS was out of date for the catchment, compared to the GeoMaps database. The GIS shapes were updated increasing the number of pipes in the model when applying the simple criteria defined above. The resultant model is a framework model, with sufficient detail for a macro drainage analysis and the ability to be further developed for targeted detailed modelling

1.2. STUDY OBJECTIVES

- Provide a framework model of the eastern side of the Whau Catchment (approx. 1625ha) which is fit to be used for options testing and business case production.
- Validate the framework model based on the survey and records available for the event of March 2017 (variation scope).
- Provide an update to the Flood Plain extent based on the framework model outputs.
- Provide an economical pathway to development of a full FHM.
- Provide time series results in waterRide dynamic TIN format for all scenarios providing a greater value to the wider Healthy Waters Department, as it will allow publishing on the H2knOwhow portal or similar.

1.3. ACTIVITIES AND SCOPE

The Whau catchment is an area facing considerable growth pressure, due to its desirable proximity – being close to the city, close to public transport, and only a short distance from both east and west coast beaches.

The framework model in this catchment is intended to:

- Develop a flood model with structures for the major floodway. The model will be used to develop business case for concept level flood mitigation options.
- Provide a new Flood Plain for publication on the GIS Viewer, that will reduce the inherent conservative nature of the Flood Plain published from RFHA modelling.
- Have a model available for 2, 5, 10, 20, 50 and 100-year plus climate change events for the MPD impervious conditions, as well as 2, 5, 10, 20, 50 and 100 year no climate change ARI flood modelling results for ED to better answer developer and public queries. Both component of this model, 1D and 2D, will be exported and merged in waterRide offering a significant improvement to customer service, compared to the information that can currently be given out, as this will provide a pathway to directly publish these results in H2KnowHow.

- Validate the flooding issues identified by the 2017 flood survey and in the ICS Report, and provide modelling results that can be used to identify propose and prioritize stormwater management options and the accompanying modelling work to address these.

1.1.1 MARCH 12TH FLOOD VALIDATION

During model development a significant flooding event occurred in the Whau catchment the 12th of March 2017. Ewaters undertook flood investigation surveys on behalf of Auckland Council as part of the emergency works in the Whau catchment. A significant amount of flood levels and pictures were collected for the catchment. It was agreed to include an additional validation stage for the project. The validation scope has been included in this report, as well as the sensitivity tests required to gain confidence in the modelling result and highlighted during the Whau FWM peer review.

The present model delivered contains final model results for ED, MPD and validation event. The deliverables include the following items:

- Innovyze ICM Model in icmt format (run on AC computer system)
- This model report on AC template.
- 100yrs plus climate change, MPD land use floodplain extent GIS shape files, with other GIS files used on process. Details listed on Appendix A.
- 2, 5, 10, 20, 50 and 100 years event for MPD (plus climate change) and ED (no climate change) land use in waterRide (wrb TIN file format) and full timesteps.
- Revised catchment boundary polygon, for use in the defining Flood Plain update extents.

The details of the model build and assumptions are described in the model build section.

2. CATCHMENT DESCRIPTION

2.1 LOCATION

The framework study area is a portion of the Whau catchment, specifically the Avondale Stream and Whau River, with its outlet at the Rata Street Bridge. The catchment is approximately 1625ha, including a portion of Rosebank plains which drains into the Whau River.

2.2 TOPOGRAPHY

The topography is typical of Auckland catchments. The upper catchment is predominantly hilly steep slopes that collect quickly into gullies and become small streams. The main streams are relatively steep in the upper catchments and flatten in the lower catchment. The longest stream length is approximately 7.1 km with a total stream length, main streams and tributaries, of 52.8 km. The current catchment is 42% impervious.

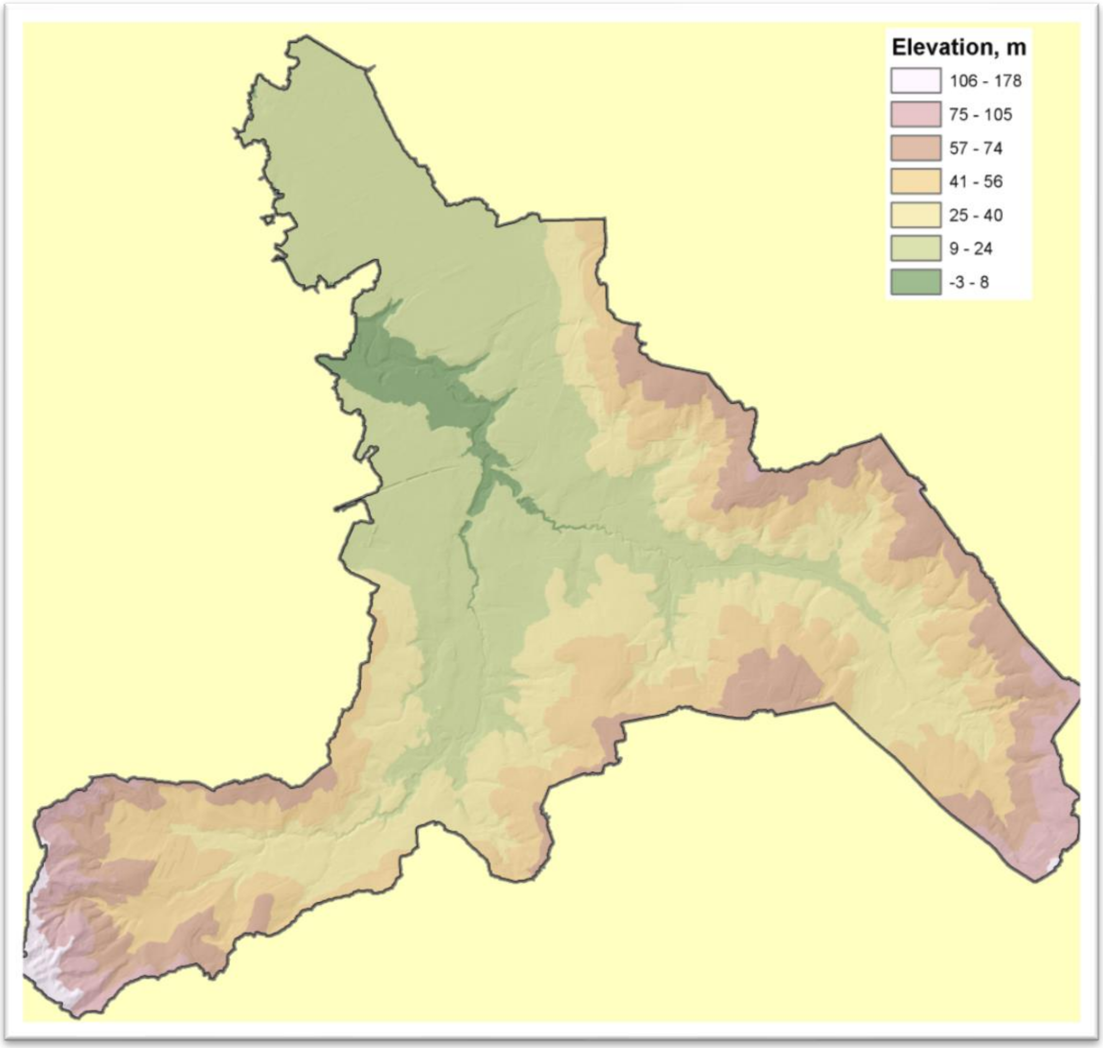


Figure 1 Topographic DEM

2.3 GEOLOGY AND SOILS

The Whau catchment is comprised of two main soil types Alluvial Soils USCS soil type B and Waitemata Residual Soils USCS soil type C1.

Table 1 Soil Types and Areas

Soil Name	USCS Soil Type	Area (Ha)
Alluvial Soils	B	619
Waitemata Residual Soils	C1	987

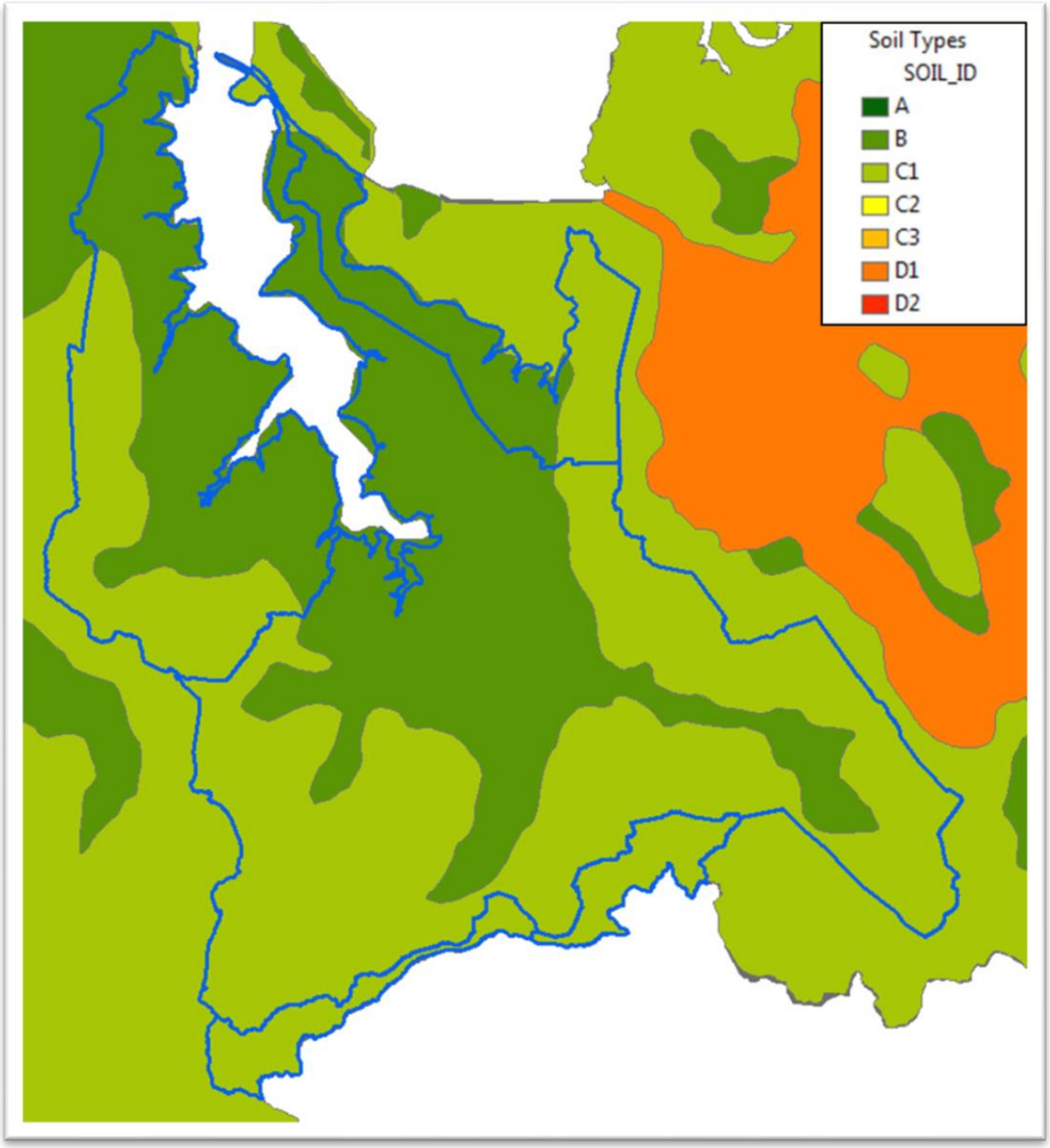


Figure 2 . US SCS Soil types in at the Whau Catchment

2.4 EXISTING AND FUTURE LAND USE

2.4.1 EXISTING DEVELOPMENT

The Existing Development scenario of the Whau east catchment is composed primarily of residential areas (%60 % approx..), roads (14 %), with few areas of green spaces ((xxx%16 %) and just a few industrial/commercial areas (xxx7 %), Figure 4 show the Whau land use. The Imperviousness for the existing development are based on the impervious shapes and building footprints from the Corporate AC GIS database. The two impervious shapes overlap in some areas. The duplicated portion was removed from consideration. The urbanization of the catchment is considered typical for Auckland consisting of mainly single-family homes and centralized commercial/retail services. The catchment is generally urbanized with various reserves scattered throughout. The upper portion of the Avondale stream originates in the Waitakere Ranges.

2.4.2 MAXIMUM PROBABLE DEVELOPMENT

Imperviousness for the maximum probable development scenario (MPD) was based on the latest district plan shapes and the latest respective imperviousness allowance (PAUP). The final imperviousness was checked to assure the MPD imperviousness were not smaller than the existing values. The PAUP Zone Imperviousness table used in Whau catchment is shown in Table 2.

The MPD impervious percentage is 58% on average for the entire catchment which is an increase from the existing situation. The character of the catchment is expected to remain similar with more intensive development and redevelopment.

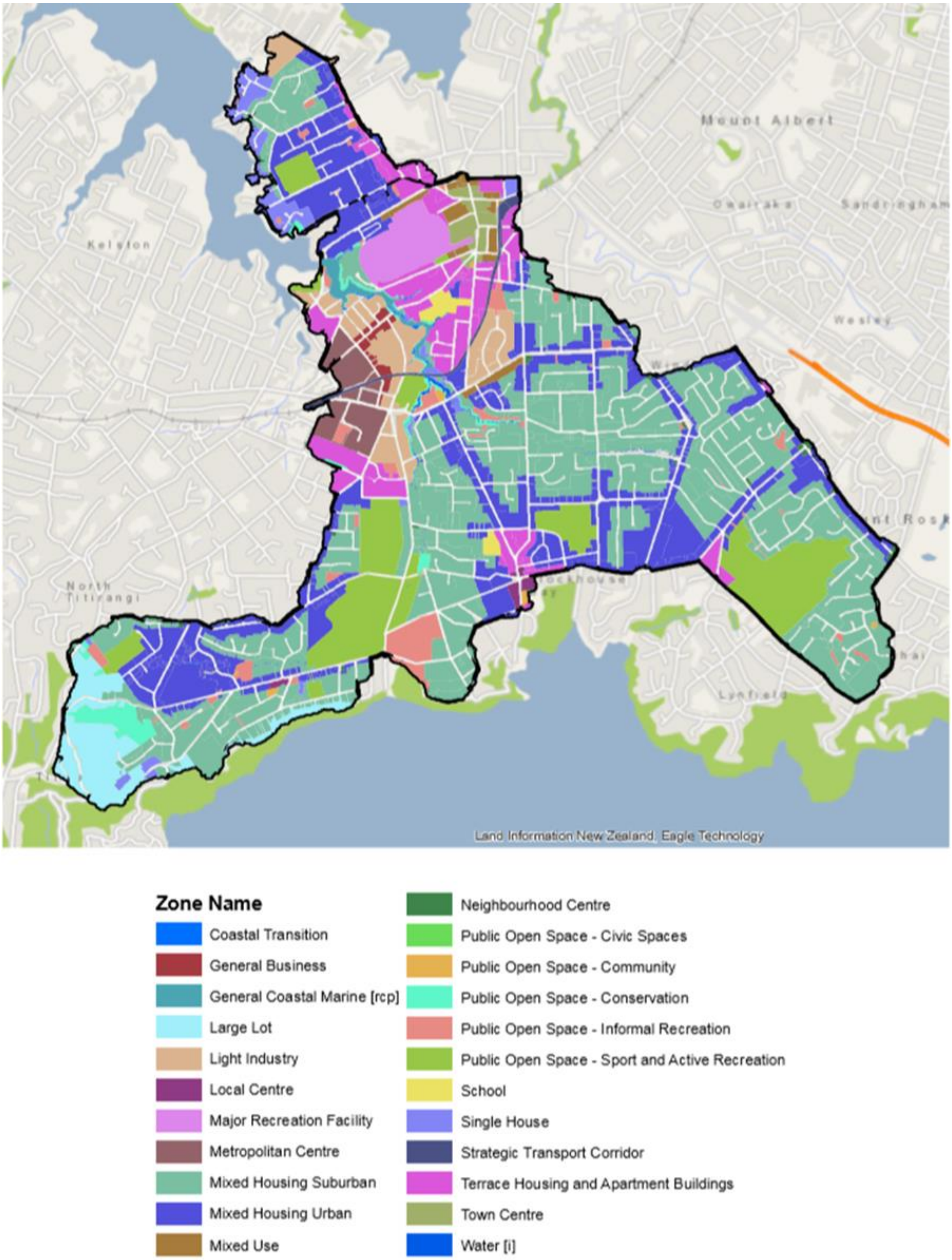


Figure 3 Whau Land Use

2.5 VALIDATION

The Validation event utilizes the existing development condition with the pervious areas divided by the two soil types in the area: Soil B and Soil C. This is to allow for a better representation of the conditions present for the validation event of 12th March 2017.

Table 2 PAUP table used for Whau FWM

PAUP Zone Imperviousness		
Zone_Code	**Zone_Name**	**Impervious %**
1	Business Park	80
3	Countryside Living	10
4	Future Urban	80
5	Heavy Industry	90
7	Local Centre	90
8	Terrace Housing and Apartment Buildings	60
10	Metropolitan Centre	90
11	Mixed Rural	20
12	Mixed Use	90
15	Rural Conservation	10
16	Rural Production	20
17	Light Industry	90
18	Mixed Housing Suburban	60
19	Single House	60
20	Rural and Coastal Settlement	10
22	Town Centre	90
23	Large Lot	10
25	Water	100
26	Strategic Transport Corridor	100
27	Road	80
29	Strategic Transport Corridor	100
30	General Coastal Marine	0
31	Public Open Space - Conservation	10
32	Public Open Space - Informal Recreation	30
33	Public Open Space - Sport and Active Recreation	40
34	Public Open Space - Community	70
35	City Centre	90
37	Minor Port	80
39	Defence	80
40	Marina	100
41	Mooring	0
43	Hauraki Gulf Islands	60
44	Neighbourhood Centre	90
45	Ferry Terminal	100
46	Rural Coastal	0
48	Strategic Transport Corridor	100
49	General Business	80
50	Strategic Transport Corridor	100
51	Special Purpose	70
52	Special Purpose	60
53	Special Purpose	60
54	Special Purpose	70
55	Special Purpose	80
56	Special Purpose	80
57	Special Purpose	70
58	Special Purpose	60
59	Coastal Transition	20
60	Mixed Housing Urban	70
61	Green Infrastructure Corridor	10
62	Public Open Space - Civic Spaces	90
63	Special Purpose	70
64	Special Purpose	70

2.6 STORMWATER DRAINAGE SYSTEM

The Whau river, with its outlet at the SH16, has a catchment of 3445ha approximately, and collects the runoff of the Whau Catchment (2207ha) and the Te Atatu South Catchment (854ha). The lower portion of the Whau River is a large estuary, which tidal influence goes as far as Great North Rd. Several small tributaries discharge into the estuary, primarily from the Te Atatu South catchment and from the Rosebank area. However, the larger portions of the drainage system are defined by the Manawa stream (514ha) and the Avondale and Whau streams (1476ha), which converge at the railway bridge, and discharge into the estuary at the Ash St bridge. There are portions of the Whau River catchment that are combined sewers. The effect of the combined system was not considered for this study.

This project focuses on the eastern portion of the catchment, which considers the Avondale and Whau stream, as well as the portion of Rosebank Peninsula discharging into the estuary, with a total catchment area of 1625ha approximately.

The stormwater drainage system of interest is driven by gravity only, and it is composed primarily of these two streams (Avondale and Whau streams), which cross several roads through culverts, and few bridges such as the railway, Great North Rd and Ash St bridges. The stream generally has sufficient capacity. However, the capacity of the system is limited by the culvert capacity, and the flood risk is noteworthy around these crossings and in areas where the river plains are developed.

Beyond the Avondale and Whau streams, the drainage is still dominate by a mixture of piped network and streams. The storage in the upper catchment is limited, and primarily defined by the river basins, for which the Avondale stream holds the most as it passes though large parks and undeveloped areas. The piped network is generally in good condition, composed mainly of concrete pipes, and providing a service near the 5 years event, though with several exceptions with larger and lower capacities.

The system outlet is well defined in the Whau estuary at SH16, however, the Rosebank area is flat and the overland flow paths do not necessarily follow the piped network, so the catchment border is not evident. In this regard, a portion of the underground network in Rosebank crosses towards the Water View Catchment (near Ash St and Rosebank Rd), which produces an overflow of the Whau runoff when the hydraulic heads allow. As such, part of the neighboring Water View catchment has been included in the model.

Figure 4 summarizes the Whau drainage system.

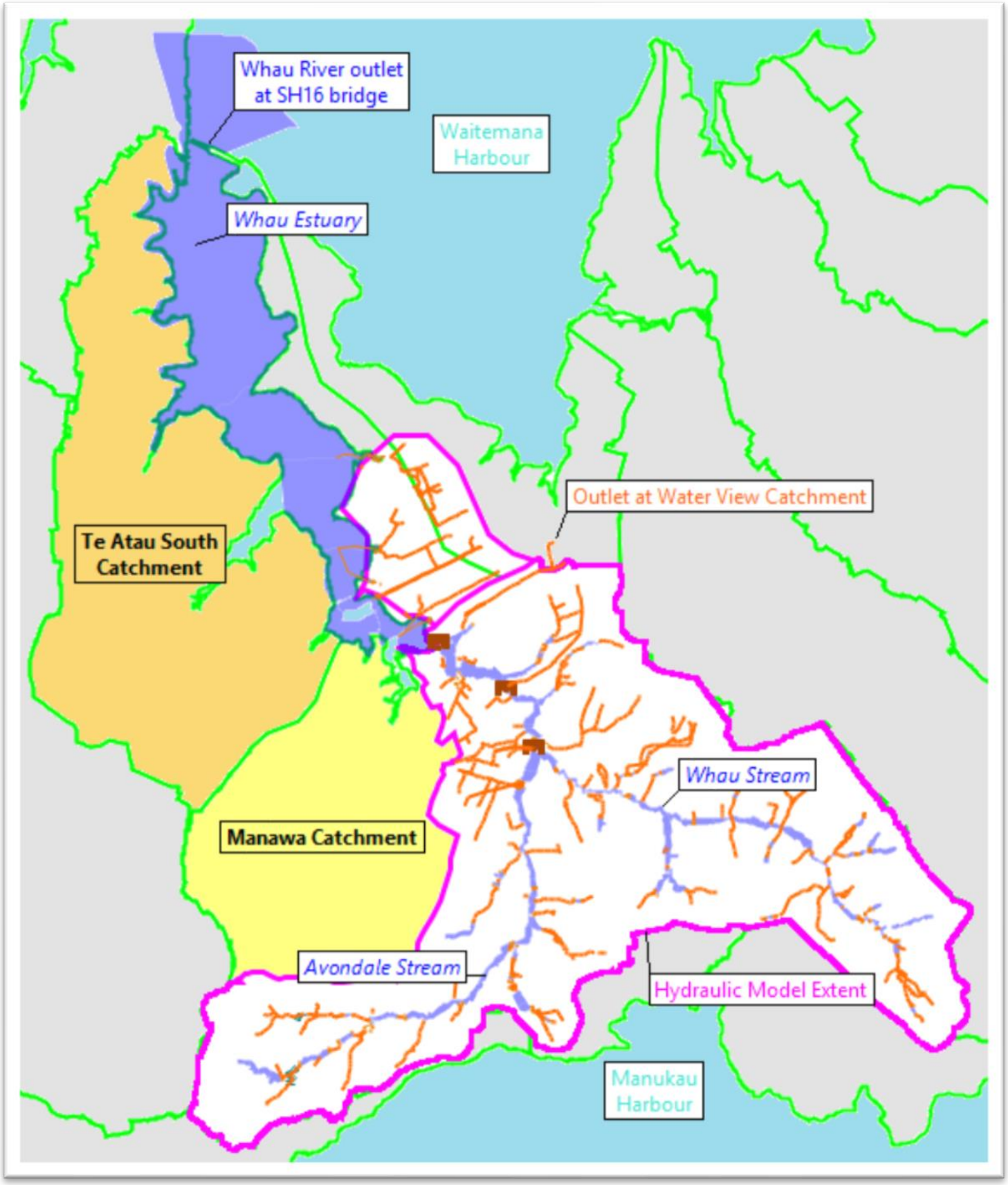


Figure 4. Whau River Drainage System

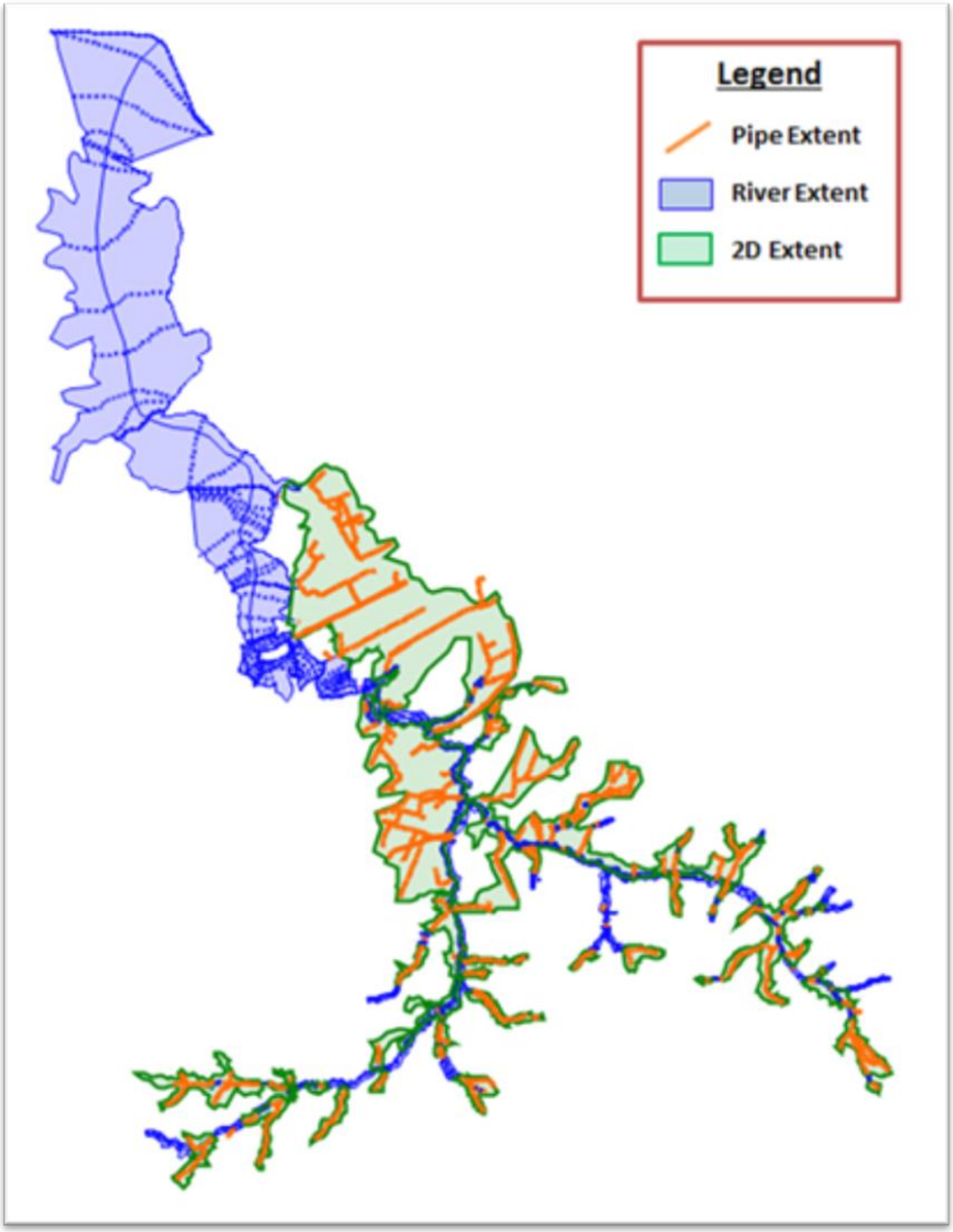


Figure 5 Hydraulic Network Extent

2.7 REPORTED FLOODING ISSUES

There are many flooding issues within the Whau catchment as evidenced by the March 2017 flood event. The figure below shows the reported issues for the March 2017 flood. The reported flood issues are mainly flooded roadways, sections and homes with some commercial property at risk in the lower catchment. Under sized reticulation, lack of storage in the upper catchment and blocked inlets are the biggest contributors to the flooding issues. Shapefiles accompany this report that detail the areas that reported flooding from the 2017 event, surveyed homes and proposed future survey of home to determine their finished floor levels are at risk.

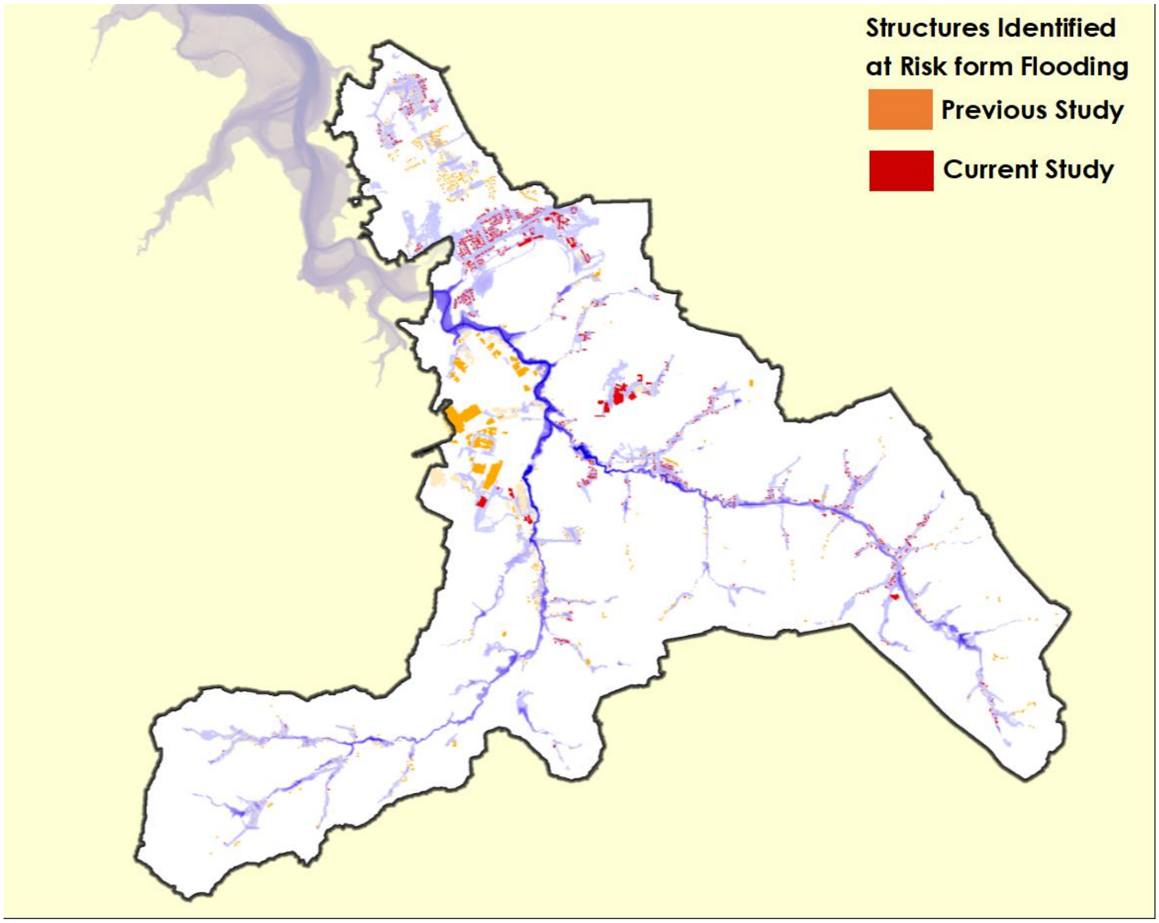


Figure 6 Structures at Risk from Flooding

3 MODEL BUILD

3.1 MODELLING SOFTWARE AND GENERAL MODELLING APPROACH

The AC SW Modelling Specifications (Nov 2011) were the basis for the technical approach. The specifications were deviated from due to requirements of the scope as defined for the framework model with AC staff. The methodologies were further refined during the project execution in accordance with technical discussions between the project team (AC storm water modelling team and Ewaters staff). The resultant framework model is a 1D/2D coupled model that focuses on the main rivers and large diameter pipes with inclusion of overland flow paths as 2D modelled areas.

The model was built in Innovyze ICM version 7.5. as a 3-way couple model (1D rivers/streams, 1D pipes/manholes and 2D zones for overland flow paths), and hydrological model according to TP108 guidelines.

3.2 MODEL BUILD DATA

3.2.1 ASSET DATA

Most of the model data comes from the AC GIS Asset Database received Nov. 2016 and February 2017. Two survey data collections were also used for the model build. The first was survey data collected during 2013/2014 by Walker Surveyors. The second survey data was collected 2016/2017 site visits and flood survey after the March 2017 event performed by Ewaters, Opus and AC staff.

The manhole, and pipes database were found to be significantly complete, and the survey information allowed to fill most of the GIS data gaps. The remaining gaps were filled based on fragmented data, interpolations, estimations or assumptions which are described in more detail in the following sections.

Refer to Overview of Model objects for complete table of asset data and sources.

3.2.2 HYDROMETRIC DATA

Hydrometric data is available for rainfall and tides in the Whau catchment and were utilized for the March 12th flood validation. The gauges and data are obtained from H2knowhow. Recording was of good quality without any significant gaps or anomalies identified. Groundwater gauging was not considered for the model. There are no stream flow or level gauges available.

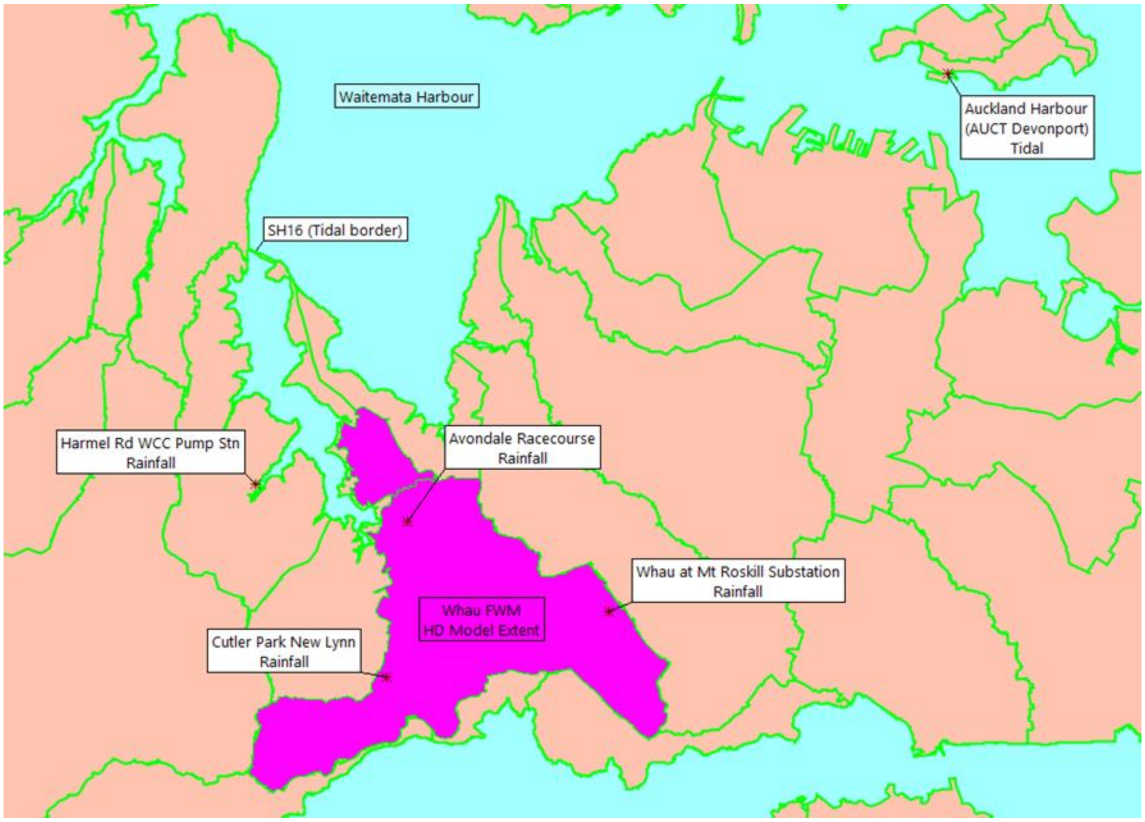


Figure 7 Hydrometric Data Sources

Table 3 Hydrometric Data Sources

Gauge Station	Type	X_NZTM, m	Y_NZTM, m
Avondale Racecourse Rain	Rainfall	1750345	5914938
Cutler Park New Lynn	Rainfall	1749991	5912354
Harmel Rd WCC Pump Stn	Rainfall	1747820	5915559
Whau @ Mt Roskill Substn Rain	Rainfall	1753684	5913432
Auckland Harbour (AUCT)	Tidal	1759290	5922360

3.2.3 TOPOGRAPHICAL DATA

3.2.3.1 DEM

A provisional catchment boundary was supplied by the AC at the start of the project. In addition, a 1 m x 1 m raster grid was also provided for the entire catchment area to serve as a base for the development ICM flexible 2D mesh.

Review of the 2013 LiDAR for errors was undertaken to assure it was fit for purpose. This involved tests such as depression mapping and visual review of crossings to assess the representation of structures in the catchment.

A spot check analysis was performed to identify any potential errors resulting from algorithmic interpolations or multiple fly over combined data sets.

Only one adjustment to the DEM was done: on Bolton Street Bridge (near Portage Rd), where the road deck was added to the grid for flood mapping purposes.

3.2.3.2 2D POLYGONS FOR OLFP

2D polygons were generated from the DEM and OLFP were represented by 2D mesh with a resolution of about $4m^2$. The 2D polygons aim to cover all OLFP not covered by the 1D model extent, and according to the RFHM flood extent used as a guide. Many OLFP were represented by 1D-objects when possible, to reduce the numerical load of the simulations.

Three types of surfaces were defined:

- Building polygons, defined by porous polygons with a 10% porosity (which is an accepted practice in AC Modelling Office).
- Roads and impervious areas, with a roughness of n= 0.025
- For the rest of the 2D surfaces, a conservative value of 0.080 was used primarily to describe urban vegetation.

3.3 HYDROLOGICAL MODEL

3.3.1 METHOD USED

The hydrological model was defined in accordance with TP108 and the AC SW Specifications. The SCS method described in TP 108 was used to determine effective rainfall for the model. The hydrologic model was built in accordance with specifications except for the two large catchments that are not included in the hydraulic model extent.

3.3.2 HYDROLOGICAL MODEL EXTENTS

The model outlet was originally set at the Ash St Bridge, according to the model extent required by the model scope. When performing the validation modelling it was found to be important to consider the influence of the Whau estuary up to the SH16. Therefore, additional hydrological catchments were included. The river was then extended, and the additional sub-catchments were incorporated into the model. Figure 3 shows the new model extent all the way to SH16.

Each sub-catchment is discharged into one of three model objects types: SW manhole, stream reach, or an OLFP over the 2D mesh.

The majority of catchments are connected to manhole nodes or stream reaches. Upper catchment areas without a defined 1D network are connected to OLFP on the 2D mesh

There are only 6 sub catchment polygons that were directly discharged into the OLFPs on the 2D mesh. These are green areas including the racecourse and parks and undeveloped areas near Portage Rd and Godley Rd. They are small steep tributaries well defined by the Lidar and the 2D mesh areas.

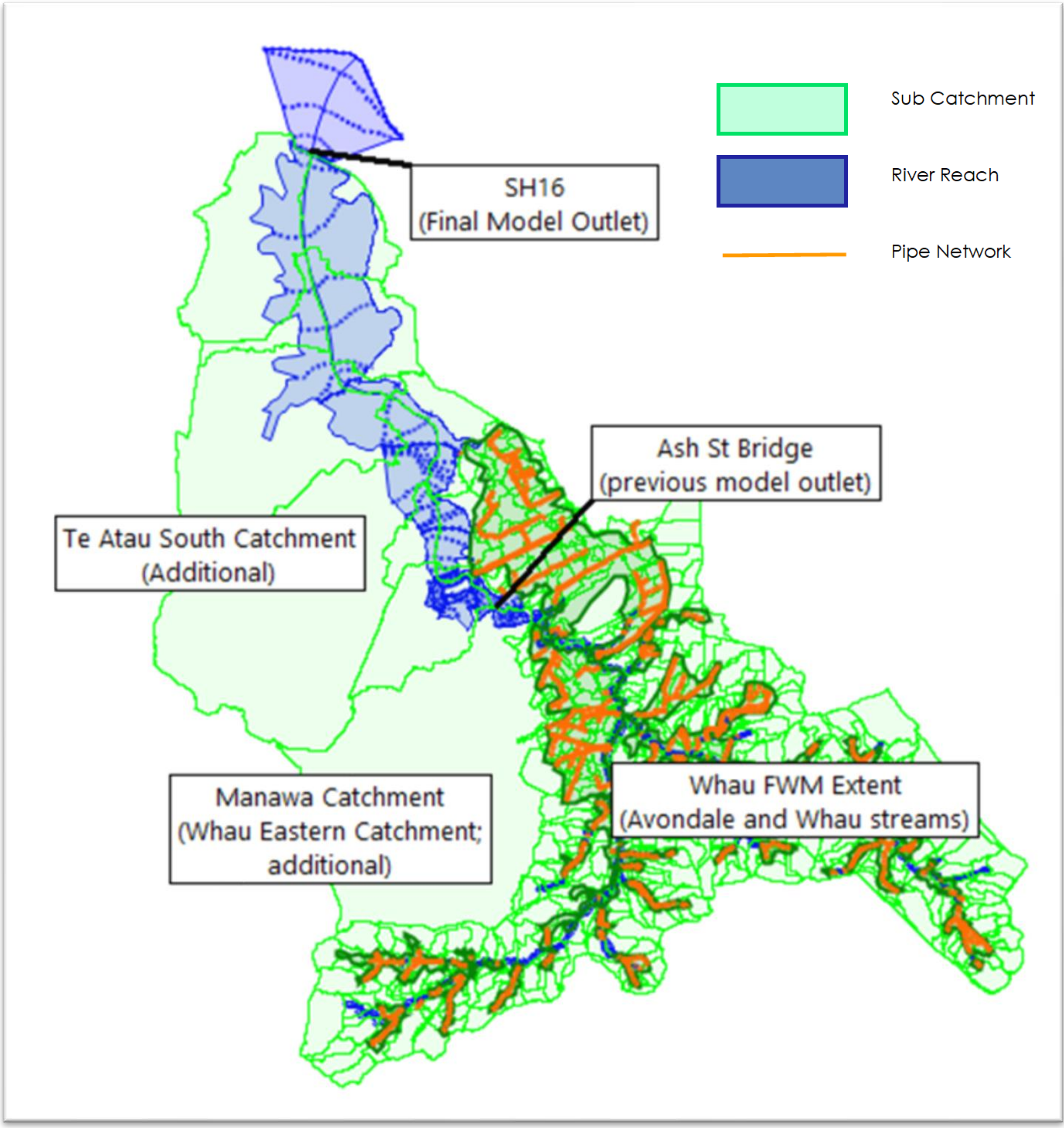


Figure 8 Whau FWM extent. Previous and newer model outlet and extent.

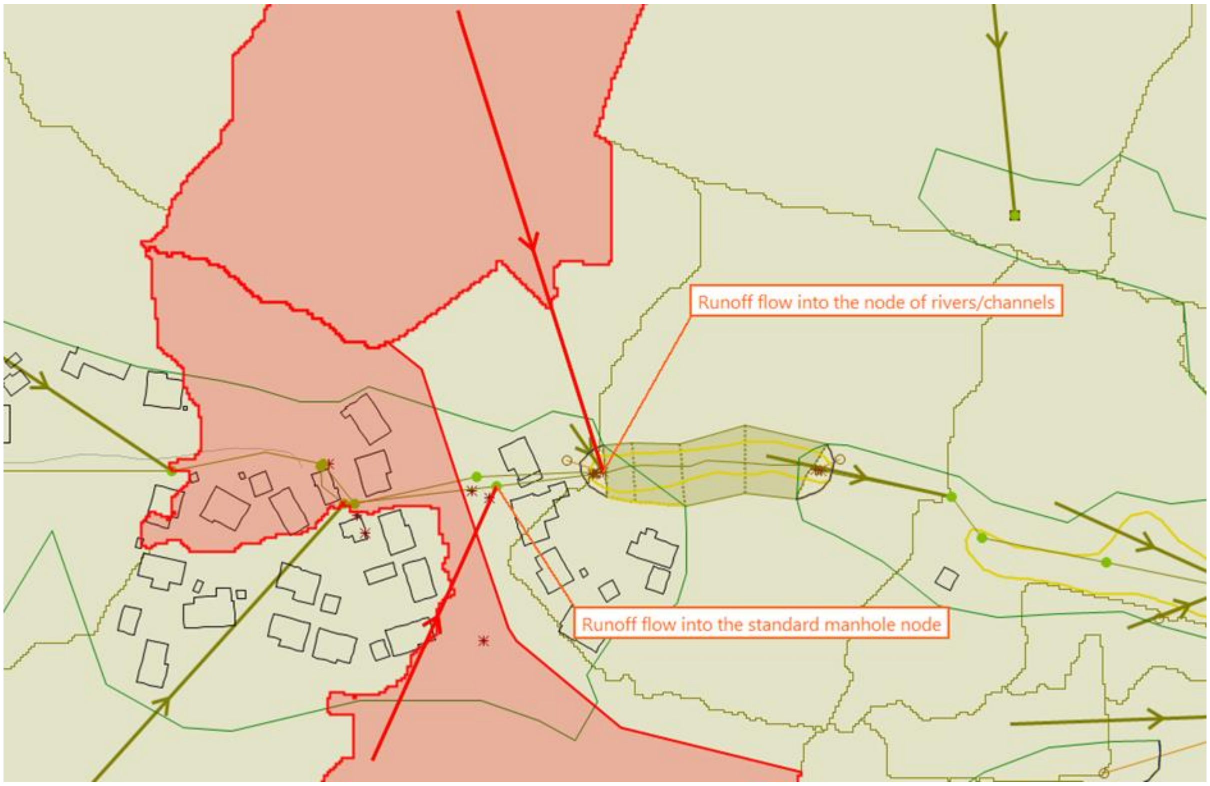


Figure 9 Sub-catchment connection example

Hydrological connections between the sub-catchments and the 1D model objects. The runoff generated by the sub-catchments flow to the standard manhole nodes or the river/channel nodes.

3.3.3 SUB-CATCHMENT PARAMETERS

Sub-catchments have been defined requisite to the parameter set forth by the framework model. Due to minimum pipe size being modelled, sub-catchments do not strictly adhere to the AC specifications. Sub-catchments are predominantly defined by topography with a few isolated catchments adjusted to more accurately reflect reality created by the reticulation network.

Sub-catchments for Manawa and Te Atatu South are outside of the required model extent, but they were included to provide a more realistic downstream flow level for the modelled outlet. The final model extent includes the sub-catchments from Ash St Bridge (previous model outlet) to SH16 (the new model outlet).

The impervious and pervious areas are effectively separated from each other through the runoff surface areas fields. The impervious and pervious areas are in the same sub-catchment shape and therefore one time of concentration is defined for both. This approach is not defined in the AC Stormwater Specifications (Nov 2011), but it is done this way for simplicity considering most sub-catchment Tc = 10 minutes, and if not, the difference of the two is negligible. Time of concentration parameters were processed in GIS based on AC GIS layers and the 2013 Lidar grid. The channelization factor was used as C=0.7 for the urban areas with significant open channels and streams and C=0.9 for upper catchments which are mainly urban and without significant reticulation. These parameters are available in the model in the sub-catchment data tables for each scenario.

The hydrological model was defined in accordance with TP108 and the AC SW Specifications and considered the dominant soil Type C for the entire catchment. This includes the equal area slope and longest flow path, as well as CN and other parameters as is standard for ED and MPD. Soil type C was used for the entire catchment as it was considered more conservative for flood mapping. It is noted that the validation event considered further details by including both soils present in the area: Type B and C, as shown in Figure 2. Refer to Validation and Sensitivity section for further detail.

The sub-catchment imperviousness was estimated for three scenarios ED, MPD and Validation. The hydrology was re-processed for the entire catchment according to the new model extent which ends at the SH16.

Table 4 Overview of modelled sub catchments

Hydrological Model Components	Model scope	Extra Catches
Number of Sub-catchments	583	15
Range of sub catchments (ha)	0.1 ha - 28 ha	5 ha - 514 ha
SCS curve number for pervious areas (soil type C)	74	74
SCS curve number for pervious areas (soil type B for validation event)	61	61
SCS curve number for impervious areas	98	98
Initial loss for pervious areas (mm)	5	5

Initial loss for impervious areas (mm)	0	0
Existing development imperviousness %	42	34
Maximum probable development imperviousness %	62	55
Channelization factor (TC as per TP108)	0.7 - 0.9	0.7

3.4 HYDRAULIC MODEL

3.4.1 METHOD USED

The AC SW Modelling Specifications (Nov 2011) were the basis for the technical approach. The specifications were deviated from due to the requirements of the scope as defined for the framework model. The methodologies were further refined during the project execution in accordance with technical discussions between the project team (AC storm water modelling team and Ewaters staff).

The model was built in Innovyze ICM version 7.5., as a 3-way coupled model. This considers all rivers and open basins to be described mainly as 1D river objects, as well as manholes and underground pipes which are described by 1D nodes and conduits. Both 1D systems are inter connected through culvert inlets/outlets, and other connecting structures. Manholes are coupled to the 2D mesh to define the OLDFs, and river banks are also coupled to 2D to allow river plains to flood. Most of the coupled ground data, such river banks, and manhole lids levels, are based on the 1m Lidar grid from 2013, except in some areas where further details are available from survey

3.4.2 HYDRAULIC MODEL EXTENTS

As described in the Introduction, the framework model considers the major streams and culverts of the catchment defined in the scope, which is primarily the Avondale and Whau stream with its outlet at Ash St Bridge, as well as a portion of Rosebank draining into the Whau River (refer to Figure 4).

As a rule, pipes over 550 mm and relevant streams were included. The model covers the main flood extent defined by the RFHM. To provide complete coverage, several smaller pipes less than 550 mm were included in the model, as well as streams contained in between. A preliminary model extent derived from the RFHM was agreed during the preparation of the model scope. The extent was later modified to account for newer GIS information. The 2D extent covers the main OLFP, inside the RFHM flood extent, and was used to assist these criteria.

Figure 10 details a portion of the model where river, pipes and 2D extent can be appreciated.

Table 5 Hydraulic Summary

Objects	Entire Network (MPD)
Nodes Total	1758
Nodes Manholes	1158
Nodes Storage	31
Nodes Break	427
Nodes (others)	142
Pipes	1180
Pipe Length (m)	43025.19

Pipe Size (mm)	225 - 4800
Rivers	173
River Length (m)	24094.2
Bridge Structures	3
Orifice Fixed	58
Weir Fixed	25
Culvert Inlets	91
Culvert Outlets	130
2D Zones	35
2D Zone total area (ha)	487.96
2D Mesh Elements	1515009
Network Results Points (1D)	45 (for validation)
Network Results Points (2D)	21 (for validation)

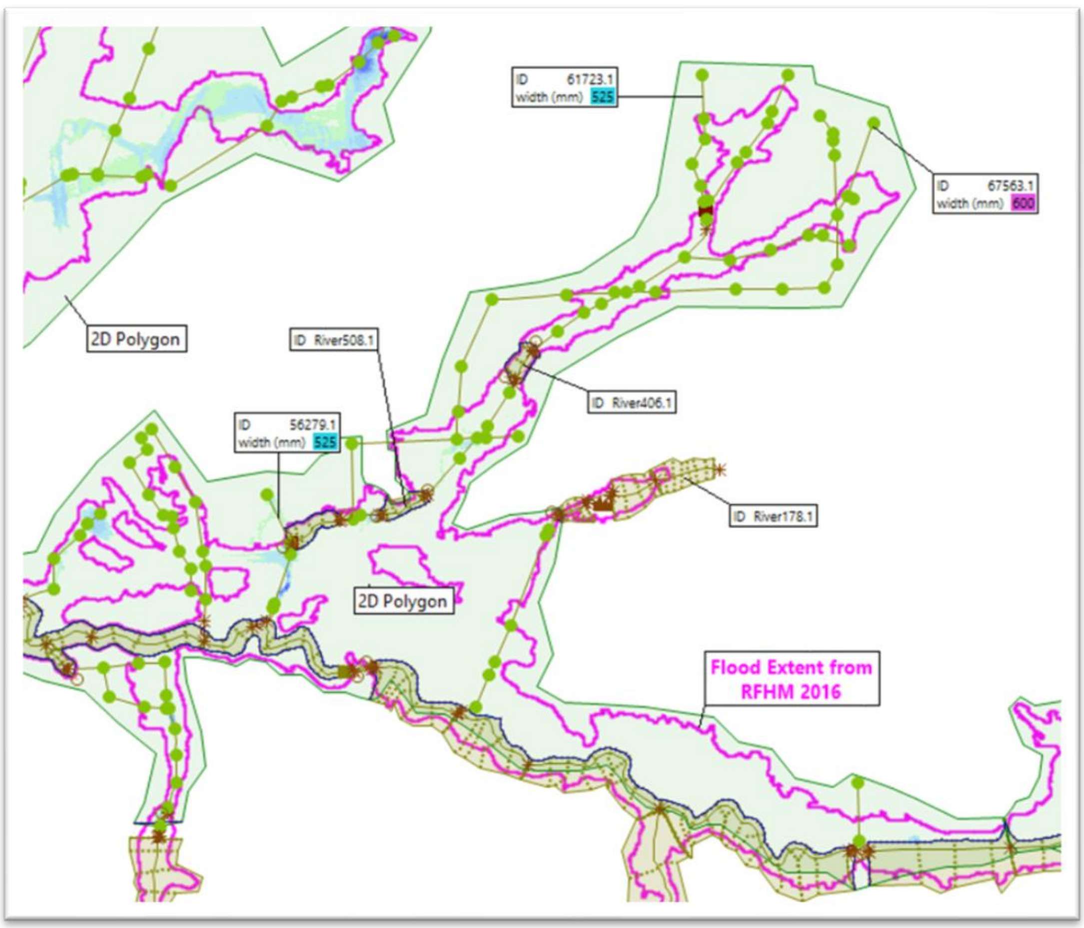


Figure 10. Example of model extent features

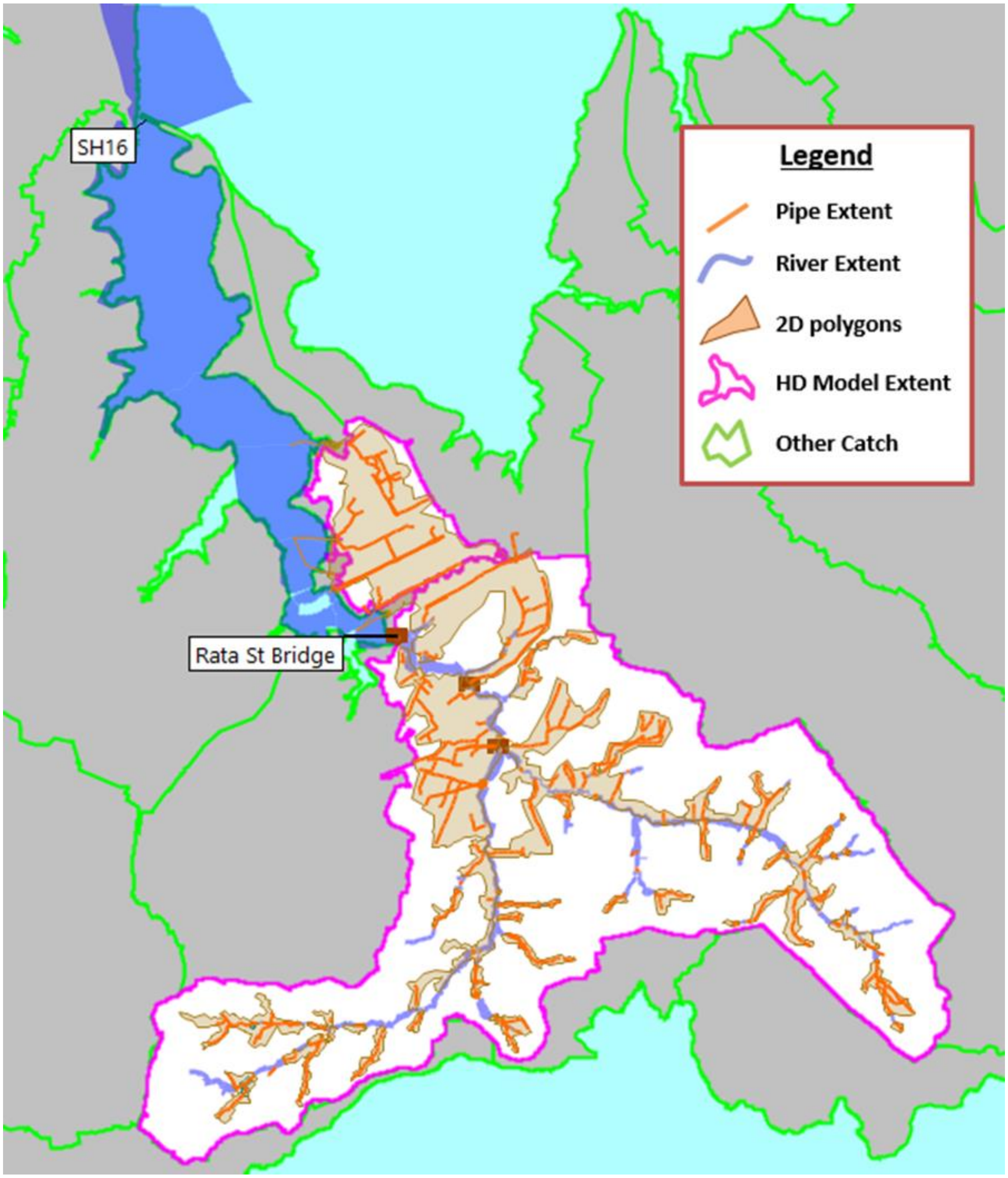


Figure 11 Hydraulic Model Extent

3.4.3 MODEL OBJECTS

3.4.3.1 OVERVIEW OF MODEL OBJECTS

Error! Reference source not found. shows an overview of the model objects contained in the model. Further details on each object type is develop further below.

Table 6 Asset Data Type and Source

Asset Data Type	No.	Data Source
Manholes	115	Survey
	908	AC GIS database
	135	Assumptions (missing manholes at pipe ends, dummies)
Culvert / pipe inlets and outlets	39	Survey
	10	Inference (based on surrounding AC and survey data)
	22	AC GIS database
	20	Assumption based on Lidar
Pipes	715	AC GIS database
	213	Survey
	117	Inference (based on surrounding AC and survey data)
	63	Assumptions based on Lidar

3.4.3.2 DATA FLAGS AND COMMENTS

Data flags were used to label data sources and assumptions in the modelling objects. It is advised to review flags and comments for objects at, or near, areas of concern. Comments and flags address plausibly foreseeable issues or concerns that may arise during the model review. **Error! Reference source not found.** shows the Whau data flags.

Table 7 Data Flags used on Whau FWM ICM model

id	Description	Comment
#A	"Asset Data"	ICM Default
#D	"System Default"	ICM Default
#G	"Data from GeoPlan"	ICM Default
#I	"Model Import"	ICM Default
#S	"System Calculated"	ICM Default
#V	"CSV Import"	ICM Default
AC	"Data from AC	Corporate AC GIS
AS	"Assumption"	Assumed value
CK	"Survey checked (source or site)"	Data which was confirmed during site visit
CL	"Data from AC provided (2012/2103)"	Data provided by client during 2013 scope (records)
ES	"Estimation based on fragmented data"	Based on surrounding data
EW	"Engineering Judgement"	Ewaters NZ judgement. Usually for numerical variables or comments.
GIS	"Data from GIS (AC GIS has different values!)"	Data generated in GIS. This flag also show data from the old AC GIS dataset, which is not available in the latest AC database (which is flagged as "AC").
GM	"Elevation from Ground Data"	Value from 2013 Lidar DEM
IF	"Inference/Interpolation"	ICM inference or interpolation, generally for invert levels
SU	"Survey data"	Survey data, whether from 2013 or later.
RC	"Regional Council Data 2012/2013 (previous URS2013 model flag/data)"	There might be just a few "RC" flagged data, which are mainly for old pieces of data which were collected from the 2013 project data folder and had no later replacement.
OP	"Options"	For optioning. Not for this project stage

3.4.3.3 PIPED NETWORK AND CULVERTS

The reticulation system is based on AC GIS information. The GIS information included most of the pipe diameters and significant amount of invert levels, as well as other relevant information.

A significant amount of survey was completed in 2013 by Walker Surveyors for a previously uncompleted Whau model that was developed by URS. The survey data was extensively reviewed at that time, and it is considered reliable for use. The survey included mainly culvert inlet/outlet and manholes invert levels/diameters which were used to improve the model quality. The survey also has a large amount of cross sections which were useful for estimating missing data at various inlets and outlets.

During the site visit, and the emergency works of the storm of March 2017, further survey was done to complete critical missing information primarily inlet/outlet culverts and bridges.

Data gaps were filled by utilizing surrounding data, or by simple interpolation. Flags and comments are applied to engineering judgements made.

Additionally, the pipe roughness was estimated considering the conduit material and the entrance/exit head losses utilizing the ICM inference tools. There are several extraordinary cases, where pipe velocities are too high to be considered reasonable, and these are denoted in the model with the proper flag or comment. Refer to the Energy loss section for details.

3.4.3.4 MANHOLES AND NODES

Manholes and nodes are mainly derived from the AC GIS shapes. It is noted that several nodes were created for rivers, missing manholes and other structures or features as required by ICM network structure. Most manhole lid levels are supplied directly from the AC shapes data and is noted that a significant amount was supplied from survey or extracted from the Lidar 2013 ground model.

The hierarchy of data is survey lid levels followed by AC GIS data and then Lidar lid level sampling. The final lid levels were then compared with Lidar and adjustments were made if the vertical differences were greater than 0.25m and include comments and flags.

The remainder of the required fields were populated with default values suitable for modelling, such as floor level taken from pipe inverts, or manhole size taken from attached pipe sizes. Pertinent comments and flags are included in the model.

3.4.3.5 RIVERS AND STREAMS

River and stream cross section were primarily based on the 2013 survey available. The coverage survey is significant, and the Lidar 2013 was used to define river sections for areas without survey. When Lidar cross section was needed, the low flow channel was estimated from the surrounding survey, such as nearby inlet/outlet information, site visit, photographic records, aerial photograph and long profile assessment using surveyed cross sections. The Lidar cross section is adjusted at the bottom part to properly describe the low flow channel of streams.

It was agreed with AC manager to simplify the model structure by avoiding 1D/2D coupling when possible. Therefore, when suitable, cross sections were extended to the total width of the flood plains, so the entire OLFP can be effectively described by the 1D river reaches. Adjustments were made to critical areas to account for obstructions and houses, to better represent the capacity of cross sections in the 1D objects.

Manhole and river bank lines were used for the 1D/2D coupling to the 2D zone polygon.

Figure 12 1D/2D coupling example

3.4.4 ENERGY LOSSES

Head losses are mainly described by the roughness of pipes and rivers, manhole entrance/exit losses, and culvert inlets/outlets. These losses are defined according to the criteria defined fort each section; such as rivers, pipes and manholes. Other head loss applies as well, such as weir discharge coefficients, orifice and obstructions along overland flow paths such as buildings and fences, and rivers for example houses footprint partially blocking river flow. Comments and flags have been applied for each case.

3.4.4.1 RIVER ROUGHNESS

The manning roughness estimates for cross sections were determined considering surface coverage from 2.5cm aerial photographs, site visit and site photo records. The coverage is summarized on the "User_Text_4" of the ICM Cross Section Line; comments in the "Note" field may also be available. The roughness considers a rule which was developed based on the land coverage and the elevation of the cross-section bottom. The criterion for the river roughness is summarized in the table below.

Table 8 Roughness Final Values

Land Coverage	Bottom	Banks	Count
Bridge	n=f(z)	0.1	8
Bush	n=f(z)	0.12	478
Bush grass	0.04	0.1	11
Bush/Channel	0.04	0.09	50
Bush/Pedestrian bridge	n=f(z)	0.2	6
Grass/Channel	0.035	0.065	40
Main channel + bush	n=f(z)	0.12	124
Over road XS	0.025	0.025	7
Tidal	n=f(z)	0.12	78
US/DS pedestrian bridge	n=f(z)	0.2	22
Wide River/ Bush banks	n=f(z)	0.12	55
Grass	0.045	0.065	1
Road (main)	0.016	0.016	4
road grass	0.025	0.04	6
road pavement	0.018	0.025	1

Note that the bottom roughness is sometimes defined as a function of the elevation (n=f(z)). It is considered (and confirmed by general observation) that the river bed gets smoother as it gets closer to the tidal control. This should apply only to the main channel, which is defined by the vegetation line at each cross section. Based on the available surveyed data and photos, the main channel depth's assigned roughness is simplified by the table below. A bank transition of about 1m has been allowed.

Table 9 River Roughness

Min Z, mRL	n bottom	Main channel depth, m
-3	0.025	3.5
-1	0.035	1.5
-0.45	0.052	1
0.5	0.06	1
5	0.065	1
10	0.07	1
20	0.075	0.7

60	0.075	0.5

Some river obstructions were defined as exception where required, such as buildings or small pedestrian or driveway bridges. Flags and comments applies.

There are several driveway bridges over the streams, with insufficient information available to model in detail. Considering the lack of information and to maintain a more stable simplified modelling approach, these losses were included in the river manning roughness by slightly increasing the roughness less than 20%.

3.4.4.2 PIPES, MANHOLES,CULVERT AND BRIDGES

The pipe roughness was estimated considering the conduit material and the entrance/exit head losses utilizing the ICM inference tools. There are several extraordinary cases, and these are denoted in the model with the proper flag or comment. Overall, the pipe manning roughness is between 0.014 and 0.016 for 97% of the pipe network, and other values outside of this range are based on site visit, photo impactions and few assumptions.

Inlet and outlet coefficients are based on the photo description and site visits, to determine the type and parameters values as described on the ICM standard values. These are typically based on shape, type of headwall, angle of headwalls, and type of culvert edges.

The head losses at entrance and exit of manholes was calculated by the ICM inference tool, which calculate the angles of approach and applies the default suggested head losses coefficients. Additionally, when results velocities are higher than 6m/s (as model review requires), further analysis were done, and an orifice link was added at the entrance of those conduits which flow is inlet controlled. 55 inlet controls were defined this way at key locations.

Table 10 Pipe Roughness Manning's n

Material	Roughness (n)
Aluminium	0.012
Steel	0.012
Concrete	0.014
Ceramic/Earthenware	0.014
ABCM	0.014
Polyethylene	0.014
PVC	0.014
Unknown	0.016, 0.02, 0.045

Figure 13Pipe velocity Control Setup

58 orifice links were used in Whau FWM as the pipe inlet control for the proper description of the hydraulic.

Figure 14 Bridge Setup locations

The bridge object is available in ICM as a single object comprised of a link between two nodes and an associated polygon. It allows the simulation of the flow under the bridge and the flood above the bridge deck. In Whau FWM, bridge object was modelled at 3 locations (Rata St/Ash St bridge, Great North Rd bridge and Railway bridge).

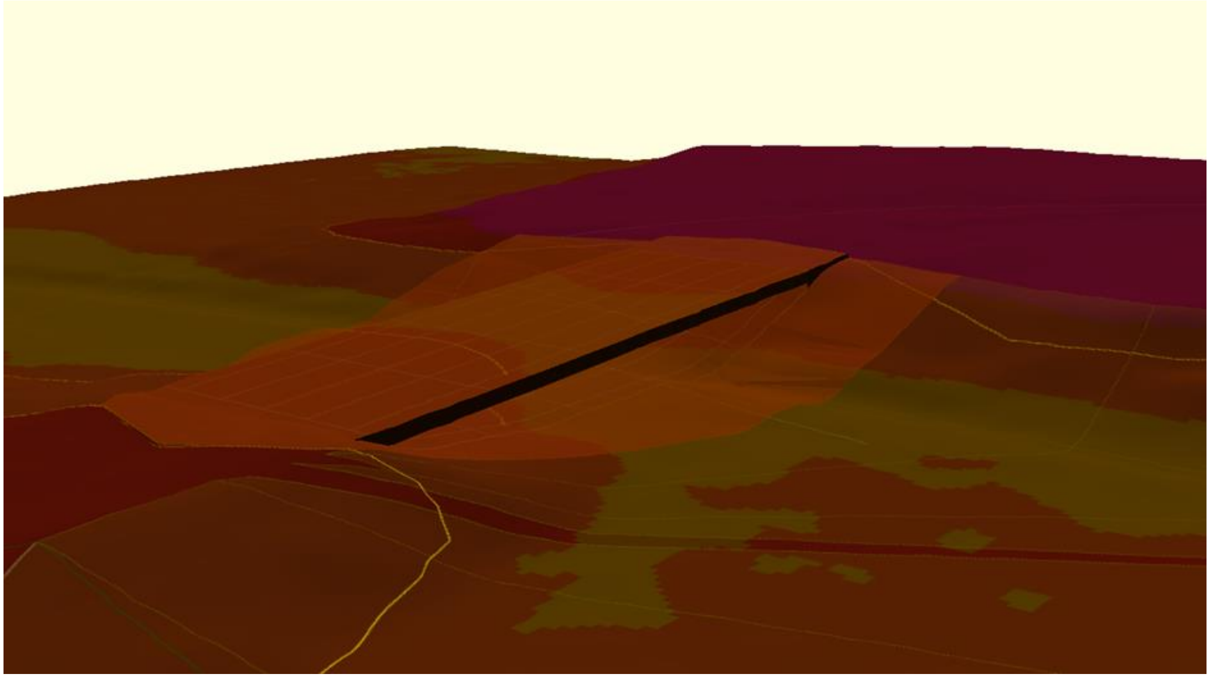


Figure 15 LiDAR modified to show bridge deck

The bridge at Ash St had the LiDAR modified to replace the bridge deck that did not appear on the LiDAR to accurately represent the flood mapping extent. This did not influence hydraulics.

3.4.4.3 OLFP ROUGHNESS

The 2D mesh contains various hydraulic features embedded in the mesh elements. The most relevant being the building footprints, which were modelled as porous polygons. This account for the limited storage at buildings footprints, as well as the fact that they are not entirely impervious obstruction, as they let flows pass through in a large portion of the buildings. The description has some limitations, as the fact that the water levels might be slightly lower than the surrounding areas, as the head required to pass through the walls. Porosity for the porous walls representing building footprints is p-10%, which means it is a 90% impervious.

Fences is also a feature included in some key locations of the 2D mesh. They were used as consequence of the validation/calibration event. Fences are in most cases partially impervious, letting a large portion pass through, the range of its porosity might be wide, and as general assumption it was assumed to be between 40 to 60% pervious (or in other words: 60 to 40% impervious). All fences added were in the upper catchment of the Whau river as shown in the figures below.

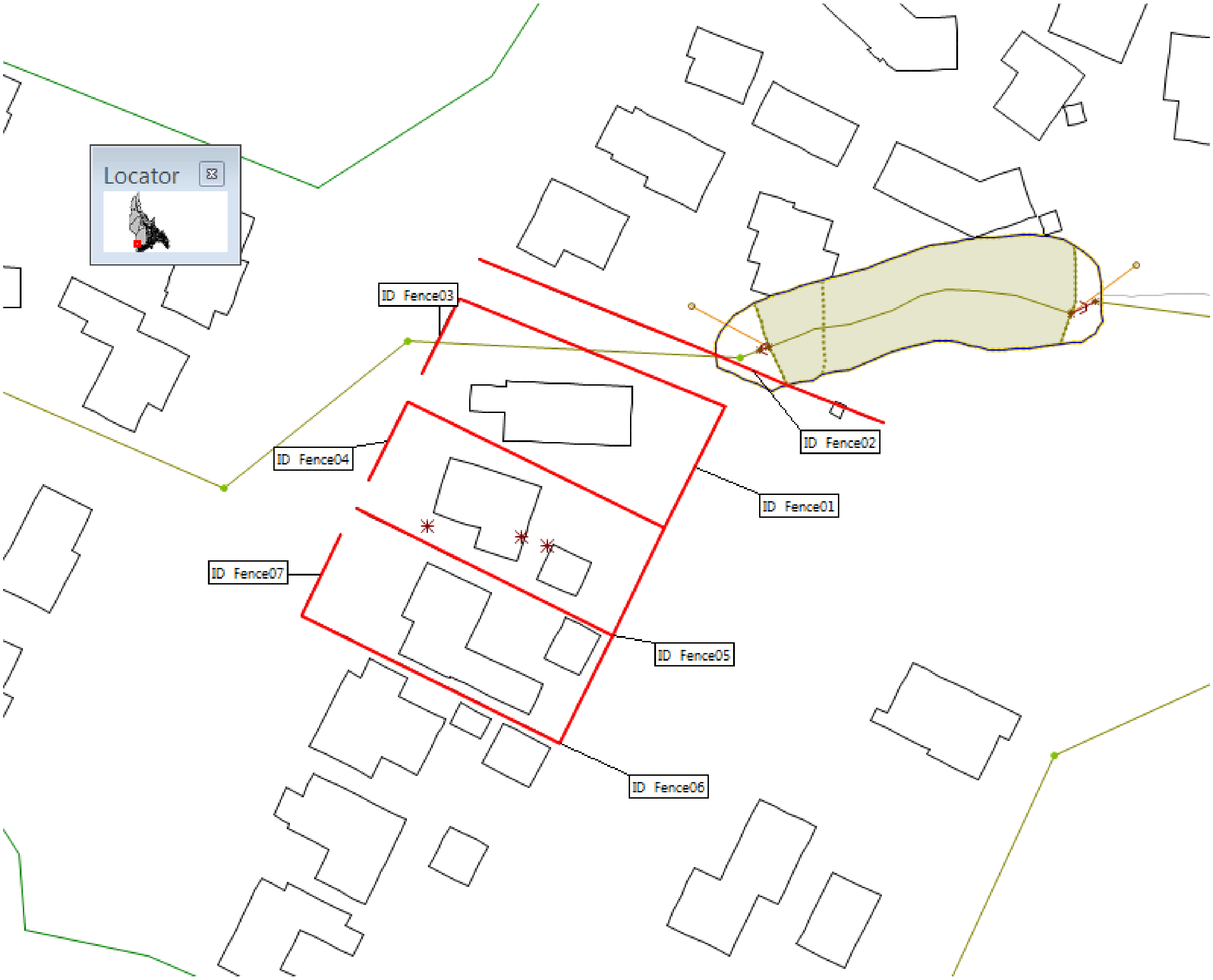


Figure 16 Fences Included in model

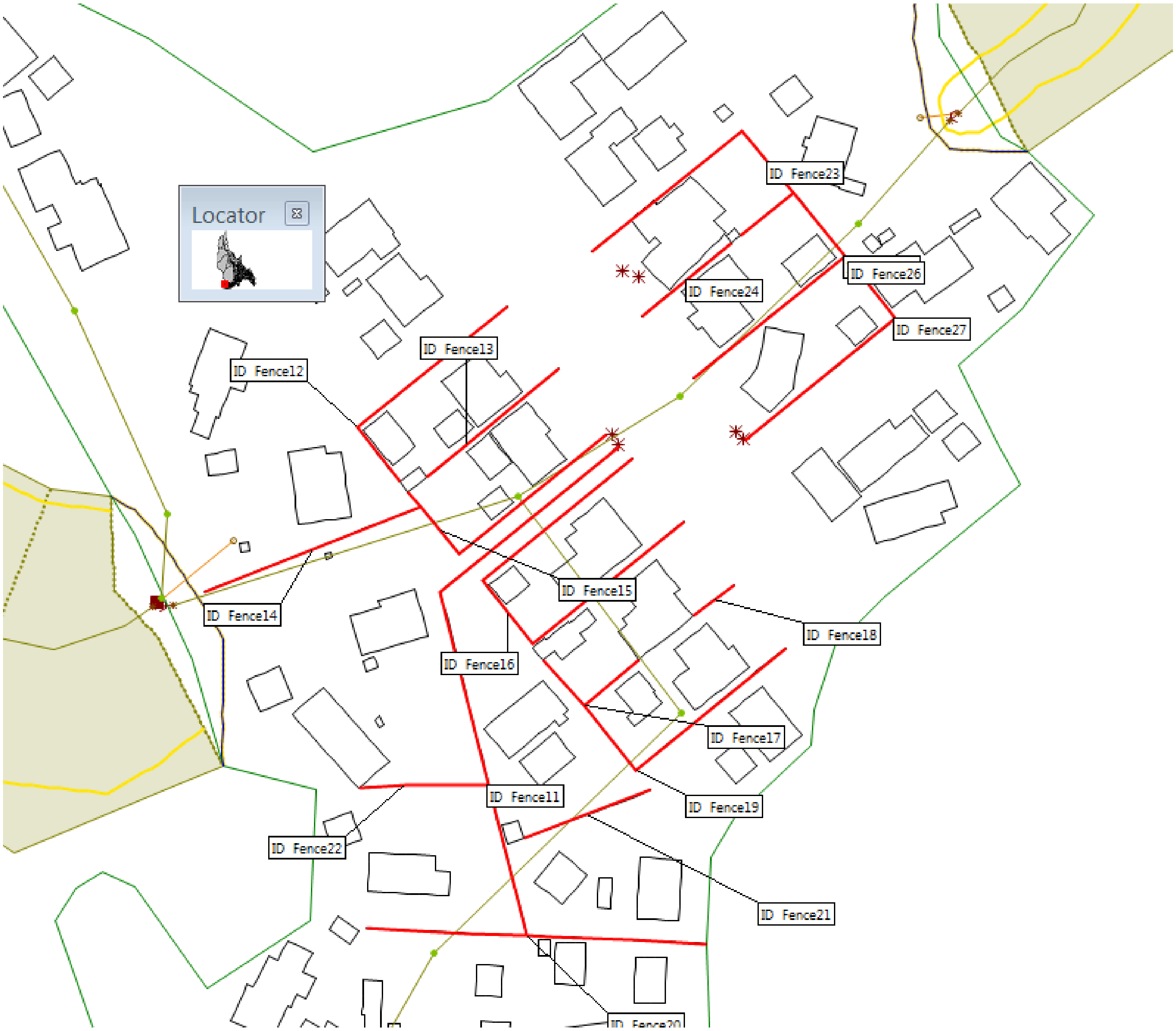


Figure 17 Fences added in model

Most of the 2D mesh roughness is defined for roads and remaining parcel surfaces. Roads are defined with a manning roughness of n=0.025, and for any other portion of the 2D mesh a manning roughness of n=0.080 was used, as suggested by the AC Modelling Specs for urban residential parcel

3.4.4.4 OTHER STRUCTURES

Other structure coefficients are mainly orifice and weir coefficients, and bank discharge coefficient. These were kept inside standard ranges as suggested by literature and AC Specs:

- Weirs Cd=0.8 – 1.0
- Circular weirs: Cd=0.50 – 0.60
- Orifice: Cd = 0.7 – 1.0

- Bank Cd = 0.7 – 1.0. If large obstructions are present, lower values would apply.
- Irregular weirs (mainly 1D over road flow): Cd = 1.0.

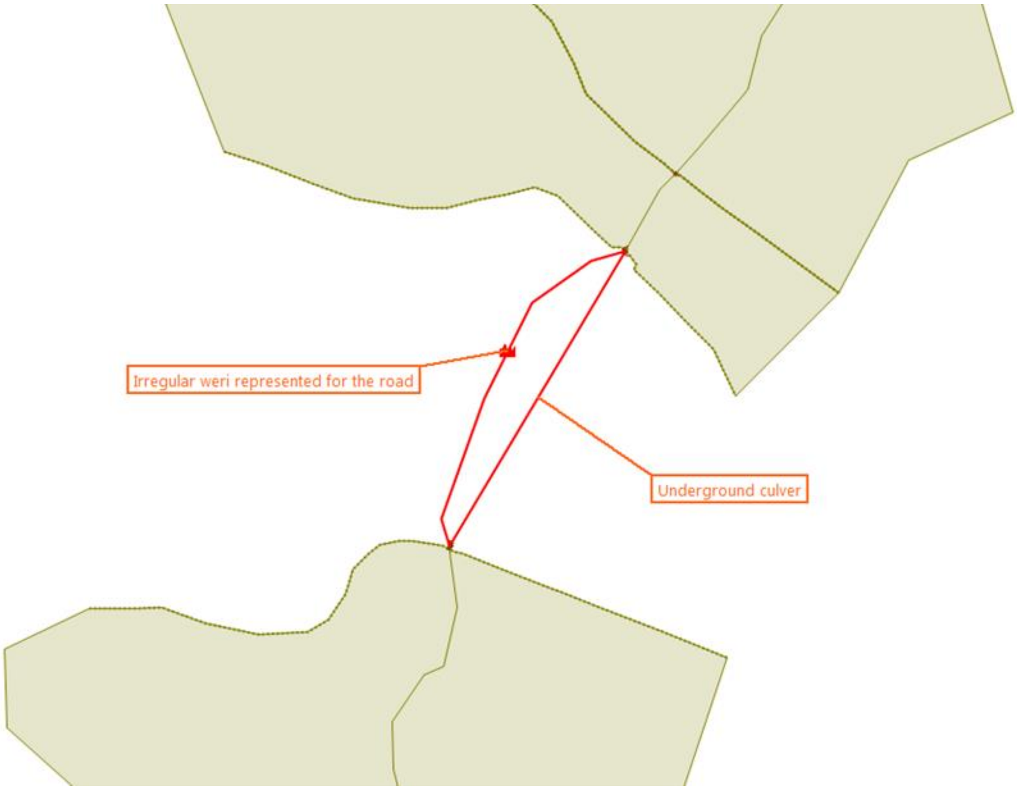


Figure 18 Typical 1D road culvert with irregular weir

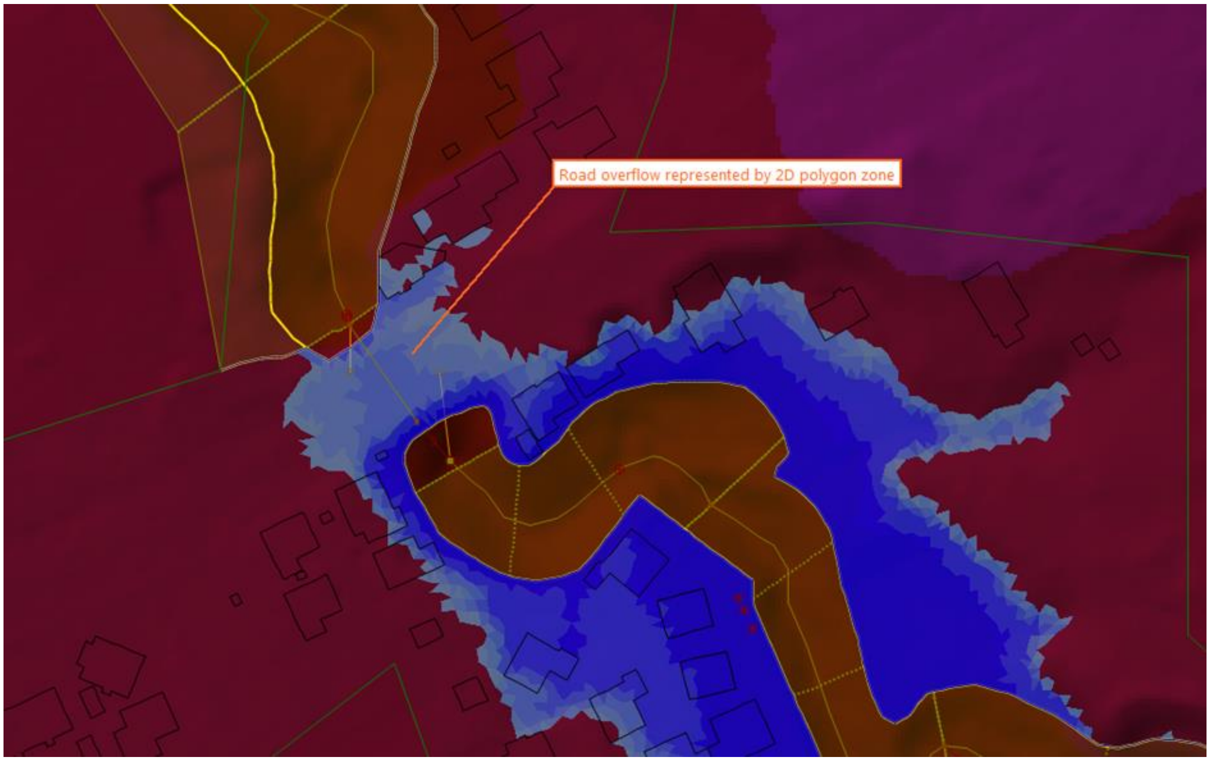


Figure 19 2D road setup

3.5 BOUNDARY CONDITIONS

3.5.1 RAINFALL DATA

The design rainfall storm profile has been developed in accordance with the AC TP108 methodology and Stormwater Flood Modelling Specifications (Auckland Council, November 2011) for the 2, 5, 10, 20, 50 and 100-year design events with and without climate change. Standard hydrographs were applied to all sub-catchments. No aerial reduction factors were applied. . The table below summarize the rain depths for all ARI events.

Table 11 24hr rainfall depth used for Whau FWM model

ARI event, years	Whau Min 100ARI 24hr rain depth, mm	Whau Max 100ARI 24hr rain depth, mm	2.1o Climate Change %	Whau Rain depth mm	Whau Rain depth+CC, mm
2	77	85	9.0	83	91
5	105	115	11.3	113	126
10	125	135	13.2	133	151
20	140	152	15.1	150	172
50	165	180	16.8	177	207
100	180	200	16.8	196	229

3.5.2 TIDAL DATA

The future tidal boundary condition is set to 2.57mRL, which consists on the LINZ MHWS level plus 1m of standard increment for climate change. This value was confirmed with AC as the standard tidal condition for the Waitemata Harbor and used for future events. 1.57mRL was used for existing climate events.

3.6 MODEL LIMITATIONS AND ASSUMPTIONS

3.6.1 LIMITATIONS

There are inherent limitations to the model and model results. These naturally occur due to the available data and the nature of the numerical resolution. Most of the data uncertainties were minimized by confirming the AC GIS database through survey and justified estimations. The specific details regarding these decisions are described in the relevant sections.

The validation event provides further assurance of the quality of the model, minimizing the uncertainties of parameters such as roughness, culvert inlet losses and other key coefficients relevant to the validation process.

Regardless of these efforts, there are still uncertainties related to the source data, which affect the validation and data gap analysis, such:

- Survey and GIS data accuracy.
- Rain gauge coverage and accuracy
- Debris flood survey accuracy (survey done 2-5 days post floods)
- No flow records available
- Unknown level of obstruction of culverts during validation event.
- Unknown antecedent soil moisture conditions for the validation event

The numerical resolution and model setup for each proposed optioning exercise will need to be evaluated as to whether the model set up will return results that are correctly approximated. For example, areas where additional detail may need to be added to test options such as additional pipes or replacement pipes. The current sub-catchment set up will need to be evaluated and adjusted to assure the flow is appropriated correctly.

The Auckland Council Specifications have been followed with the exceptions listed in this report. This should provide consistency for future users of this model.

Other limitations are related to the accuracy of certain type of objects approximating reality. Building and fences are examples. Building footprints are described by porous polygons accounting for the limited storage at buildings footprints, as well as the fact that they are not entirely impervious obstruction, as they let flows pass through in a large portion of the buildings The description has some limitations, as the fact that the water levels might be slightly lower than the surrounding areas, as the head required to pass through the walls. Similar examples are fences, which were only included as they were found to be important in some locations. They were used as consequence of the validation/calibration event. Fences are in most cases partially impervious, letting a large portion pass through, the range of its porosity might be wide, and as general assumption it was assumed to be between 40 to 60% pervious (or in other words: 60 to 40% impervious).

3.6.2 HYDROLOGICAL MODEL ASSUMPTIONS

The general standard assumptions inherent to using the AC Specification and TP 108 apply to this model. Rainfall runoff is generated using the SCS unit hydrograph method with initial abstractions of 5mm for impervious areas and 0mm for pervious areas.

The notable assumption in the hydrological model is the sub-catchment break down, which defines the size and time of concentration of the sub-catchments. Large sub-catchments outside of the hydraulic model extent (such Te Atatu South and Manawa catchments) are simplified and described as large hydrological catchments discharging directly into the Whau estuary. These sub-catchments do not contain the main hydraulic features, such storage and constriction, which affect the runoff hydrograph.

Further details are available in the Hydrological Model section of this report.

3.6.3 HYDRAULIC MODEL ASSUMPTIONS

Modelling assumption meet the agreed specification. Head losses are notable assumptions of the hydraulic model. The uncertainty related to these losses have been reduced by the methodology of utilizing pipe type and shape to set the associated losses. Also, critical pipes were visited onsite to determine reasonable associated losses. Photos are georeferenced in the model. Pipe losses do not change for future development scenarios. No blockages were considered for this model. Inlet and outlet nodes were utilized for culvert to assure they perform well hydraulically. Topography is assumed to not change for future land use.

- Pipes have no blockages,
- Pipe state will remind unchanged over time,
- Stream sections will remind unchanged over time,
- Ground surface has no changes over time.
- Vegetation (which impact in the river roughness) does not change over time.

River roughness is likely the most impactful assumption. River roughness values were estimated based on the land coverage, aerial photograph and site photos, as described in the section **Error! Reference source not found.** of the chapter Model Build of this report.

3.6.4 INITIAL CONDITIONS

- ICM version 7.5
- Simulation Period: 00:00 to 18:00 (18hrs run for design events)
- Dt0 = 10 seconds, ICM engine simulates then with dt = 0.01s to 10s as required.
- Mesh created from 1m grid 2013 LiDAR DEM
- Flooding and Drying Depth – 0.001 and 0.001 m respectively;
- Results saved at an interval of 5 minutes.
- Models were run on AC computers with GPU (PC15), producing stable and reliable model outputs.

3.7 QUALITY ASSURANCE

3.7.1 TP 108 CHECK

Individual sub-catchments were checked against manual TP108 calculations. Most of estimations are well inside the ±5% error, and just a hand full of slightly over. The TP108 hydrological model is found to be well represented.

3.7.2 ALANBROOKE PI MODEL CHECK

The Alanbrooke PI Model is a model of the lower river catchment. As requested by AC staff it was used to compare and analyze possible uncertainties within both models.

It is important to note that the Alanbrooke Model uses inflow captured from the RFHM at about 700m upstream of the Great North Rd Bridge. Figure 12 and Figure 13 show the comparison between the Whau FWM model results (MPD scenario), and the various scenarios tested for the Alanbrooke PI Model.

The figures display the following aspects of interest:

- The Whau FWM peak flow arrives later and it is smaller with similar volumes. This is due to the additional upper storage, which is not fully utilized in the RFHM. Depressions are fully filled in the RFHM per modelling criteria.

- The water levels at the Ash St Bridge are sensitive to the river roughness. This confirms the findings of the sensitivity tests completed for the Whau FWM.

- The peak water level for the Whau FWM is nearly the same than the Alanbrooke base model. This conclusion should account for the two previous statements, as both: higher roughness, and lower peak flows; apply to the Whau FWM results.

Overall, the analysis is consistent with expectations, and the Whau FWM is considered well justified with reliable outputs.

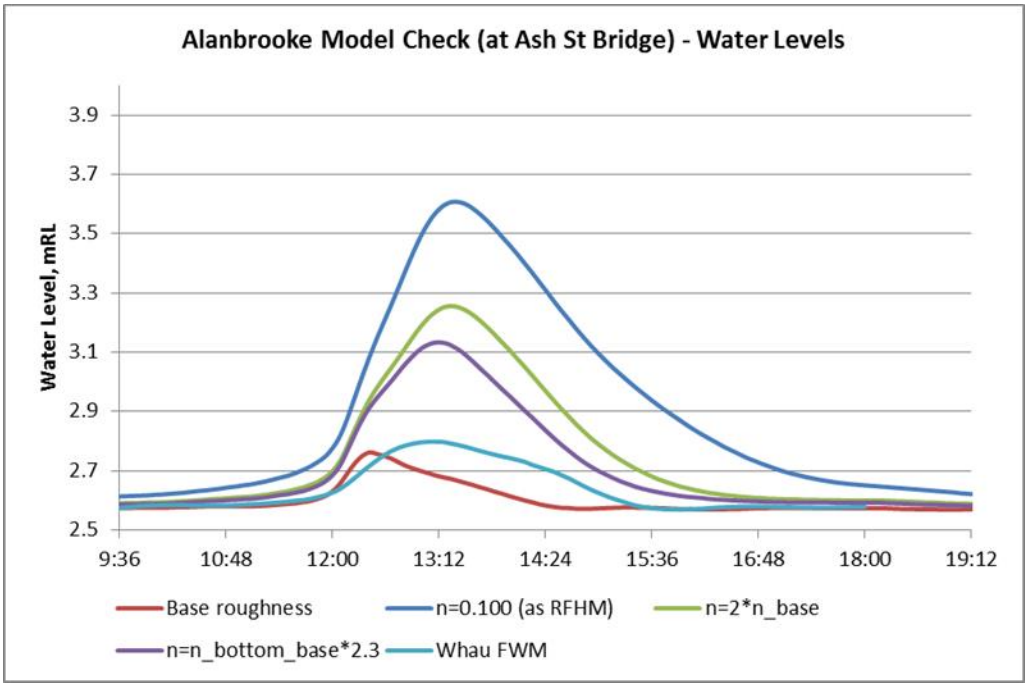


Figure 20 Alanbrooke Model checks. Water Levels

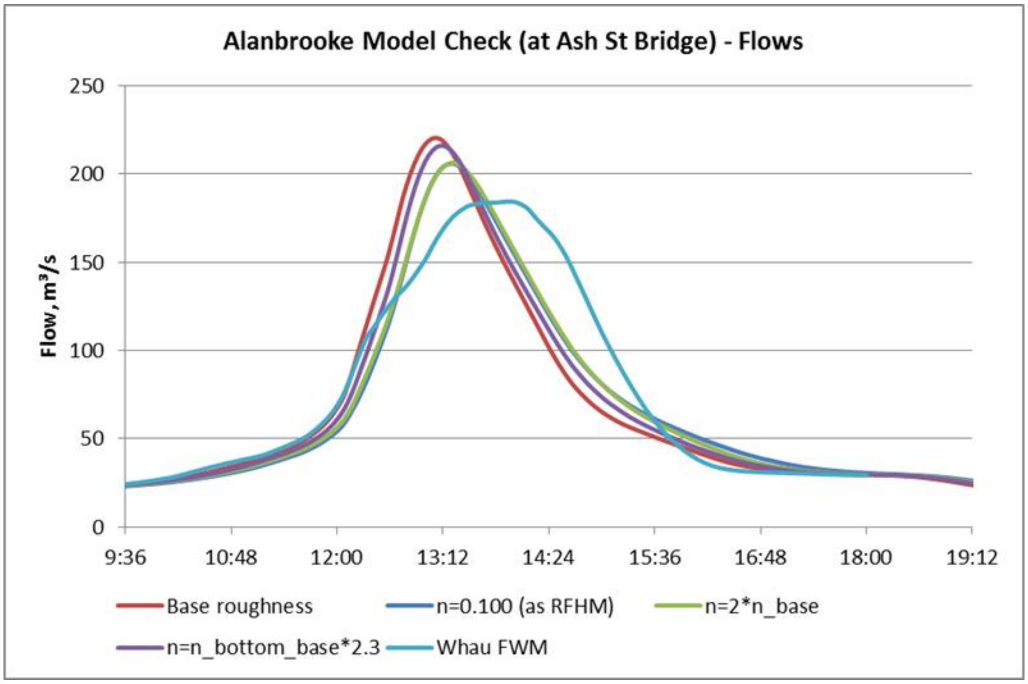


Figure 21 Alanbrooke Model checks. Flows

4 VALIDATION AND SENSITIVITY ANALYSIS

4.1 12TH MARCH 2017 VALIDATION

A validation event was requested for the 12th March 2017. Which appears to be just exceeding the existing 100-year ARI. The model considers 4 rain gauges, 1 tidal gauge, and several flood levels, mainly from debris floods surveyed few days post floods. The gauges are listed below:

Table 12 Gauge stations used for the Validation event of 12th March 2017

Gauge Station	Type	X_NZTM, m	Y_NZTM, m
Avondale Racecourse Rain	Rain	1750345	5914938
Cutler Park New Lynn	Rain	1749991	5912354
Harmel Rd WCC Pump Stn	Rain	1747820	5915559
Whau @ Mt Roskill Substn Rain	Rain	1753684	5913432
Auckland Harbour (AUCT)	Tide	1759290	5922360

The model was validated to the greatest extent possible with the limited data available. Soil B and C are present in the catchment and appropriately distributed for the Validation run. Base Existing and MPD scenarios use the dominate soil type. When reviewing the validation, the following uncertainties should be considered:

- Rain gauge coverage and accuracy
- Debris flood survey accuracy (survey done 2-5 days post floods)
- No flow records available
- Unknown obstruction of culverts, as well as "no culvert blockage" AC criteria to define flood risk.
- Antecedent moisture conditions

A validation is considered successful when the difference in water level was predicted within 300mm (as defined in AC Stormwater Specifications (Nov 2011) of the surveyed levels. The current validation mostly met this criteria with a few exceptions. Further analysis was undertaken to understand these areas of discrepancies. Most discrepancies can be attributed to the uncertainties listed above. The exceptions are well documented in section 3.1.

The validation event started primarily around 10am the 12th March 2017, with light rainfall occurring during the previous 24-hour period. The summer conditions allow for a quick drainage of moisture in the soil, and an average wetness (wet index Type II) should represent the conditions found on the storm of 12th March 2017. The model simulation starts at 6 am the 12th March 2017 to account for some of the light rainfall, and the higher tide levels, both experienced before the storm's heavier rainfall began 10 am. The heavy rainfall lasted for approximately 2hours. The simulation was run for 10 hours (until 4pm) to capture the storm's recession.

4.2 VALIDATION RESULTS

Validation results are shown in Table 13 and Table 14.

Table 13 Surveyed floods vs modelled water level. Validation 12th March 2017. 1D objects.

Point ID	Flood Z, mRL AVD46	Point Type	Max Depth (m)	Max Elevation (m AD)	Err	Comments
20170315_3052	5.25	2D Net	0.00	4.945	-0.305	Within parameters except one point 5 mm out
20170315_3053	5.227	2D Net	0.00	4.945	-0.282	
20170315_3054	5.237	2D Net	0.00	4.945	-0.292	
20170317_4004	41.556	2D Net	0.12	41.118	-0.438	One point of non-conformance, however, surrounding points within parameters.
20170317_4005	41.31	2D Net	0.464	41.22	-0.090	
20170317_4006	41.594	2D Net	0.561	41.303	-0.291	
20170317_4007	45.384	2D Net	0.319	45.644	0.260	Slightly overestimated, but nearby points support average model WL
20170317_4008	45.461	2D Net	0.227	45.644	0.183	
20170317_4009	45.451	2D Net	0.292	45.606	0.155	
20170317_4010	45.358	2D Net	0.404	45.636	0.278	
20170317_4011	45.295	2D Net	0.383	45.649	0.354	
20170317_4012	45.375	2D Net	0.518	45.65	0.275	
20170317_4020	35.369	2D Net	0.324	35.578	0.209	Within parameters
20170317_4021	35.213	2D Net	0.183	35.473	0.260	
20170317_4025	37.633	2D Net	1.361	37.461	-0.172	Within parameters
20170317_4027	37.17	2D Net	0.131	37.082	-0.088	
20170317_4028	37.476	2D Net	0.00	37.242	-0.234	
20170317_4029	37.142	2D Net	0.029	37.182	0.040	
20170317_4032	30.18	2D Net	0.095	30.156	-0.024	
20170317_4024!	37.604	2D Net	1.208	37.46	-0.144	
20170317_4026!	37.588	2D Net	1.32	37.459	-0.129	

Table 14 Surveyed floods vs modelled water level. Validation 12th March 2017. 2D objects

Point ID	Flood Z, mRL AVD46	Point Type	Max Depth (m)	Modelled WL, mRL	Error, m	Comments
20170315_3003	1.517	1D Net	2.884	1.786	0.269	Conservative tail water (mainly tide dependant)
20170315_3004	1.472	1D Net	2.886	1.788	0.316	
20170315_3032	2.459	1D Net	3.606	2.742	0.283	Conservative tail water (roughness dependant)
20170315_3033	2.348	1D Net	3.550	2.723	0.375	
20170315_3034	2.554	1D Net	3.441	2.636	0.082	
20170315_3035	4.114	1D Net	3.634	3.768	-0.346	Error improved significantly with Validation. Zone of turbulence and WL might not be accurate.
20170315_3036	4.31	1D Net	3.860	4.011	-0.299	
20170315_3037	4.15	1D Net	4.066	4.600	0.450	These points of non-conformance are supported by surrounding points which are within 300mm.
20170315_3038	4.197	1D Net	4.060	4.595	0.398	
20170315_3039	4.219	1D Net	4.054	4.589	0.370	
20170315_3040	4.108	1D Net	3.931	4.469	0.361	One point of non-conformance supported by surrounding points within 300mm
20170315_3041	4.257	1D Net	3.759	4.394	0.137	
20170315_3042	4.326	1D Net	3.546	4.414	0.088	
20170315_3043	4.405	1D Net	3.546	4.414	0.009	
20170315_3044	5.234	1D Net	6.021	6.278	1.044	It's likely debris flood levels are underestimated. Several sensitivity tests and analysis done. Best outputs achieved.
20170315_3045	5.31	1D Net	5.907	6.179	0.869	
20170315_3046	5.63	1D Net	6.149	6.389	0.759	
20170315_3048	4.743	1D Net	3.816	4.883	0.140	error improved significantly points are within parameters
20170315_3049	4.958	1D Net	3.652	4.977	0.019	
20170315_3050	4.262	1D Net	2.780	4.336	0.074	
20170315_3051	4.272	1D Net	2.777	4.334	0.062	
20170315_3095	9.504	1D Net	2.628	9.659	0.155	
20170315_3096	15.387	1D Net	2.162	15.286	-0.101	
20170315_3097	16.007	1D Net	2.406	16.040	0.033	
20170315_3098	16.029	1D Net	2.382	16.048	0.019	
20170315_3099	16.187	1D Net	2.241	16.354	0.167	
20170315_3100	16.252	1D Net	2.122	16.330	0.078	
20170315_3101	16.204	1D Net	2.000	16.335	0.131	
20170315_3102	16.476	1D Net	2.188	16.959	0.483	Driveway bridge described with roughness. Conservative results.
20170315_3103	16.542	1D Net	2.083	17.023	0.481	
20170315_3104	16.883	1D Net	1.899	16.990	0.107	

Table 15 Table 11. Surveyed floods vs modelled water level. Validation 12th March 2017. 2D objects (continuation)

Point ID	Flood Z, mRL AVD46	Type	Max Depth (m)	Modelled WL, mRL	Error, m	Comments
20170315_3106	20.179	1D Net	2.210	20.116	-0.063	
20170315_3107	20.007	1D Net	2.202	20.101	0.094	
20170315_3108	20.427	1D Net	2.244	20.314	-0.113	
20170315_3109	20.515	1D Net	2.124	20.331	-0.184	
20170315_3110	20.586	1D Net	2.132	20.330	-0.256	
20170315_3111	20.373	1D Net	2.108	20.336	-0.037	
20170317_4013	40.052	1D Net	2.674	39.980	-0.072	Two points of non-conformance. Nearby points support average model WL
20170317_4014	39.856	1D Net	2.843	39.990	0.134	
20170317_4015	39.757	1D Net	3.474	40.078	0.321	
20170317_4016	39.743	1D Net	3.584	40.095	0.352	
20170317_4023	30.836	1D Net	1.842	30.442	-0.394	slightly off model river location
20170317_4031	30.28	1D Net	4.683	30.193	-0.087	

The following figure shows examples of the flood survey points.

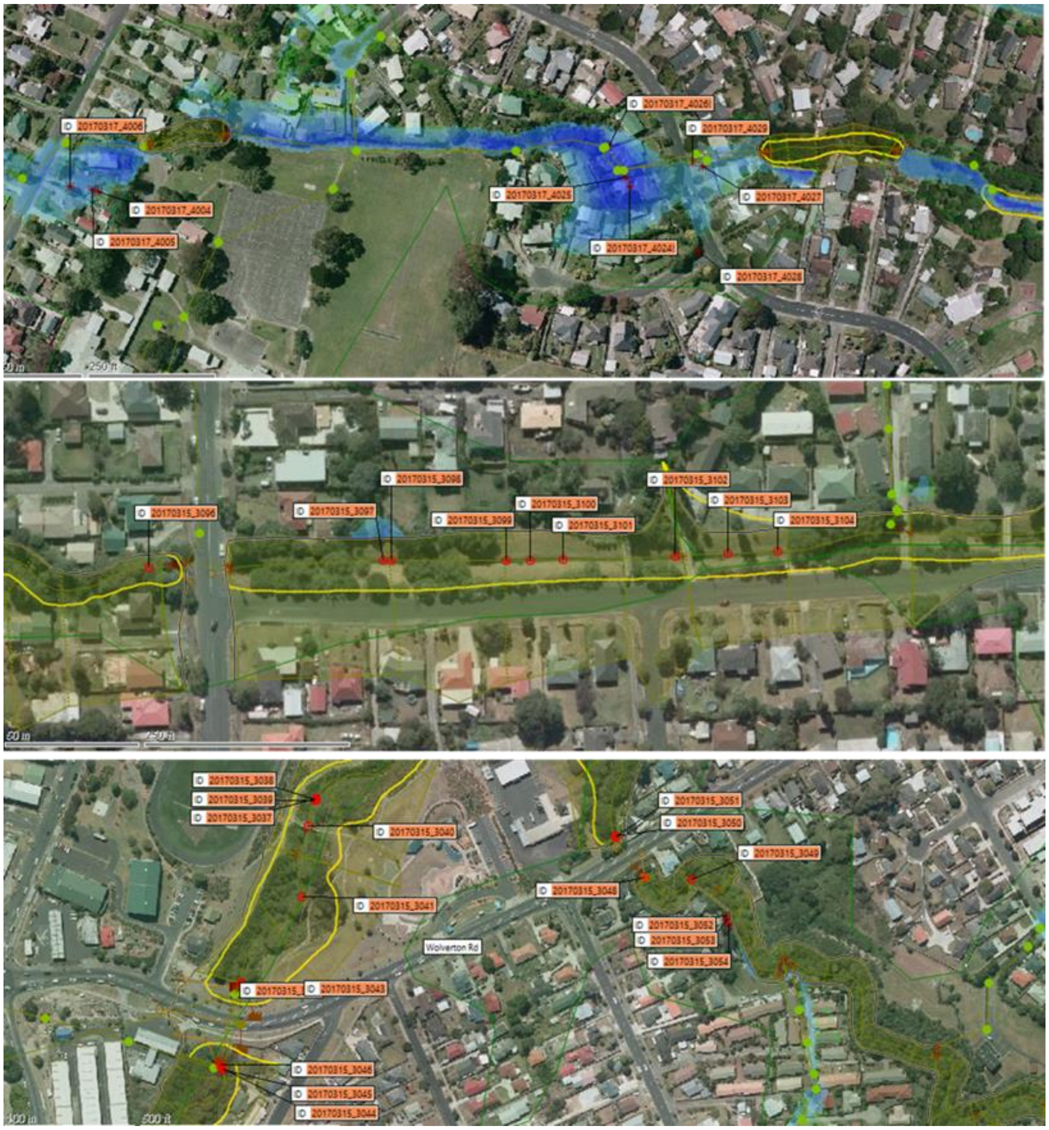


Figure 22 Survey flood points for validation run (example of few locations)

4.3 MASS ERROR

Water balance error was checked for all 1D and 2D objects. The overall error is well under the required 5% in the AC Stormwater Specifications (Nov 2011). The table below summarized the water balance and mass error check for the MPD scenarios for the 10yrsCC and 100yrsCC design events.

Table 16. Volume balance and mass error for MPD 10yrsCC

MPD 10yrsCC	
Item	**Value**
Initial Storage Volume, m3	8474445
Runoff Volume (on sim), m3	3658408

Outflow Volume (on sim), m3	3035916
Final Storage Volume, m3	9058710
Mass Error, m3	-38226
Mass Error, %	**-1.0%**
Total Rainfall (on sim)	4653358
Runoff coefficient (on sim)	**0.786**

Table 17. Volume balance and mass error for MPD 100yrsCC

MPD 100yrsCC	
Item	**Value**
Initial Storage Volume, m3	8474445
Runoff Volume (on sim), m3	5909986
Outflow Volume (on sim), m3	5447147
Final Storage Volume, m3	9102723
Mass Error, m3	165439.1
Mass Error, %	**2.8%**
Total Rainfall (on sim)	7075665
Runoff coefficient (on sim)	**0.835**

4.4 SENSITIVITY ANALYSIS

Sensitivity analysis comparisons are at the Ash St Bridge, which is the actual Whau catchment outlet as defined by AC, and the location of the previous (superseded) model extent.

4.4.1 IMPACT OF ESTUARY

It compares two scenarios which only difference is that the outlet of the model is at Ash St Bridge and SH16 respectively. Comparison is done for the MPD, 10-year CC and 100-year CC, with 2.57mRL as tide.

Figure 13 and Figure 14 is a comparison of the water levels and flows respectively. Values are taken just downstream of the Ash St Bridge. The figures show significant impact on the estuary. For this the reason the final model sub-catchment was extended to SH16.

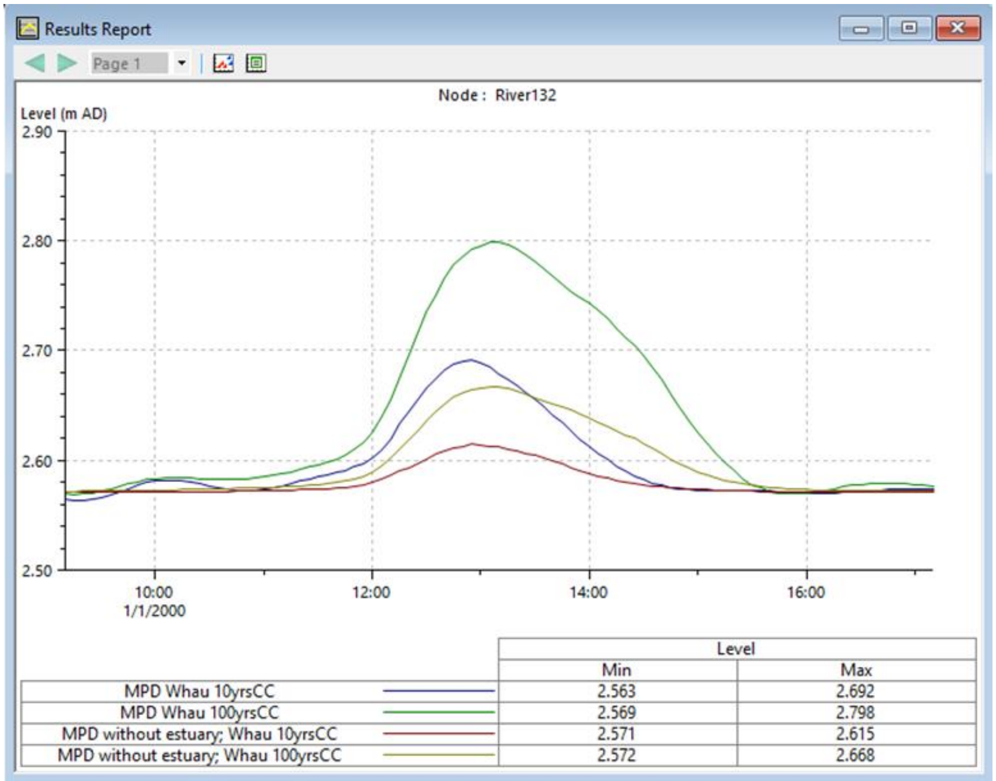


Figure 23 Sensitivity Test. Impact on Estuary. Water Levels at Ash St Bridge

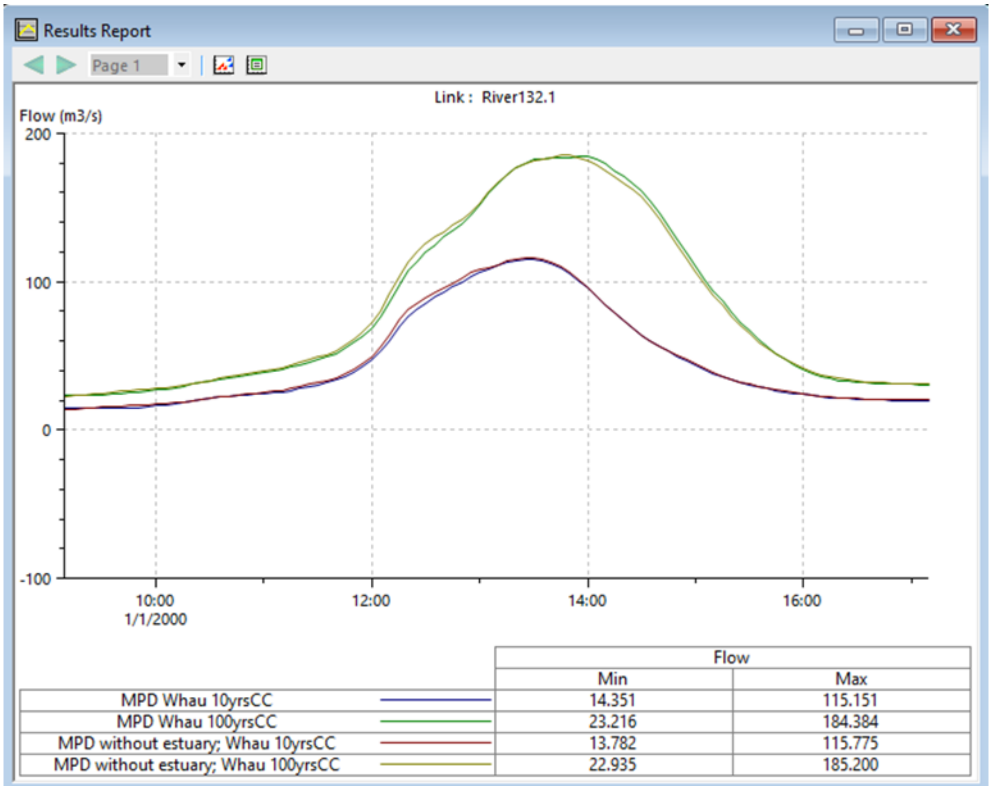


Figure 24 Sensitivity Test. Impact on Estuary. Flows at Ash St Bridge.

4.4.2 IMPACT OF ROUGHNESS

The following two scenarios only difference is a 33% reduction of the river roughness. Both scenarios include the Whau estuary, with outlet at SH16. The base scenario corresponds to the validated network. Comparison is done for the MPD, 10-year CC and 100-year CC, with 2.57 mRL tidal level.

Figure 8 and Figure 9 is a comparison of the water levels and flows just downstream of the Ash St Bridge. The figures show significant sensitivity to the river roughness. This is especially true closer to the model outlet confirming the estuary plays a significant role impacting downstream water levels. The validation event allowed minimization of the uncertainties related to the manning roughness, as this parameter was found to be the most critical to achieve a well-represented 12th March 2017 flood event.

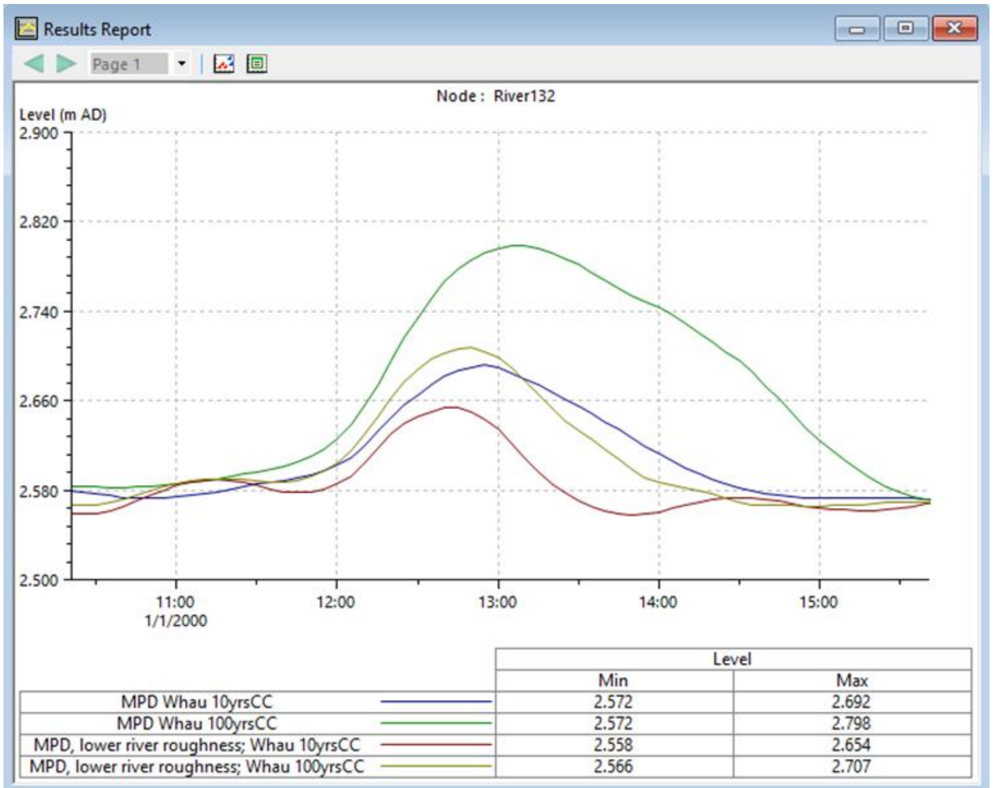


Figure 25 Sensitivity Test. Impact of River Roughness. Water Levels at Ash St Bridge.

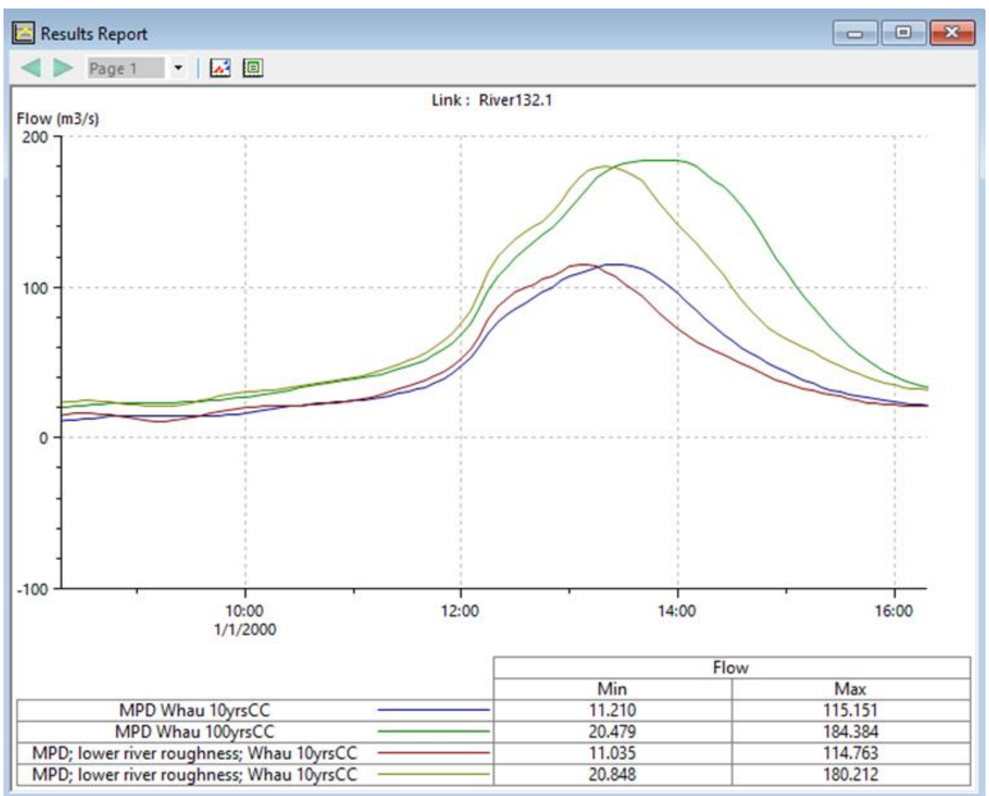


Figure 26 Sensitivity Test. Impact of River Roughness. Flows at Ash St Bridge.

4.4.3 IMPACT OF SOIL DEFINITION

The following two scenarios only difference is the dominant soil type. These compare the differences of a catchment hydrology that has one dominant soil type C vs the more detailed combination of soil types B and C. The combination of soil types was required to achieve a realistic validation run, and the dominant soil type C is then overwritten to be applied for the final ED and MPD scenarios. Both scenarios include the Whau estuary, with outlet at SH16. Since this analysis involved the existing land use scenario, the comparison is done for the existing development only, with 10-year CC and 100-year CC events, and 2.57 mRL tidal condition.

Figure 10 and Figure 11 is a comparison for water levels and flows just downstream of the Ash St Bridge. The figures show little impact on water levels, flows and total volumes. This is particularly true for long duration storm events, such as the 24 hr. TP108 rain profile, which when applied to the Whau Catchment allow saturation of the runoff surface before the peak intensity arrives. However, this was found to be critical for the validation event, which only lasted 2-3 hours, and producing noticeable difference between the two scenarios. Therefore, the combination soil type was adopted for the final calibration run.

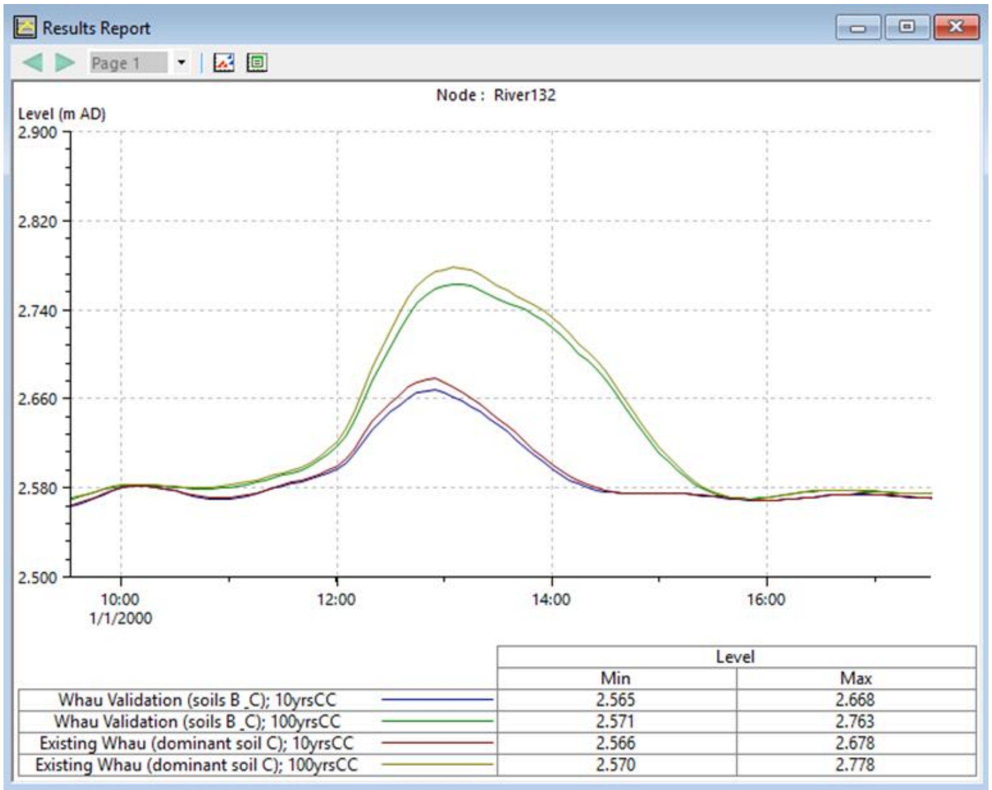
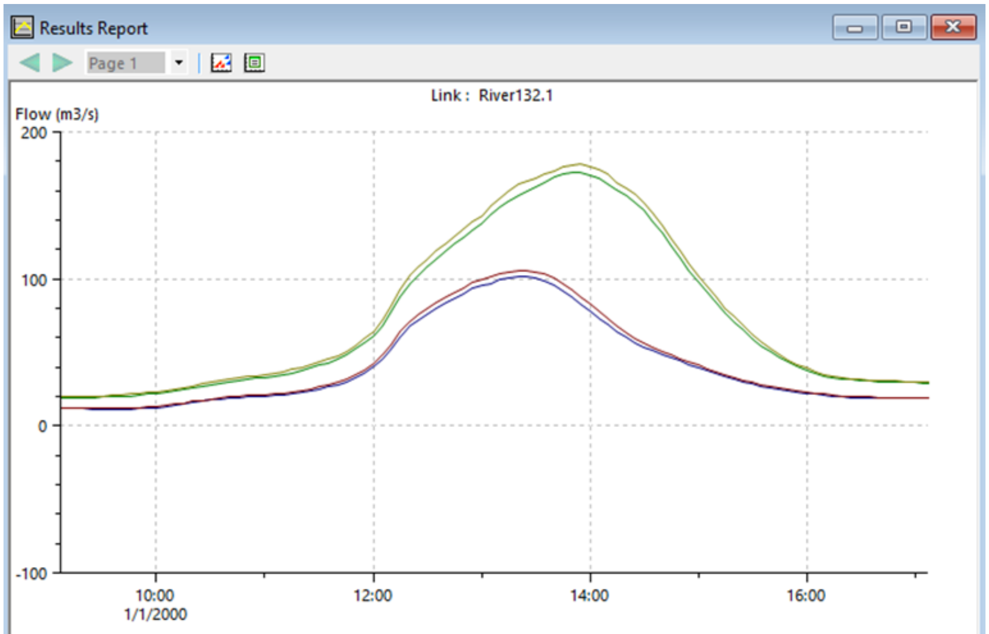


Figure 27 Sensitivity Test. Impact of Soil Type in Hydrology. Water Levels at Ash St Bridge



	Flow	
	Min	Max
Whau Validation (soils B_C); 10yrsCC	11.311	101.208
Whau Validation (soils B_C); 100yrsCC	19.149	172.535
Existing Whau (dominant soil C); 10yrsCC	11.854	105.805
Existing Whau (dominant soil C); 100yrsCC	19.904	178.000

Figure 28 Sensitivity Test. Impact of Soil Type in Hydrology. Flows at Ash St Bridge.

5 SYSTEM PERFORMANCE AND MAPPING

5.1 MODEL SCENARIOS AND SIMULATIONS

The table below summarizes the scenarios simulated

Table 18 Simulation matrix summary

Scenario	Events	Climate Change	Tide	Duration
Validation	12-Mar-17	No	Recs	3 hrs
Existing	TP108 design event 2, 5, 10, 20, 50, 100yrs	No	1.57mRL	18hrs
MPD	TP108 design events 2, 5, 10, 20, 50, 100yrs	Yes	2.57mRL	18hrs

Additional sensitivity tests were completed, which are summarized below.

Table 19 Sensitivity test simulation matrix

Scenario	Comments	Event
Base Validation	Model outlet at SH16; combination of Soil C and B; existing development.	10yrCC and 100yrCC, with tidal WL = 2.57mRL (MHWS+1m of climate change)
Base Existing	Model outlet at SH16; dominant soil C; existing development.	
Base MPD	Model outlet at SH16; dominant soil type C, MPD.	
No Estuary MPD	Same as Base MPD, without estuary. i.e. tidal condition is applied at Rata St Bridge.	
River Roughness	Same as Base MPD with river roughness reduced to about 2/3 of validation values.	

5.2 FLOODPLAIN MAPPING

For this project scope, only the 100-year MPD 'future' ARI floodplain shape extent is required as a deliverable. The flood extent shape is developed from the model results and processed in GIS following the latest AC Flood Mapping rules and tools, including the automated tool for analysis the impact on building footprints and properties. The flood plain extent shape is delivered as a GIS shape file, together with all supporting shapes used in the process, including the catchment extent, flow cross sections depth/level raster, among others. The whole set of shape files are delivered as an ArcGIS package (mpk) for easy access and review by the client.

Additionally, a list of flooded properties and survey details is included in Appendix 7.3. The appendix includes a brief explanation of the method and assumptions used for the analysis.

The floodplain did change appreciably from the previous ICS published floodplain. As the previous model was not investigated it is difficult to explain the differences in the floodplain. Likely sources are the change in modelling specification, the higher resolution hydraulic modelling, the higher resolution hydrologic model, changes in roughness and/or changed in the design rainfall depths. The current FWM does differ from the previous RFHA performed by Ewaters in the predictable manner. This is to say the floodplain is slightly smaller than the RFHA which is to be expected as the FWM is less conservative in many assumptions.

5.3 FINAL MODEL RESULTS

Model results are available for scenarios shown in Table 7 and Table 8. The Whau FWM scope required the existing network to be run for the ED 2, 5, 10, 20, 50 and 100-year events without climate change and MPD 2, 5, 10, 20, 50 and 100-year events all with climate change. These simulations results are to be processed in waterRide as part of the Whau FWM scope.

Model results are all available in the model files. The icmt file delivered for review contains scenarios for the 10yrsCC and 100yrsCC events, as well as the validation event.

5.4 PIPE CAPCITY

Pipe capacity was assessed based on two criteria. The first is when the pipe was full and assessed based upon the design event when the water level reached the pipe soffit. The second was overland flow. This criterion looked at when a pipe or culvert overtopped and began to flow overland downstream. The pipe capacity is defined by when the overland flow began. Therefore, pipes are determined to be "less than" the design storm year assessed. The 100-year capacity did not have overland flow.

Pipe diameter greater than 550 mm were assessed for system performance. The following table shows the summary results of the pipe capacity analysis. The full results are in Appendix 7.2. The analysis has been saved in the model and shapefiles are available for geospatial review of the information.

Pipe Capacity

	< 2 year	< 5 year	< 10 year	< 100 year	100 year	Total
Asset #	231	107	63	150	309	860
Asset%	26.9%	12.4%	7.3%	17.4%	35.9%	100.0%

The main pipe system shows just over a quarter of the culverts and pipes do not have 2-year capacity and just over a third have adequate capacity to serve the 100-year event. The results have been determined from the full model results and MPD scenarios.

6 CONCLUSIONS AND RECOMMENDATIONS

The Whau FWM is a validated model that accurately represents the flooding for the hydraulic model extents. The model matches the validation surveyed points well without significant differences in the flood levels examined for the validation event. Hydraulic structures have been well represented considering the level of detail of the framework model and information available.

During the model build, validation and analysis of design event simulation results, the Whau FWM revealed several aspects of interest regarding the hydraulic performance of the stormwater system and highlights the major flooding issues in the area.

The drainage system capacity and performance in the Whau is governed by the flow capacity of the bushy streams, culvert crossings and bridges. The system needs to be assessed as one system to optimize the capacity of the system whilst reducing the overall flood risk.

The hydrological and hydraulic analysis of the Whau system suggests that there is little storage within the Whau and minimal mitigation to offset the increased runoff due to development. The result is flash flood type conditions that will worsen as the catchment further develops and climate change brings increasingly intense storm events.

The Whau FWM offers a tool for assessing the key system limitations and will allow comprehensive and detailed assessment of mitigation and flood control options for the framework network.

The 100-year flood plain was also updated based on this validated model, providing a tangible tool for developers and planners in the catchment. The model itself has demonstrated to be useful during the emergency works and key development queries triggered by the large event of March 2017.

Following the completion of this project scope, it is recommended to utilize the Whau FWM model to set targets by determining suitable and reasonable capacity of the system. The model is suited to provide the necessary assessment, set targets and designs options to fit the growing demand of urban stormwater services.

6.1 PIPE CAPACITY OPTIMISATION

Pipe capacity can be improved in several areas of the catchment. It is recommended that an optimization study be undertaken to determine the effective sizing of the culverts in the river channel to improve hydraulic capacity. The optimization study should consider channel capacity, flood risk including people, buildings/homes and roadways, as well as potential detention in the upper catchment. It is crucial that the system is treated as a whole to assure that any increased flows associated with culvert upgrades can be handled by the downstream system and avoid shifting flood risk from one area to another.

6.2 SURVEY OF HOMES/STRUCTURES AT RISK

Finished floor level survey is critical for determining risk within the catchment. GPS survey has limitation as it requires clear line of site to satellites. Therefore, a combination of surveying is required using GPS to establish a base point and level to determine the floor elevation of the home that is being surveyed. This is standard practice of surveying today. Often the survey that is received does not detail the structure that is being surveyed and the associated points sent are usually located in a field or garden not at the structure, with addresses or descriptions omitted. This creates confusion as to which structure was surveyed and is a generally inefficient method for transferring data.

Ewaters received survey recently of homes at risk within the Whau catchment. The survey was of typical quality for finished floor elevations. Significant work was required to process the information from the survey and quality cannot be guaranteed as sufficient information was often not supplied to match the point surveyed to the structure surveyed. This is a common problem and should be remedied in the future.

It is recommended that GIS field capture is employed in the future in conjunction with the GPS survey. This will provide real time survey capture and quality can be assured as the surveyor completes the field and the information is updated in the cloud. Additional information can also be supplied simultaneously such as photos of the structure or other significant features that can assist the modelers and engineers in providing higher quality solutions. This will not only improve the quality of the survey but also reduce the overall cost of surveying, processing and use of the survey data.

7 REFERENCE

Auckland Council (2012), Draft Stormwater Rapid Flood Hazard Assessment Specifications, August 2012.

Auckland Council (2011), Stormwater Flood Modelling Specifications, November 2011.

Auckland Council (1999), Guidelines for Stormwater Runoff Modelling in the Auckland Region, TP108, April 1999.

Ewaters NZ (2016), Rapid Flood Hazard Modelling – Whau Catchment, Final Report and Modelling Data, November 2016.

Ewaters NZ (2016), Whau RFHM Roughness Sensitivity Tests, Memo report and relevant data, November 2016.

Connell Wagner Ltd (2005) Flood Hazard Mapping Report Avondale Integrated Catchment Study Stage 2B-1

Connell Wagner Ltd (2005) Flood Hazard Mapping Report Kinross Integrated Catchment Study Stage 2B-1

Connell Wagner Ltd (2005) Flood Hazard Mapping Report Whau Integrated Catchment Study Stage 2B-1

8 APPENDICES

8.1 LIST OF DELIVERED FILES

All files delivered are listed and described in the table below.

Table 20. List of deliverable files

Folder\File	Description
U:\COO\IES\STW\SW CAMP\SW CP\Waitemata\Whau\02 Flooding\ACPN 16010 MPO MDL Ewaters Whau East Framework Model 2017\Deliverables\Final Deliverables\	Final deliverables folder in AC server
…\1 ICM model	
Whau_FWM_final_06_11_2017.icmt	Model files. ICM and flags
Whau_FWM_Flags.csv	
…\2 Report	
Whau Framework Report Final V2.docx	Final Report based on Model Build and System Performance Assessment Report AC template.
…\3 MPD 100yrsCC Flood Extent	
New Flood Extent.shp	Whau FWM MPD 100yrs flood extent shp file
REVIEW_v2.mpk	ArcGIS package with all files used for mapping, including the automated tool for analysing impact on building footprints and properties. Further details in Figure 29.
…\4 WaterRide files	
DEM\rastert_whau_dem2013.wrr	Lidar 2013 as waterRide file format (raster)
ED 02yrs\Combined TIN\Whau_WR_TIN_ED_002yr.wrb	WaterRide dynamic results in TIN format (wrb)
ED 05yrs\Combined TIN\Whau_WR_TIN_ED_005yr.wrb	WaterRide dynamic results in TIN format (wrb)
ED 10yrs\Combined TIN\Whau_WR_TIN_ED_010yr.wrb	WaterRide dynamic results in TIN format (wrb)
ED 10yrs\Raster peak\Whau_ED_10yrs_mapd_peak_v2.wrr	WaterRide peak values in raster format mapped against Lidar2013 (wrr)
ED 20yrs\Combined TIN\Whau_WR_TIN_ED_020yr.wrb	WaterRide dynamic results in TIN format (wrb)
ED 50yrs\Combined TIN\Whau_WR_TIN_ED_050yr.wrb	WaterRide dynamic results in TIN format (wrb)
ED 100yrs\Combined TIN\Whau_WR_TIN_ED_100yr.wrb	WaterRide dynamic results in TIN format (wrb)
ED 100yrs\Raster peak\Whau_ED_100yrs_mapd_peak_v2.wrr	WaterRide peak values in raster format mapped against Lidar2013 (wrr)

Table 20. List of deliverable files (continuation)

Folder\File	Description
MPD 02yrsCC\Combined TIN\Whau_WR_TIN_MPD_002yrCC.wrb	WaterRide dynamic results in TIN format (wrb)
MPD 05yrsCC\Combined TIN\Whau_WR_TIN_MPD_005yrCC.wrb	WaterRide dynamic results in TIN format (wrb)
MPD 10yrsCC\Combined TIN\Whau_WR_TIN_MPD_010yrCC.wrb	WaterRide dynamic results in TIN format (wrb)
MPD 10yrsCC\Raster all timesteps\Whau_full_MPD_10yrsC_mapd.zip\Whau_full_MPD_10yrsC_mapd.wrr	WaterRide dynamic results (all time steps) in raster format mapped against Lidar2013 (wrr)
MPD 10yrsCC\Raster peak\Whau_MPD10yrCC_mapd_peak_v2.wrr	WaterRide peak values in raster format mapped against Lidar2013 (wrr)
MPD 20yrsCC\Combined TIN\Whau_WR_TIN_MPD_020yrCC.wrb	WaterRide dynamic results in TIN format (wrb)
MPD 50yrsCC\Combined TIN\Whau_WR_TIN_MPD050yrCCv2.wrb	WaterRide dynamic results in TIN format (wrb)
MPD 100yrsCC\Combined TIN\Whau_WR_TIN_MPD100yrCCv2.wrb	WaterRide dynamic results in TIN format (wrb)
MPD 100yrsCC\Raster all timesteps\Whau_Whole_MPD0100yrCC-mapd.zip\Whau_Whole_MPD0100yrCC-mapd.wrr	WaterRide dynamic results (all time steps) in raster format mapped against Lidar2013 (wrr)
MPD 100yrsCC\Raster peak\MPD Whau 100yrsCC_MPD-2D-mapd_v2.wrr	WaterRide peak values in raster format mapped against Lidar2013 (wrr)
...\5 Catchment boundary\	
Catchment_extent.shp	Revised catchment boundary polygon, for use in defining Flood Plain update extents, and for use in the Horizon Model Register

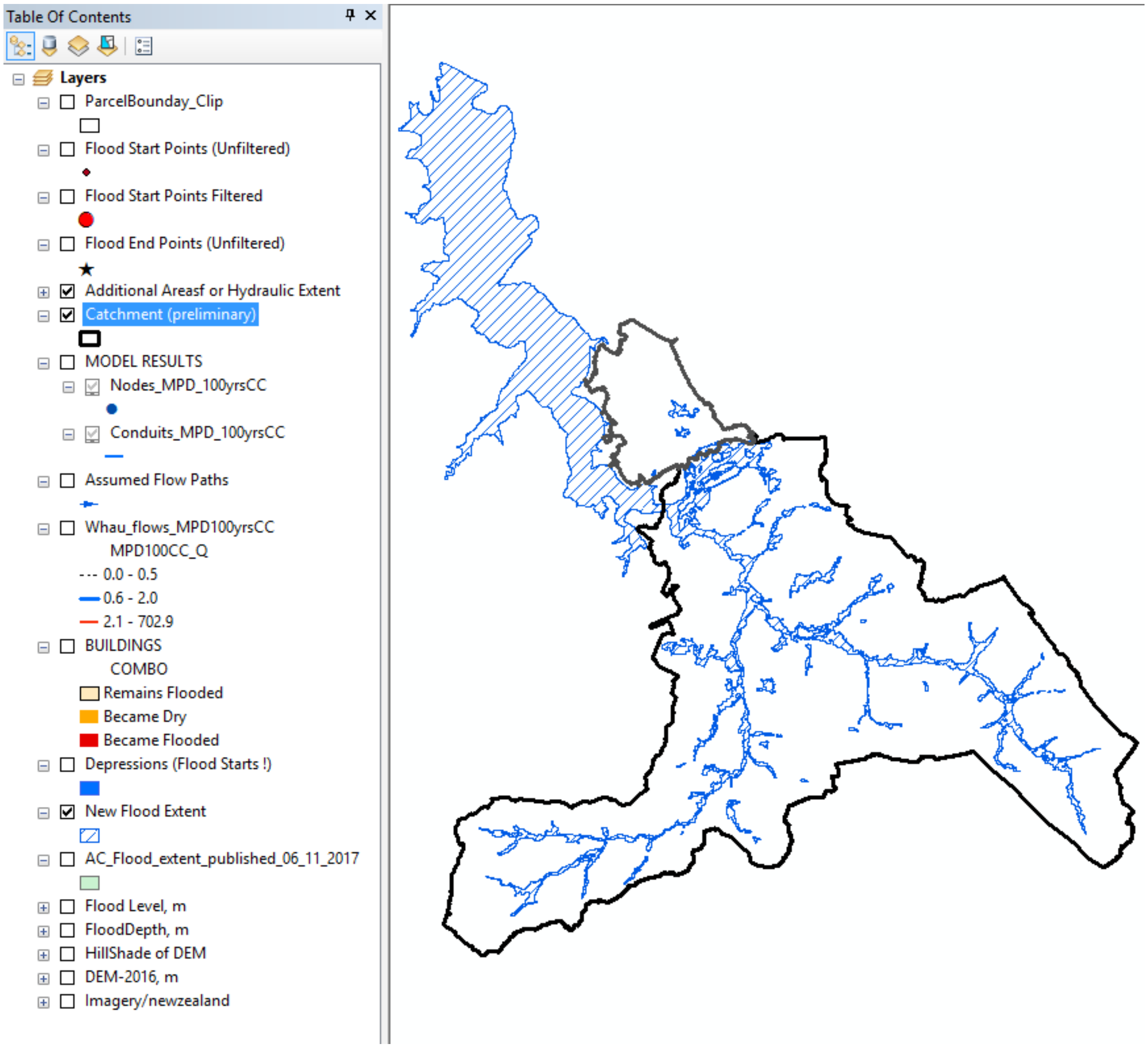


Figure 29. Content of the ArcGIS package file REVIEW_v2.mpk (showing flood extent shape and catchment)

8.2 PIPE CAPACITY RESULTS

Table 21 Less Than 2 year capacity

US node ID	DS node ID	Asset ID	Length (m)	Width (mm)	Height (mm)	Pipe Full	Overland Flow
6803	5156	62328	25.1	1500	1500	2yrs	2yrs
7547	Node015	76393	5	1500	1500	2yrs	2yrs
5818	Node016	266166	13.8	900	900	2yrs	2yrs
4761	Node014	66854	43.2	1500	1500	2yrs	2yrs
7600	Node011	66853	59.4	1500	1500	2yrs	2yrs
5763	5574	267086	7.5	900	900	2yrs	2yrs
5573	7500	266677	21	900	900	2yrs	2yrs
5324	6381	67635	55.5	900	900	2yrs	2yrs
Node012	4822	65501	21.1	1500	1500	2yrs	2yrs
Node016	6614	266166	73.9	900	900	2yrs	2yrs
Node011	4767	65401	5	1500	1500	2yrs	2yrs
Node014	5311	66714	22	1500	1500	2yrs	2yrs
Node017	Node018	N/A	12.1	1050	1050	2yrs	2yrs
30294	276514	220668	51.1	1850	1850	2yrs	2yrs
32767	32764	220669	55.8	1850	1850	2yrs	2yrs
32766	32765	220670	55.8	1850	1850	2yrs	2yrs
River070	River068	N/A	24.1	1800	1800	2yrs	2yrs
River071	River072	N/A	24	1800	1800	2yrs	2yrs
27704	30625	225894	49.2	1800	1800	2yrs	2yrs
286214	117191	182815	18.2	1050	1050	2yrs	2yrs
117191	286216	182816	44.2	1050	1050	2yrs	2yrs
286216	27790	182817	48.1	1050	1050	2yrs	2yrs
26796	286214	182814	45.8	1050	1050	2yrs	2yrs
127028	Node601	182781	14.4	1350	1350	2yrs	2yrs
127409	27867	183617	28.4	1050	1050	2yrs	2yrs
1032932	136163	214438	24.2	900	900	2yrs	2yrs
116604	127392	221800	47.2	600	600	2yrs	2yrs
127392	127393	183574	66	600	600	2yrs	2yrs
127393	127394	183575	37.2	600	600	2yrs	2yrs
127394	117293	183576	36	600	600	2yrs	2yrs
117293	333061	214433	31.8	900	900	2yrs	2yrs
127397	117293	183582	52	750	750	2yrs	2yrs
136175	1032932	215037	10.5	900	900	2yrs	2yrs
136163	337401	214435	40.4	900	900	2yrs	2yrs
122426	127469	209417	33	900	900	2yrs	2yrs
123294	30906	211552	5	900	900	2yrs	2yrs
333061	136175	215038	32.9	900	900	2yrs	2yrs
337401	122426	209416	40.6	900	900	2yrs	2yrs
117297	127468	183689	43.4	750	750	2yrs	2yrs
127468	27223	183731	40.7	750	750	2yrs	2yrs

120420	127467	183687	53.4	750	750	2yrs	2yrs
27869	120420	186433	17.1	1050	1050	2yrs	2yrs
27871	27868	N/A	50	1200	1200	2yrs	2yrs
127467	26795	181650	33.9	1050	1050	2yrs	2yrs
27868	117297	183688	17.7	750	750	2yrs	2yrs
27870	127450	183691	77	1200	1200	2yrs	2yrs
Node008	297703	N/A	5.8	1350	1350	2yrs	2yrs
7029	River110	70833	14.6	4000	2000	2yrs	2yrs
50377	6596	65894	20.6	1050	1050	2yrs	2yrs
52380	6795	65911	57.1	1200	1200	2yrs	2yrs
6773	Node034	66584	5	1050	1050	2yrs	2yrs
50303	52392	75894	48.9	600	600	2yrs	2yrs
Node036	7203	65820	3.7	900	900	2yrs	2yrs
52238	Node022	65074	71.8	1200	1200	2yrs	2yrs
49127	49188	75924	38.8	900	900	2yrs	2yrs
49188!	49177	65209	54.4	900	900	2yrs	2yrs
56199	49188	70653	36.1	675	675	2yrs	2yrs
58000	58001	71884	58.2	675	675	2yrs	2yrs
58001	56199	71190	14.2	675	675	2yrs	2yrs
68780!	69935	231048	9.9	600	600	2yrs	2yrs
67797!	68780	231005	8	600	600	2yrs	2yrs
Node022	Node025	83346	2	1200	1200	2yrs	2yrs
Node025	Node026	86516	2	1200	1200	2yrs	2yrs
Node026	6883	230084	2	1200	1200	2yrs	2yrs
62498	4956	59210	5	1050	1050	2yrs	2yrs
56243	5502	71132	57.3	750	750	2yrs	2yrs
Node031	Node038	N/A	23.9	1000	1000	2yrs	2yrs
Node038	Node039	N/A	6	1000	1000	2yrs	2yrs
5502	River165	N/A	9.7	3000	1000	2yrs	2yrs
River165	River166	N/A	7	3000	1000	2yrs	2yrs
River166	River167	N/A	11	3000	1000	2yrs	2yrs
River167	River005	N/A	31.2	3000	1000	2yrs	2yrs
50916	50930	266381	33.9	1200	1200	2yrs	2yrs
50930	5101	266676	39.2	900	900	2yrs	2yrs
7277	52073	266789	29.7	750	750	2yrs	2yrs
50381	50257	65582	7.8	600	600	2yrs	2yrs
50257	50415	66640	24.5	600	600	2yrs	2yrs
52387	5854	66858	64.5	1200	1200	2yrs	2yrs
7321	50381	68087	26	600	600	2yrs	2yrs
Node045	Node046	N/A	28.2	900	900	2yrs	2yrs
66506	66343	89419	51.2	600	600	2yrs	2yrs
66343	66507	86967	42.4	600	600	2yrs	2yrs
66507	69459	86326	27.9	1050	1050	2yrs	2yrs
69459	7272	84929	16.7	650	650	2yrs	2yrs
50236	5675	65337	63.9	600	600	2yrs	2yrs

56159	55594	75751	65.2	600	600	2yrs	2yrs
57940	56159	75754	23.7	600	600	2yrs	2yrs
58058	7201	247941	25.6	1050	1050	2yrs	2yrs
68314	57940	N/A	46.4	600	600	2yrs	2yrs
Node052	Node053	72322	36	900	900	2yrs	2yrs
64160	6238	83849	17.7	975	975	2yrs	2yrs
56265	58087	72314	53.9	750	750	2yrs	2yrs
58087	56264	71317	63.6	900	900	2yrs	2yrs
56294	5885	71731	57.7	900	900	2yrs	2yrs
56332	61539	83005	18.2	900	900	2yrs	2yrs
55855	4858	71775	37.5	1050	1050	2yrs	2yrs
6086	58087	71098	41.7	600	600	2yrs	2yrs
5367	Node058	82984	12.8	1200	1200	2yrs	2yrs
61539	56294	82038	31.3	1200	1200	2yrs	2yrs
Node058	56332	72626	47.1	900	900	2yrs	2yrs
63685	4786	87439	13.9	1800	1800	2yrs	2yrs
7443	Node130	N/A	6	1500	1500	2yrs	2yrs
Node129	7443	71267	61.9	1500	1500	2yrs	2yrs
Node130	5732	230821	16.3	1500	1500	2yrs	2yrs
6977	55793	90209	13.4	600	600	2yrs	2yrs
5161	55793	88253	13.2	675	675	2yrs	2yrs
55835	Node065	230821	91.7	675	675	2yrs	2yrs
7742	5369	92065	4.9	1350	1350	2yrs	2yrs
6595	6026	88821	7.8	675	675	2yrs	2yrs
Channel003	Channel007	N/A	4.9	3000	750	2yrs	2yrs
Channel007	Channel002	N/A	13.6	3000	750	2yrs	2yrs
Channel008	Channel003	N/A	15.7	3000	750	2yrs	2yrs
46329	54209	71599	294.5	675	675	2yrs	2yrs
44175	Node132	61490	207.5	675	675	2yrs	2yrs
42986	44176	88820	93.4	675	675	2yrs	2yrs
54209	54843	71063	25.5	675	675	2yrs	2yrs
54843	54400	71064	93.7	675	675	2yrs	2yrs
54404	Node095	72320	99.7	675	675	2yrs	2yrs
Node132	46329	61640	96.3	675	675	2yrs	2yrs
55237	55342	75585	89.6	750	750	2yrs	2yrs
55342	55490	72927	70.1	750	750	2yrs	2yrs
55344	55237	72589	43.9	675	675	2yrs	2yrs
55307	55344	73138	90	600	600	2yrs	2yrs
57646	57678	71209	82.9	750	750	2yrs	2yrs
55429	55430	71347	61.5	750	750	2yrs	2yrs
55932	66312	71346	73.3	750	750	2yrs	2yrs
55430	55486	71208	9	750	750	2yrs	2yrs
55488	55489	77773	37.1	750	750	2yrs	2yrs
55489	57646	72890	86.1	750	750	2yrs	2yrs
55490	55938	78027	10.8	750	750	2yrs	2yrs

55938	55488	73266	46.2	750	750	2yrs	2yrs
61274	32716	82093	56.3	750	750	2yrs	2yrs
66312	55429	86911	10.1	750	750	2yrs	2yrs
55402	7397	70912	33.2	675	675	2yrs	2yrs
73899!	Node067	91620	42.2	1050	1050	2yrs	2yrs
55468	55466	72721	92.8	675	675	2yrs	2yrs
55926	55468	77678	88	600	600	2yrs	2yrs
55987	56535	77975	25.9	675	675	2yrs	2yrs
58144	56094	76932	67.9	900	900	2yrs	2yrs
56749	56094	76944	36.3	600	600	2yrs	2yrs
56094	158436	72501	12.8	900	900	2yrs	2yrs
56149!	6206	72052	18.3	750	750	2yrs	2yrs
61365	55926	89919	7.8	600	600	2yrs	2yrs
46339	61219	73265	4.7	600	600	2yrs	2yrs
57699	6827	75952	20	675	675	2yrs	2yrs
61219	55436	80577	19.6	600	600	2yrs	2yrs
61194	5793	79478	24.7	900	900	2yrs	2yrs
62018	61194	79477	72.4	900	900	2yrs	2yrs
Dome	67393	71464	28.7	900	900	2yrs	2yrs
67393	Node085	88325	30.6	900	900	2yrs	2yrs
5575	5061	87240	5	900	900	2yrs	2yrs
128849	32756	186959	79.7	900	900	2yrs	2yrs
124009	123213	213717	10.4	900	900	2yrs	2yrs
117742	117741	186891	28	900	900	2yrs	2yrs
123213	117742	211316	29	900	900	2yrs	2yrs
128834	124009	213716	73.1	900	900	2yrs	2yrs
5187692	123213	224986	43.6	1050	1050	2yrs	2yrs
152840	32769	246336	7.4	1200	1200	2yrs	2yrs
141110	152840	246334	8.4	900	900	2yrs	2yrs
121872	30293	220667	68.4	900	900	2yrs	2yrs
Node124	120649	204153	73.5	600	600	2yrs	2yrs
120649	553241	204154	75.4	600	600	2yrs	2yrs
553241	Node125	204155	46.9	675	675	2yrs	2yrs
Node125	27136	204156	68	675	675	2yrs	2yrs
27137	27138	204157	36.1	1100	1100	2yrs	2yrs
Node127	Node126	204160	37.6	900	900	2yrs	2yrs
55144	7106	71683	52.9	600	600	2yrs	2yrs
55175	66086	73362	17.7	675	675	2yrs	2yrs
6543	55175	70249	33.4	600	600	2yrs	2yrs
69535	4699	86118	10.7	675	675	2yrs	2yrs
55067	Node301	70455	8.9	1200	1250	2yrs	2yrs
River205	River206	N/A	10.2	1000	750	2yrs	2yrs
River206	River207	N/A	6.9	1000	750	2yrs	2yrs
River207	River208	N/A	6.4	1000	750	2yrs	2yrs
River208	River204	N/A	7.4	1000	750	2yrs	2yrs

158437	74042	91957	76.2	1200	1200	2yrs	2yrs
74037	74042	91958	36.4	1200	1200	2yrs	2yrs
27868	27869	N/A	2	1050	1050	2yrs	2yrs
7093	Node100	N/A	2	600	600	2yrs	2yrs
127532	127533	183850	42	600	600	2yrs	2yrs
127533	127025	183864	24.9	600	600	2yrs	2yrs
127025	127014	182766	38.1	600	600	2yrs	2yrs
127014	127015	182767	16	600	600	2yrs	2yrs
127015	127016	182768	48.3	600	600	2yrs	2yrs
127016	127017	182769	51.4	600	600	2yrs	2yrs
127017	127018	182770	29.9	600	600	2yrs	2yrs
127018	286053	182771	45.8	675	675	2yrs	2yrs
Node105	123515	212043	24.4	675	675	2yrs	2yrs
286053	Node105	212040	55.7	675	675	2yrs	2yrs
57984	5328	73352	25.4	900	900	2yrs	2yrs
126391	126388	186427	78	600	600	2yrs	2yrs
126388	126387	181451	33.7	600	600	2yrs	2yrs
126387	126386	181452	10.9	600	600	2yrs	2yrs
126386	126385	181458	76.4	600	600	2yrs	2yrs
126385	126384	227031	28	600	600	2yrs	2yrs
117291	26803	183558	17.4	825	825	2yrs	2yrs
127424	297768	183633	16.2	600	600	2yrs	2yrs
127474	127475	183701	43.2	600	600	2yrs	2yrs
127475	141661	226440	27.7	600	600	2yrs	2yrs
141694	123992	226516	16.4	900	900	2yrs	2yrs
123992	136040	213620	23.3	600	600	2yrs	2yrs
128751!	128752	186719	75.2	600	600	2yrs	2yrs
141107	152840	246333	7.1	600	600	2yrs	2yrs
74150	74153	92150	36.4	1200	1200	2yrs	2yrs
74153	53341	92149	16.1	1200	1200	2yrs	2yrs
63749	5325	267415	11.2	600	600	2yrs	2yrs
68311	67039	88299	31.7	600	600	2yrs	2yrs
5085	46011	74110	6.1	675	675	2yrs	2yrs
62595	6109	82766	9.8	600	600	2yrs	2yrs
137011!	137075	215248	39.3	750	750	2yrs	2yrs
276514!	32763	220668	4.8	1800	1800	2yrs	2yrs
117741	152831	N/A	76.2	900	900	2yrs	2yrs
River500	River501	N/A	13.3	800	800	2yrs	2yrs
River501	River502	N/A	11.4	800	800	2yrs	2yrs
River502	River503	N/A	11	800	800	2yrs	2yrs
River503	River504	N/A	11	800	800	2yrs	2yrs
River504	River505	N/A	15.3	800	800	2yrs	2yrs
4784	Pond10	N/A	2	600	600	2yrs	2yrs
Node250	Node251	N/A	16.5	600	600	2yrs	2yrs
Node251	River364	N/A	16.5	600	600	2yrs	2yrs

River364	River365	N/A	32	600	600	2yrs	2yrs
River365	River366	N/A	12.1	600	600	2yrs	2yrs
River366	6182	N/A	46.4	600	600	2yrs	2yrs
6182	River362	N/A	5.4	600	600	2yrs	2yrs
River362	River363	N/A	48.5	600	600	2yrs	2yrs
River363	Node140	N/A	16.5	600	600	2yrs	2yrs
River368	River369	N/A	26.2	600	600	2yrs	2yrs
River369	Node250	N/A	20.6	600	600	2yrs	2yrs
River530	River531	N/A	6.8	1000	1000	2yrs	2yrs
Node301	6683!	70455	8.3	1200	1250	2yrs	2yrs
Node040	Node600	N/A	5.3	850	850	2yrs	2yrs

Table 22 Less Than 5 year capacity

US node ID	DS node ID	Asset ID	Length (m)	Width (mm)	Height (mm)	Pipe Full	Overland Flow
Node015	Node012	66715	2	1500	1500	2yrs	5yrs
117295	127409	183616	51.1	1050	1050	2yrs	5yrs
127410	117295	183615	39.3	1050	1050	2yrs	5yrs
27786	127026	182778	17.6	1200	1200	5yrs	5yrs
127450	27871	183692	94.6	1200	1200	2yrs	5yrs
River089	River088	N/A	6.6	1200	1200	5yrs	5yrs
Node120	52381	65442	22.7	1050	1050	5yrs	5yrs
Node034	Node033	65891	5	1050	1050	2yrs	5yrs
52390	50397	76359	19.3	675	675	2yrs	5yrs
52391	52390	76394	39	600	600	2yrs	5yrs
50309	50303	65890	21.3	600	600	2yrs	5yrs
50320!	50309	66311	47.1	600	600	2yrs	5yrs
6522	52275	65290	20.8	675	675	2yrs	5yrs
49177	Node145	67819	12	1500	1500	2yrs	5yrs
49181	52238	76353	106.5	1200	1200	2yrs	5yrs
49127	49177	65080	78.4	1050	1050	2yrs	5yrs
69935!	58000	79519	30.3	600	600	2yrs	5yrs
Node145	49181	67819	17.8	1500	1500	2yrs	5yrs
66249	Node028	84778	17	675	675	5yrs	5yrs
50545	51089	266367	25.4	750	750	2yrs	5yrs
50587	50545	266510	49.1	675	675	2yrs	5yrs
51576	53341	266377	31	1200	1200	2yrs	5yrs
53341	50927	266678	14	1200	1200	2yrs	5yrs
52073	50587	266819	62.3	675	675	2yrs	5yrs
51560	51567	76272	63.7	900	900	2yrs	5yrs
51567	68576	85560	11.4	1050	1050	2yrs	5yrs
53332	64155	83847	15.1	825	825	5yrs	5yrs
7254	53332	67512	66.4	600	600	2yrs	5yrs

64155	Node043	84013	20	825	825	2yrs	5yrs
7269	50236	76166	74.6	600	600	2yrs	5yrs
55558	61691	81294	53.8	675	675	2yrs	5yrs
57922	56265	71316	49.1	600	600	2yrs	5yrs
56264	Node060	72315	17	900	900	2yrs	5yrs
67563!	55558	72127	92.7	600	600	2yrs	5yrs
Node060	55858	76766	32	900	900	2yrs	5yrs
57916	57922	73342	48.6	600	600	2yrs	5yrs
65824	4935	86443	41.4	1200	1200	5yrs	5yrs
55518	65394	81250	32.7	675	675	2yrs	5yrs
55525	61285	74899	22.5	675	675	2yrs	5yrs
61555	55835	81991	25.6	675	675	2yrs	5yrs
60978	61555	61993	20.5	675	675	2yrs	5yrs
61556	60978	81992	8.1	675	675	2yrs	5yrs
61285	61556	83995	17.7	675	675	2yrs	5yrs
63933	62191	83562	90.4	675	675	2yrs	5yrs
62191	55518	83624	45	675	675	2yrs	5yrs
54417	54431	72205	57.4	600	600	5yrs	5yrs
54431	54432	72063	62.3	600	600	5yrs	5yrs
61619	5807	84396	16.5	1300	1600	2yrs	5yrs
67039	57285	88298	44.9	600	600	2yrs	5yrs
River197	River191	N/A	24.4	1000	1000	2yrs	5yrs
55396	55307	72923	18.3	600	600	2yrs	5yrs
55393	55334	71113	121.6	675	675	2yrs	5yrs
55428	55455	71196	72.5	675	675	2yrs	5yrs
56044	55898	78265	37.5	600	600	2yrs	5yrs
58137	55428	71919	54.1	675	675	2yrs	5yrs
55903	58137	72098	92.4	675	675	2yrs	5yrs
158436	58178	72448	61.1	900	900	2yrs	5yrs
58178	58179	72449	75.9	900	900	2yrs	5yrs
58179	158457	248835	71.4	900	900	2yrs	5yrs
43012	43013	60668	49	600	600	2yrs	5yrs
61195	62018	79368	48.5	900	900	2yrs	5yrs
64995	61195	83903	46.9	900	900	5yrs	5yrs
67391	61195	71458	48	750	750	2yrs	5yrs
138674	138673	218764	60.9	600	600	5yrs	5yrs
138673	138671	218763	39	600	600	5yrs	5yrs
121564	120051	207213	19.8	600	600	5yrs	5yrs
263473	263480	181259	35.6	1050	1050	5yrs	5yrs
263480	589619	181278	5	1050	1050	5yrs	5yrs
Node126	117136	204161	5	900	900	2yrs	5yrs
27139	Node127	204159	59.1	900	900	5yrs	5yrs
55179	55129	75943	58.9	675	675	2yrs	5yrs
57347	55123	70762	60.6	675	675	2yrs	5yrs
57357	57347	70832	34.6	675	675	2yrs	5yrs

55123	69535	86117	47.1	675	675	2yrs	5yrs
55072	54263	71829	49.7	750	750	5yrs	5yrs
6683!!	55072	71422	57.5	750	750	2yrs	5yrs
158436	158437	268693	97.4	750	750	2yrs	5yrs
158431	158211	268477	22.6	1200	1200	2yrs	5yrs
158434	158431	268689	72.8	1200	1200	2yrs	5yrs
33443	153660	247007	7.3	900	900	2yrs	5yrs
30667	141346	226672	46.9	600	600	5yrs	5yrs
Node028	Node027	83946	2	675	675	5yrs	5yrs
River225	Node107	N/A	24.2	1050	1050	2yrs	5yrs
123515	136031	212042	49.3	675	675	2yrs	5yrs
136031	Node150	212041	20.2	675	675	2yrs	5yrs
Node150	127019	182772	48.6	675	675	5yrs	5yrs
126384	126408	227032	42.2	675	675	2yrs	5yrs
126408	127417	183626	71.5	675	675	2yrs	5yrs
127422	127423	183631	19.1	600	600	2yrs	5yrs
127423	127424	183632	72.5	600	600	2yrs	5yrs
141661	127450	226441	46.1	600	600	2yrs	5yrs
127449	127450	183668	26.6	675	675	2yrs	5yrs
140700	140699	224189	12.7	675	675	5yrs	5yrs
140699	140697	224190	47.5	675	675	2yrs	5yrs
140698	126984	224186	29.6	600	600	5yrs	5yrs
126984	126985	182699	30.6	600	600	5yrs	5yrs
5567490	140752	228312	28.3	675	675	5yrs	5yrs
140752	268470	225602	15.2	675	675	5yrs	5yrs
268470	5566852	225603	31.5	675	675	2yrs	5yrs
5566852	5567067	226514	24.1	675	675	2yrs	5yrs
141802	141804	226723	26.3	600	600	2yrs	5yrs
141804	30037	226722	52	600	600	2yrs	5yrs
6192	54085	84986	29.8	600	600	2yrs	5yrs
55835!	68776	71143	12	600	600	2yrs	5yrs
6879!	50339	68411	19.1	750	750	2yrs	5yrs
River451	River450	N/A	3.2	600	1200	2yrs	5yrs
Node302	55067	N/A	11.7	1200	1250	5yrs	5yrs

Table 23 Less Than 10 Year Capacity

US node ID	DS node ID	Asset ID	Length (m)	Width (mm)	Height (mm)	Pipe Full	Overland Flow
7009	Node013	75961	2	1800	1800	10yrs	10yrs
Node013	6049	75965	13.6	1800	1800	10yrs	10yrs
297819	121653	181643	10.2	1350	1350	2yrs	10yrs
121653	117294	183618	63.3	1350	1350	10yrs	10yrs
297703	297819	181642	15.1	1350	1350	2yrs	10yrs

Node033	Node035	76977	10.2	1200	1200	2yrs	10yrs
Node035	52380	65342	5	1200	1200	2yrs	10yrs
50040!	50041	65387	23.9	600	600	2yrs	10yrs
69191	67797	230896	24.6	600	600	2yrs	10yrs
Node027	64167	84850	21	675	675	5yrs	10yrs
Node144	62498	83947	7.4	910	910	2yrs	10yrs
50927	51574	266380	30.2	1200	1200	2yrs	10yrs
50415	7093	65340	36.3	600	600	2yrs	10yrs
5726	Node042	66053	27.6	750	750	2yrs	10yrs
6587	4838	65926	19.9	900	900	2yrs	10yrs
Node050	58058	247940	72.3	1050	1050	2yrs	10yrs
62574	64160	84016	41	975	975	2yrs	10yrs
61691	57916	84324	18	675	675	2yrs	10yrs
54418	54417	229321	33.1	600	600	5yrs	10yrs
54412	74099	92061	50.2	600	600	2yrs	10yrs
Channel006	Channel008	N/A	11.3	3000	750	10yrs	10yrs
57678	57681	77894	88.5	750	750	2yrs	10yrs
57681	55932	72727	75.5	750	750	2yrs	10yrs
55356	55402	70863	63.5	675	675	5yrs	10yrs
56085	158432	72805	35.2	675	675	2yrs	10yrs
158432	158434	268690	2.3	675	675	2yrs	10yrs
158433	56088	72444	38.1	675	675	2yrs	10yrs
56746	158197	73111	30.2	750	750	2yrs	10yrs
158197	158212	268490	10.4	750	750	2yrs	10yrs
158457	158458	268727	29.8	900	900	2yrs	10yrs
128855	26868	186977	47.2	1500	1500	10yrs	10yrs
141043	141044	224984	40.9	1050	1050	2yrs	10yrs
141044	5187692	224985	13.9	1050	1050	2yrs	10yrs
1037134	117679	217376	47.6	1050	1050	5yrs	10yrs
1037135	122893	217379	51.3	1050	1050	5yrs	10yrs
128738	1037134	217375	26.3	1050	1050	5yrs	10yrs
122893	128738	210481	66	1050	1050	5yrs	10yrs
122892	1037135	217378	37.2	1050	1050	5yrs	10yrs
117136	263473	181258	24.2	1050	1050	5yrs	10yrs
589619	263594	181279	28.2	1050	1050	5yrs	10yrs
122315	27317	209164	28.3	1300	1300	2yrs	10yrs
550246	27124	203675	5.4	1050	1050	2yrs	10yrs
74035	158438	91940	51.6	900	900	2yrs	10yrs
158438	158439	268695	75.2	900	900	5yrs	10yrs
158211	158459	268511	30.9	1200	1200	2yrs	10yrs
158212	157733	267854	37.7	1200	1200	2yrs	10yrs
158459	158212	268512	42.4	1200	1200	2yrs	10yrs
61782	62859	85003	32.8	675	675	5yrs	10yrs
127019	119064	199866	3.2	675	675	2yrs	10yrs
119064	140013	221434	7	675	675	5yrs	10yrs

127417	127410	183625	56	675	675	2yrs	10yrs
5566444	140700	224192	34.6	600	600	5yrs	10yrs
5567067	141696	226520	6.9	900	900	2yrs	10yrs
141695	141694	226518	4.7	900	900	2yrs	10yrs
136040!	126986	212792	27.4	600	600	10yrs	10yrs
141803	141802	226725	20.9	600	600	5yrs	10yrs
74144	74142	92135	52.5	560	560	10yrs	10yrs
74142	74143	92140	76	560	560	2yrs	10yrs
Node200	Node201	N/A	35.8	750	750	10yrs	10yrs
73845!	62389	91566	31.4	600	600	2yrs	10yrs
Node201	Node500	N/A	2	750	750	10yrs	10yrs
Node303	Node302	N/A	12.7	1200	1250	5yrs	10yrs
Node304	Node303	N/A	15.7	1200	1250	10yrs	10yrs

Table 24 Less Than 100 Year Capacity

US node ID	DS node ID	Asset ID	Length (m)	Width (mm)	Height (mm)	Pipe Full	Overland Flow
Node003	5610	70631	14.9	3700	3700	100yrs	100yrs
Node007	Node004	N/A	30.5	2300	2300	2yrs	100yrs
Node006	Node005	N/A	30.5	2800	3400	10yrs	100yrs
5865	5592	68103	13.8	2740	2740	5yrs	100yrs
6218	7001	65073	13.8	2740	2740	5yrs	100yrs
Node010	Node019	N/A	25.3	4800	3200	5yrs	100yrs
127026	127027	182779	38.8	1200	1200	5yrs	100yrs
127027	127028	182780	45.3	1200	1200	2yrs	100yrs
117294	268862	223164	19.9	1350	1350	5yrs	100yrs
5187366	27866	223165	21.1	1350	1350	2yrs	100yrs
141346	116604	225621	36.5	600	600	2yrs	100yrs
127469	123294	211554	46.5	900	900	2yrs	100yrs
Node020	Node021	N/A	37.8	1350	1350	100yrs	100yrs
52381	Node032	65910	17.2	900	900	2yrs	100yrs
52275	52442	65835	52.7	675	675	2yrs	100yrs
52392!	52391	76392	34.2	600	600	2yrs	100yrs
52442	50320	76456	11.1	675	675	2yrs	100yrs
55656!	69191	85468	26.9	600	600	5yrs	100yrs
6707	49127	65151	122.2	900	900	2yrs	100yrs
62496	62497	83503	52.5	600	600	5yrs	100yrs
62497	Node144	229987	5	900	900	2yrs	100yrs
56256	55749	70970	47.8	900	900	10yrs	100yrs
Node030	Node031	N/A	16.6	1000	1000	100yrs	100yrs
51574	50916	266379	20.2	1200	1200	2yrs	100yrs
51575	74150	92145	4.5	1200	1200	5yrs	100yrs
50933	74148	92146	8.4	1200	1200	2yrs	100yrs

51091	74147	267528	50.1	675	675	2yrs	100yrs
74147	50581	92147	8.3	675	675	2yrs	100yrs
50252	52386	68088	53.3	1200	1200	2yrs	100yrs
50382	52387	66860	68.2	750	750	2yrs	100yrs
52386	52387	66718	58.5	1200	1200	2yrs	100yrs
66151	50252	83751	34.7	1050	1050	5yrs	100yrs
68576	Node044	65963	40.8	1050	1050	2yrs	100yrs
Node041	50382	75932	12.4	750	750	2yrs	100yrs
Node042	Node041	65828	13.1	750	750	2yrs	100yrs
Node044	66151	65963	40.1	1050	1050	2yrs	100yrs
55594	4652	247072	8	700	700	100yrs	100yrs
1309864	153953	247947	46.8	1050	1050	100yrs	100yrs
153953	Node050	247944	11.9	1050	1050	10yrs	100yrs
55849	64159	77154	47.4	830	830	5yrs	100yrs
64159	62574	83848	16	975	975	2yrs	100yrs
Node057	55849	71043	114.3	900	900	100yrs	100yrs
61538	158971	270405	124.1	1200	1200	5yrs	100yrs
65815	61538	82972	32.9	975	975	5yrs	100yrs
65816	65815	82850	52.9	975	975	10yrs	100yrs
62560	65818	84459	57	975	975	10yrs	100yrs
61706	62560	81180	48.3	825	825	10yrs	100yrs
7246	Node129	N/A	11.1	1500	1500	100yrs	100yrs
55793	Node062	88255	17.5	600	600	2yrs	100yrs
6472	61716	84616	26	1200	1200	100yrs	100yrs
62188	63933	83999	5	675	675	10yrs	100yrs
67689	62188	89840	28.9	600	600	10yrs	100yrs
River181	River195	N/A	32.2	1000	1000	100yrs	100yrs
57285	Node138	72705	8.7	914	914	2yrs	100yrs
57297	54883	71081	55.2	750	750	5yrs	100yrs
54432	57297	70248	41.8	600	600	5yrs	100yrs
56009	Node135	81046	29.6	1600	1600	5yrs	100yrs
55519	56009	71501	62.8	1600	1600	5yrs	100yrs
Node135	61619	85187	25.1	1600	1600	2yrs	100yrs
46011	6971	62439	53.3	675	675	2yrs	100yrs
57269	5121	72771	52.8	1200	1200	2yrs	100yrs
Node110	74098	92056	6.6	1200	1200	100yrs	100yrs
7743	74097	92917	21.9	900	900	100yrs	100yrs
74097	7741	92059	95.7	900	900	100yrs	100yrs
Node112	1430830	92053	34.1	1050	1050	10yrs	100yrs
1430830	1430831	92057	40.9	1050	1050	2yrs	100yrs
River195	River196	N/A	32.7	1000	1000	100yrs	100yrs
River196	River197	N/A	31.6	1000	1000	100yrs	100yrs
43019	44175	74428	122.1	675	675	2yrs	100yrs
55486	55431	71302	19.3	750	750	2yrs	100yrs
55933	61274	71304	30	750	750	5yrs	100yrs

55324	55356	70734	86.9	675	675	2yrs	100yrs
55466	65397	75809	27.8	750	750	2yrs	100yrs
158456	153185	246840	9.1	600	600	2yrs	100yrs
55985	158456	77931	58.3	600	600	2yrs	100yrs
153189	70271	246844	34.3	600	600	2yrs	100yrs
56535	65933	87177	10.8	675	675	2yrs	100yrs
55991	55324	75804	57.1	750	750	2yrs	100yrs
55905	55991	71694	145	750	750	5yrs	100yrs
55999	58144	71275	31.2	900	900	2yrs	100yrs
56744	56085	72837	69.1	600	600	2yrs	100yrs
56088	56746	71854	30.2	750	750	2yrs	100yrs
56875	56149	71972	60.5	600	600	10yrs	100yrs
65933	56534	72326	67.5	685	685	2yrs	100yrs
70271	55985	246844	50.6	600	600	2yrs	100yrs
64996	64995	81121	72.1	900	900	5yrs	100yrs
6089	7618	89905	30.7	925	925	5yrs	100yrs
7590	6089	88760	5	925	925	100yrs	100yrs
137075	29772	215206	6	750	750	2yrs	100yrs
117748	128830	186928	85.2	925	925	100yrs	100yrs
128830	343679	186916	5	1200	1200	100yrs	100yrs
343679	343688	186917	9.2	1200	1200	100yrs	100yrs
343688	343704	186919	6.7	1200	1200	100yrs	100yrs
343690	343691	186914	2	1350	1350	100yrs	100yrs
343691	117764	186913	40.1	1375	1375	100yrs	100yrs
343704	343690	186915	19.1	1350	1350	100yrs	100yrs
128842	128841	226407	57.5	900	900	100yrs	100yrs
128843	128842	186949	77.7	750	750	100yrs	100yrs
124011	117755	224954	65.6	900	900	5yrs	100yrs
117755	121044	205305	48.5	900	900	2yrs	100yrs
121044	128834	186939	34.3	900	900	2yrs	100yrs
138671	138670	218755	68.1	750	750	5yrs	100yrs
138670	155806	218753	18.9	750	750	5yrs	100yrs
128737!	121872	186704	66.8	900	900	5yrs	100yrs
340480	122892	210480	11.9	700	700	5yrs	100yrs
122890	122892	210479	20.7	700	700	5yrs	100yrs
263593	122315	181281	20.5	1050	1050	2yrs	100yrs
263594	263593	181280	5	1050	1050	5yrs	100yrs
57346	55151	72847	82	675	675	2yrs	100yrs
55129	57346	72848	59.8	675	675	2yrs	100yrs
6683	65509	84741	22.3	1050	1050	100yrs	100yrs
Node142	Node304	N/A	20.2	1200	1250	100yrs	100yrs
55065	7599	70487	22.4	900	900	2yrs	100yrs
55095!	5130	86875	13.3	750	750	100yrs	100yrs
55078	55130	72286	6.3	900	900	100yrs	100yrs
153660	153661	247006	41.8	900	900	5yrs	100yrs

69541	55132	77023	52.4	600	600	2yrs	100yrs
64659	6410	86756	8	1500	1500	100yrs	100yrs
5023	6056	89252	9.4	1050	1050	10yrs	100yrs
153180	74035	247204	22.2	900	900	2yrs	100yrs
158458	158211	267855	6.5	900	900	2yrs	100yrs
157733	158196	267851	43.6	1200	1200	2yrs	100yrs
134950	141101	225126	34.7	600	600	5yrs	100yrs
140013	127021	221435	29.3	600	600	2yrs	100yrs
140013	127020	221436	39.8	750	750	2yrs	100yrs
127020	127027	181638	25.3	600	600	2yrs	100yrs
127020	127030	182775	25.7	900	900	2yrs	100yrs
127030	127028	182774	25.8	900	900	2yrs	100yrs
74150	51576	92152	18.4	1200	1200	2yrs	100yrs
126985	140753	224286	11.1	600	600	5yrs	100yrs
140753	5567490	228311	12.1	675	675	5yrs	100yrs
142602	5567490	228316	39.9	600	600	5yrs	100yrs
141696	141695	226519	53.9	1050	1050	2yrs	100yrs
127133	Node169	183077	152.5	600	600	5yrs	100yrs
67624	61665	230720	22.2	600	600	5yrs	100yrs
61665	67173	82818	47.2	600	600	100yrs	100yrs
67173	4736	87096	14.4	750	750	2yrs	100yrs
74145	74144	92133	7.9	560	560	10yrs	100yrs
51078	51576	266579	77	600	600	2yrs	100yrs
74151	74150	92141	73.6	1200	1200	2yrs	100yrs
74148	74151	92134	47.4	1050	1050	2yrs	100yrs
63741	63749	91720	75.1	600	600	2yrs	100yrs
62337	65638	82351	14.3	600	600	100yrs	100yrs
60910	73945	91839	5.9	630	630	5yrs	100yrs
62389!	61586	82164	16.1	600	600	2yrs	100yrs
73945	4784	91833	23	600	600	2yrs	100yrs
42783	5744	82726	27.6	900	900	5yrs	100yrs
128858	128857	186988	27.5	600	600	100yrs	100yrs
128857	128856	186989	35.1	600	600	100yrs	100yrs
Node305	Node142	N/A	21.1	1200	1250	100yrs	100yrs

Table 25 100 Year or Greater Capacity

US node ID	DS node ID	Asset ID	Length (m)	Width (mm)	Height (mm)	Pipe Full	Overland Flow
268862	5187366	223166	6.4	1350	1350	5yrs	>100yrs
6301	5708	89318	14.9	1650	1650	>100yrs	>100yrs
50477	5919	66649	8.3	600	600	10yrs	>100yrs
6077	6709	66650	25.2	1200	1200	>100yrs	>100yrs
50262	50377	67302	22	900	900	2yrs	>100yrs

Node032	50262	65819	7.8	900	900	2yrs	>100yrs
50397	Node036	75931	27.2	750	750	2yrs	>100yrs
64167	62584	83684	13	675	675	5yrs	>100yrs
64168	62585	83501	54.1	675	675	>100yrs	>100yrs
62585	62496	83502	48.3	600	600	10yrs	>100yrs
62584	64168	83739	38.3	675	675	5yrs	>100yrs
55740	56243	71133	21.7	600	600	10yrs	>100yrs
55749	5495	71089	10.3	750	750	>100yrs	>100yrs
5495	Node030	N/A	18.6	1000	1000	>100yrs	>100yrs
50532!	50534	266438	24	675	675	5yrs	>100yrs
50534	50933	266954	38.4	1200	1200	5yrs	>100yrs
51089	50985	266581	40.8	750	750	2yrs	>100yrs
50985!	50933	266417	13.2	750	750	5yrs	>100yrs
50928	51575	266599	41.2	1200	1200	5yrs	>100yrs
50996	50928	266376	58.6	1200	1200	>100yrs	>100yrs
50533	51084	266419	22.2	600	600	100yrs	>100yrs
51084	51091	266338	77.7	600	600	5yrs	>100yrs
50581	50532	92155	28.4	675	675	2yrs	>100yrs
52074	6430	266813	17.8	900	900	2yrs	>100yrs
51558	51560	76260	57.1	900	900	2yrs	>100yrs
Node043	51558	84264	77.8	825	825	2yrs	>100yrs
50214	Node047	N/A	17.7	1050	1050	>100yrs	>100yrs
6784	Node048	230729	18.7	1050	1050	>100yrs	>100yrs
Node048	50214	65395	33.6	1050	1050	100yrs	>100yrs
4652	55631	247946	12.4	1050	1050	>100yrs	>100yrs
55631	1309864	247947	59.7	1050	1050	>100yrs	>100yrs
Node055	55859	72161	20.1	650	650	>100yrs	>100yrs
55859	Node057	83344	8.1	900	900	>100yrs	>100yrs
55769	58082	76701	15.2	600	600	2yrs	>100yrs
58082!	6763	71537	57.3	600	600	2yrs	>100yrs
58111	55855	71739	36.9	1050	1050	2yrs	>100yrs
55858	58111	71255	24.5	900	900	2yrs	>100yrs
65817	65816	82853	86	975	975	10yrs	>100yrs
65818	65817	81481	88.3	975	975	10yrs	>100yrs
62561	61706	91285	94.9	825	825	100yrs	>100yrs
61707	62561	83120	56.1	825	825	>100yrs	>100yrs
61540!	61707	82763	48.5	825	825	>100yrs	>100yrs
61541	61540	83121	31.9	825	825	>100yrs	>100yrs
61708	61541	81458	57.6	825	825	>100yrs	>100yrs
62562	61708	84993	71.3	750	750	>100yrs	>100yrs
61711	Node061	87802	8.8	750	750	>100yrs	>100yrs
65820	61711	83116	25.2	600	600	>100yrs	>100yrs
Node061	62562	81181	17.8	750	750	>100yrs	>100yrs
158971	63685	270406	88.6	1200	1200	2yrs	>100yrs
55839	63685	82037	10.5	1350	1350	2yrs	>100yrs

5160	55839	72625	22.4	900	900	>100yrs	>100yrs
65823	65824	81457	34.6	1200	1200	10yrs	>100yrs
61716	65823	81178	42.9	1200	1200	100yrs	>100yrs
55526	55525	60918	20.3	675	675	2yrs	>100yrs
65394	55526	80822	13.9	675	675	2yrs	>100yrs
66144	66145	83137	82.3	600	600	>100yrs	>100yrs
66145	66146	83747	37.8	600	600	>100yrs	>100yrs
66146	63932	84230	51.5	600	600	>100yrs	>100yrs
63932	67689	83819	46.6	600	600	100yrs	>100yrs
54416	54254	71622	70	1800	1800	100yrs	>100yrs
54858	Node134	88725	34.8	1800	1800	100yrs	>100yrs
54236	54860	73096	105.8	600	600	>100yrs	>100yrs
54860	54426	72680	97.3	675	675	100yrs	>100yrs
54237	54254	N/A	7.2	1050	1050	100yrs	>100yrs
54424	54423	75147	9.1	1050	1050	100yrs	>100yrs
54425	54424	75396	74.3	1050	1050	100yrs	>100yrs
54426	54425	75264	43.6	1050	1050	100yrs	>100yrs
54879	54246	71818	33.8	1067	1067	>100yrs	>100yrs
54246	54880	70299	133.7	1067	1067	2yrs	>100yrs
54880	57306	70370	30.3	1067	1067	100yrs	>100yrs
57306	57307	70384	7.2	1200	1200	100yrs	>100yrs
57307	54248	70301	51.1	1200	1200	100yrs	>100yrs
54248	54433	71082	29.1	1200	1200	100yrs	>100yrs
54883	54248	N/A	5	750	750	5yrs	>100yrs
54433	54416	75257	8.5	1200	1200	100yrs	>100yrs
Node134	55519	71025	50.7	1500	1500	10yrs	>100yrs
Node136	Node137	71622	43.9	1800	1800	100yrs	>100yrs
Node137	54858	71622	98.7	1800	1800	100yrs	>100yrs
Node138	Node139	72705	37	914	914	2yrs	>100yrs
Node139!	54879	72705	13.4	914	914	>100yrs	>100yrs
74099	74098	92063	23.5	600	600	100yrs	>100yrs
74098	57269	92062	74.2	1200	1200	100yrs	>100yrs
57268	57269	71360	24.7	600	600	5yrs	>100yrs
64527	Node133	83144	61.2	675	675	100yrs	>100yrs
63148	64527	86080	8.6	675	675	100yrs	>100yrs
68892	57268	84186	24.8	600	600	100yrs	>100yrs
6971	5835	88642	20	750	750	2yrs	>100yrs
5776	5586	88858	4.9	900	900	>100yrs	>100yrs
Node133	68892	87185	8.4	600	600	100yrs	>100yrs
1430831	Node146	92055	6.4	1050	1050	2yrs	>100yrs
Channel001	Channel004	N/A	25.7	3000	750	>100yrs	>100yrs
Channel004	Channel009	N/A	12.7	3000	750	>100yrs	>100yrs
Channel005	Channel006	N/A	5.6	3000	750	>100yrs	>100yrs
Channel009	Channel005	N/A	18.8	3000	750	>100yrs	>100yrs
44176	43019	73674	17.8	675	675	2yrs	>100yrs

54400	54401	72772	91.9	675	675	>100yrs	>100yrs
54401	54402	72113	27.2	675	675	>100yrs	>100yrs
54402	54403	72773	45.4	675	675	>100yrs	>100yrs
54403	54404	72114	52	675	675	>100yrs	>100yrs
55303	55264	73139	38.9	600	600	>100yrs	>100yrs
55247	55303	72587	32.5	600	600	>100yrs	>100yrs
55264	55396	72392	61.3	600	600	2yrs	>100yrs
55431	61275	84197	15.8	750	750	2yrs	>100yrs
61275	55933	71303	21.6	750	750	2yrs	>100yrs
55334	55569	73925	69	675	675	2yrs	>100yrs
55569	55591	71230	103	600	600	2yrs	>100yrs
57454	57461	70869	91.6	600	600	100yrs	>100yrs
73890!	73899	91615	35.2	1050	1050	5yrs	>100yrs
55455	55456	72418	2	675	675	2yrs	>100yrs
55456	57454	71236	122.9	675	675	2yrs	>100yrs
55906	55484	72724	30.2	675	675	5yrs	>100yrs
55467	55477	71788	22	750	750	2yrs	>100yrs
55910	55478	72138	21.4	600	600	5yrs	>100yrs
55478	55906	71789	30.3	600	600	5yrs	>100yrs
55484	6654	71787	33.7	675	675	>100yrs	>100yrs
55900	74366	92477	10.1	600	600	2yrs	>100yrs
153184	55999	246841	67	900	900	2yrs	>100yrs
153185	153184	246839	54.4	900	900	2yrs	>100yrs
56534	55986	77974	20.6	685	685	2yrs	>100yrs
55986	55900	76827	80.1	685	685	2yrs	>100yrs
55909	55903	89190	49.5	675	675	2yrs	>100yrs
65397	66719	89187	31.6	750	750	2yrs	>100yrs
66719	55467	86832	43.4	750	750	2yrs	>100yrs
73893	73890	91622	10.3	1200	1200	5yrs	>100yrs
73907	73893	91635	92.5	1200	1200	100yrs	>100yrs
73908	73907	91634	123.7	1200	1200	>100yrs	>100yrs
73909	73908	91605	149.9	1200	1200	>100yrs	>100yrs
73900	73909	91629	136.2	1200	1200	>100yrs	>100yrs
73902	73900	91614	171.5	1200	1200	>100yrs	>100yrs
73891	73902	91595	97.9	1200	1200	>100yrs	>100yrs
73901	73891	91597	71.5	1200	1200	>100yrs	>100yrs
73896	73901	247649	35.1	1200	1200	>100yrs	>100yrs
73910	73900	91621	9	600	600	100yrs	>100yrs
73892	73910	91626	93.3	600	600	100yrs	>100yrs
73903	73892	91631	114.8	600	600	5yrs	>100yrs
73903	55905	91642	106.1	600	600	2yrs	>100yrs
57461	73890	91623	12.3	600	600	100yrs	>100yrs
43013	56006	71465	85.4	685	685	5yrs	>100yrs
56006	57699	76412	94.6	750	750	5yrs	>100yrs
65066	64996	83902	65.7	750	750	5yrs	>100yrs

65067	65066	81120	57.2	750	750	10yrs	>100yrs
64465	Node131	87877	14.6	600	600	100yrs	>100yrs
7618	6397	89194	6.3	925	925	5yrs	>100yrs
5563806	137075	215158	79.7	750	750	2yrs	>100yrs
276702	27730	182308	10.5	1050	1050	>100yrs	>100yrs
117109	276702	182309	53.5	1050	1050	>100yrs	>100yrs
276708	117109	182302	9.9	1350	1350	>100yrs	>100yrs
276712	276708	182301	58.6	1350	1350	>100yrs	>100yrs
276716	276712	182293	23.6	1350	1350	>100yrs	>100yrs
340237	276716	186694	5	1350	1350	>100yrs	>100yrs
121366	340237	186693	5	1350	1350	>100yrs	>100yrs
128824	128829	186923	61.7	825	825	100yrs	>100yrs
128826	134941	200534	5.3	675	675	100yrs	>100yrs
128827	128824	186901	34.8	675	675	>100yrs	>100yrs
128829	117746	186924	54.6	825	825	100yrs	>100yrs
117746	117747	186926	56	750	750	10yrs	>100yrs
117747	117748	186927	22.6	750	750	10yrs	>100yrs
117764	128855	186976	13.2	1375	1375	100yrs	>100yrs
134938	134939	200505	61.3	600	600	>100yrs	>100yrs
134939	Node121	200513	50.6	600	600	>100yrs	>100yrs
134940	128826	N/A	92.3	600	600	100yrs	>100yrs
134941	128827	186900	20.5	675	675	100yrs	>100yrs
Node121	134940	200515	64.2	600	600	100yrs	>100yrs
128841	344230	226405	7.5	900	900	100yrs	>100yrs
128844	128843	186948	70.4	600	600	100yrs	>100yrs
344230	344231	226406	11.1	900	900	100yrs	>100yrs
344231	128849	186993	5	900	900	100yrs	>100yrs
127965	319606	184684	58.6	600	600	100yrs	>100yrs
319606	128747	184682	17.1	600	600	100yrs	>100yrs
128747	141025	224933	11	600	600	100yrs	>100yrs
5187689	141025	224940	26.5	1050	1050	100yrs	>100yrs
5187690	5187689	224939	5	1050	1050	100yrs	>100yrs
5187691	141041	224971	51.4	1050	1050	>100yrs	>100yrs
5187709	141094	225106	22.1	825	825	100yrs	>100yrs
5187710	5187709	225105	18.9	825	825	100yrs	>100yrs
5187711	5187710	225104	5	825	825	100yrs	>100yrs
5187714	141096	225110	66.3	1050	1050	100yrs	>100yrs
5187715	5187716	225123	23.4	1050	1050	100yrs	>100yrs
5187716	5187717	225124	13.6	1050	1050	100yrs	>100yrs
5187717	141097	225125	5	1050	1050	100yrs	>100yrs
5187718	141100	225135	7.9	1050	1050	5yrs	>100yrs
5187719	141103	225145	29.7	1050	1050	5yrs	>100yrs
141013	141022	224926	11.7	675	675	100yrs	>100yrs
141014	141013	224918	37.7	675	675	100yrs	>100yrs
141016	141014	224917	44.6	675	675	100yrs	>100yrs

141020	5187690	224938	32.9	1050	1050	100yrs	>100yrs
141021	141020	224928	76.6	825	825	100yrs	>100yrs
141022	141021	224927	18.1	825	825	100yrs	>100yrs
141024	141028	224948	42.9	1050	1050	100yrs	>100yrs
141025	141024	224941	6.7	1050	1050	100yrs	>100yrs
141027	141038	224968	15.3	1050	1050	100yrs	>100yrs
141028	141027	224949	36.2	1050	1050	100yrs	>100yrs
141036	5187691	224970	26.5	1050	1050	100yrs	>100yrs
141038	141036	224969	16.9	1050	1050	100yrs	>100yrs
141041	141043	224976	53.2	1050	1050	>100yrs	>100yrs
141090	5187711	225103	24.7	825	825	100yrs	>100yrs
141091	141090	225096	7.8	675	675	100yrs	>100yrs
141092	141091	225095	34.2	675	675	>100yrs	>100yrs
141093	141092	225094	19	675	675	>100yrs	>100yrs
141094	5187714	225109	27	1050	1050	100yrs	>100yrs
141096	5187715	225122	16.6	1050	1050	100yrs	>100yrs
141097	5187718	225134	35.6	1050	1050	10yrs	>100yrs
141100	5187719	225144	6.3	1050	1050	5yrs	>100yrs
141102	124011	225147	19.1	1050	1050	5yrs	>100yrs
141103	141102	225146	22.1	1050	1050	5yrs	>100yrs
117685	5187693	224990	52.7	600	600	>100yrs	>100yrs
5187693	141051	224991	5	600	600	>100yrs	>100yrs
5187695	141050	225002	12.5	600	600	100yrs	>100yrs
5187696	141048	225003	16.8	675	675	>100yrs	>100yrs
5187697	5187696	225004	5	675	675	>100yrs	>100yrs
140023	140024	221611	31.6	825	825	>100yrs	>100yrs
140024	141110	225156	51.6	825	825	10yrs	>100yrs
141048	140023	224988	41.1	675	675	>100yrs	>100yrs
141049	5187697	225001	13	675	675	>100yrs	>100yrs
141050	141049	225005	23.2	600	600	>100yrs	>100yrs
141051	5187695	225000	11.2	600	600	>100yrs	>100yrs
155806	340464	218751	22.5	800	800	5yrs	>100yrs
340464	138668	218829	54.1	825	825	5yrs	>100yrs
138668	138667	218830	13.5	825	825	2yrs	>100yrs
138667	138666	218828	73.8	825	825	2yrs	>100yrs
138666	128735	218827	30.8	900	900	2yrs	>100yrs
128735	128737	186703	68.7	1050	1050	2yrs	>100yrs
117679	128735	186699	78.6	1050	1050	2yrs	>100yrs
128758	128761	186733	25.7	600	600	5yrs	>100yrs
128761	128762	186734	23.5	600	600	5yrs	>100yrs
128762	128765	186741	42	750	750	5yrs	>100yrs
128765	340480	186746	70.7	750	750	5yrs	>100yrs
120048	117679	202519	48.6	675	675	2yrs	>100yrs
120049	120048	202520	57.6	675	675	5yrs	>100yrs
120050	120049	202521	45	600	600	5yrs	>100yrs

120051	121560	207202	66.2	600	600	5yrs	>100yrs
138675	138674	218765	18.1	600	600	5yrs	>100yrs
121560	120050	202522	43	600	600	5yrs	>100yrs
55151	55144	77227	39.6	600	600	2yrs	>100yrs
54093	6819	70089	7	1050	1050	5yrs	>100yrs
54263	65511	70643	98.4	750	750	2yrs	>100yrs
6819	Node147	N/A	28.2	1050	1050	2yrs	>100yrs
62275	7074	74134	5	1050	1050	100yrs	>100yrs
61371	62275	81746	74.1	1050	1050	100yrs	>100yrs
62276	61371	82048	42.7	1050	1050	100yrs	>100yrs
61372	62276	82199	51.8	1050	1050	100yrs	>100yrs
65508	61372	84740	47.5	1050	1050	100yrs	>100yrs
65509	65508	81936	5	1050	1050	100yrs	>100yrs
65510	4871	81975	7.9	750	750	2yrs	>100yrs
65511	65510	73776	5	750	750	2yrs	>100yrs
Node147	Node148	N/A	2	1050	1050	5yrs	>100yrs
55130	69540	86702	32.4	600	600	10yrs	>100yrs
55130	7220	71677	50.8	600	600	10yrs	>100yrs
55130!	Node108	86722	43.1	750	750	>100yrs	>100yrs
55080!	55081	86862	50.6	750	750	100yrs	>100yrs
55081!	55095	85856	89.6	750	750	10yrs	>100yrs
55084	55080	85550	26.5	750	750	10yrs	>100yrs
55132	55084	72213	28.5	675	675	100yrs	>100yrs
55137	55130	77224	7.2	600	600	2yrs	>100yrs
153659!	55065	83210	24.2	900	900	5yrs	>100yrs
69540	7220	86703	21.6	600	600	10yrs	>100yrs
120478	550246	203656	140.4	1050	1050	100yrs	>100yrs
27125	120478	203674	11.1	1050	1050	100yrs	>100yrs
4809	Node143	87011	20.2	1500	1500	>100yrs	>100yrs
Node143	64659	87011	128.8	1500	1500	100yrs	>100yrs
158439	158437	91960	10.6	900	900	2yrs	>100yrs
153185	153180	247209	4.7	600	600	2yrs	>100yrs
153181	153180	247203	74.2	900	900	2yrs	>100yrs
153189	153183	247211	5.7	600	600	2yrs	>100yrs
153183	153182	247206	3.3	900	900	2yrs	>100yrs
153182	153181	247205	65.9	900	900	2yrs	>100yrs
74366	73903	92471	4.4	600	600	2yrs	>100yrs
158209	Node096	268476	25.8	1200	1200	2yrs	>100yrs
Node096!	34330	268692	36.8	1200	1200	>100yrs	>100yrs
158475	158209	267849	52.3	1200	1200	2yrs	>100yrs
158196	158475	267850	25.4	1200	1200	2yrs	>100yrs
54254	Node136	71622	15.1	1800	1800	100yrs	>100yrs
54423	54237	75395	16.5	1050	1050	100yrs	>100yrs
141101	141100	225136	5.4	600	600	5yrs	>100yrs
153661	153659	246801	35.3	900	900	2yrs	>100yrs

127021	127020	182773	14.3	600	600	2yrs	>100yrs
56186	57984	70937	32.9	600	600	2yrs	>100yrs
57983	55636	73351	13.3	900	900	5yrs	>100yrs
55636	57984	70936	16.3	900	900	5yrs	>100yrs
127446	127447	183665	36.4	600	600	>100yrs	>100yrs
127447	127448	183666	48.8	675	675	>100yrs	>100yrs
127448	127449	183667	74.8	675	675	2yrs	>100yrs
126986	126987	182700	17.7	900	900	10yrs	>100yrs
126987	29861	216411	25.8	900	900	2yrs	>100yrs
141799	141803	226724	2.9	600	600	10yrs	>100yrs
64015	153659	246802	31.1	900	900	2yrs	>100yrs
Node170	Node143	88790	44.1	700	700	100yrs	>100yrs
550251	120479	203668	16.5	600	600	>100yrs	>100yrs
120479	120478	203665	44.9	675	675	100yrs	>100yrs
54085	57142	70081	12.5	600	600	2yrs	>100yrs
57142	54308	76756	23.6	600	600	2yrs	>100yrs
141106	141107	225162	55.9	600	600	10yrs	>100yrs
Node173	Node175	225165	37.5	710	710	>100yrs	>100yrs
Node175	141106	225154	244.2	710	710	100yrs	>100yrs
Node184	Node185	88211	14.5	600	600	>100yrs	>100yrs
Node185	Node186	88671	4.4	600	600	>100yrs	>100yrs
5566678	5566677	224909	33.6	600	600	>100yrs	>100yrs
5566677	5566676	224910	21.9	600	600	>100yrs	>100yrs
5566676	5566675	224911	3.6	600	600	>100yrs	>100yrs
5566675	5566674	224912	5	600	600	>100yrs	>100yrs
5566674	141018	224908	3.3	600	600	>100yrs	>100yrs
61586!	60910	84290	36.6	580	580	5yrs	>100yrs
128818	342272	186890	4.9	700	700	>100yrs	>100yrs
342272	357027	187823	11.6	700	700	>100yrs	>100yrs
357027	128817	187824	3.2	700	700	>100yrs	>100yrs
128817	128816	226401	40.3	700	700	>100yrs	>100yrs
128816	32755	226402	30.3	700	700	>100yrs	>100yrs
57698	65067	80930	6.9	750	750	>100yrs	>100yrs
128856	117764	186979	6.5	600	600	100yrs	>100yrs

8.3 CRITICAL SECTION FLOW ANALYSIS

An analysis of the sub-catchments was performed to better understand the flow generated at critical points within the catchment. This was done as well as the pipe system capacity analysis to help determine the effectiveness of possible detention within the catchment. As stated previously in this report the Whau catchment has virtually no detention or attenuation in the catchment. Best practice stormwater management targets detention in the upper catchment to alleviate flooding downstream, provide water quality control and promotes increased hydraulic capacity in the lower catchment.

To this end an analysis was undertaken that looked at the catchment in thirds, considering hydraulic length. The upper third and upper two thirds of the catchment were used to define the critical flow sections within the catchment. This analysis is intended to determine the feasibility of providing detention within public reserve without impacting road services. The total sub catchment areas are shown in the following figure.

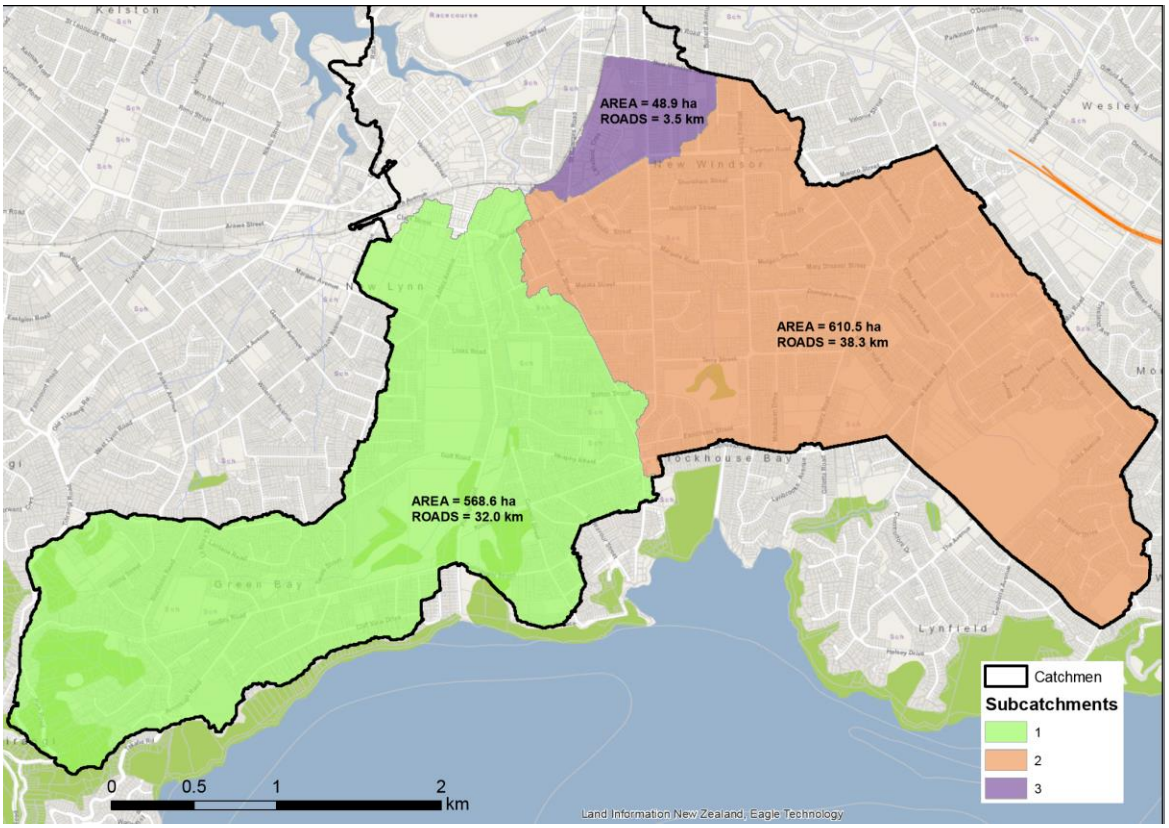


Figure 30 Total Sub-catchment area targeted for detention

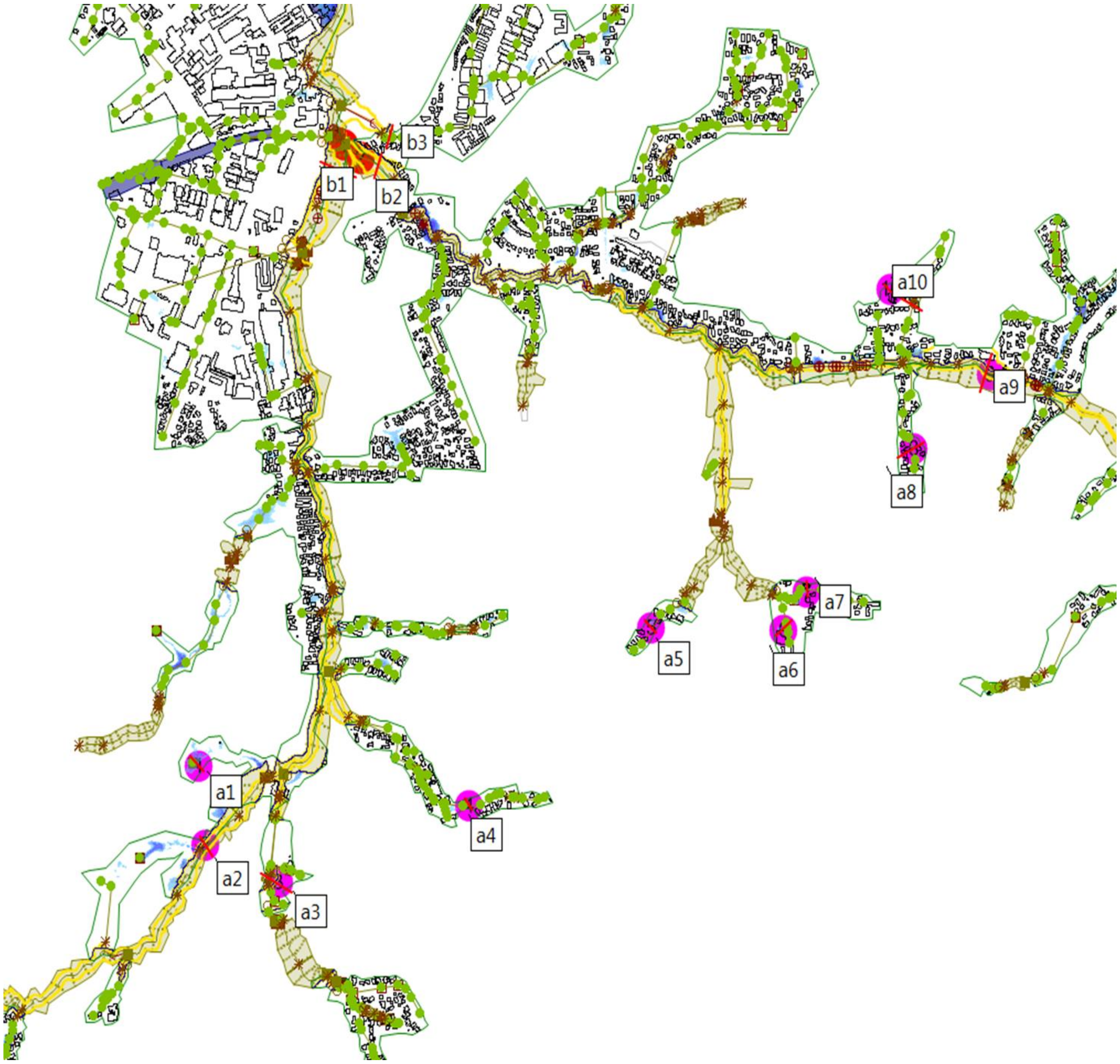


Figure 31 Critical Cross Section Analysis

The cross sections denoted with alpha numeric a1, a2 etc. are the upper third of the catchment and those denoted with b1, b2, etc. are the upper two thirds of the catchment. The 2-year, 5-year, 10-year MPD and validation storms were analyzed, and results are summarized in the following tables.

Table 26 2 Year Flow Analysis

2yrs	Max Flow Rate (m3/s)			Max 1 Hour Volume (m3)		
ID	Overland flow	Pipe Channel Flow	Total	Overland flow	Pipe Channel Flow	Total
a1	0.38	0.00	0.38	1,005.33	0.00	1,005.33
a2	0.00	16.39	16.39	0.00	50,957.21	50,957.21
a3	0.00	1.75	1.75	0.00	5,307.81	5,307.81
a4	0.00	0.66	0.66	0.00	1,336.67	1,336.67
a5	0.00	0.42	0.42	0.00	1,030.25	1,030.25
a6	0.00	0.70	0.70	0.00	1,303.58	1,303.58
a7	0.17	0.66	0.83	107.25	1,532.79	1,640.04
a8	0.01	1.01	1.01	2.99	1,932.90	1,935.89
a9	0.00	18.59	18.59	0.00	54,873.20	54,873.20
a10	0.00	0.93	0.93	0.00	1,723.01	1,723.01
	0.56	41.11	41.67	1,115.57	119,997.43	121,113.00
b1	0.00	24.92	24.92	0.00	86,071.40	86,071.40
b2	0.00	34.29	34.29	0.00	107,477.05	107,477.05
b3	0.00	4.97	4.97	0.00	10,671.73	10,671.73
Total	0.00	64.19	64.19	0.00	204,220.19	204,220.19

Table 27 5 Year Flow Analysis

5yrs	Max Flow Rate (m3/s)			Max 1 Hour Volume (m3)		
ID	Overland flow	Pipe Channel Flow	Total	Overland flow	Pipe Channel Flow	Total
a1	0.55	0.00	0.55	1,432.78	0.00	1,432.78
a2	0.00	20.68	20.68	0.00	66,585.92	66,585.92
a3	0.00	2.04	2.04	0.00	6,988.28	6,988.28
a4	0.00	0.68	0.68	0.00	1,812.56	1,812.56
a5	0.45	0.44	0.89	357.75	1,263.35	1,621.10
a6	0.06	0.92	0.98	34.93	1,856.26	1,891.19
a7	0.60	0.66	1.26	513.25	1,928.06	2,441.31
a8	0.36	1.12	1.48	166.43	2,624.28	2,790.71
a9	0.00	24.89	24.89	0.00	78,237.45	78,237.45
a10	0.00	1.21	1.21	0.00	2,470.02	2,470.02
	2.03	52.65	54.67	2,505.13	163,766.18	166,271.31
b1	0.00	32.17	32.17	0.00	112,709.03	112,709.03
b2	0.00	45.36	45.36	0.00	149,811.10	149,811.10
b3	0.00	6.86	6.86	0.00	14,938.13	14,938.13
Total	0.00	84.39	84.39	0.00	277,458.26	277,458.26

Table 28 10 Year Flow Analysis

10yrs	Max Flow Rate (m3/s)			Max 1 Hour Volume (m3)		
ID	Overland flow	Pipe Channel Flow	Total	Overland flow	Pipe Channel Flow	Total
a1	0.68	0.00	0.68	1,769.67	0.00	1,769.67
a2	0.00	23.44	23.44	0.00	77,037.28	77,037.28
a3	0.00	2.15	2.15	0.00	7,519.22	7,519.22
a4	0.14	0.70	0.84	219.21	2,117.03	2,336.24
a5	0.62	0.47	1.09	600.29	1,385.95	1,986.24
a6	0.25	0.95	1.20	144.83	2,167.76	2,312.58
a7	0.96	0.66	1.62	871.05	2,105.12	2,976.17
a8	0.75	1.16	1.91	463.04	3,003.84	3,466.88
a9	0.00	29.61	29.61	0.00	94,856.00	94,856.00
a10	0.13	1.22	1.35	52.50	2,934.43	2,986.93
	3.53	60.36	63.89	4,120.59	193,126.62	197,247.22
b1	0.00	38.02	38.02	0.00	133,569.41	133,569.41
b2	0.00	51.89	51.89	0.00	177,340.25	177,340.25
b3	0.00	7.89	7.89	0.00	17,450.71	17,450.71
Total	0.00	97.80	97.80	0.00	328,360.37	328,360.37

Table 29 Validation Storm Flow Analysis

Validation	Max Flow Rate (m3/s)			Total Volume (m3)		
ID	Overland flow	Pipe Channel Flow	Total	Overland flow	Pipe Channel Flow	Total
a1	0.37	0.00	0.37	1,343.71	0.00	1,343.71
a2	0.00	23.45	23.45	0.00	129,471.45	129,471.45
a3	0.00	2.16	2.16	0.00	13,497.11	13,497.11
a4	0.13	0.74	0.87	270.24	2,928.02	3,198.26
a5	0.56	0.46	1.02	999.43	2,058.09	3,057.52
a6	0.00	0.59	0.59	0.00	1,639.10	1,639.10
a7	0.02	0.67	0.69	10.91	2,055.20	2,066.12
a8	0.00	0.84	0.84	0.00	2,344.81	2,344.81
a9	0.00	15.16	15.16	0.00	77,952.30	77,952.30
a10	0.00	0.75	0.75	0.00	2,109.26	2,109.26
	1.08	44.81	45.89	2,624.29	234,055.34	236,679.63
b1	0.00	37.92	37.92	0.00	254,978.66	254,978.66
b2	0.00	29.84	29.84	0.00	181,144.07	181,144.07
b3	0.00	6.82	6.82	0.00	25,784.96	25,784.96
Total	0.00	74.58	74.58	0.00	461,907.69	461,907.69

The flows and volumes are generated within the Whau catchment are significant nearly half a million cubes for the validation storm, yet these are not unmanageable. The difficulties of providing detention within a developed catchment are well understood. The lack of space is a primary constraint, as well as management and maintenance difficulties. Therefore, Ewaters has devised a solution of micro detention integrated into the footpaths of the road reserve using permeable pavement technology. This approach seeks to provide an average of 1 cubic meter of storage for every meter length of identified suitable roadway.

The logic in pursuing such a solution is that roads, during storm events, are our new ephemeral streams. If stormwater can be managed before it gets to the roadway, then this will not only reduce flood risk to homes and structures, but also reduce flood risk in roadways and reduce overall road maintenance costs. Also, by providing a diffused system that achieves a standardized approach the design and construction quality can be well controlled, and the regular maintenance can be minimized.

Engineering criteria was defined to determine suitable roadways to target solution areas. Roadways of less than 10% slope for continuous lengths of greater than 50m were considered for further investigation. The following figures show the roads that are considered suitable for further investigation.

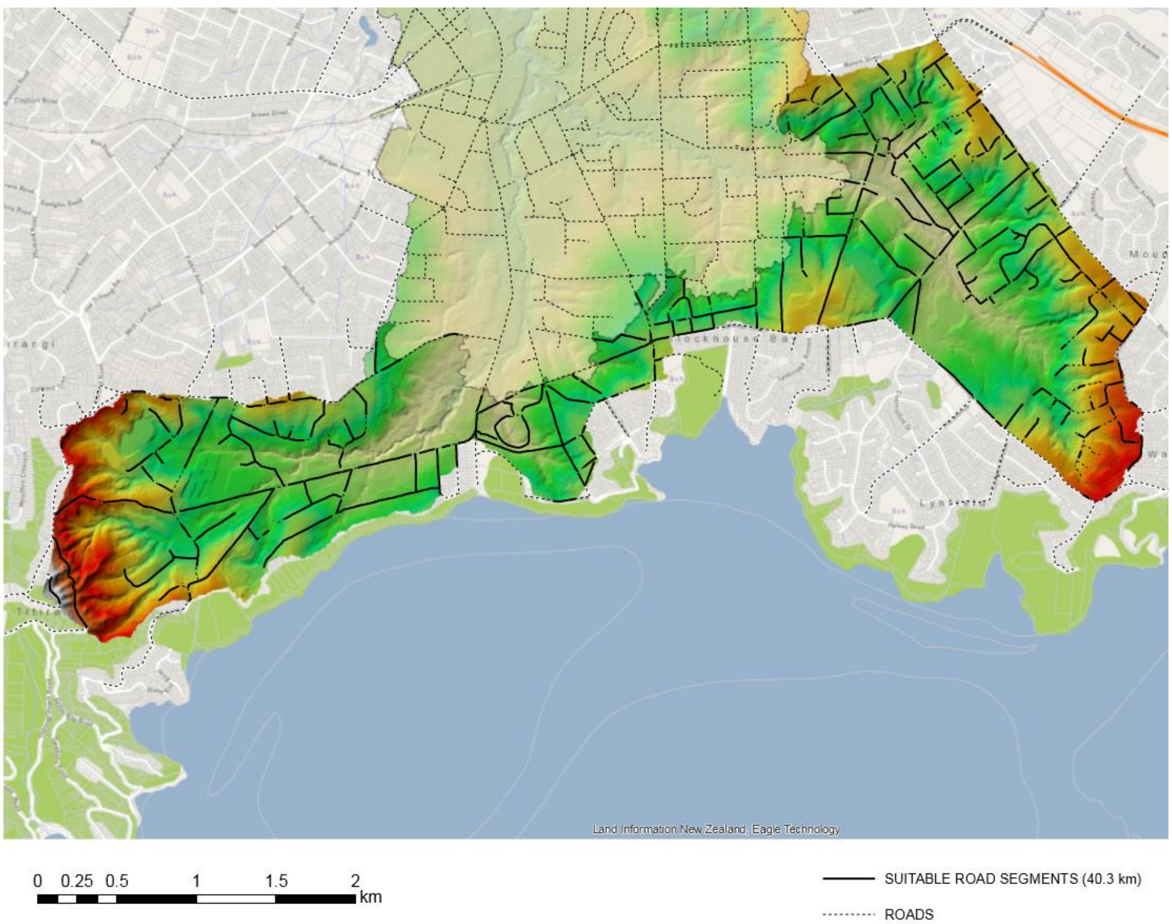


Figure 32 Upper one third of the catchment roads identified for further investigation

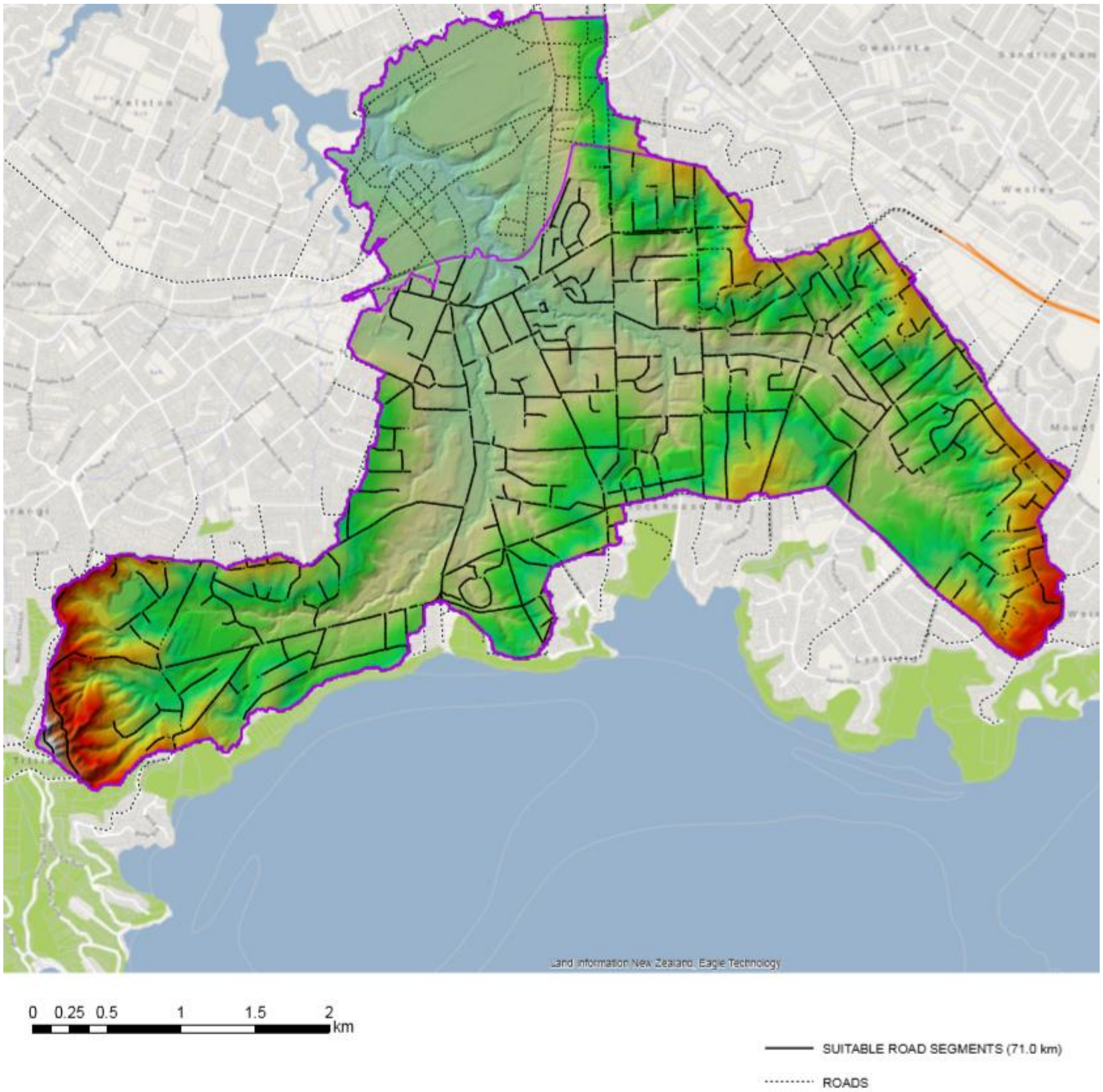


Figure 33 Upper Two Thirds Catchment Suitable Roadways

Utilizing this approach, it is possible to provide 41,000 cubic meters of detention for the upper third of the catchment or 71,000 cubic meters of storage for the upper two thirds. This would be approximately 15% of the total of runoff volume generated within the catchment considering the March 2017 flooding event. 15% is a significant number, as when it is appropriately designed, this percentage of storage can offset the increased runoff due to development and greatly reduce flood risk.

It is understood that the storage will need to be appropriately designed to be available during the peak hour of the storm and this is achievable with proper design and construction. It should also be understood that this approach can provide water quality control as well as flood control. Furthermore, targeted solutions can provide relief needed for the combined sewers in the Whau catchment without installing a new separated sewer. A similar solution was applied to the City of Chicago alleyways and has been highly successful for managing and reducing stormwater runoff.

8.4 SURVEYD FLOODED PROPERTIES ANALYSIS

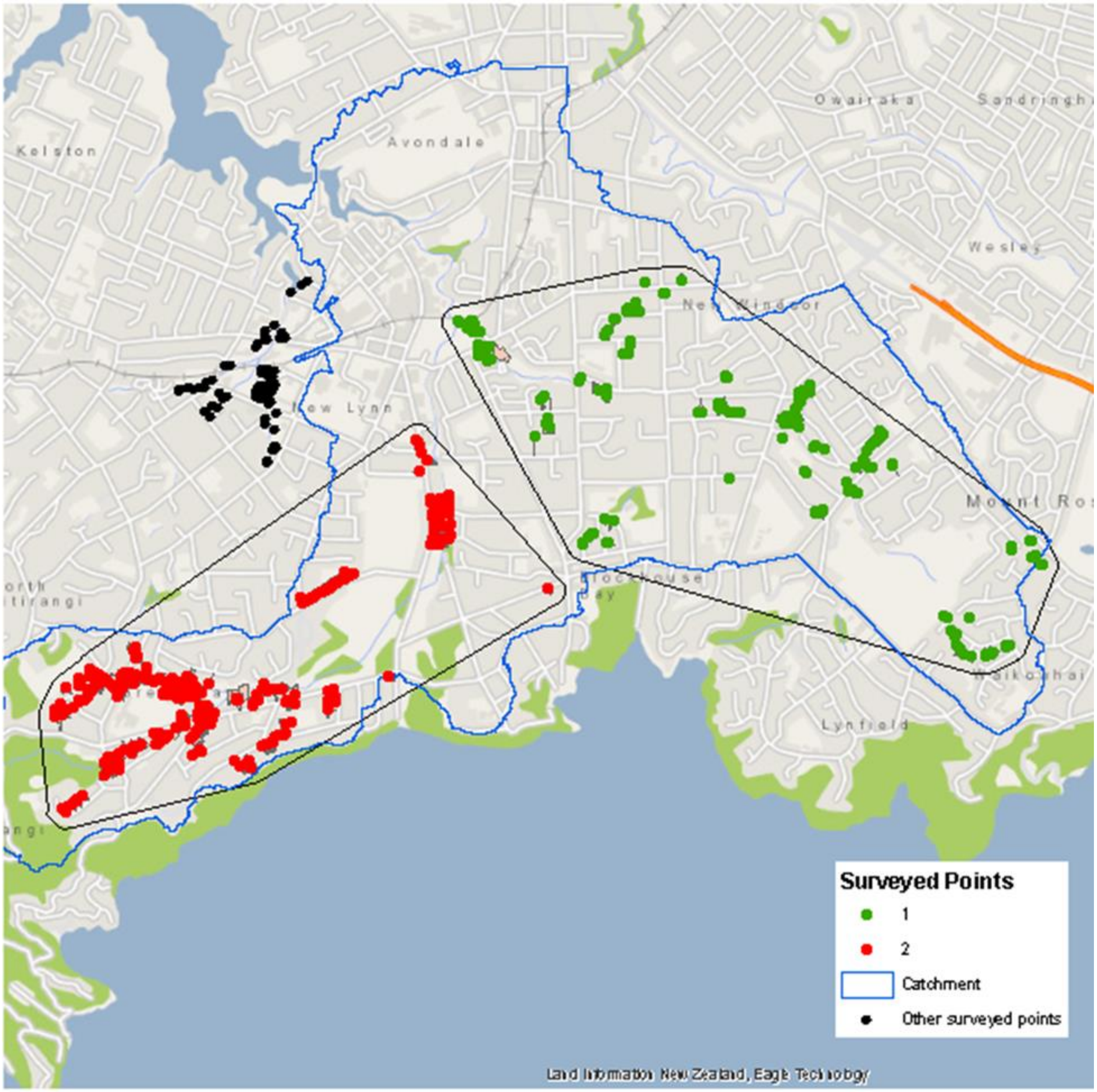


Table records had coordinates and codes: FL, SH and GL, assumed HOUSE FLOOR, SHED and GROUND LEVEL. Largest building inside parcel was assumed HOUSE, second largest – SHED. If more than one FL level found, largest building received value from 1st record. No assignments for other buildings if any. There are cases with 3 surveyed points and single building inside parcel.

ASSIGNING FLOOR LEVELS FOR AREA 2 – POOR LEVEL OF CONFIDENCE

This dataset (396 records) has no surveyed coordinates, just addresses, so they were geo-coded first, resulting in multiple overlapping points per parcel.

Floor levels were assigned to buildings in order they appeared in the table, largest building <> value from first relevant row, second largest <> second row, etc. Note some of the records in the table had no level values at all.

8.5 SURVEYED FLOOR LEVELS DELIVERABLES

Attribute table of BUILDINGS (shapefile)

GISBUILDIN	Building ID, provided	NO DATA

PAR_ID	Parcel ID, provided	
WET_010	Area of the building flooded for 10 years flood, %	
D_010_MIN	Depth (MIN) in the building flooded for 10 years flood, m	-9999
D_010_MAX	Depth (MAX) in the building flooded for 10 years flood, m	-9999
RL_010_MIN	RL (MIN) in the building flooded for 10 years flood, m	-9999
RL_010_MAX	RL (MAX) in the building flooded for 10 years flood, m	-9999
WET_100	Area of the building flooded for 100 years flood, %	-9999
D_100_MIN	Depth (MIN) in the building flooded for 100 years flood, m	-9999
D_100_MAX	Depth (MAX) in the building flooded for 100 years flood, m	-9999
RL_100_MIN	RL (MIN) in the building flooded for 100 years flood, m	-9999
RL_100_MAX	RL (MAX) in the building flooded for 100 years flood, m	-9999
SVD_FLOOR	Estimated floor level, m	-9999

PARCELS

Due to nature of data provided (ONE parcel – MANY surveyed records) we are also delivering surveyed parcels as feature dataset in file geodatabase (DELIVERABLE_2.gdb) where each surveyed parcel has extract from source table attached as CSV file, e.g.

STREET_NUM	ADDRESS	FLOOR_LEVE	BLDG_TYPE	FLOOR_TYPE	ORIGIN
37	37 La Rosa Street	36.17	Garage		
37	37 La Rosa Street	36.73	House-ground		

37	37 La Rosa Street	39.33	House-upper	CORRECT	Opus 2000/01

Or

LOCATION	NZTMY	NZTMX	MSL	CODE	COMMENT
FL36BOUNDRY	5913388.87	1752978.28	23.23	FL	
GL36BOUNDRY	5913383.68	1752981.03	21.96	GL	
SH36BONDRY	5913381.39	1752974.87	22.1	SH	

Depending on the parent dataset.

8.6 UPDATE REASSIGNMENT OF SURVEY RESULTS TO AREA 2 BUILDINGS

Client comments:

For Area 2 (Avondale Stream Survey) the memo says were an address has 2 or more data points you have assumed the first entry is the floor level. I don't think this is correct. There is a "Bldg Type" field with type of floor of codes in it. I don't have any information on what the codes mean but I think we can assume the following:

Habitable:

H = House

H – Lowest = lowest floor level on a house

Bottom = Bottom floor of house

Top = Top floor of house (multi storey?)

SO = Sleep out

Non-Habitable:

G = Garage

C = Carport

S = Shed

G&C = Garage and Carport

If a building has multiple entries, i.e. surveyed levels for a sleep out (SO) and a house (H), largest building = value with code H , second largest = SO, etc. Similar to the process you used for Area 1.

Turned out to be non-feasible, because Bldg_Type field in contains 55 unique values, i.e. shows complete lack of database management practice (see page "Bldg_Type" in attached Excel book). One possible approach was to assign ranks to above 55 entries and transfer it back to survey table and further to building assignment. This doesn't work either because there is a risk of gaps in rankings, i.e. no rank=1 (even for parcel with single building), or rank = 2 for parcel with more than 1 building. Therefore, we were forced to manually shuffle through 66 parcels and rank related records from surveyed table using our best judgement (see page “RANKED_TABLE” in attached Excel book). When we saw that number of records exceeded number of houses inside parcel, those extra records were ranked 100.

Last column in attached Excel book is copy of buildings attribute table, the rows that

"SURVEYED" = 'N' AND "WET_010" >0 OR "WET_100" >0

store value of “Y” in last column called “TO_SURVEY”, total 2666 rows

8.7 MAPS

See A3 map file

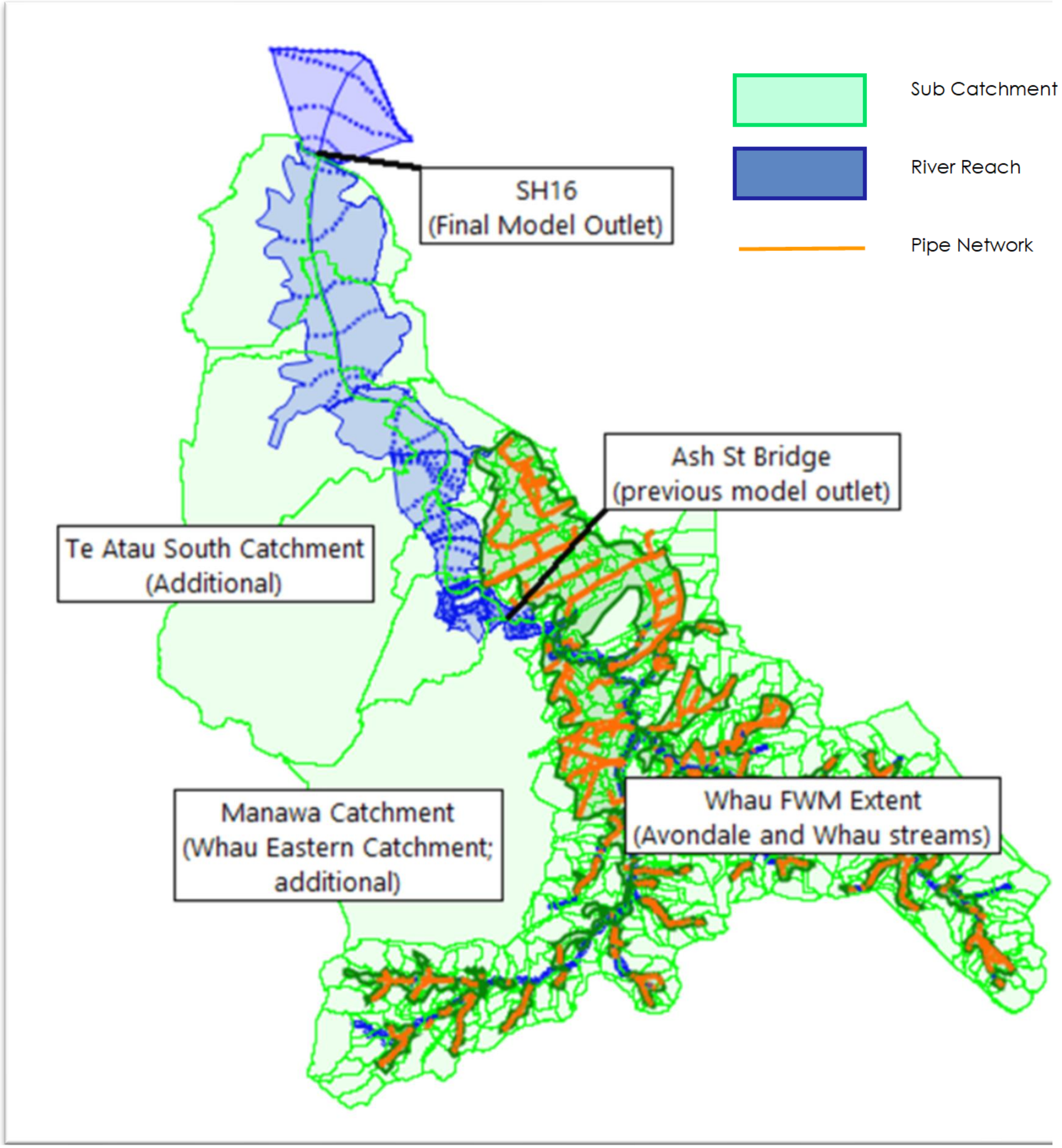


Figure 8.7.2 Model Overview

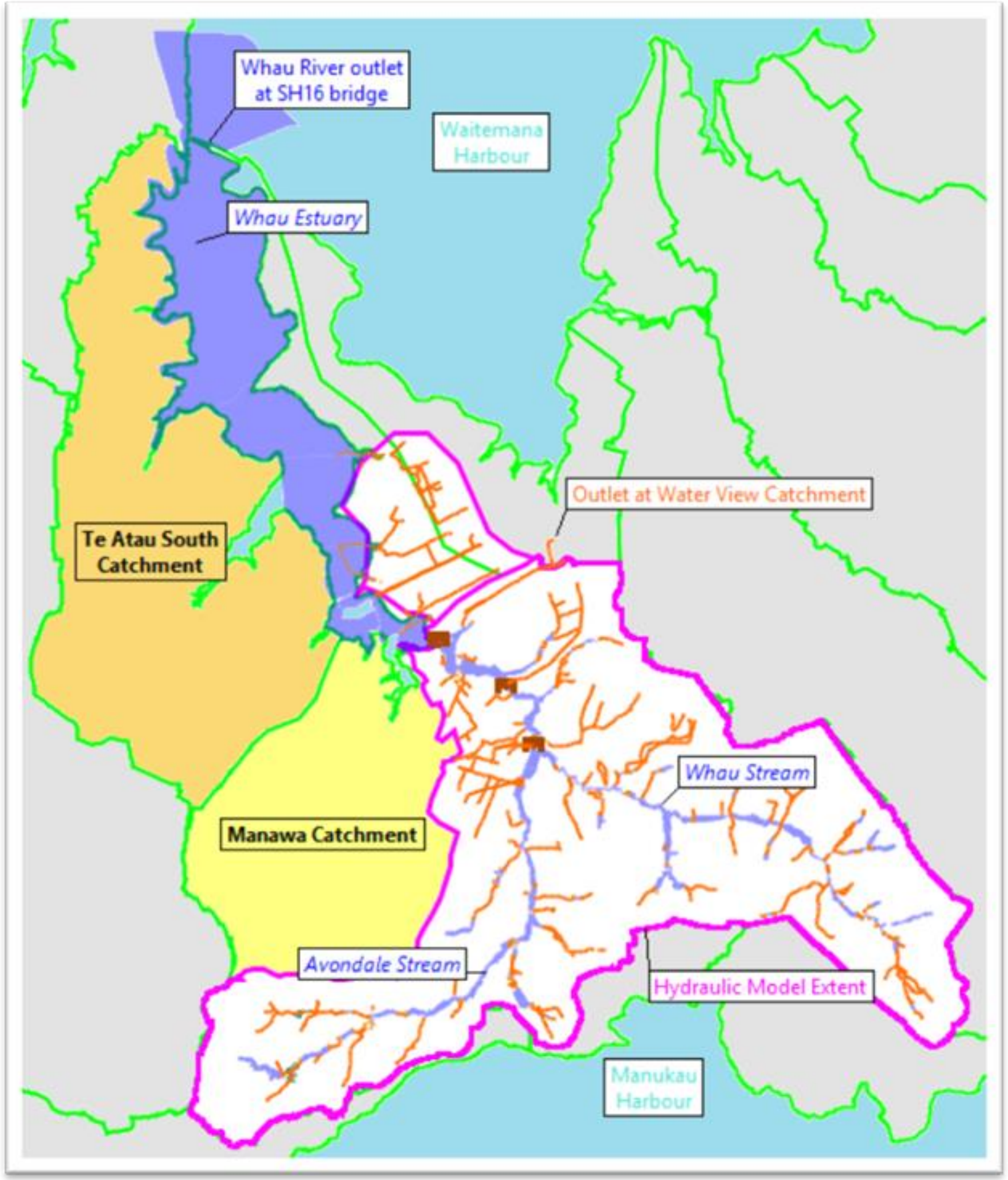


Figure 8.7.8.7. 1 Hydrologic Model

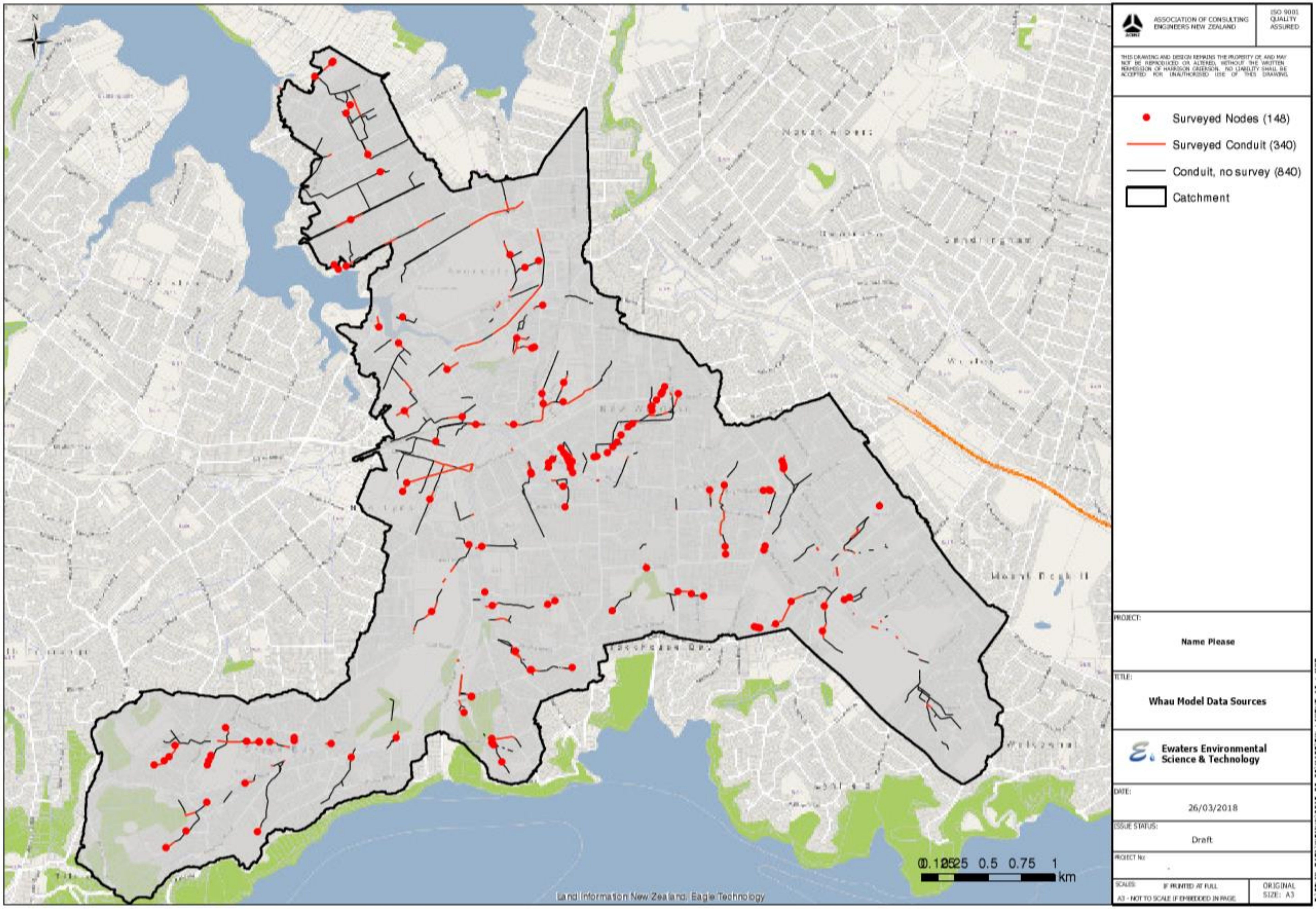


Figure 8.7.3 Surveyd Assets

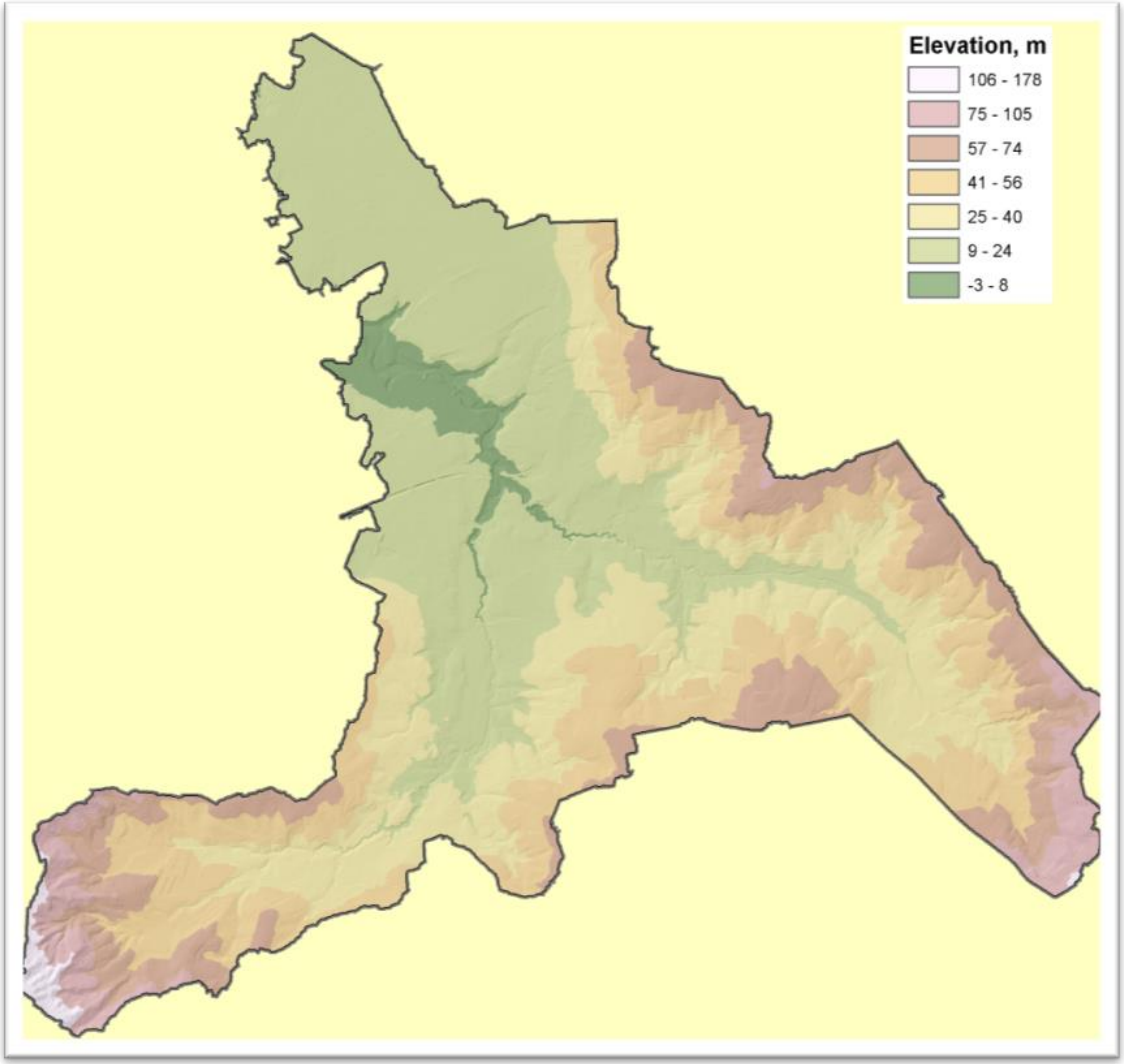


Figure 8.7.4 Elevation Model

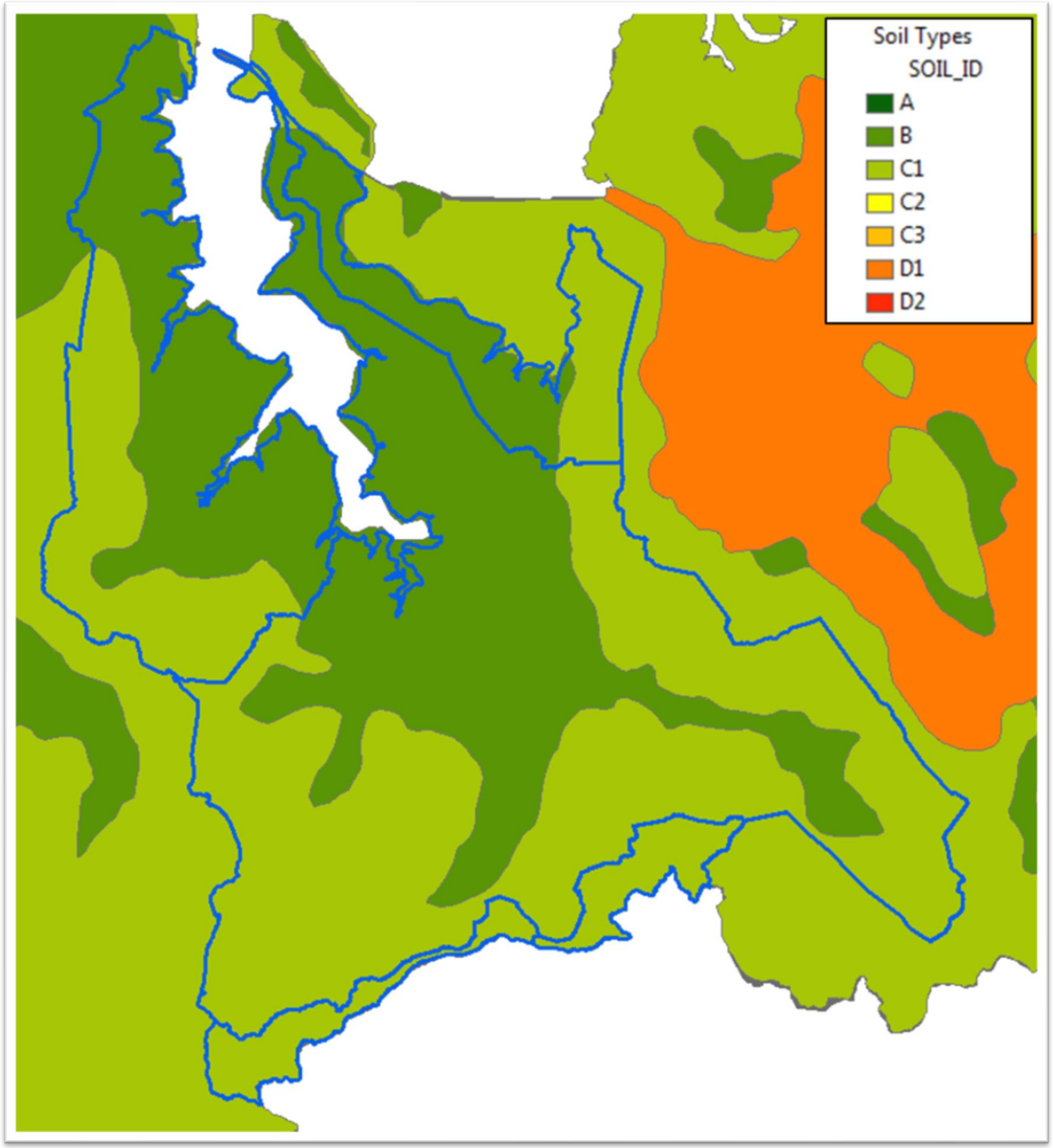
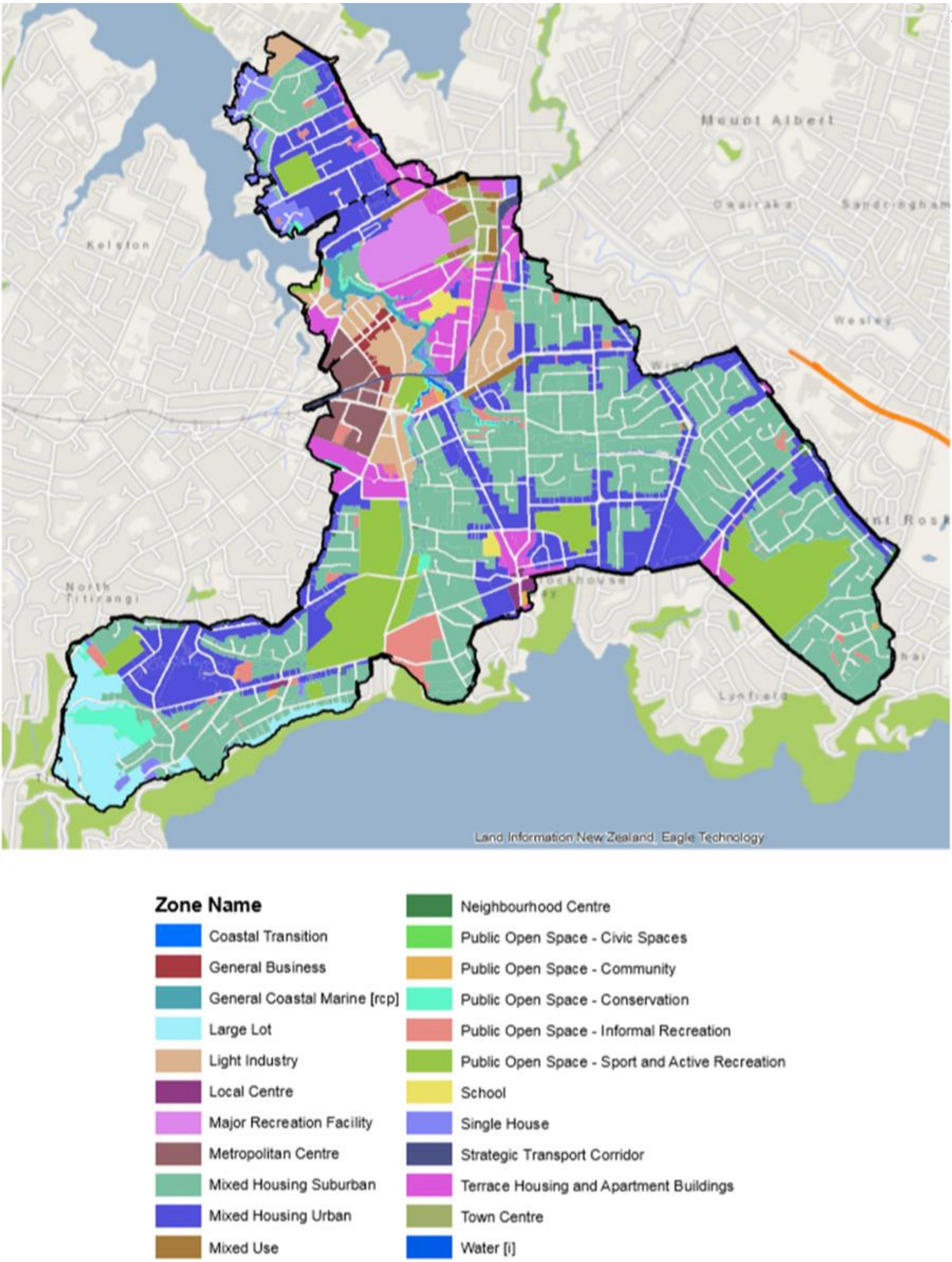
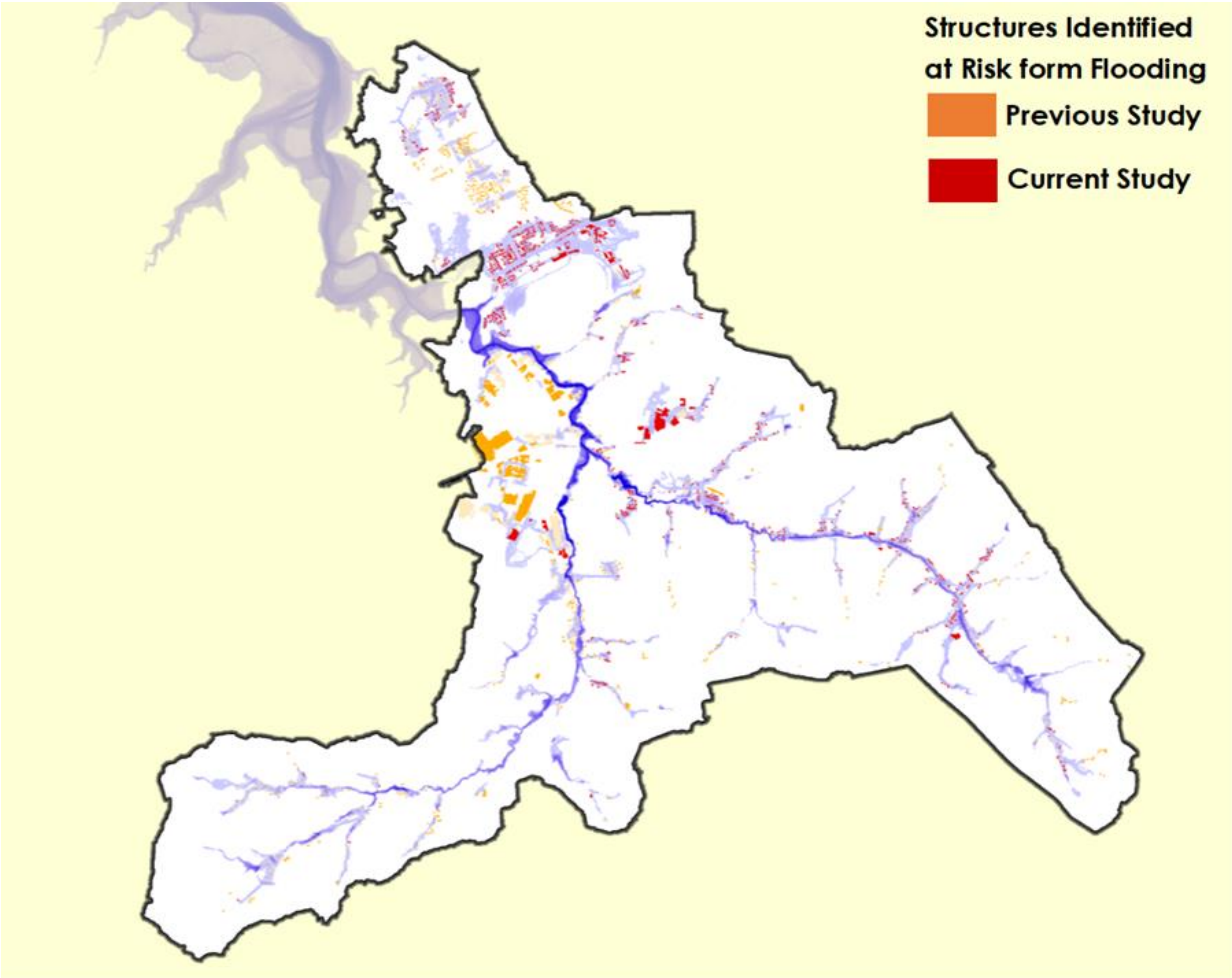
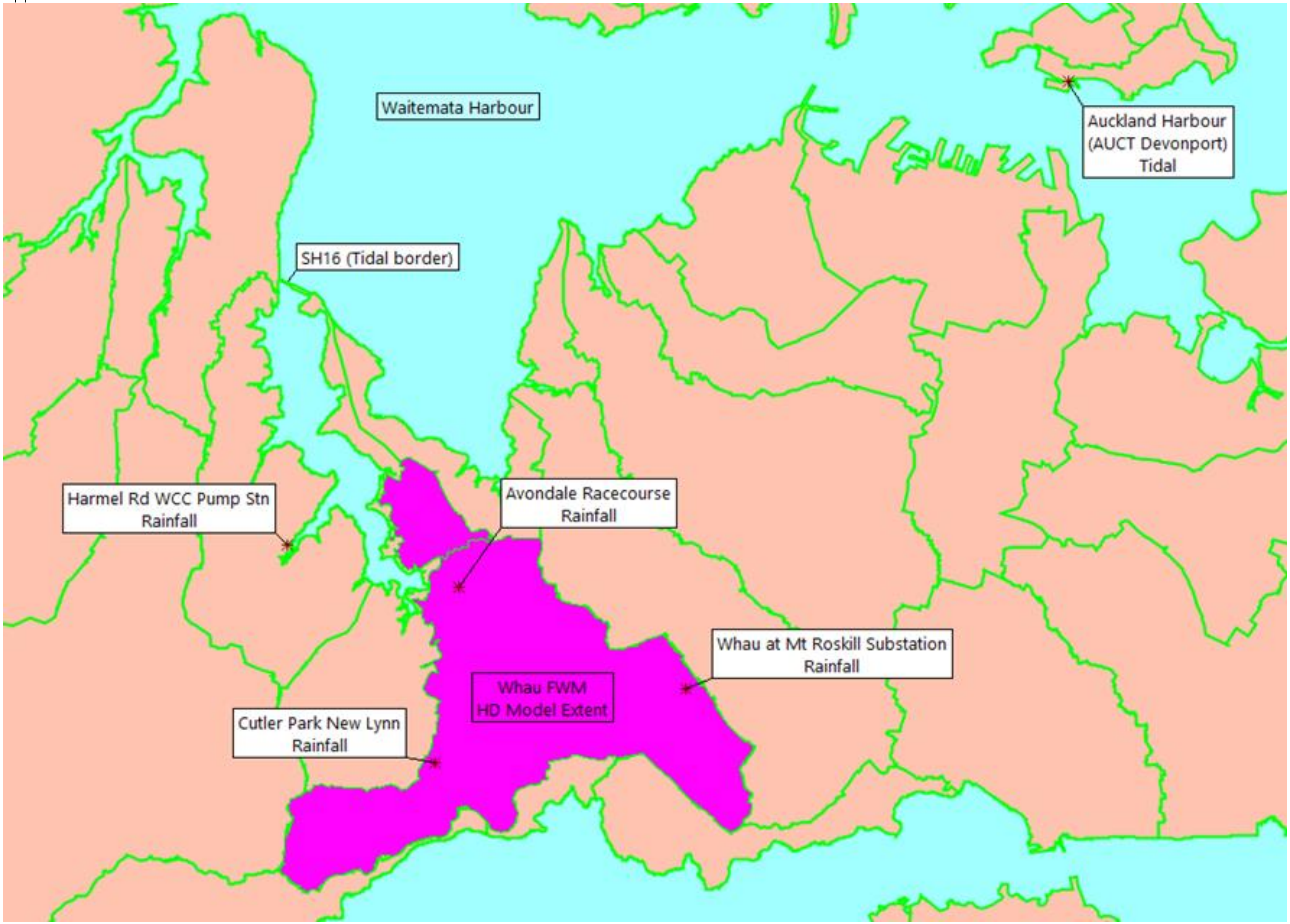


Figure 8.7.5 Soil Types

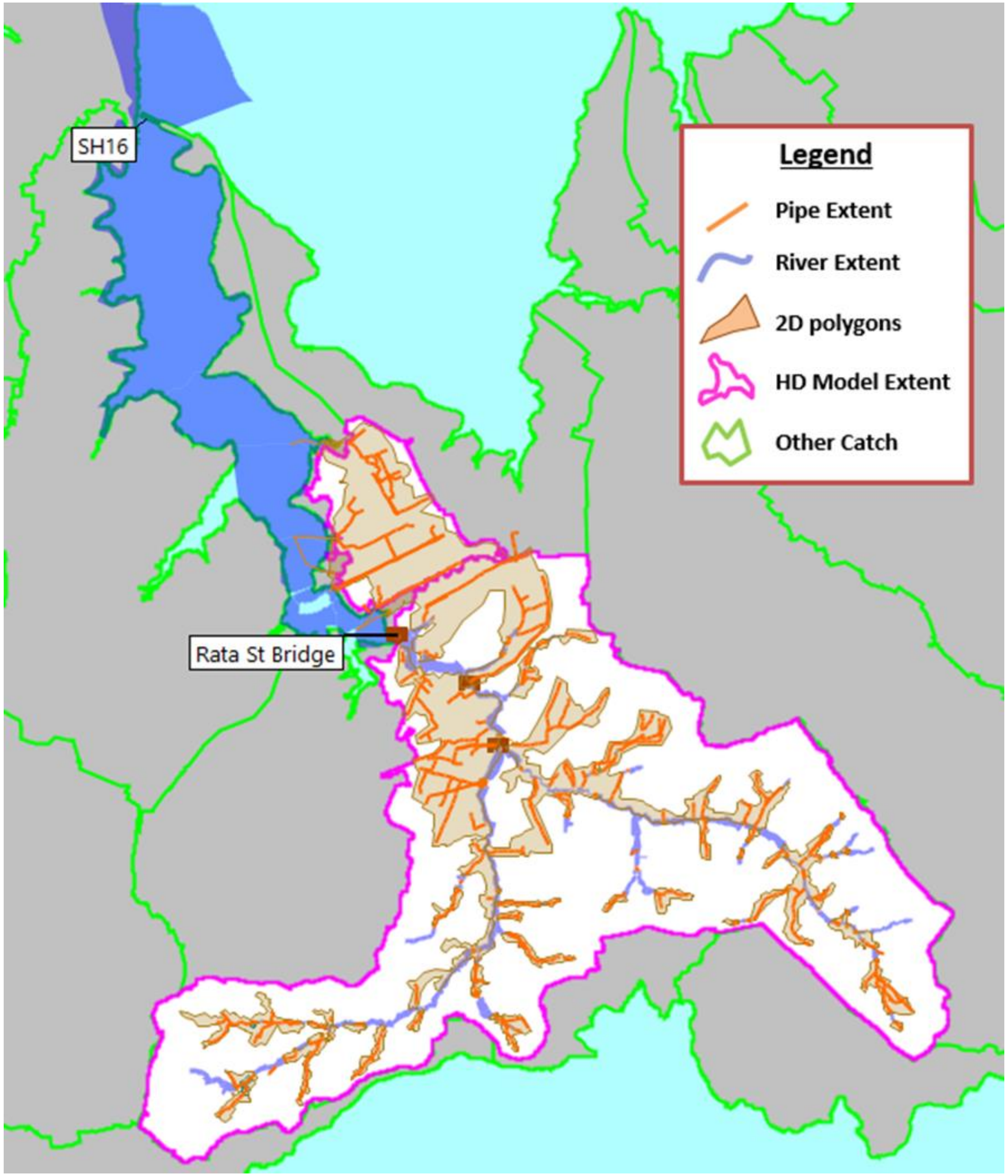

Mount Albert
Owairaka
Sandringham
Kelston
Wesley
North Titirangi
Lynfield
Land Information New Zealand, Eagle Technology
Zone Name
Coastal Transition
General Business
General Coastal Marine [rcp]
Large Lot
Light Industry
Local Centre
Major Recreation Facility
Metropolitan Centre
Mixed Housing Suburban
Mixed Housing Urban
Mixed Use
Neighbourhood Centre
Public Open Space - Civic Spaces
Public Open Space - Community
Public Open Space - Conservation
Public Open Space - Informal Recreation
Public Open Space - Sport and Active Recreation
School
Single House
Strategic Transport Corridor
Terrace Housing and Apartment Buildings
Town Centre
Water [i]


Structures Identified at Risk form Flooding
Previous Study
Current Study

Appendix 8.7



Waitemata Harbour
Auckland Harbour (AUCT Devonport) Tidal
SH16 (Tidal border)
Harmel Rd WCC Pump Stn Rainfall
Avondale Racecourse Rainfall
Whau at Mt Roskill Substation Rainfall
Whau FWM HD Model Extent
Cutler Park New Lynn Rainfall


SH16
Rata St Bridge
Legend
Pipe Extent
River Extent
2D polygons
HD Model Extent
Other Catch

Appendix 8.7

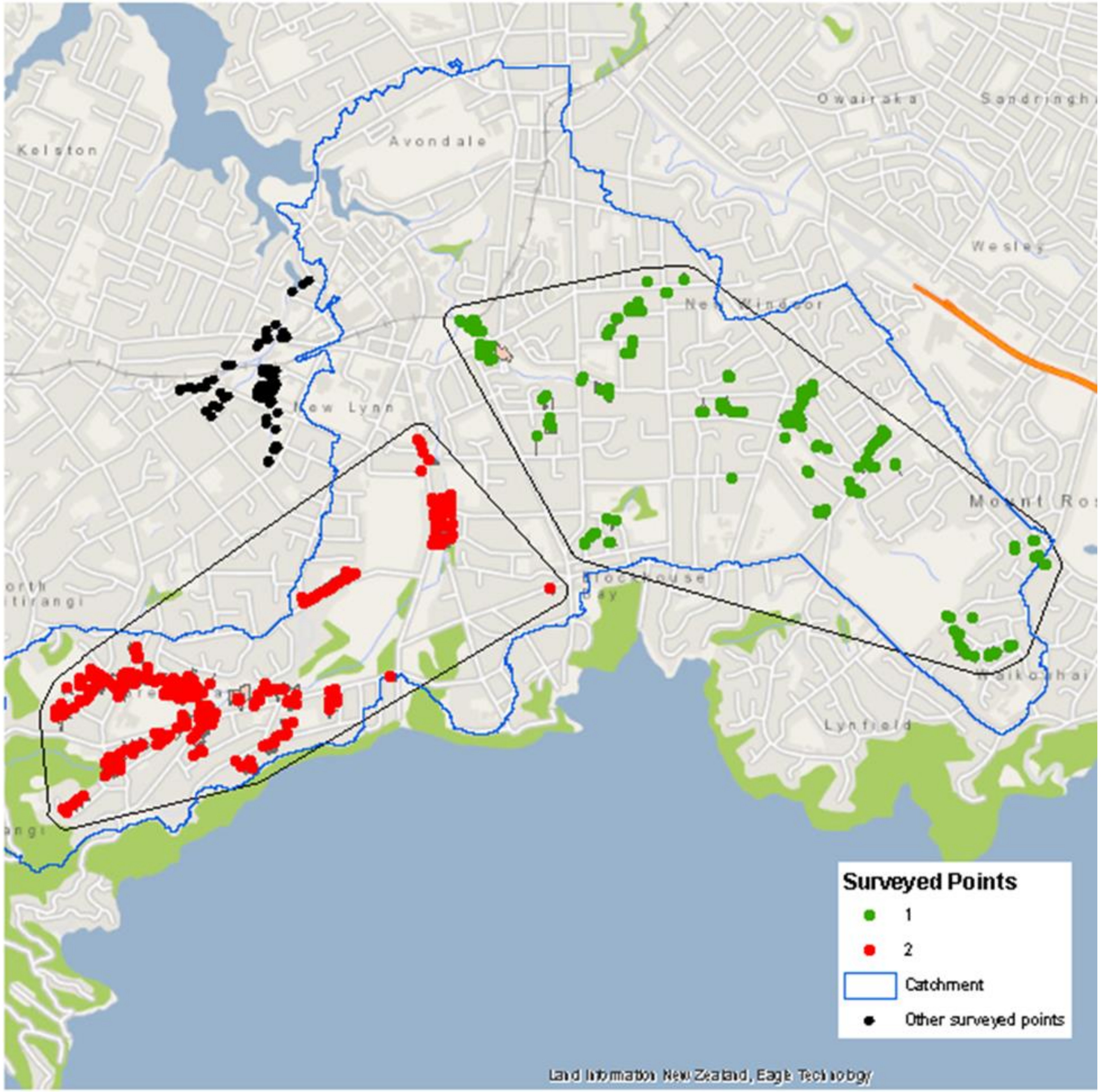


Figure 6 Habitable Floor Survey