REPORT

Manukau City Council

Clevedon Flood Hazard Mapping
FINAL (Contract No. 4518)

Report prepared for:

Manukau City Council

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Executive summary

This Report details the flood hazard mapping study of the Wairoa River and Taitaia Stream that Tonkin & Taylor have carried out for Manukau City Council. The purpose of the study is to provide flood extents that can be used in the Clevedon Village Sustainable Development Plan (SDP), and be incorporated into a plan change to the Manukau Operative District Plan for Clevedon Village. The plan provides for the expansion of the existing Clevedon settlement onto the rural land outside the village core and between the Wairoa River and Taitaia Stream.

The flood hazard mapping methodology was divided into catchment hydrology and catchment hydraulics. Where information was available, calibration and validation of the catchment hydrology and catchment hydraulics was carried out.

Calibration and validation of the hydrological model identified very good agreement between predicted flows from the model and recorded flows from the Tourist Road flow gauge.

The catchment characteristics of the calibrated hydrological model were used to define the catchment characteristics in the catchments where there are no flow records available (with the exception of the Cosseys Dam and Wairoa Dam catchments). Due to differences in vegetation cover between the Cosseys Dam and Wairoa Dam catchments and the rest of the catchment, parameters considered representative of the dammed catchments were used. These parameters reflected the more dense vegetation cover of the dammed catchments.

The hydrological model was used to determine inflows to the hydraulic model. The 100 year ARI design inflows were calculated using the ARC Technical Publication 108 methodology. Allowances for climate change (+16.8%) and an areal reduction factor (0.83) were incorporated into the design hyetograph. The runoff from the dammed catchments conservatively assumed that the dams were full at the start of the design storm.

The hydrological model predicted peak flows for the 100 yr ARI design storm up to 527 m^3/s from the catchments upstream from Tourist Road. Additional inputs to the Wairoa River and Taitaia Stream from sub-catchments downstream of the Wairoa River were also accounted for. The Taitaia Stream catchment was divided into 8 sub-catchments and these contributed individual catchment flows ranging from 11 m^3/s to 158 m^3/s.

A hydraulic model of the SDP area was built using a combined 1 dimensional and 2 dimensional modelling approach. Additional representation of the Wairoa River continued downstream from the SDP area to the mouth of the river to ensure that coastal effects on flood levels were accounted for. The model build utilised topographic data from survey and LiDAR to build a representative model of the Wairoa River, Taitaia Stream and the floodplains around the study area.

Hydraulic model calibration was undertaken for a July 2008 storm event. Model predictions were compared to flood levels that were photographed during the storm event. The levels were surveyed for the purposes of this Report.

The hydraulic model calibration used boundary conditions from the Tourist Road flow gauge for flows upstream of Tourist Road, and by the hydrological model for all other catchments. The downstream water level boundary was derived from tide gauge records at Port of Auckland. The coastal water levels were modified to account for the Wairoa River mouth being located approximately 35km to the east of Port of Auckland.

An adequate level of calibration was achieved between the predicted water levels from the model and the surveyed July 2008 flood levels. However any further calibration was limited by the availability of water level records in both the Wairoa River and Taitaia Stream and by the availability of flow records in the Taitaia Stream.

An assessment of the 100 year ARI design storm flood extents was carried out using flows estimated from the hydrological model. A 100 year ARI sea level, including sea level rise to 2090, was used as a downstream sea level. The assumption to apply 100 year ARI sea levels with 100 year ARI rainfall is in accordance with the SDP which states that "future development in Clevedon should take a conservative approach based on available information regarding climate change, particularly with respect to floodplains and sea level changes."

The results shown in this Report identify the flood extent, flood depth and flood elevations for the 100 year ARI design storm.

A sensitivity assessment of flood extents was carried out using increases in flow of 10% and decreases in flow of 10% and a reduction in sea level. The results of the sensitivity assessment indicated that there can be a good level of confidence in the flood extents since the extents are relatively insensitive to small changes in flood levels in most areas. The sensitivity assessment identified a small number of areas where a precautionary approach may be best adopted to determining development areas.

1 Introduction

1.1 General

The Clevedon Village Sustainable Development Plan (SDP) sets out a strategy to guide the development of Clevedon over the next 50 years. The SDP outlines the key principles, concepts and outcomes to be incorporated into a plan change to the Manukau Operative District Plan for Clevedon Village. In time this will inform growth decisions for Clevedon within the future Auckland Plan and any future resource consent applications in the plan area.

The plan provides for the expansion of the existing Clevedon settlement onto the rural land outside the village core and between the Wairoa River and Taitaia Stream.

The SDP area was determined by the natural boundaries to the north, west and east created by the Wairoa River and Taitaia Stream respectively. To the south the boundary is defined by Tourist Road. The study area is 558.1 ha between the Wairoa River, Taitaia Stream, Tourist Road and includes the existing village (Draft Clevedon Village Sustainable Development Plan, Aug 2010).

The draft land use map for the SDP is shown in Appendix A.1.

Much of the study area is located in low-lying terrain and therefore flooding is a key issue and a constraint to growth in Clevedon. This Report details the flood hazard mapping study that Tonkin & Taylor (T&T) have carried out for Manukau City Council (MCC) and provides flood extents that can be used for the SDP and the plan change.

1.2 Clevedon watercourses

The Wairoa River is the largest east coast river in the Auckland region. The headwaters of the river lie in the Hunua Ranges where the headwater stream and a tributary are impounded by the Wairoa and Cosseys dams. The Wairoa River flows into the Tamaki Strait part of the Hauraki Gulf. The Wairoa Estuary comprises of a range of habitats including intertidal flats and shell banks, areas of mangrove and salt marsh, saline vegetation and freshwater vegetation. The Wairoa River and Estuary is identified as an Area of Significant Conservation Value within the Auckland Regional Plan: Coastal.

There are a number of perennial streams within the Clevedon Study Area that feed into the Wairoa River and Estuary. To the west of the village is the Taitaia Stream, to the north-east of the village is the Aroaro Stream which flows from the Ness Valley and into the Urungahauhau Stream. The Taitaia Stream has the most significant effect of all the previously mentioned perennial streams on flood extents around Clevedon. The other streams are all located downstream of Clevedon township.

A number of ephemeral streams also cross the study area. Some of these are re-aligned farm drains whilst others are overland flowpaths that are typically dry during the summer months. These ephemeral streams are largely outside the scope of this flood study.

1.3 Study purpose

The purpose of this study is to provide a flood hazard assessment of the Wairoa and Taitaia Stream catchments at Clevedon village within the area affected by the SDP. This Report has been written specifically to meet the requirements of the SDP. The requirement of the flood hazard mapping for the SDP was to identify the flood extents during a 100 year ARI (Average Recurrence Interval) design flood. The 100 year ARI flood extents will be used to limit development to areas outside the floodplain.

The 100 year ARI flood extents were determined in accordance with one of MCC's sustainable development and urban design principles, which required a conservative approach to climate change adaptation and resilience to natural hazards.

This study can also be used to assist MCC with their responsibilities relating to the following:

- The definition of flood prone areas
- The provision of advice to the community, regarding the fixing of minimum floor levels, and the development of infrastructure within floodable areas
- The provision of information to infrastructure owners within the region to enable risk to be considered in future planning, design or in the upgrade of existing facilities
- The provision of engineering works to minimise or eliminate flood hazards.
- Emergency management.

1.4 Methodology Overview

The methodology used to determine the flood hazard at Clevedon can be divided into two broad areas:

1. Catchment hydrology

   The catchment hydrology determines the quantity and rate of runoff to the SDP area from the Wairoa and Taitaia catchments. The extents of the Wairoa and Taitaia catchments can be seen in Appendix A.2.

2. River and floodplain hydraulics

   The river and floodplain hydraulics determines the flood characteristics of the flows generated by the catchment hydrology (e.g. flood extent, flood depth, flow velocity). The river and floodplain hydraulics were focussed on the SDP area, although external factors outside of the SDP area were included where necessary (e.g. river channel downstream of SDP area and sea level).

Mapping of the flood extents was carried out using the results of the hydraulic modelling. The flood extents were overlaid on aerial photographs of Clevedon township to identify the areas affected.

2 Hydrology – methodology & data

2.1 Overview

The approach taken of the hydrological assessment of the Wairoa River and Taitaia Stream catchments was firstly to represent the catchments in a hydrological model. The model represents catchment characteristics that convert rainfall into runoff so that flow hydrographs for any given storm event can be derived.

In order to ensure confidence in the hydrological model, a calibration and validation process was carried out based on historical rainfall and flow records, where available.

2.2 Methodology

The locations of the sub-catchments were defined based on topography or locations of flow monitoring stations. The sub-catchments were then represented using a hydrological model. The internationally accepted US Army Core of Engineers HEC-HMS model was selected to represent the hydrological processes. The Soil Conservation Service (SCS) method was used for rainfall runoff processes in accordance with the Auckland Regional Council (ARC) Technical Publication 108 (TP108).

The approach taken was to calibrate and validate a hydrological model based on historical rainfall and flow records where available. The calibration process involved modifying hydrological parameters so that the flows predicted by the hydrological model reasonably simulate the flows recorded by gauges for a number of storm events. The catchment characteristics needed to calibrate the model can vary from one historical event to the next, reflecting the heterogenous nature of the catchment and storm event over time and space (e.g. ground cover changes at different times of the year and temporal or spatial variability in rainfall is different across the catchment and for each storm event).

The validation process involved analysing each of the calibrated storm events and choosing a single set of design catchment characteristics that best represent the catchment. The hydrological model was then rerun for a historical storm event not used in the calibration process to determine whether the model was predicting flows accurately.

Calibration of the Wairoa and Mangawheu sub-catchments was carried out using the Tourist Road and Mangawheu flow gauges respectively. The calibration of the Tourist Road catchment included recorded flows from Mangawheu, Wairoa and Cosseys dams.

It was not possible to calibrate the Wairoa and Cosseys dam catchments because flows from the dams are significantly affected by operational decisions (e.g. diversion for water consumption).

It should be noted that the Taitaia catchment is not gauged for river flows, therefore it was not possible to calibrate this catchment.

The runoff from the Taitaia, Wairoa and Cosseys catchments was determined using catchment characteristics that we considered to be representative of the catchments.

The rainfall from a 100 year ARI design storm was then applied to the validated hydrological model to determine design 100 year ARI flows.

2.3 Catchments

The hydrological sub-catchments of the Wairoa River and Taitaia Stream are shown in Appendix A.2. The catchment areas are summarised in Table 2-1.

Table 2-1 Hydrological sub-catchments for the Wairoa River and Taitaia Stream

Catchments	Sub-catchments	Area
Wairoa Upstream of Tourist Road	Mangawheu (30.4 km^2)	148.1 km^2
	Cosseys Dam (21.3 km^2)	
	Wairoa Dam (13.2 km^2)	
	Wairoa upstream of Tourist Road (83.2 km^2) (excluding Mangawheu, Cosseys and Wairoa)	
Taitaia		43.6 km^2
Clevedon township		5.5 km^2
Holdens Road catchment		11.0 km^2
Clevedon North		9.3 km^2
Wairoa Mouth		3.7 km^2
Urungahauhau		41.1 km^2

Our calculated area for the Taitaia catchment is 43.6km^2, which is 2.4 km^2 smaller that the area indicated by Beca (1995).

2.4 Hydrological data

The following subsections detail the rainfall and flow gauging records that were used to assist with the hydrological model calibration. Analysis of the records also helped to formulate and support modelling assumptions discussed later in the Report.

2.4.1 Rainfall

There are four rain gauges located in the Wairoa catchment and no rain gauges in the Taitaia catchment. There is an additional rain gauge (Hays Creek) that is located outside of both the Taitaia and Wairoa catchments, but located nearby to both catchments. The rain gauges are described in Table 2-2 and their locations can be seen in Appendix A.2.

Table 2-2 Rain gauge details

	Site start date	Elevation	Location (NZTM)
Trig Rain Gauge	August 1997	RL 339m	1786551, 5900514
Cosseys Dam	November 1996	RL 175m	1787291, 5896146
Wairoa Dam	July 1992	RL 144m	1788403, 5891214
Hunua Rain Gauge*	September 1997	RL 75m	1784237, 5894142
Hays Creek Dam	August 1997	RL 159m	1779867, 5896200
* Prior to September 1997, there was a rain gauge called Hunua at Nursery located approximately 50m away from the Hunua Rain Gauge site.			

Annual rainfall in the Wairoa catchment (including Hays Creek) typically varies from an average of 1450 mm in the west (Hays Creek and Hunua gauges) to 1600 mm in the east (Wairoa, Cosseys and Trig Rain gauges). The annual rainfall between 2000 and 2009 is shown in Figure 2-1. The increase in rainfall from west to east can also be observed in the TP108 rainfall isohyets. The TP108 isohyets for the 100 year ARI are shown in Appendix C. There is further discussion regarding the use of average rainfall versus spatially varying rainfall in the model calibration section (Section 3).

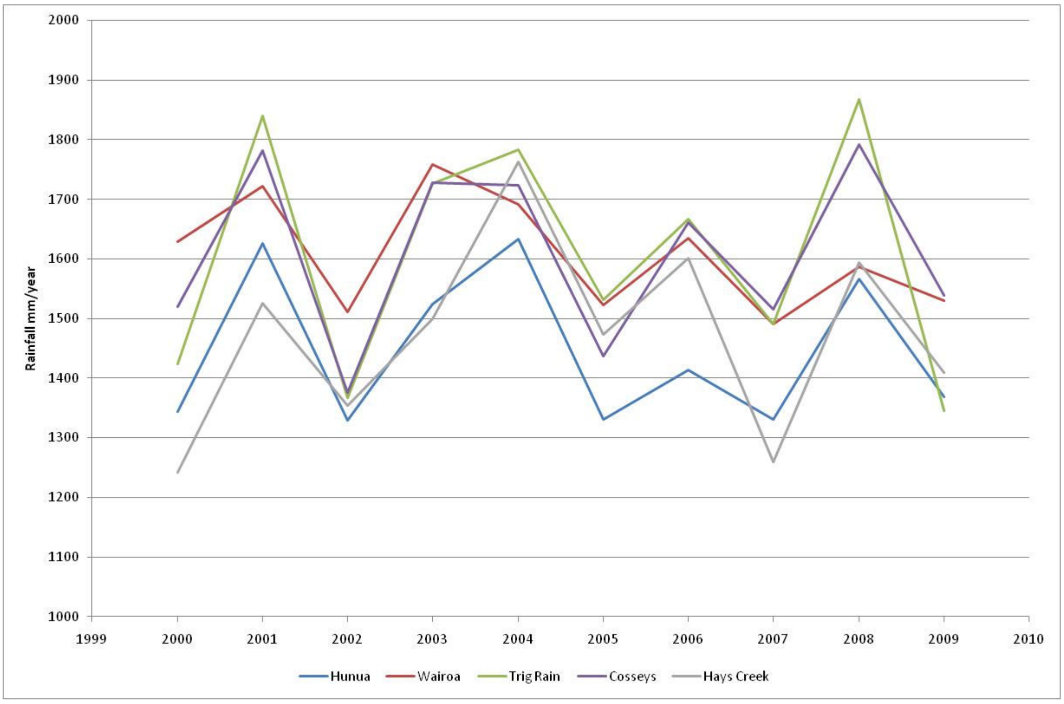

Figure 2-1 Wairoa catchment annual rainfall (2000-2009)

A long term time series of rainfall from the five rain gauges is shown in Appendix B from 2000 to 2009.

2.4.1.1 Calibration rainfall

The rainfall hyetograph used in the hydrological model calibration was based on recorded rainfall at the gauges identified in Table 2-2. Detailed hyetographs for the calibration storm events are shown in Appendix B.

Section 2.4.3 provides a discussion on the choice of storm events used for hydrological model calibration.

2.4.1.2 Design rainfall

The design rainfall depth and temporal distribution was determined using the methodology detailed in Auckland Regional Council Technical Publication 108 (TP108).

Furthermore and in accordance with Ministry for Environment (MfE) guidance, an allowance for climate change was included in the design rainfall storm. MCC requested adoption of medium projections for climate change for planning purposes. The MfE guidance for the medium projection of climate change indicated a 2.1^{o}C projected increase in annual temperature for the Auckland Region. This corresponds to a 16.8% increase in the 24 hour, 100 year ARI rainfall depth. The effect of climate change on rainfall can be seen in Table 2-3.

An areal reduction factor of 0.83 was used across the catchment in accordance with TP108 based on the time of concentration and catchment area. The areal reduction factor was conservatively not applied to rainfall in the Hunua Ranges that affects the runoff from the Cosseys and Wairoa dams.

In order to reflect the difference in rainfall from the east side of the catchment to the west side of the catchment, and in accordance with TP108, the catchments that are dammed (Cosseys and Wairoa) used an increased rainfall depth. The rainfall depths can be seen in Table 2-3.

Table 2-3 Design rainfall depths

Description	Rainfall depth (mm/24 hrs)	
	Wairoa, Taitatia, Mangawheu catchments	**Cosseys and Wairoa Dam sub-catchments**
100 year rainfall depth and areal reduction factor	199	242
100 year rainfall depth incorporating 16.8% allowance for climate change	232	283

The design rainfall hyetograhs for the 100 year ARI were based on TP108 and can be seen in Figure 2-2.

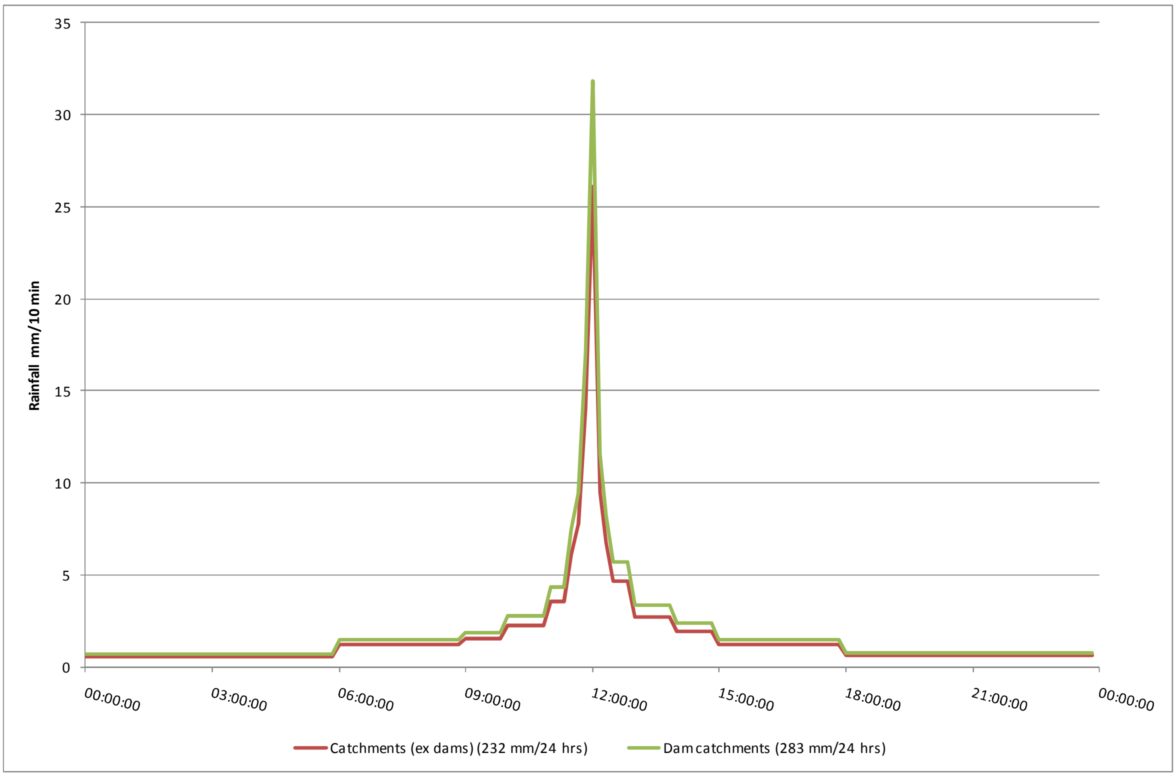

Figure 2-2 100 year ARI Design rainfall hyetograph

2.4.2 River Flows

There are two flow gauges that monitor river flows in the Wairoa catchment. These are the Tourist Road and Mangawheu flow stations, which are described in Table 2-4 and their locations can be seen in Appendix A.2. In addition there are a further two gauges that record flows released from Cosseys and Wairoa dams. There are no flow gauges in the Taitaia catchment.

Table 2-4 Flow gauge details

	Site start date	Elevation	Upstream catchment area	Location
Tourist Road	June 1979	RL 20m	148.1 km^2 *	1782664, 5901676
Mangawheu	June 1988	RL 100m	30.4km^2	1783781, 5891411

* The ARC site description indicates that the catchment upstream of Tourist Road is 161 km^2. It is noted in the Wairoa catchment consents that "the catchment area is 150.5km^2 and not 161 km^2 as written elsewhere" (p11, T&T, 1996). Our calculation of area, based on LINZ 20m contours indicates that an area of 148.1 km^2 should be used which is similar to the area used by T&T in 1996. The area includes the water supply dam catchments.

The Mangawheu flow station is situated on the Mangawheu River in a steep gorge 3.25 km upstream from its confluence with the Wairoa River in the Hunua foothills. The upstream catchment is primarily pasture with some native and exotic plantation forest.

Flows in the Wairoa River are recorded by a flow gauge at Tourist Road. The flow gauge has been recording flows and levels since 1979. The gauge is located in a shifting gravel bed site.

Figure 2-3 shows the annual maximum flows (determined from mean hourly records) recorded at Tourist Road flow gauge between 1979 and 2009.

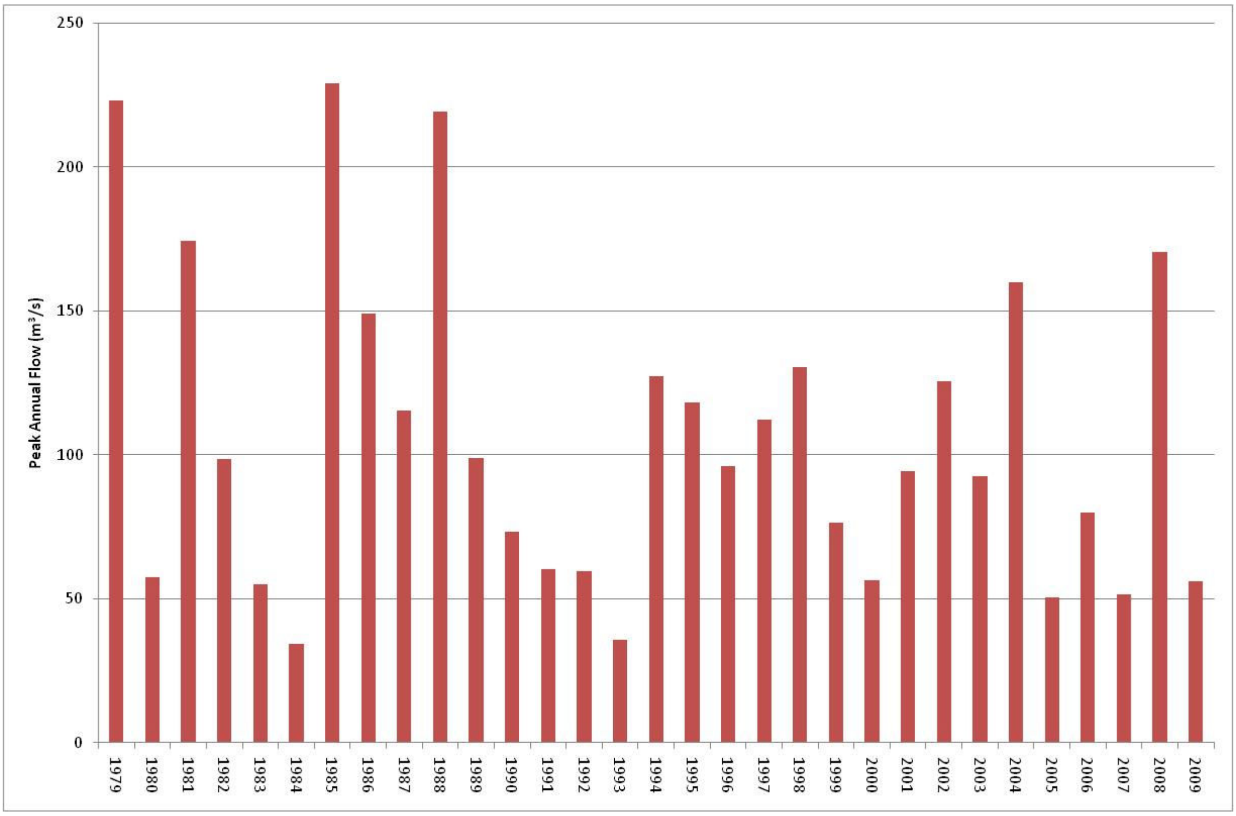

Figure 2-3 Annual maximum (mean hourly) flows for Tourist Road flow gauge for 1979-2009

A time series from 2000 to 2009 of flow gauging at Tourist Road and Mangawheu is shown in Appendix B.1. The time series was used to identify storm events for model calibration (discussed in Section 2.4.3).

It should be noted that there is uncertainty regarding the accuracy of the Tourist Road flow rating curve for high flows. There is generally a reduction in rating curve confidence at the upper end of the return period spectrum due to the lack of gauging at high flows. In addition, at the Tourist Road flow gauge, flood flows in the Wairoa River can break out across the road causing increased uncertainty. This increased uncertainty occurs for two main reasons. Firstly, once the flood level exceeds the river banks there can be large increases in discharge for relatively small increases in water level. Therefore, the error margins in the water depth can reflect much larger error margins on the discharge. Secondly, once the road overtops, access to the river to obtain velocity and level gaugings (used to determine the stage: discharge relationship) becomes difficult.

Anecdotal information suggests that floodwaters overtop the road shortly after the water level rises above the underside of the road bridge. As noted in the T&T (1996) Report, recorded flows above about 125m^3/s are likely to have been underestimated because of significant overbank flows above this level.

2.4.2.1 Calibration flows

The flow records from the Mangawheu and Tourist Road flow gauges were primarily used to assist with the hydrological model calibration process (i.e. to check whether the hydrological model was predicting similar flows to those that were recorded for historical rainfall events).

A detailed analysis of rainfall during the storm events used for model calibration are shown in Appendix B.2.

The calibration included known flows from Wairoa and Cosseys dams. It was not possible to calibrate the Wairoa and Cosseys dams catchments due to flows from the dams being significantly affected by operational decisions (e.g. diversion for water consumption).

2.4.2.2 Design flows

The flow records at Tourist Road were used to assist with the hydraulic model calibration. There is more discussion on the use of the Tourist Road flow gauge as a boundary condition for the hydraulic model calibration in Section 4.

2.4.3 Discussion of rainfall and flow gauge information for model calibration

We identified four storm events over a five year period that were suitable for model calibration purposes. Calibration events over the last five years were chosen so that calibration reflects the existing catchment land use and development including dam operations and improvements. The events were chosen as they were the largest storm event of each year (defined by peak flow). The events are identified in Table 2-5.

Table 2-5 Calibration storm events

Event start date	Peak flow (m^3/s)	
	Mangawheu Flow Gauge	Tourist Road Flow Gauge
17/7/2005	14.1	50.4
7/8/2006	22.3	80.0
29/7/2007	19.5	52.3
29/6/2009	24.9	55.6

The largest storm event since 1988 occurred on 30 July 2008 and produced the largest flow (170 m^3/s) at the Tourist Road flow gauge since the rainfall records began in 1992. However, the rainfall depths recorded at each of the gauges were comparatively low, and flows from the dams were minimal. We therefore excluded the event because the relationship between rainfall records and flow records was abnormal for this particular event. This abnormal relationship is likely to have occurred due to particularly wet antecedent conditions. In the days prior to 30 July 2008 another storm event with peak flows approaching $90m^3/s$ occurred. It is also possible that localised severe rainfall in the part of the catchment was not measured by any of the rain gauges.

In addition to the reasons discussed above, the July 2008 event produced flows greater than the flows in which there are confidence limits in the Tourist Road flow gauge (see Section 2.4.2).

The maximum 24 hour rainfall depth that has occurred at the Wairoa rainfall gauge (longest record) since 1992 is 116 mm during the 24 hours from 10 am on 22 July 1996. This rainfall caused peak flows of 96 m^3/s flows in the Wairoa River at Tourist Road. Interestingly a 24 hour rainfall depth of 116 mm approximately corresponds with a 5 year ARI return period from ARC TP108.

2.4.4 Dams

Anecdotal information suggests concerns from local residents regarding a negative impact of the dams on flood flows in the Wairoa River. In contrast to this perception, a technical Report (T&T, 1996) into Wairoa River hydrology for Watercare's Wairoa Catchment Consents indicated that flood flows were reduced by between 18% and 25% at the Tourist Road flow gauge in comparison to a pre-dam case. This is well illustrated in the February 1985 flood event, which would have been a 25 year return period flood, but was reduced to a 5 year event due to the flood attenuation in the Cossey and Wairoa reservoirs (T&T, 1996).

3 Hydrological model calibration

3.1 Overview

The hydrological model was calibrated using selected storm events for catchments that had corresponding flow records. The choice of rainfall events used for hydrological model calibration was discussed in Section 2.4.3.

3.2 Calibration potential

The hydrological model can be divided into sub-catchments where flow records were available and sub-catchments where flow records were not available. Hydrological model calibration can only be carried out in catchments where flow records were available.

A summary of the hydrological sub-catchments and calibration details is provided in Table 3-1.

Table 3-1 Hydrological calibration details

Catchments	Sub-catchments	Area (km^2)	Calibration	Details
Wairoa Upstream of Tourist Road	**Mangawheu**	30.4	Yes	Calibration based on Mangawheu flow gauge.
	Cosseys dam	21.3	No	Flows from dam are influenced by operational decisions regarding water supply to Auckland.
	Wairoa dam	13.24	No	
	Wairoa upstream of Tourist Road (excluding Mangawheu, Cosseys and Wairoa)	83.2	Yes	Calibration based on Tourist Road flow gauge, with known inputs from Mangawheu, Cosseys and Wairoa.
Taitaia	Further divided into 8 sub-catchments based on topography	43.6	No	No flow records available.
Clevedon Wairoa u/s	Located upstream of bridge	5.17	No	No flow records available.
Clevedon Wairoa d/s	Located downstream of bridge	0.35		No flow records available.
Holdens Road Catchment		11.0	No	No flow records available. Catchment located downstream of Clevedon township. Flood levels at Clevedon are likely to be less sensitive to these flows than the other catchments.
Clevedon North		9.30	No	
Wairoa Mouth		3.70	No	

This section relates only to the Mangawheu and Tourist Road catchments where calibration was possible. Note that the calibrated Tourist Road catchment excludes the catchments upstream from Cosseys dam and Wairoa dam.

For uncalibrated model catchments, refer to Section 4.2.

3.3 Calibration parameters

The hydrological parameters used by the model to define the catchments include the rainfall, loss method, transformation method, hydraulic routing and sub-catchment area. These parameters are adjusted individually or in combination to obtain a good calibration between model predictions and recorded flows.

3.3.1 Rainfall

An assessment of rain gauges was undertaken to assess the consistency of rainfall across the catchment. The results of the assessment are provided in the hydrological calibration results (Section 3.4).

For the Mangawheu catchment, only the Hays Creek Rain Gauge and the Hunua Rain Gauge were used because these were the two closest gauges to the sub-catchment.

All rain gauges were considered for the Wairoa Catchment. The details of how the rain gauges were applied are explained in Section 3.4.

As part of the calibration process we considered the possibility that the rain gauges did not reflect the general rainfall across the catchment. The details of how the rain gauges were applied are explained in Section 3.4.

3.3.2 Loss method

The SCS curve number method was used to represent the rainfall-runoff process. The method applies initial abstraction values to account for all the losses that occur before runoff begins, and a Curve Number to account for runoff variability due to soil type, ground cover type, soil treatment and hydrological condition. The SCS model is the preferred approach for hydrological assessment in the Auckland Region (ARC, TP108).

The Curve Number was the most varied hydrological parameter in the model calibration process with values ranging from 70-90.

3.3.3 Transformation method

Two different transformation method types were assessed for the hydrological model calibration. The transformation method relates to how precipitation excess is “transformed” into point runoff. The two methods used were the SCS standard transformation and the SCS Delmarva transformation. The difference between the two methods can be seen in the unit hydrograph comparison shown in Appendix D.

Generally the standard SCS transformation is used in the Auckland region. However, consideration to the Delmarva SCS transformation was given due to the coastal plain characteristics of the Wairoa River and Taitaia Stream. In comparison with the standard SCS method (peak factor 484) the Delmarva transformation (peak rate factor 284) reduces the peak discharge and places more emphasis on the volume occurring after the peak discharge than the Standard SCS method. Peak rate factors have been shown to vary from 600 in steep terrain to 100 or less in flat, swampy country (USDA, 2007).

Lag time was assessed as a calibration parameter within the transformation method. Initially lag time was calculated based on an estimate of two-thirds time of concentration, and then subsequently modified to assess its effect on the calibration.

3.3.4 Hydraulic routing

Open channel flow in the catchment, upstream of the hydraulic model was carried out using the Muskingum routing model within HEC-HMS.

The Muskingum routing model uses an estimate of flood wave travel time and a weighted difference that relates storage and inflow to calculate an outflow hydrograph. Therefore, the travel time and weighted difference values were used as calibration parameters for all areas in the hydrological model represented by a watercourse.

3.3.5 Catchment area

The catchment area was not modified for the calibration process.

3.4 Hydrological calibration results

In this section the results of the hydrological model calibration for the Mangawheu and Tourist Road catchments are discussed and hydrological model parameters are selected.

3.4.1 Mangawheu catchment

Calibration of the Mangawheu sub-catchment was attempted using rainfall from the Hays Creek and Hunua rainfall gauges for the four calibration storm events (see Table 2.5). In three of the four events, better calibration was achieved using the rain gauge from Hunua. For each of the three events, the rainfall at Hays Creek was more variable than at Hunua and consequentially produced a more variable flow than the historical flow records indicated. For the fourth event (2009) there was very little difference between the records from the two gauges.

We were able to calibrate peak flows using the Standard SCS transformation method. However, for three of the four storm events we were unable to satisfactorily calibrate the hydrograph shape using the Standard SCS transformation. Therefore, we applied the Delmarva SCS transformation to the model, which places more of the runoff volume in the time after the peak discharge than the Standard SCS method. The SCS curve number used to calibrate the model varied between 81 and 84.

The SCS curve number is typically higher than we would expect for the region and may reflect wet antecedent conditions for the calibration events. We did not consider it appropriate to increase the curve number further, but we believe that the rain gauges were likely to represent a greater source of uncertainty. In order to match peak flows we then increased rainfall by up to 15%.

The lag time has greatest control over the timing of the peak flow. In order to calibrate the model we varied the lag time by up to 45 minutes (approx 25% of the longest lag time).

The calibrated parameters for the four storm events can be seen inTable 3-2. Hydrographs of the model results using the calibrated parameters can be seen in Appendix E.1. The results are shown in comparison with recorded flows at the Mangawheu gauge to compare predicted and recorded flows.

Table 3-2 Mangawheu catchment calibration parameters

	Calibration event			
	17/7/05	**7/8/06**	**29/7/07**	**29/6/09**
Rainfall	Hunua Rainfall +15%	Hunua Rainfall +10%	Hunua Rainfall +10%	Hunua Rainfall + 15%
Transformation	Delmarva SCS	Delmarva SCS	Delmarva SCS	Standard SCS
SCS Curve Number	84	81	82	82
Lag time	210 mins	180 mins	165 mins	165 mins
Open channel	N/A	N/A	N/A	N/A

The calibration process has indicated that a good comparison between model predictions and recorded flows has been obtained. The Delmarva transformation method in three of the four storm events is the most appropriate method to use, and rainfall from the Hunua Rainfall gauge should be increased by between 10% and 15%. The SCS curve number in all events was similar, varying by only 3 points. The lag time varies by up to 45 minutes. However, for three of the four storm events there was only a 15 minute variation.

Based on the results of the calibration, the parameters shown in Table 3-3 were used for model validation.

Table 3-3 Validation parameters for Mangawheu catchment

Rainfall	Hunua Rainfall +10%
Transformation	Delmarva SCS
SCS Curve Number	84
Lag time	180 mins

The results of the hydrological model validation, and the generation of boundary conditions from non-calibrated hydrological models for the hydraulic model are shown in Appendix E and discussed in Section 4.

3.4.2 Tourist Road catchment

Initial calibration of the Tourist Road sub-catchment was attempted using rainfall from individual rain gauges. However, we were unable to identify the most representative rain gauge for the catchment since there were differences for each event. We therefore investigated the use of between two and four gauges to represent rainfall across the catchment. We determined that an average rainfall from all the rain gauges was the most appropriate rainfall source for the Tourist Road catchment.

Better calibration was achieved for all calibration storm events using the Standard SCS transformation than the Delmarva SCS transformation.

The SCS curve number used to calibrate the model varied in a narrow range from 80 to 82. Increases in rainfall were required for two of the four storm events to achieve good calibration.

The combination of lag time for the Tourist Road catchment and the hydraulic routing parameters affects the timing of peak flows from each of the catchments, which consequentially affects peak flows considerably at Tourist Road. An iterative process where timings were altered for each of the sub-catchments along with adjustments to the lag time in the Tourist Road sub-catchment was carried out and the calibrated parameters for the four storm events can be seen in Table 3-4. It should be noted that there is very little information available to support or reject the 0.5 hours used to represent the travel time from Wairoa dam to the confluence of the Wairoa River with Mangawheu Stream.

Hydrographs of the model results using the calibrated parameters can be seen in Appendix E.2. The results are shown in comparison with recorded flows at the Tourist Road flow gauge to compare predicted and recorded flows.

Table 3-4 Tourist Road catchment calibration parameters

		Calibration event			
		17/7/05	**7/8/06**	**29/7/07**	**29/6/09**
Rainfall		Average gauge	Average gauge + 10%	Average gauge	Average gauge + 10%
CN		82	80	81	82
Lag time		450 mins	520 mins	450 mins	520 mins
Hydraulic Routing (travel time/weighed difference)	**Mangawheu flow gauge to Tourist Road**	5.5 hrs	6 hrs	5.5 hrs	6 hrs
	Confluence of Mangawheu Stream and Wairoa River to Tourist Road	3.5 hrs	4 hrs	3.5 hrs	5 hrs
	Cosseys dam to confluence with Wairoa River	0.25 hrs	0.5 hrs	0.25 hrs	0.25 hrs
	Wairoa dam to confluence of Wairoa River with Mangawheu Stream	0.5 hrs	0.5 hrs	0.5 hrs	0.5 hrs

The calibration process has indicated that a good comparison between model predictions and recorded flows can be obtained by the hydrological model. The calibration parameters shown in

Table 3-4 indicate that there are only small differences between the calibration parameters for each storm event, which suggests that a good degree of validation should be able to be achieved.

Based on the results of the calibration, the parameters shown in Table 3-5 were used for model validation.

Table 3-5 Validation parameters for Tourist Road catchment

Rainfall		**Average Rainfall from all gauges +10%**
Transformation		Standard SCS
SCS Curve Number		82
Lag time		450 mins
Hydraulic Routing (travel time/weighed difference)	**Mangawheu flow gauge to Tourist Road**	5.5 hrs
	Confluence of Mangawheu Stream and Wairoa River to Tourist Road	4 hrs
	Cosseys dam to confluence with Wairoa River	0.25 hrs
	Wairoa dam to confluence of Wairoa River with Mangawheu Stream	0.5 hrs

The results of the hydrological model validation, and the generation of boundary conditions from non-calibrated hydrological models for the Hydraulic model are discussed in Section 4.

3.5 Hydrological model validation

3.5.1 Overview

The results of the calibration assessment for the Mangawheu and Tourist Road sub-catchments identified parameters that should be used for the model validation. The model validation process involved using the same hydrological model parameters for each of the historical storm events, running the model and then analysing the results to determine whether these adequately predict the observed flow.

The catchment parameters used for the model validation for the Mangawheu catchment and Tourist Road catchment are shown in Table 3-3 and Table 3-5 respectively.

3.5.2 Validation event

We identified the storm event of 12 October 2003 as being suitable for model validation. It was a suitable event because it represented a large and relatively recent storm event, where flows were less than 125 m^3/s as recorded at Tourist Road (see section 2.4.2 for explanation).

Flows less than $1m^3/s$ were recorded from the Wairoa dam during this storm event, and no flows were recorded from Cosseys dam. Therefore for the purposes of model validation, flows from the dams were excluded.

3.5.3 Results

The result of the model predicted flows and the Tourist Road flow gauge flows for the storm event of 12 October 2003, can be seen in Figure 3-1.

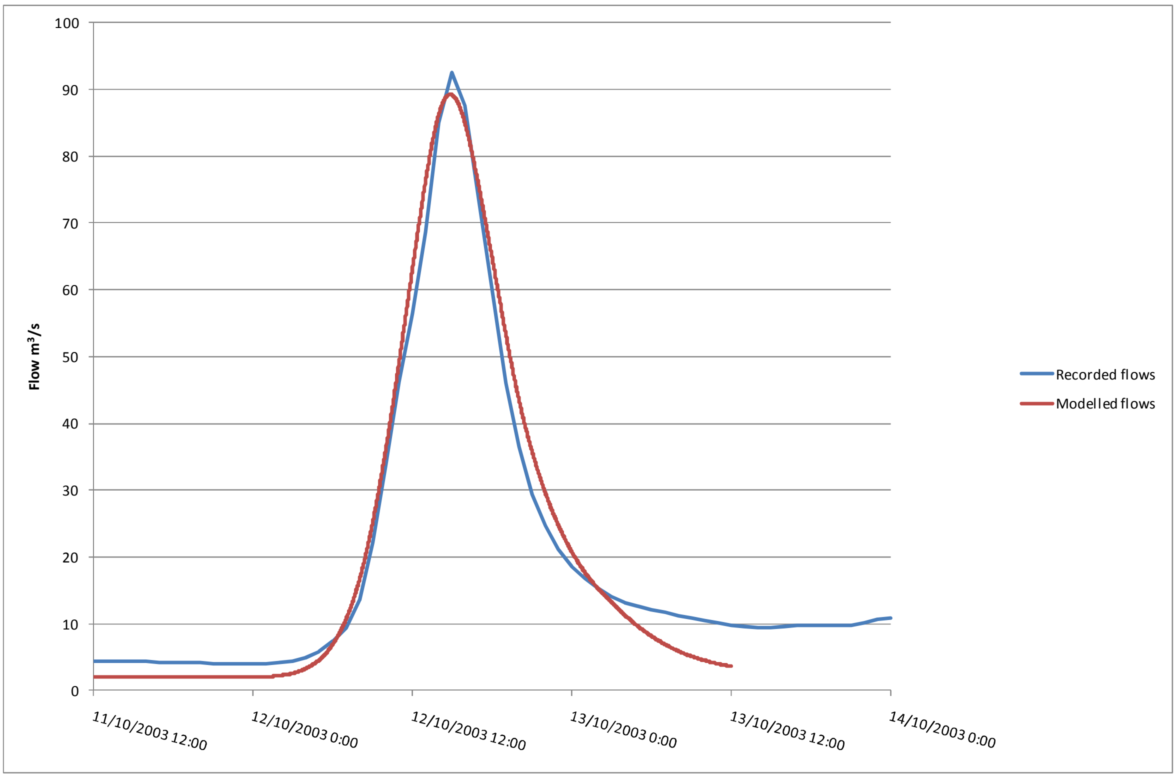

Figure 3-1 Model validation result

The results shown in Figure 3-1 relate very closely to the flows predicted by the model. This gives good confidence that the hydrological model represents the catchment runoff characteristic from upstream of Tourist Road very well.

In addition to the main validation event discussed above the results of the model validation can be seen alongside the calibration run results in Appendix E.1 and E.2 for the Mangawheu and Tourist Road catchments respectively.

The validated model results for the Tourist Road catchment reflect recorded flows very well for three of the four storm events (2005, 2006, 2009) (Appendix E2). The peak flows for the 2005 and 2006 storm exceed the recorded levels by approximately 3m^3/s and 8m^3/s respectively. The peak flow for the 2009 event under predicts the peak flow by approximately 3m^3/s.

Model predictions from the 2007 storm event reflect the rise and peak of the recorded flows to within 1m^3/s. However in both the Mangawheu and Tourist Road model validation, the model predicts a second peak that is higher than the first and does not fit well with the recorded flows. This is mainly due to a double peak that can be observed in the rainfall data (but not observed in the flow data). In addition, the 2007 storm event at Tourist Road was particularly sensitive to the timing of the peak flows from the Tourist Road and Mangawheu catchments.

The validated model results for the Mangawheu catchment are similar to the recorded flows for the 2005 and 2006 storm events. However the model predictions for the 2009 storm event under predict the peak flows by approximately 8m^3/s from a peak recorded flow of 25m^3/s.

The 2009 storm event was the one storm event in the Mangawheu catchment that was best represented by the SCS Standard transformation, and as noted in the Catchment Calibration, the rainfall was increased by 15% from the recorded flows to ensure good calibration.

In order to further check the calibration values for the Mangawheu catchment, an additional storm event was calibrated for the 24/25 August 2008 event. In order to calibrate the model, rainfall from the Hunua gauge was used and increased by 10%. Furthermore, a curve number of 80 was used, with a lag time of 165 minutes. The results of the calibration for the additional storm event can be seen in Figure 3-2.

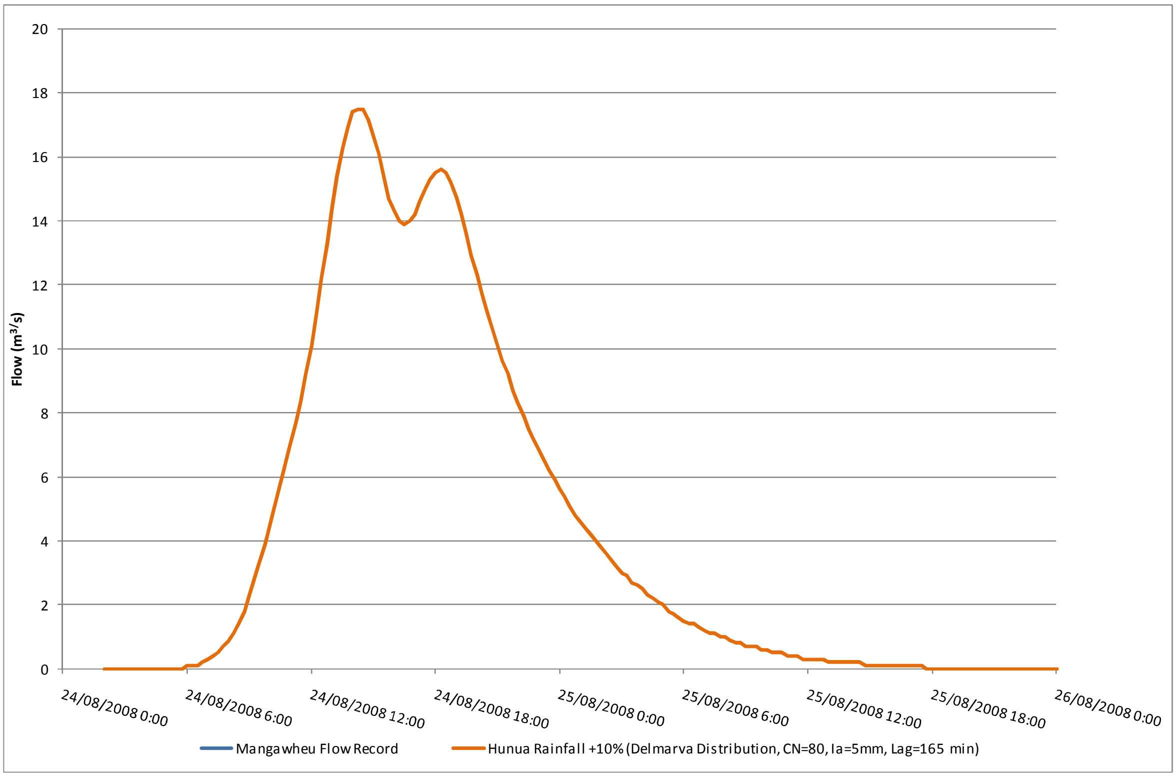

Figure 3-2 Additional storm event calibration for Mangawheu catchment

The results of this additional calibration event, combined with the previous calibration model runs and the validation results suggest that the hydrological model parameters for the Mangawheu catchment are appropriate.

Therefore the model validation process has confirmed that the hydrological model for the Tourist Road and Mangawheu catchments can be used to determine runoff hydrographs for use in the hydraulic model.

In Section 4 the application of the hydrological model, including the hydrological parameters for uncalibrated sub-catchments, are used to set flow boundary conditions for the hydraulic model.

4 Flow boundary conditions for hydraulic model

4.1 Overview

Inflow hydrographs into the hydraulic model are required from each of the sub-catchments shown in Appendix A.2, and described in Section 2. The hydrological model was used to generate the inflow hydrographs for the design rainfall events.

A calibrated hydrological model has been built for the Tourist Road and Mangawheu catchments (see Section 3). It was not possible to calibrate the additional sub-catchments that contribute flow to the Wairoa River and Taitaia Stream due to the lack of flow records for these sub-catchments. Therefore, runoff from these additional sub-catchments was determined by applying the Tourist Road calibration parameters to the additional catchments (excluding dammed catchments). The hydrological model parameters from the calibrated catchments can reasonably be applied to these additional sub-catchments because of similarities in hydrological characteristics such as rainfall, land use and soils/geology.

4.2 Additional catchments

The additional catchments added to the hydrological model were:

- Taitaia (divided into 8 sub-catchments)
- Clevedon township
- Holdens Road Catchment
- Clevedon North
- Wairoa Mouth
- Urungahauhau.

In addition to the above, the two catchments at Cosseys Dam and Wairoa Dam are treated differently due to a number of assumptions regarding dam operation that differentiates them from the other catchments.

The locations of the sub-catchments can be seen in Appendix A.2, and further details can be found in Table 4-1.

The SCS loss method and transformation method was used to represent the catchment losses (see Section 3.3 for more details). For each sub-catchment, an assessment of lag time and initial abstraction was made. The curve number for all additional catchments was based on the calibrated curve number used in the Tourist Road catchment (excluding Wairoa and Cosseys Dam catchments).

Table 4-1 Subcatchment characteristics for uncalibrated catchments

Catchment		Area (km^2)	Initial Abstraction (mm)	Curve Number	Lag time (min)
Taitaia	T1	11.66	5	82	50
	T2	5.21	5	82	25
	T3	6.96	5	82	58
	T4	7.14	5	82	56
	T5	8.84	5	82	47
	T6	1.58	5	82	40

Catchment		Area (km²)	Initial Abstraction (mm)	Curve Number	Lag time (min)
	T7	0.45	5	82	10
	Clevedon Taitaia (T8)	1.78	5	82	32
Clevedon Wairoa u/s		5..17	5	82	66
Clevedon Wairoa d/s		0.35	5	82	17
Holdens Road Catchment		11.0	5	82	100
Clevedon North		9.24	5	82	79
Wairoa Mouth		3.67	5	82	18

It is likely that the SCS curve number of 82 is a conservative estimate for the catchments given that vegetation cover, particularly on the slopes of the downstream catchments, is much heavier than the upstream catchments.

4.2.1 Dam catchments

The catchments upstream from Wairoa and Cosseys Dam were independently assessed for SCS curve number and lag time. It was not considered appropriate to use the calibrated SCS curve number for Tourist Road for the two dammed catchments because the vegetation cover and terrain was so different to the rest of the catchment.

Table 4-2 Subcatchment characteristics for Wairoa and Cosseys catchments

Catchment	Area (km²)	Initial Abstraction (mm)	Curve Number	Lag time (min)
Cosseys Dam	21.3	5	74	30
Wairoa Dam	13.24	5	74	43

In discussion with MCC, we agreed that for flood hazard mapping purposes it was appropriate to assume that the dams were full at the start of the design storm event. This is a conservative assumption since it is likely that the dams will provide more attenuation than we have assumed.

The uncalibrated hydrological model of the catchments was used to determine inflow hydrographs to the dam reservoirs. Flood conveyance through the reservoirs was represented using a storage versus elevation curve for the reservoirs, and then flood conveyance across the dam spillways was calculated based on spillway rating curves (T&T, 2005) which are shown in Appendix F.

4.3 Flow boundary conditions

The design rainfall hyetographs shown in Figure 2-2 were applied to the hydrological model to determine runoff hydrographs from each of the sub-catchments.

The hydrographs for the design rainfall for each of the sub-catchments can be seen in Appendix G. The peak flows from each of the sub-catchments are summarised in Table 4-3.

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Table 4-3 Summary of peak sub-catchment flows

Catchments	Sub-catchments	Peak flow (m^3/s)
Wairoa Upstream of Tourist Road	Mangawheu	131
	Cosseys dam	224
	Wairoa dam	46
	Wairoa upstream of Tourist Road (excluding Mangawheu, Cosseys and Wairoa)	309
	Wairoa River at Tourist Road (sub-total)	**527**
Taitaia	T1	158
	T2	94
	T3	87
	T4	91
	T5	124
	T6	23
	T7	11
	Clevedon Taitaia (T8)	29
Clevedon Wairoa u/s	Located upstream of bridge	61
Clevedon Wairoa d/s	Located downstream of bridge	7
Cosseys Dam		224
Wairoa Dam		46
Holdens Road Catchment		104
Clevedon North		99
Wairoa Mouth		75

The predicted flows from Wairoa Dam and Cosseys Dam in the design 100 year ARI storm are in excess of the estimates made in 1996 (T&T). The 1996 (T&T) study carried out a flood frequency analysis of recorded flows and predicted 100 year ARI flows of 29 m^3/s and 91 m^3/s for Wairoa Dam and Cosseys Dam respectively. This study used a hydrological modelling approach and conservative assumptions regarding the level of the dam at the start of the storm, which may explain the differences.

PMF (Probable Maximum Flood) predictions for Cosseys and Wairoa Dam are 366 m^3/s and 136 m^3/s respectively (WCS, 1993). Therefore, the 100 year flow predictions are approximately 60% and 34% of the PMF flows for Cosseys and Wairoa Dam respectively.

The predicted 100 year ARI flow at Tourist Road from the hydrological models is 527m^3/s. This represents a 100 year ARI storm event, inclusive of a 16.8% increase in rainfall to account for climate change and a scenario where the dams are full at the start of the storm event.

The 100 year ARI flow prediction is higher than the Beca (1995) Wairoa River Flood Management Plan - Draft. The Beca (1995) report indicates that 100 year ARI flows at Tourist Road are approximately 452 m^3/s. However, there was no allowance for the effects of climate change orthe discharges from the Wairoa and Cosseys Dams in this prediction. The hydrological model used for this report predicts 100 year ARI flows at Tourist Road without the dam catchments, and without an allowance for climate change of approximately 360 m^3/s, which is a reduction of approximately 100 m^3/s in comparison with the Beca (1995) prediction. A comparison of the 100 year ARI design hydrographs for different dam and climate scenarios is shown in Figure 4-1.

We note that other studies (T&T 1996 and 2008) have made 100 year ARI predictions based on flood frequency analysis of the Tourist Road flow gauge. These studies indicated that peak flows of approximately 290 m^3/s were likely for the 100 year ARI storm.

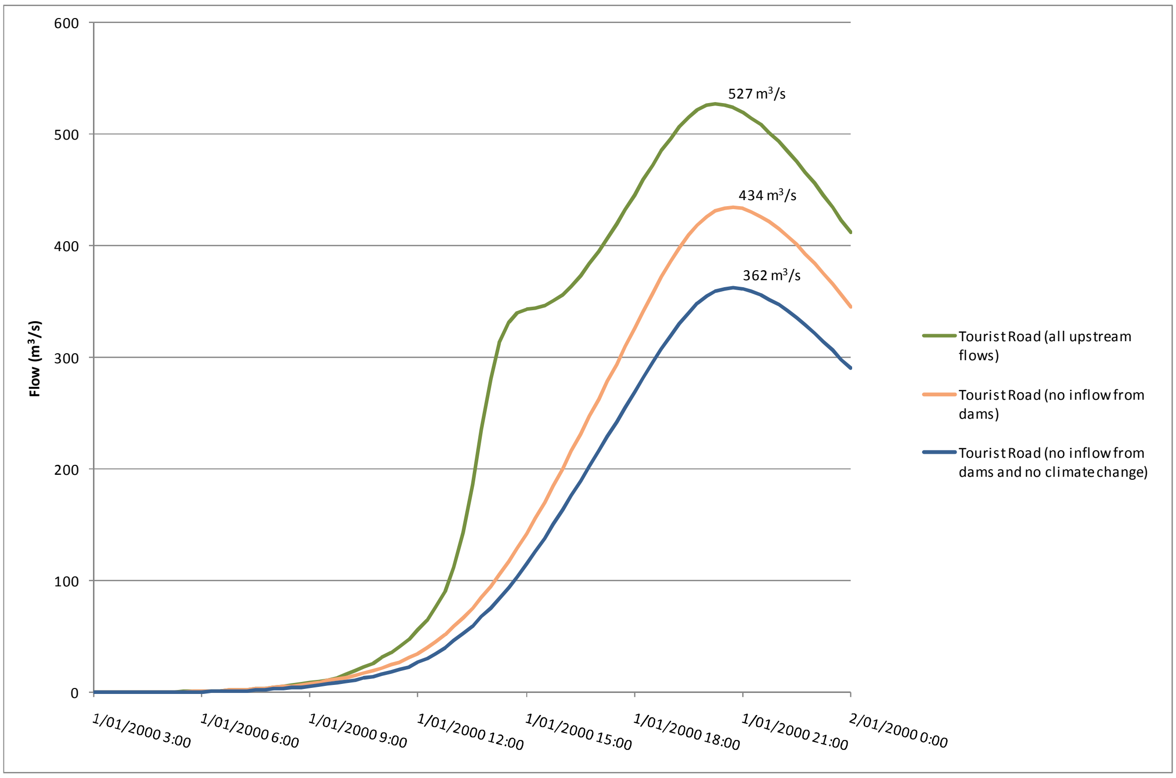

Figure 4-1 Comparison of flow hydrograph at Tourist Road with and without dams

5 Downstream boundary conditions for hydraulic modelling – methodology and data

5.1 Overview

The flow boundary conditions to the hydraulic model were determined in Section 4. The downstream end of the hydraulic model is controlled by sea water levels. The downstream boundary in the hydraulic model is located within the Tamaki Strait part of the Hauraki Gulf.

Water levels within the Hauraki Gulf include phenomena that are both deterministic and stochastic. Astronomical tides that result from the influence of the sun and moon on the earth are deterministic while the effects of storm surge, climate cycles and near shore processes are stochastic variable and vary from year to year.

Water levels in the hydraulic model are required to assist with hydraulic model calibration, and to assess the design storm.

5.2 Water level

The following sub-sections are a brief discussion of the constituents of water level.

5.2.1 Astronomical tides

Astronomical tidal levels for Manukau's East Coast have been defined in a NIWA Report (NIWA, 2008). NIWA were commissioned to provide tidal modelling services to define the Mean High Water Spring (MHWS) in terms of a recognised datum level around the Manukau City Council coastline.

NIWA used an upper level MHWS related to perigean-spring tides (referred to as MHWPS) that occur in clusters for a few months, peaking at approximately 7-month periods. MHWPS uses an additional tidal constituent (N_2) rather than the traditional nautical method for calculation MHWS, and which is based on only two constituents (M_2 and S_2). MHWPS is approximately 0.1m higher than MHWS represents a 'pragmatic' upper tide level that is exceeded by 4 to 7% of high tides.

Based on the NIWA (2008) assessment, MHWPS at the mouth of the Wairoa is approximately RL 1.8m (Auckland Vertical Datum 1946).

5.2.2 Storm surge

Storm surge results from the combination of barometric setup from low atmospheric pressure and wind stress from winds blowing along or onshore which elevates the water level above the predicted tide. Storm-surge applies to the general elevation of the sea above the predicted tide across a region but excludes nearshore effects of storm waves such as wave setup and wave runup at the shoreline.

The highest recorded storm-tide to date since measurements started in 1903 at the Port of Auckland Ltd (POAL) was RL 2.25 m on the 26 March 1936. This storm coincided with a high spring tide with a predicted astronomical high tide level of RL 1.76 m (CD+3.5 m), implying a storm surge of approximately 0.5 m. From analysis of historic water levels for the POAL gauge, water levels over RL 1.96 m (CD+3.70 m) occur at a near annual frequency. Between 1993 and 2000, water levels exceeded RL 2.11 m (CD+3.85 m) twice with storm-tide levels of RL 2.15 m and RL 2.16 m (Coastline Consultants, 2001).

Previous studies of storm surge around New Zealand's coastline have concluded that storm surge appears to have an upper limit of approximately 1.0 m (Hay, 1991; Heath, 1979; Bell et. al, 2000). Given the perceived upper limit of storm surge for New Zealand, a standard storm surge of 0.9 m is considered representative of a return period of 80 to 100 years (MFE, 2004). Based on the work of de Lange (1996), a storm surge of 0.8m represents a reasonable upper bound for a return period of 50 years.

5.2.3 Sea level rise

MfE guidance (2008) states that for planning and decision timeframes out to the 2090s:

1. *a base value sea-level rise of 0.5m relative to the 1980-1999 average should be used, along with*
2. *an assessment of the potential consequences from a range of possible higher sea-level rises (particularly where impacts are likely to have high consequence or where additional future adaptation options are limited). At the very least, all assessments should consider the consequences of a mean sea-level rise of at least 0.8m relative to the 1980-1999 average.*

5.3 Downstream boundary conditions for hydraulic model calibration

The closest permanent tide gauge to the mouth of the Wairoa is located at Port of Auckland, and there were no other water level gauges located along the Wairoa River that could be used for a downstream model boundary. Therefore water levels at the mouth of the Wairoa River were derived from Ports of Auckland Tide gauge records for the hydraulic model calibration period.

Tide levels increase as distance eastwards from Port of Auckland increases, therefore a water level increase of 0.1m was applied to the Port of Auckland tide gauge records to make them applicable to the mouth of the Wairoa River. The elevation was based on consideration of figures shown in the NIWA (2008) Report.

5.4 Downstream boundary conditions for flood hazard mapping

As stated in the SDP "future development in Clevedon should take a conservative approach based on available information regarding climate change, particularly with respect to floodplains and sea level changes." Therefore, in discussion with MCC, and in accordance with the SDP, an approach that combines the upper limits of sea level at the coast with peak design flows from the catchment was adopted.

The approach of using 100 year ARI flood flows combined with upper limits of sea levels at the coast is conservative since the probability of the peaks of all the events combining is likely to represent a lower probability event. However, the events are also not entirely independent, with tropical storms typically providing a situation of high rainfall with elevated water levels.

NIWA (2008) and T&T (2010) established 100 year ARI peak sea levels for their respective Reports. The NIWA (2008) Report identified 100 year ARI levels at three locations near the mouth of the Wairoa River for present day, 2050 and 2080 scenarios.

The levels from the NIWA (2008) Report for the Hauraki Gulf near the mouth of the Wairoa River are shown Table 5-1. The locations can be seen on Appendix A.2. The levels shown are for present day, 2050s and 2080s. The three columns for each period represent mean values, and upper and lower 95 percentile values.

Table 5-1 1% AEP water levels at mouth of Wairoa River (NIWA, 2008)

	Present Day			2050s			2080s		
Location	Mean	95% limits		Mean	95% limits		Mean	95 limits	
		Lower	Upper		Lower	Upper		Lower	Upper
Site 1 (2696660, 473160)	2.33	2.23	2.45	2.68	2.58	2.82	3.01	2.91	3.15
Site 2 (2697460, 6472760)	2.28	2.21	2.38	2.62	2.54	2.71	2.95	2.87	3.04
Site 3 (2697960, 6472460)	2.31	2.23	2.42	2.66	2.57	2.78	2.99	2.9	3.11

The NIWA (2008) Report used the following sea level rise projections for their study:

1. 2050s: a 0.33m rise in sea level relative to 1990s
2. 2080s: a 0.66m rise in sea level relative to 1990s.

The MfE guidance indicates that a sea level rise of up to 0.8m should be assessed for 2090. Therefore, the NIWA water levels should increase by a further 0.14m (0.8 – 0.66) for 2100 planning timeframes. By increasing NIWA (2008) 100 year ARI water levels for 2090 at the mouth of the Wairoa by 0.14 m the mean level varies between RL 3.09m and 3.15m (three locations), an upper range of between RL 3.29m and RL 3.18m respectively.

The approach adopted by T&T (2010) incorporated MHWS, storm surge and climatic variation to estimate an extreme water level. The 100 year ARI level used by T&T (2010) was RL 3.1m. The level was used as a downstream boundary condition for hydraulic modelling of the Lower Wairoa for a flood assessment for the Wairoa River Maritime Village proposal.

The RL 3.1m used by T&T (2010) and the range of values indicated by NIWA (2008) are in good agreement. Given the range in values indicated by NIWA, and with consideration to the T&T (2010) levels, a downstream water level of RL 3.15m was adopted for the 100 year ARI flood hazard mapping.

6 Hydraulic modelling – methodology & data

6.1 Overview

The approach to the hydraulic modelling involved utilising topographic data from survey and LiDAR to build a representative model of the Wairoa River, Taitaia Stream and the floodplains around the study area.

The models were calibrated using available information relating to observed flows and water levels for recent flooding events.

The area of interest was modelled in detail using a combined 1 dimensional (1D) and 2 dimensional (2D) modelling approach. Additional representation of the Wairoa River continued downstream to the mouth of the river to ensure that coastal effects on flood levels were accounted for. The extents of the models are shown in Appendix A.2.

6.1 Data

6.1.1 Topography

The channel topography in the Wairoa River and Taitaia Stream was determined from cross section surveys of the watercourses. The cross sections for the most downstream 3.5 km of the Wairoa River (approximate) were obtained from the ARC. Upstream of this location, in both the Wairoa River and Taitaia Stream, 23 cross sections were obtained from an MCC commissioned survey carried out by Walker Survey. The survey was carried out during April and May 2010.

In addition to the cross section survey, Walker Survey surveyed 12 culverts or bridges for inclusion in the hydraulic model.

The floodplain topography was based on LiDAR data supplied by MCC. The LiDAR was modified in locations represented only by the 2D model where culverts or other submerged structures were not represented in the LiDAR data (e.g. bridges) by creating “opening” in the topography to allow flow through.

6.1.2 Flows

For the calibration of the hydraulic model, the upstream inflows came from the Tourist Road flow gauge (see Section **Error! Reference source not found.**). All other inflows were determined from the hydrological models (see Section 4).

6.1.3 Water level

The water levels used as downstream boundaries in the hydraulic model runs were detailed in Section 5.

Historical flood levels were surveyed at a number of locations for historical storm events. These levels were used to help calibrate the hydraulic model. It is important to note that flood photographs identify a water level that occurred at some point during the flood. Anecdotal information from the photographers suggests that photographs were taken near the peak in the flood, however it is possible that peak flood elevations in excess of the photographic record occurred.

A copy of the photographs and surveyed flood levels and dates are shown in Appendix H.

A Beca (1995) Report identified flood levels from a February 1985 storm event at Clevedon Bridge, Camp Sladdin and North Road.

Table 6-1 summarises all the available information on historical flood lands.

Table 6-1 Flood level records

W'course	Location	Event date		
		February 1985	**25 April 2006**	**30 July 2008**
Wairoa	Clevedon Bridge	RL 4.28m		
Wairoa	Polo Grounds 1			RL 2.63m
Wairoa	Fire station			RL 3.53m
Wairoa	Tourist Road	RL 11.3m		RL 10.47m
Wairoa	116 Monument Rd (2 locations adjacent to property)			RL 6.01m RL 6.2m
Taitaia	Camp Sladdin	RL 5.4m		RL 4.32m *(see note 1)*
Taitaia	Camp Sladdin footbridge			RL 4.63m
Taitaia	Twilight Road (No.70?)		RL 4.23m	
Note 2	North Road	RL 4.16m		

Note 1: The Camp Sladdin location is located upstream of the Camp Sladdin footbridge, therefore it is likely that the photograph used to determine the flood levels did not record the flood peak, and should not be used for flood calibration.

Note 2: North Road crosses the Taitaia Stream and runs adjacent to the Wairoa River. The precise location of the water level record is unknown.

Not all the levels shown in Table 6-1 were used for hydraulic model calibration purposes, and therefore they are not required for the purposes of this Report. However, this Report may be a future reference document for flooding studies in the Clevedon area, so we have therefore included the information so that it can be used if necessary. In particular, some photographs from a large storm event on 1 March 1966 are included in Appendix H (no levels provided), which is anecdotally the largest flood in the Clevedon area in living memory (based on conversations with a number of local residents).

6.2 Methodology

6.2.1 Model

The hydraulic modelling was carried out using the DHI Mike Flood modelling suite. The modelling approach combined a 1D representation (Mike 11) of the river channel with a 2D representation (Mike 21) of the floodplain. This ensures optimal representation of the channel geometry and floodplain topography.

The 2D model was used to determine the flood areas within the area of interest. It extended from the Tourist Road flow gauge to approximately 6.7 km downstream from Clevedon township. The 1D model extended downstream to the coast to ensure that the coastal effects on flood levels at Clevedon were considered. The 1D and 2D models are linked dynamically within the Mike Flood package (i.e. flow can pass from one model to the other).

The figure shown in Appendix A.2 shows the extents of the 1D and 2D models.

6.2.2 Model build

The model was built using the topographic data detailed in Section 6.1.1.

In addition to the surveyed cross sections, interpolated cross sections were added to the Mike 11 model to improve hydraulic stability and improve the dynamics between the 1D and 2D models.

The 2D model grid was created using a 5m by 5m grid resolution.

It was necessary to "smooth" some of the LiDAR data along the boundary in between the 1D and 2D models to ensure smooth transition between the models.

Preliminary model runs were carried out to determine approximate floodplain extents. Based on these results, we noted that the land cover and land use within the flood extent was similar across the model. We therefore decided to use one constant roughness value for the watercourses and another constant value for the floodplain. The following Mannings n values were used:

- Wairoa River and Taitaia Stream, n = 0.0375
- Floodplain, n =0.04.

Photographs of the Wairoa River and Taitaia Stream can be seen in Appendix H (flood flows) and Appendix I (normal flow). They provide an indication of stream/river roughness.

The flood flows for the 100 year ARI design storm event are largely outside the watercourse channel, so the roughness of the watercourse is unlikely to affect the flood depths significantly.

The Mannings roughness value used for the floodplain is typical of land used for pasture (Chow, 1973) and light brush (HEC-RAS user manual). CIRIA (1990) recommended the Manning n values shown in Table 6-2 for different grass lengths.

Table 6-2 Manning n values for different grass lengths (CIRIA, 1990)

Grass length (mm)	Manning n value
<50	0.024
50-150	0.031
150-250	0.034
250-750	0.045
>750	0.065

Based on the figures shown in Table 6-2 the 0.04 value used in the modelling is therefore likely to be a slightly conservative value. A sensitivity assessment is carried out later where there is a discussion regarding the Mannings number.

7 Hydraulic model calibration

7.1 Overview

The approach taken to calibrating the hydraulic model was to use the best available information relating to flows and water levels. The hydraulic model used the recorded flow information at Tourist Road as an upstream model boundary and the concurrent sea water level based on Ports of Auckland tidal gauge with corrections. A comparison of the predicted levels with the surveyed levels was then carried out to determine the suitability of the model to predict flood extents for the design storm.

7.2 Methodology

The permanent flow gauge at Tourist Road was used to provide upstream inflows to the Wairoa River branch of the model for model calibration.

There are no flow records in the Taitaia Stream, therefore all inflows to the stream (including those into the Wairoa River downstream from Tourist Road) were determined from the hydrological model using rainfall recorded from the Hunua gauge (see Section 4.2).

The hydraulic model was used to predict water levels throughout the model domains and then water levels were compared with the surveyed water levels from flood photographs.

There are no permanent water level gauges in either the Taitaia Stream or Wairoa River downstream from Tourist Road. Therefore, water level calibration was dependant on the surveyed levels from historical photographs shown in Table 6-1 (see Appendix H for historical flood photographs).

7.2.1 Calibration event

Calibration of the hydraulic model of the Wairoa River and Taitaia Stream was limited by the availability of quality records.

The Tourist Road flow record for the three storm events identified in Table 6-1 is shown in Figure 7-1.

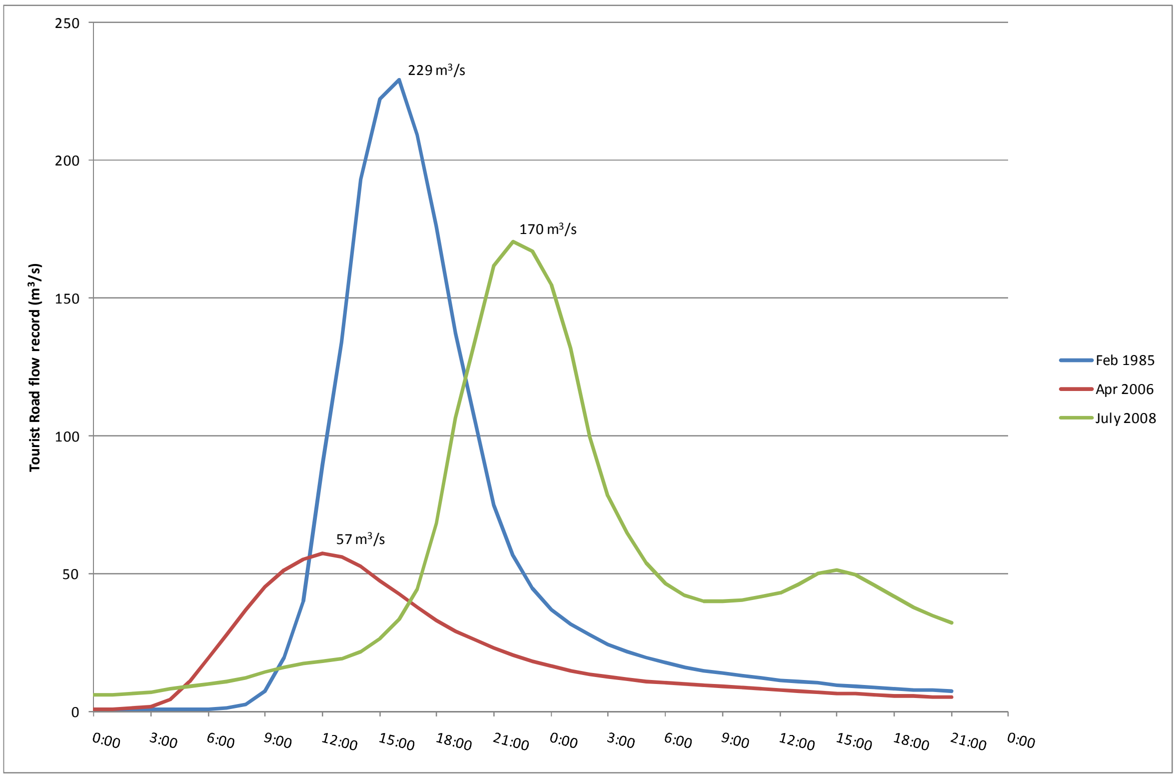

Figure 7-1 Tourist Road flow record for three historical events where water level records are available

Only one water level record was available for the April 2006 storm event, and given that the recorded flows were also comparatively small (see Figure 2-3) we did not consider the event further for hydraulic model calibration.

Both the 1985 and 2008 flood events produced flows in excess of the 125m^3/s at the Tourist Road flow gauge, which is the limiting flow for the Tourist Road gauge (see Section **Error! Reference source not found.**). Given that the peak flows for the 1985 and 2008 event were 229 m^3/s and 170m^3/s respectively, we have more confidence in the lower 2008 flows because it exceeds the 125 m^3/s limit by less. In addition, we were able to obtain more water level records for the 2008 event, over a wider area, than for the 1985 records. We were reliant on the Beca (1995) Report for the 1985 water level records which provided water levels at three locations. However for one of the three locations we were unable to identify on which river the level was recorded. We were also able to use anecdotal information from local residents to supplement the 2008 data because it was a relatively recent flood event.

Therefore the hydraulic model calibration was focussed on the storm event of 30 July 2008.

7.3 Hydraulic model calibration results

The model results for the hydraulic model calibration are shown in Appendix J. The results display the maximum water depth and flood extents for areas inundated by more than 0.1 m water depth.

A comparison of surveyed water levels and modelled water levels can be seen in Table 7-1.

Table 7-1 Hydraulic model calibration – storm event of 30 July 2008

W'course	Location	Recorded level (m RL)	Model predicted level (m RL)	Difference (m)
Wairoa	Polo Grounds 1	2.63	2.79	+0.16
Wairoa	Fire station	3.53	3.4	-0.13
Wairoa	116 Monument Rd (2 locations adjacent to property)	6.01 6.2	6.04 6.12	+0.03 -0.08
Taitaia	Camp Sladdin footbridge	4.63	4.59	-0.04
* The Tourist Road location was not included for calibration purposes because it is located too close to the model boundary to be represented in the model.				

The results of the hydraulic calibration indicate that the flood levels predicted by the model are similar to the surveyed levels from the flood photographs, to within 0.16m. Three of the locations are located along the Wairoa River and the results indicate that the model predictions slightly exceed the recorded levels in the upper part of the model. There is a suggestion that the model slightly under-predicts water levels in the Wairoa River downstream of the Clevedon – Kawakawa Roadbridge.

Given that the hydraulic model calibration could only be carried out for one storm event due to availability of data, we are unable to analyse in detail the cause of the under-prediction downstream of the Clevedon-Kawakawa Roadbridge, and whether it would be a general trend for all storm events.

Anecdotal information from farm-owners on the Taitaia Stream (along Twilight Road) would indicate that the flood extent along the Taitaia Stream for the July 2008 storm event is in good agreement with their recollections. The results also suggest that the model predictions at Camp Sladdin are similar to the peak water level recorded by the photograph of the footbridge.

As previously stated, calibration of the hydraulic model was limited by the availability of quality records. Therefore, instead of trying to achieve better calibration with the recorded levels, it was considered more important to carry out a sensitivity assessment of the design flood extents. The sensitivity assessment is detailed in Section 9.

Overall, it is considered that the hydraulic model gives a reasonable prediction of flood water levels.

8 100 year ARI flood extent

8.1 Overview

A hydrological model and hydraulic model were calibrated using the best information that was available from rainfall and flow monitoring historical records and surveyed information.

The hydrological model was used to determine flows for input into the hydraulic model for the 100 year ARI design storm. The hydraulic model has been used to determine the flooding extent and level.

The scenario that has been adopted to represent the 100 year flood extent comprises the following:

1. 100 year ARI design rainfall from TP108
2. Climate change in accordance with best practice from MfE
3. Cosseys dam and Wairoa dam both being full at the start of the design storm event
4. 100 year ARI sea level as a sea water level boundary.

8.2 Results

The model results for the hydraulic model calibration are shown in Appendix J. The results display the maximum water depth and flood extents for areas inundated by more than 0.1 m water depth.

The flood extent, and flood depth shown in Appendix K.1 identifies the 100 year flood limit for the scenario described above. In addition, the peak flood levels are shown on Appendix K.2. The flood extent does not include any freeboard, and if this is required, MCC should add a freeboard allowance on top of the flood levels.

9 Sensitivity assessment

9.1 Overview

The requirement of the flood hazard mapping was to identify the flood extents during a 100 year ARI design storm so that future development is restricted to areas outside the floodplain.

This Report has highlighted a number of areas where there is uncertainty regarding the information used and approach taken (e.g. no flow records for the Taitaia stream).

To account for areas of uncertainty we have used conservative assumptions as appropriate in determining the 100 year ARI flood extent. However in addition, and to provide further confidence in the flood extent, a sensitivity assessment was carried out.

9.2 Sensitivity scenarios

The sensitivity assessment was carried out to assess the flood extents for two scenarios:

1. An increase in design flows of 10%
2. A decrease in design flows of 10% and a reduction in the design sea level.

The increase/decrease in design flows was applied to all sub-catchments in the model. The reduction in sea level considered the effect of reducing the sea level from RL3.15 m to RL1.83m. RL1.83m is considered to be the approximate level of MHWS at the mouth of the Wairoa River based on information in NIWA (2008).

9.3 Results

The results of the sensitivity assessment have been compared for a number of known locations. The results are shown in Table 9-1.

Table 9-1 Sensitivity assessment results

Location	Peak Water Level for Scenario (m RL)				Range in peak water levels for sensitivity scenarios (m)
	100 yr ARI design	10% Increase in design flows	10% Decrease in design flows	10% Decrease in design flows and reduced sea level (RL 1.83m)	
116 Monument Road	6.80	7.06	6.63	6.63	0.43
Polo Club	5.70	5.83	5.37	5.27	0.56
Fire station	5.77	5.98	5.45	5.35	0.63
Twilight Road	7.11	7.32	6.9	6.89	0.43
Camp Sladdin	6.81	7.02	6.59	6.58	0.44

The results indicate that there is a range in predicted peak water levels of between 0.43m and 0.63m for the sesnitvity assessment. The flood extent maps shown in Appendix L identify how the increases in water level relate to changes in flood extent to provide an indication of the sensitivity for planning purposes.

The results show that for the scenarios modelled, in general the flood extent is relatively insensitive to changes in flow/water depth with the exception of the area by the fire station. An increase in flows at the fire station causes an increase in water level and a noticeable increase in the flood extent up the western bank of the Wairoa River towards Clevedon township. Other areas where an increase in flood extent can be observed for the sensitivity run is up the ephemeral streams where small increases in the gradient of the ground correspond to increased flood extents. In contrast, the majority of the banks of the Wairoa River and Taitaia Stream are well defined with relatively steep slopes along the edge of the floodplain. This indicates that the flood extents are relatively insensitive to small changes in water level.

The sensitivity assessment has been carried out to assess changes in flow, however the findings of the assessment are equally applicable to sensitivity checks of other parameters which affect water level e.g. roughness coefficient.

The results of the flood hazard mapping sensitivity assessment indicate that there can be a good level of confidence in the flood extents. It has also identified the small number of locations where a precautionary approach may be best adopted to determining development areas. The sensitivity assessment might be used in the future as a consideration for setting freeboard levels for development.

10 Applicability

This Report has been prepared for the benefit of Manukau City Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

Report prepared by: Authorised for Tonkin & Taylor by:

....	....
Jon Rix	Tim Fisher
Water Resources Engineer	Project Director

JRRR

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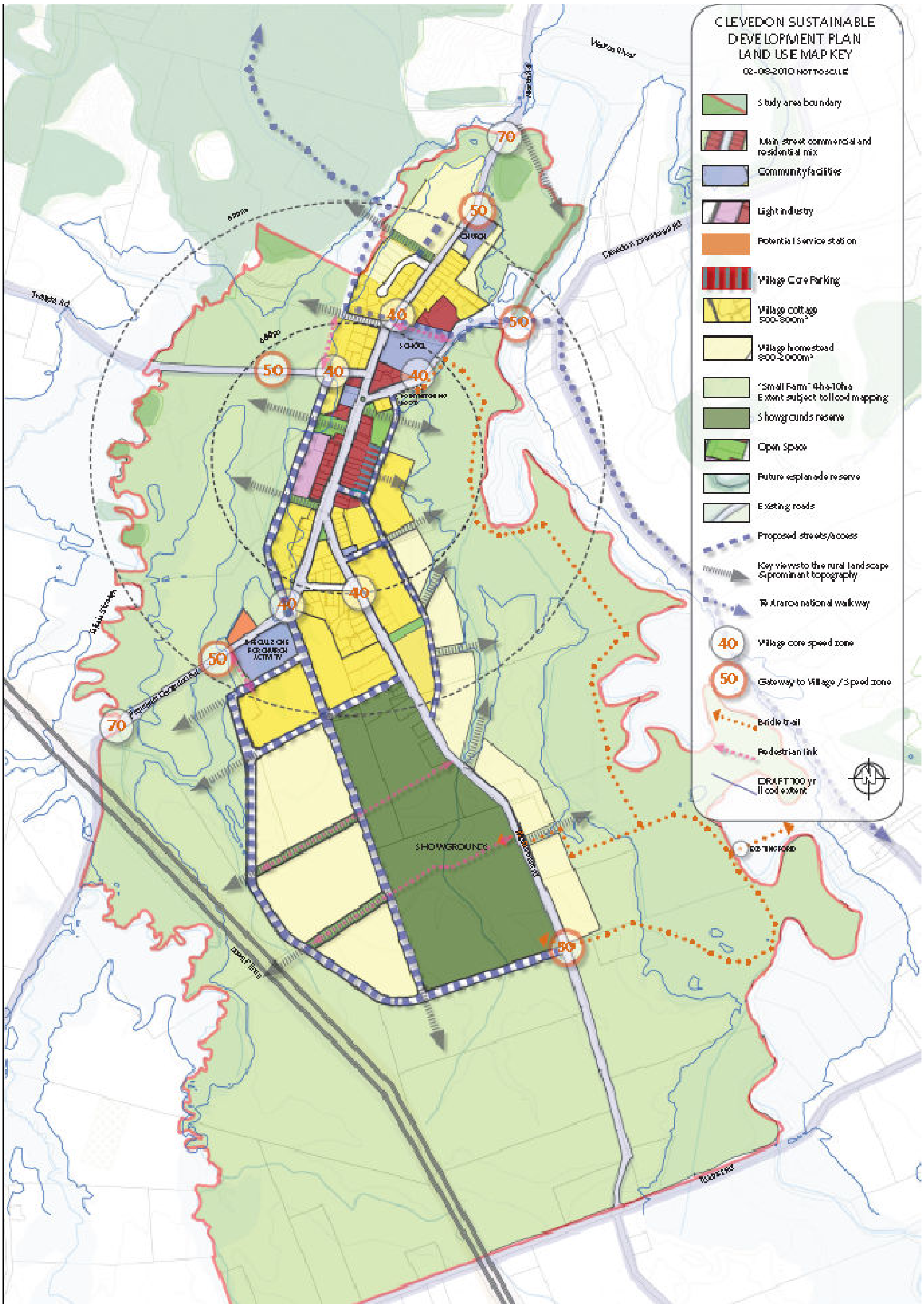
11 References

- Beca, 1995; Draft Flood Management Study and Plan - Wairoa River Flood Management Plan. Report No. 2
- Beca, 1995;. Definition of Parameters and Study Philosophy – Wairoa River Flood Management Plan. Report No. 1
- Bell, R.G., Goring, D.G and de Lange, W.P., 2000: Sea-level change and storm surges in context of climate change. IPENZ Transactions. Vol. 27, No.1/Gen.
- CIRIA, 1990. Use of Vegetation in Civil Engineering
- Coastline Consultants, 2001. Coastal Hazards and Management Browns Bay. Report prepared for ARC and North Shore City Council.
- de Lange, W.P., 1996: Storm Surges in New Zealand. Coastal Marine Group, Department of Earth Sciences, University of Waikato.
- Hay, D.N., 1991: Storm and oceanographic databases for the Western Bay of Plenty. Unpublished MSc Thesis, Dept. of Earth Sciences, University of Waikato.
- Heath, R.A., 1979: Significance of storm surges on the New Zealand coast. New Zealand Journal of Geology and Geophysics 22(2): 259-266.
- MFE, 2004: Coastal hazards and Climate Change: A guidance manual for local government in New Zealand. Publication No. ME 512, NZ Climate Change Office, Ministry for the Environment, Wellington. http://www.climatechange.govt.nz/resources/local-govt/coastal-hazards-may04/index.html
- MFE, 2008: Coastal hazards and Climate Change: A guidance manual for local government in New Zealand. Second Edition. . Publication No. ME 892, NZ Climate Change Office, Ministry for the Environment, Wellington. http://www.mfe.govt.nz/publications/climate/coastal-hazards-climate-change-guidance-manual/coastal-hazards-climate-change-guidance-manual.pdf
- NIWA, 2008. Review of rainfall intensity curves and sea levels in Manukau City. Part 2: Sea levels. Report prepared for Manukau City Council
- Soil Conservation Society, 1986. Urban Hydrology for Small Watersheds. Technical release No. 55, U.S. Department of Agriculture, Soil Conservation Service, 2nd ed., June 1986.
- Tonkin & Taylor, 1996; Wairoa Catchment Consents; Technical Report on River Hydrology. Report prepared for Watercare Services Ltd.
- Tonkin & Taylor, 2005. Revised Spillway Rating Curves for Ten Water Supply Dams. Report prepared for Watercare Services Ltd. T&T Ref 22726.
- Tonkin & Taylor, 2010. Statement of Evidence of Richard Reinen-Hamill. 28 June 2010. Plan Change Application by Wairoa River Canal Partnership.
- USDA (United States Department of Agriculture) 2007; National Engineering Handbook, Part 630 Hydrology. Chapter 16
- WCS, 1993. PMF for 10 Water Supply Dams in the Auckland Region. Works Consultancy Services

Appendix A: Catchment maps

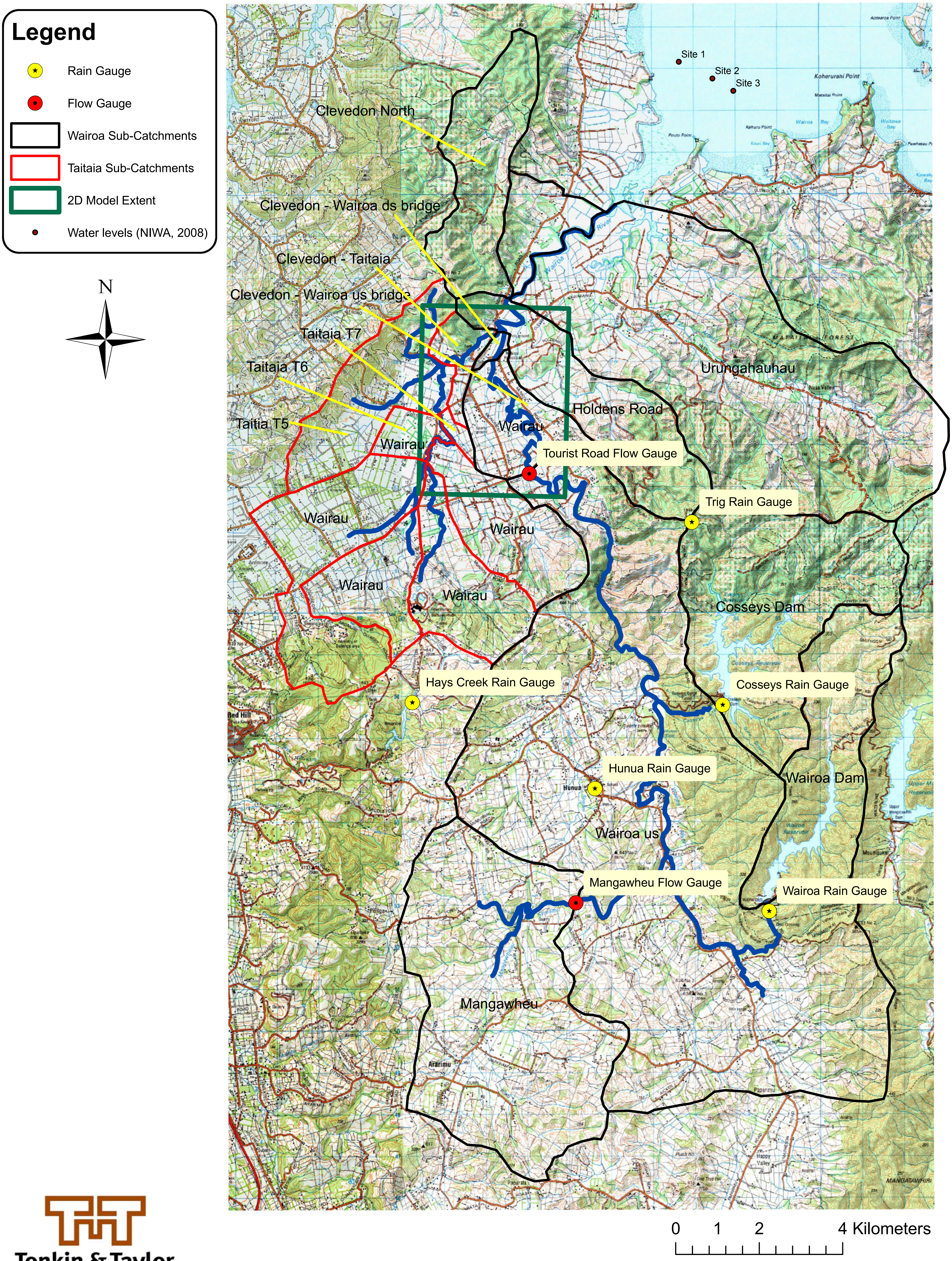
- **A.1 Draft Sustainable Development Plan Land Use Map**
- **A.2 Hydrological sub-catchments, rain gauge and flow gauge locations**

- ### A.1 Sustainable Development Plan Land Use Map



Appendix A.2

Catchment Map and Gauge Locations



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Appendix B: Flow and rain gauge records

- **B.1 Long term time series**
- **B.2 Calibration events**

Appendix B.1

Rain at Hunua
Rain at Wairoa
Rain at Trig
Rain at Cosseys
Flow at Tourist Road
Rainfall (mm/day)
Hourly flow (m³/s)
1/01/2000
1/03/2000
1/05/2000
1/07/2000
31/08/2000
31/10/2000
31/12/2000
1/01/2001
2/03/2001
2/05/2001
2/07/2001
1/09/2001
1/11/2001
1/01/2002
1/01/2002
2/03/2002
2/05/2002
2/07/2002
1/09/2002
1/11/2002
1/01/2003
1/01/2003
2/03/2003
2/05/2003
2/07/2003
1/09/2003
1/11/2003
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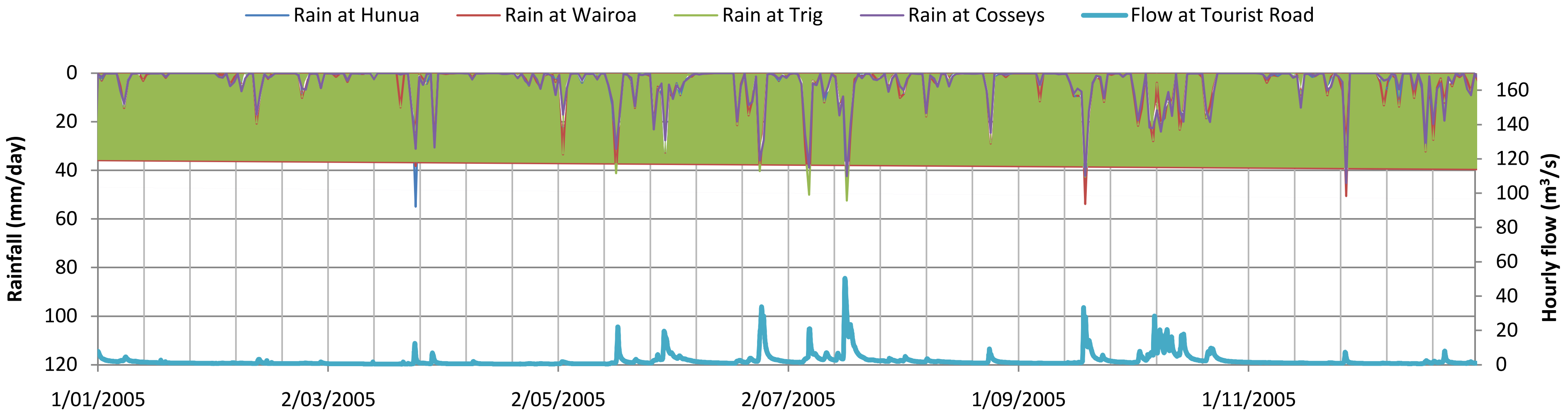
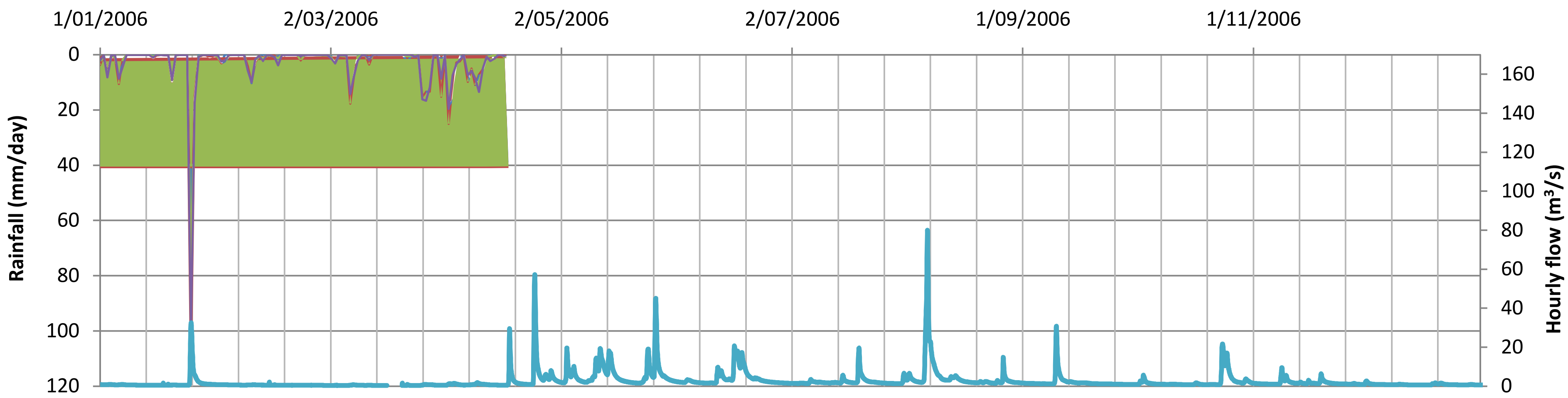
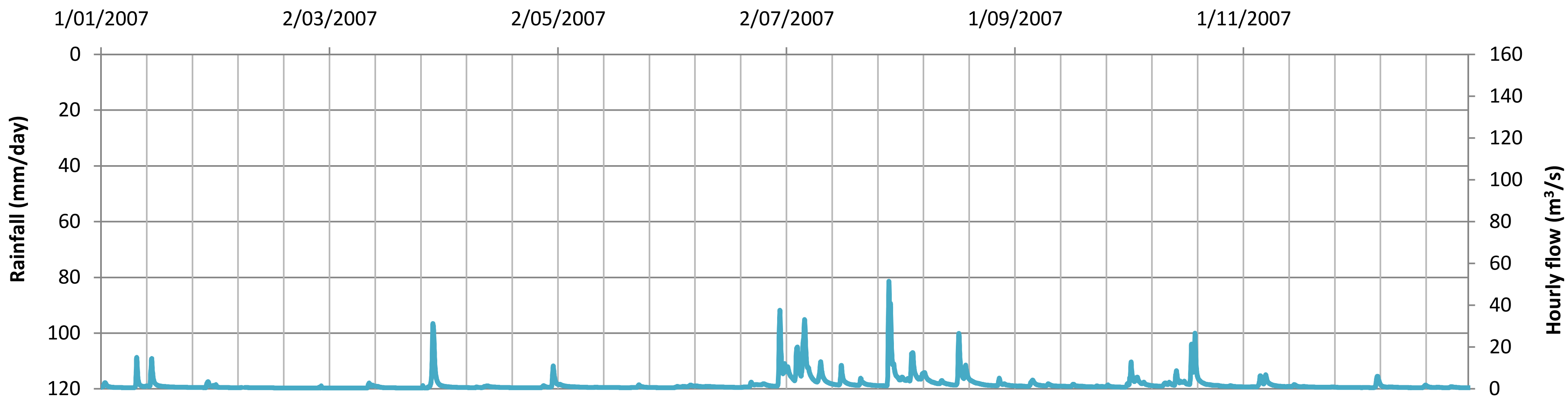
31/08/2004
31/10/2004
31/12/2004



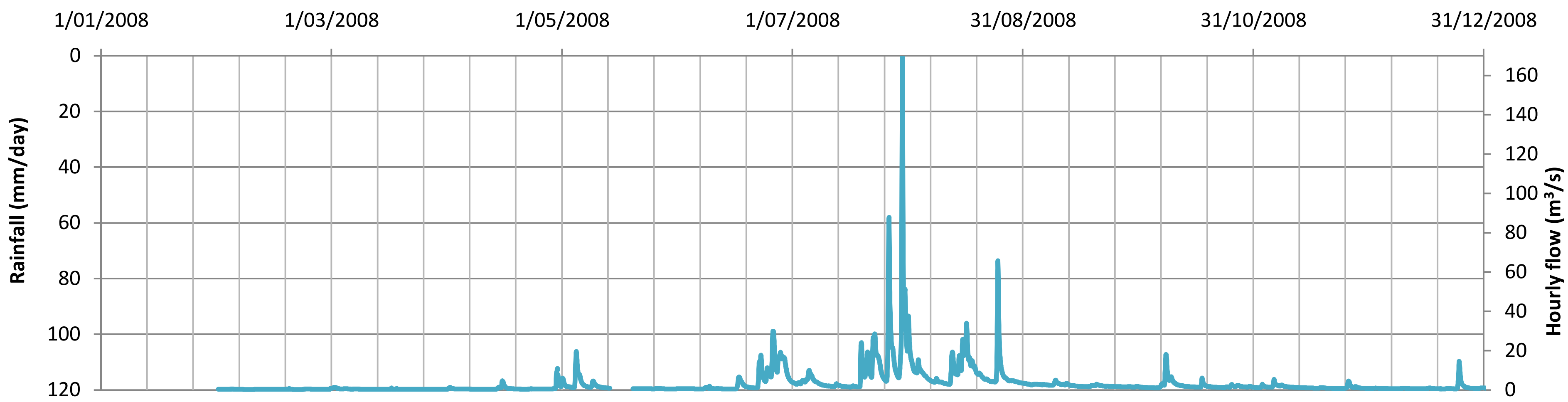
Rain at Hunua
Rain at Wairoa
Rain at Trig
Rain at Cosseys
Flow at Tourist Road
Rainfall (mm/day)
0 20 40 60 80 100 120
160 140 120 100 80 60 40 20 0
Hourly flow (m³/s)
1/01/2005 2/03/2005 2/05/2005 2/07/2005 1/09/2005 1/11/2005



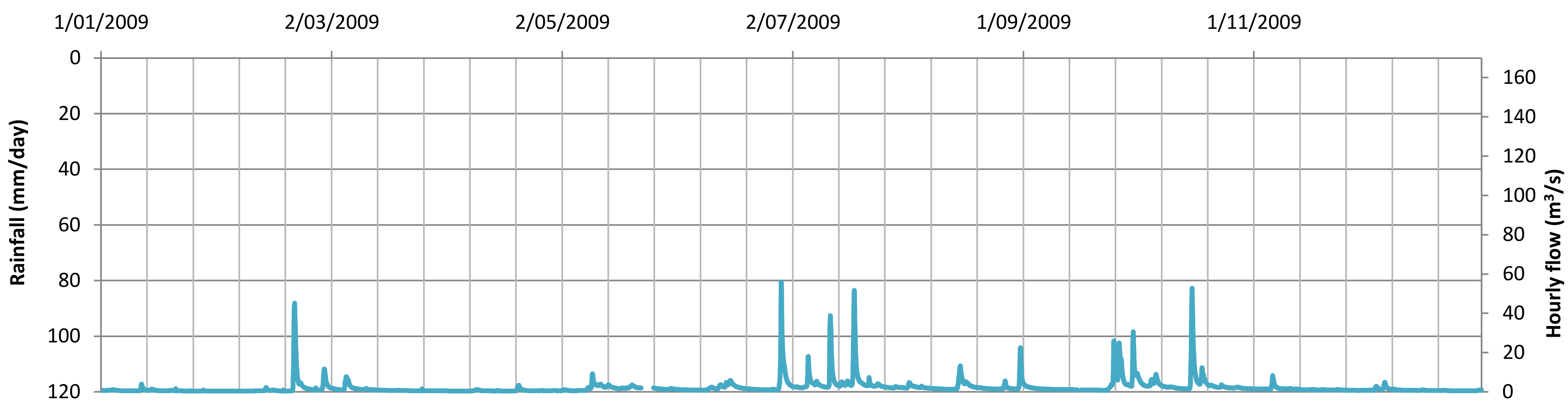
1/01/2006 2/03/2006 2/05/2006 2/07/2006 1/09/2006 1/11/2006
Rainfall (mm/day)
0 20 40 60 80 100 120
160 140 120 100 80 60 40 20 0
Hourly flow (m³/s)



1/01/2007 2/03/2007 2/05/2007 2/07/2007 1/09/2007 1/11/2007
Rainfall (mm/day)
0 20 40 60 80 100 120
160 140 120 100 80 60 40 20 0
Hourly flow (m³/s)

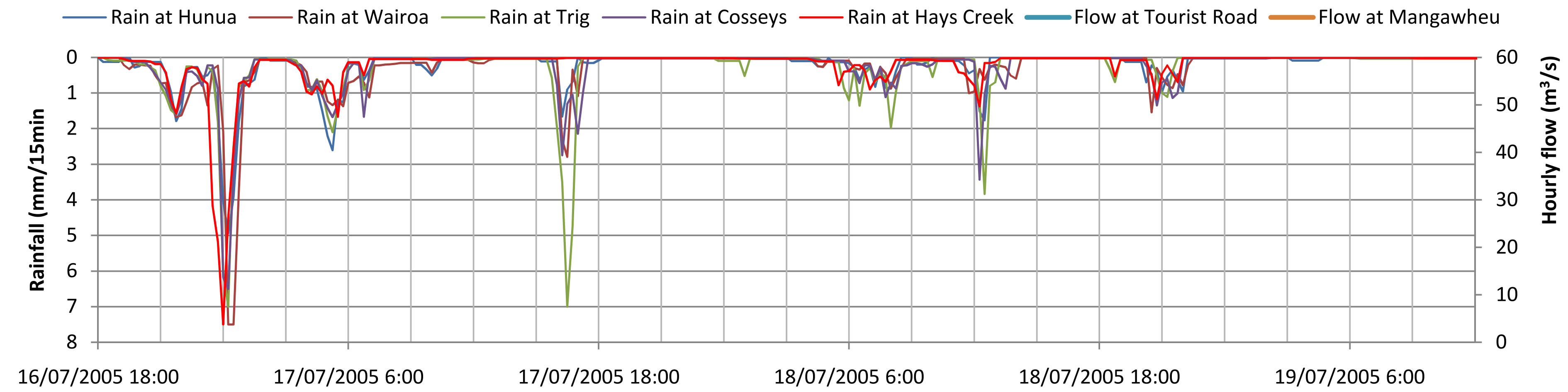


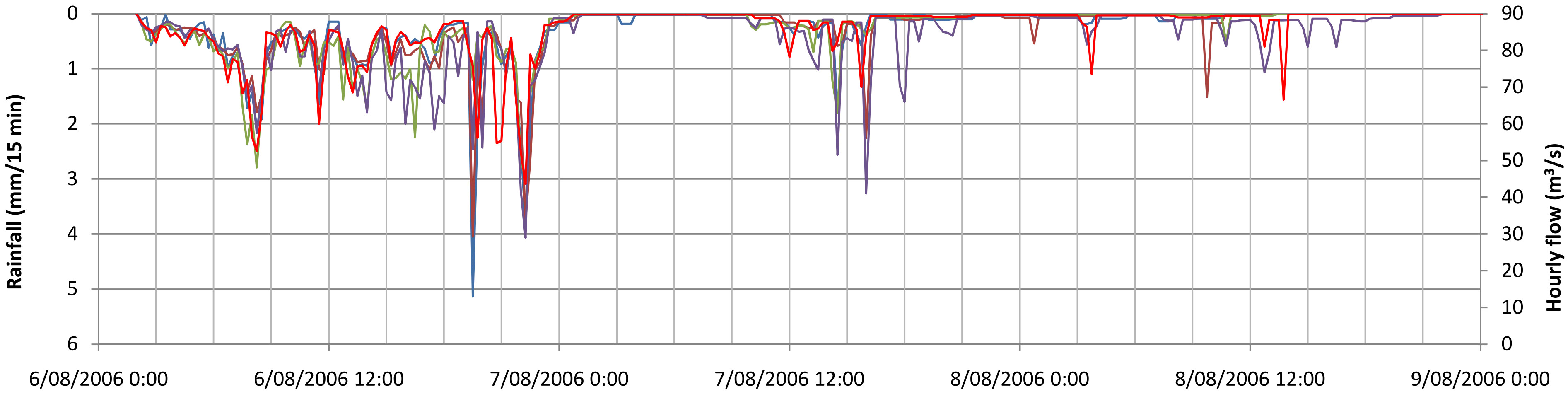
1/01/2008 1/03/2008 1/05/2008 1/07/2008 31/08/2008 31/10/2008 31/12/2008
Rainfall (mm/day)
0 20 40 60 80 100 120
160 140 120 100 80 60 40 20 0
Hourly flow (m³/s)

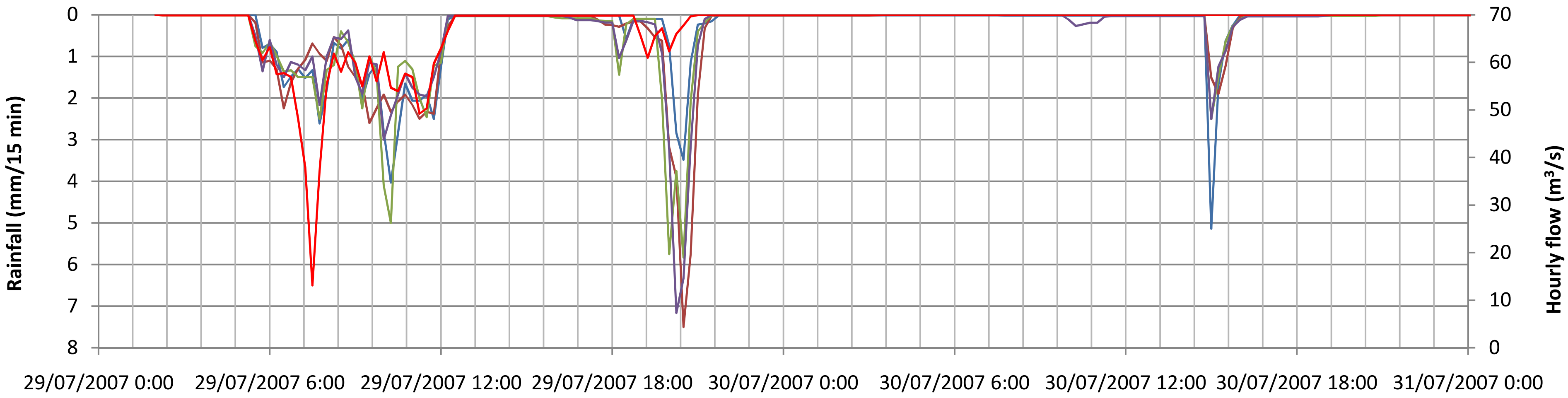


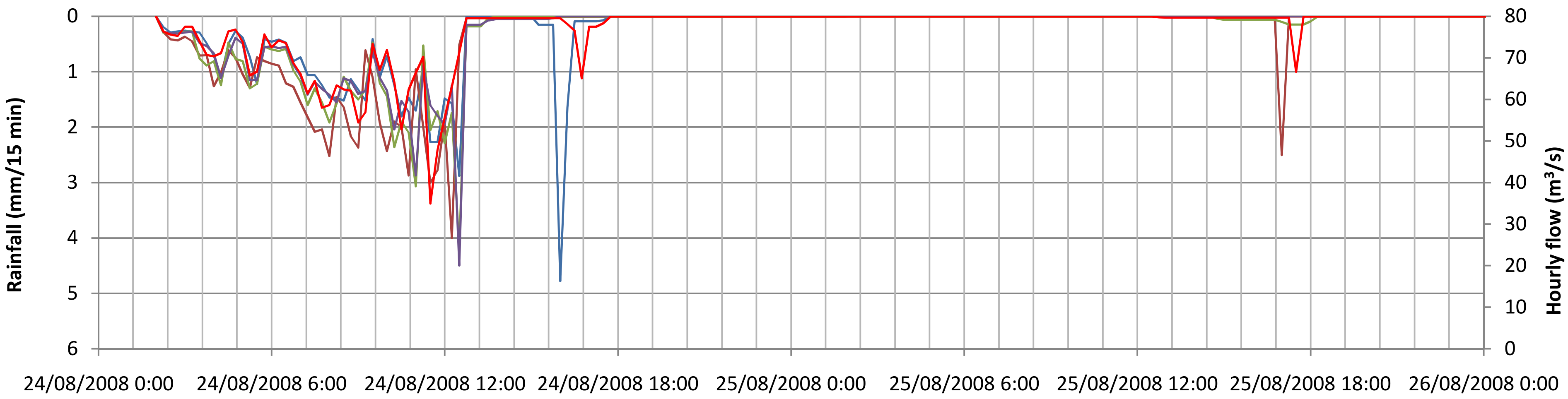
1/01/2009 2/03/2009 2/05/2009 2/07/2009 1/09/2009 1/11/2009
Rainfall (mm/day)
0 20 40 60 80 100 120
160 140 120 100 80 60 40 20 0
Hourly flow (m³/s)

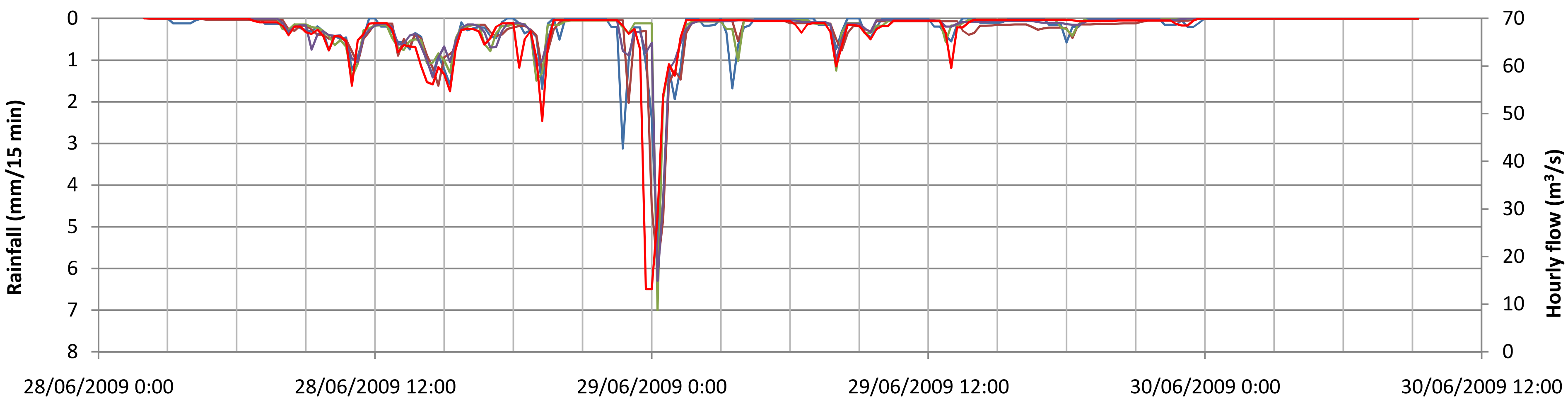
Appendix B.2


Rain at Hunua
Rain at Wairoa
Rain at Trig
Rain at Cosseys
Rain at Hays Creek
Flow at Tourist Road
Flow at Mangawheu
Rainfall (mm/15min)
Hourly flow (m3/s)
16/07/2005 18:00
17/07/2005 6:00
17/07/2005 18:00
18/07/2005 6:00
18/07/2005 18:00
19/07/2005 6:00

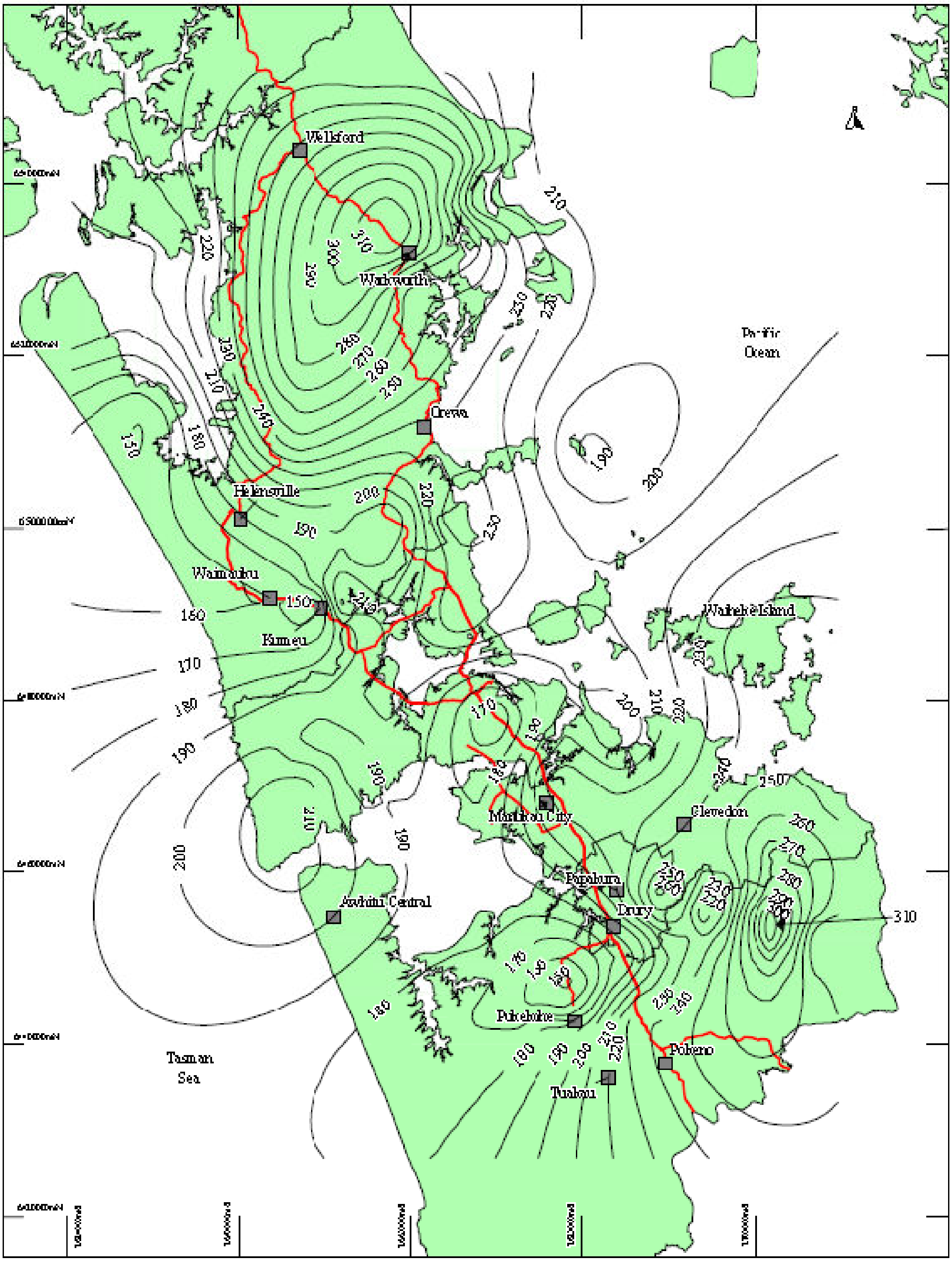

Rainfall (mm/15 min)
Hourly flow (m3/s)
6/08/2006 0:00
6/08/2006 12:00
7/08/2006 0:00
7/08/2006 12:00
8/08/2006 0:00
8/08/2006 12:00
9/08/2006 0:00


Rainfall (mm/15 min)
Hourly flow (m3/s)
29/07/2007 0:00
29/07/2007 6:00
29/07/2007 12:00
29/07/2007 18:00
30/07/2007 0:00
30/07/2007 6:00
30/07/2007 12:00
30/07/2007 18:00
31/07/2007 0:00


Rainfall (mm/15 min)
Hourly flow (m3/s)
24/08/2008 0:00
24/08/2008 6:00
24/08/2008 12:00
24/08/2008 18:00
25/08/2008 0:00
25/08/2008 6:00
25/08/2008 12:00
25/08/2008 18:00
26/08/2008 0:00


Rainfall (mm/15 min)
Hourly flow (m3/s)
28/06/2009 0:00
28/06/2009 12:00
29/06/2009 0:00
29/06/2009 12:00
30/06/2009 0:00
30/06/2009 12:00

Appendix C: TP108 Isohyets



A

Auckland Regional Council

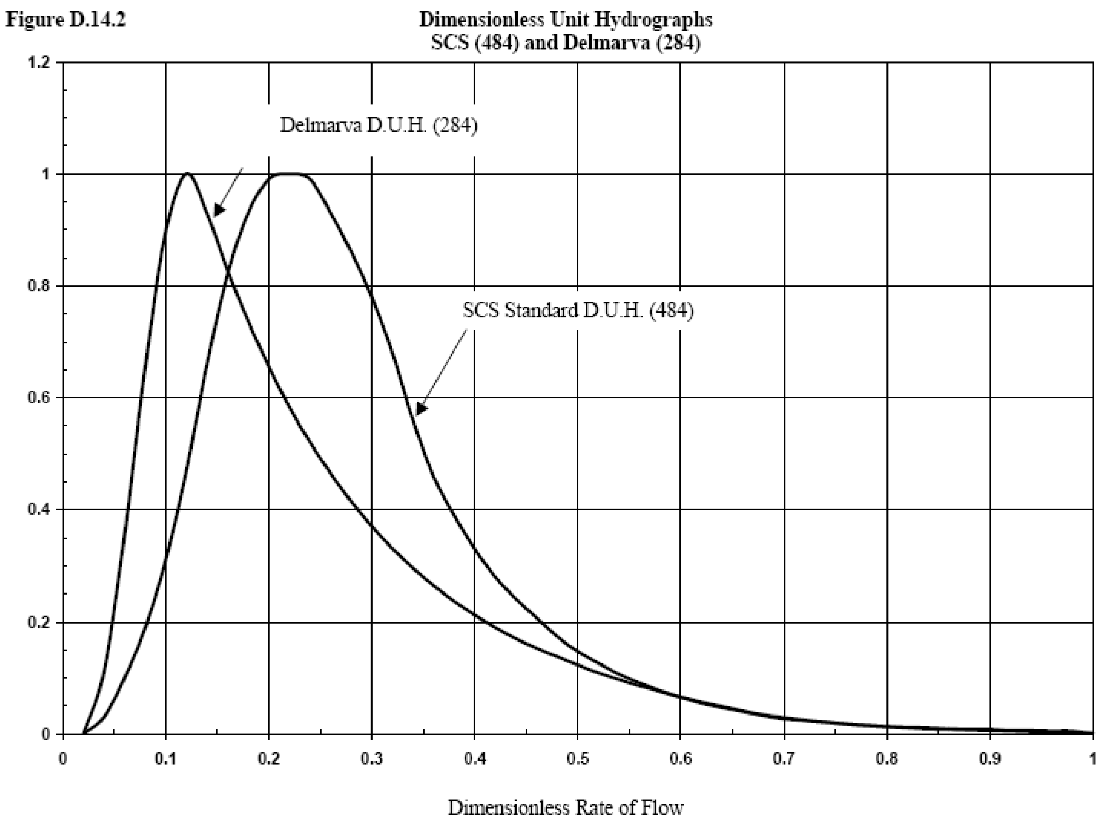
Legend: — 90 — Rainfall Contour (mm)

State Highways

Figure A.6
100 Year ARI
Daily Rainfall Depth

Scale: 1:600,000 (at A4)
(Revised 25/08/1999)

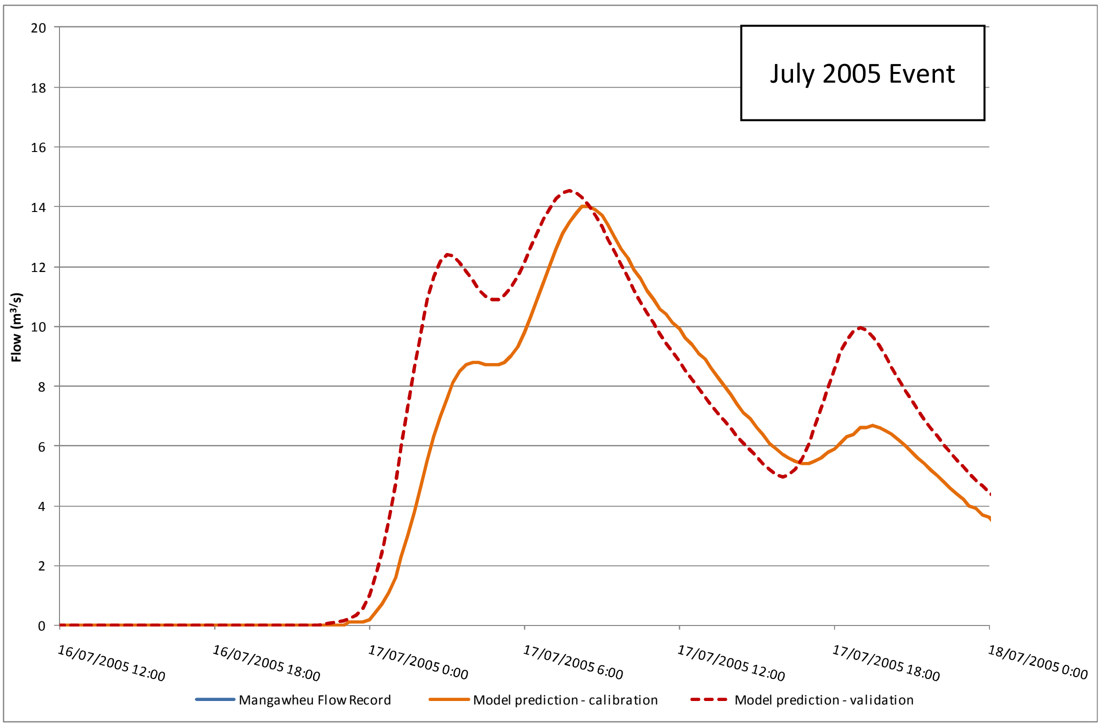
Appendix D: SCS and Delmarva Unit Hydrograph

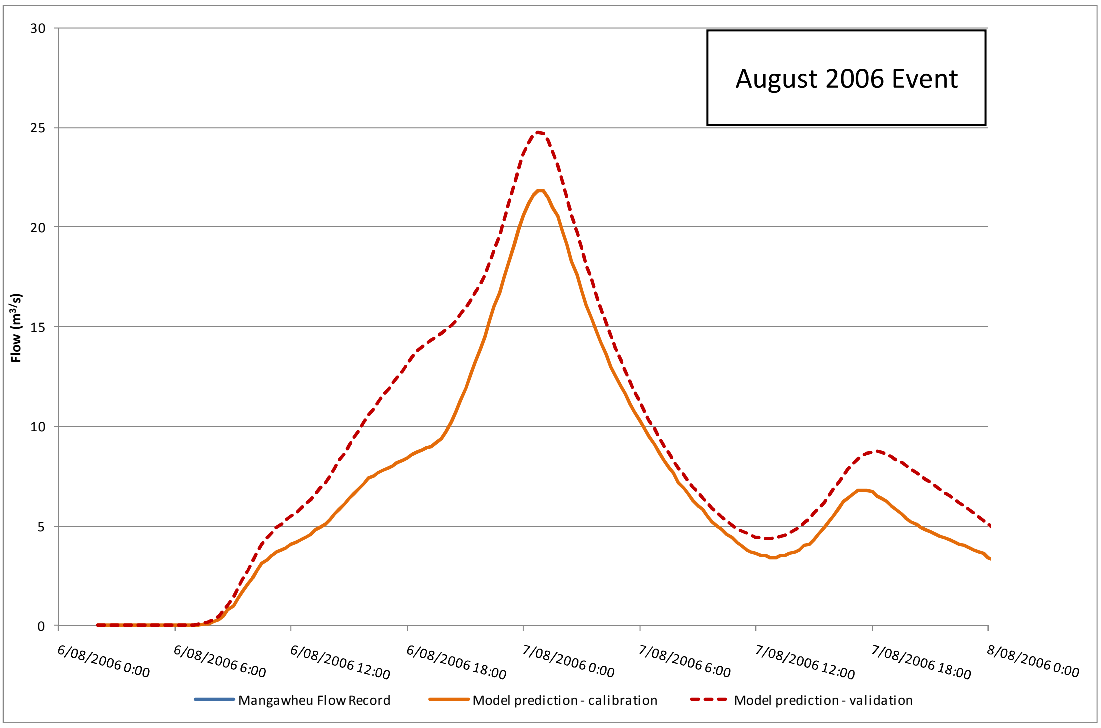


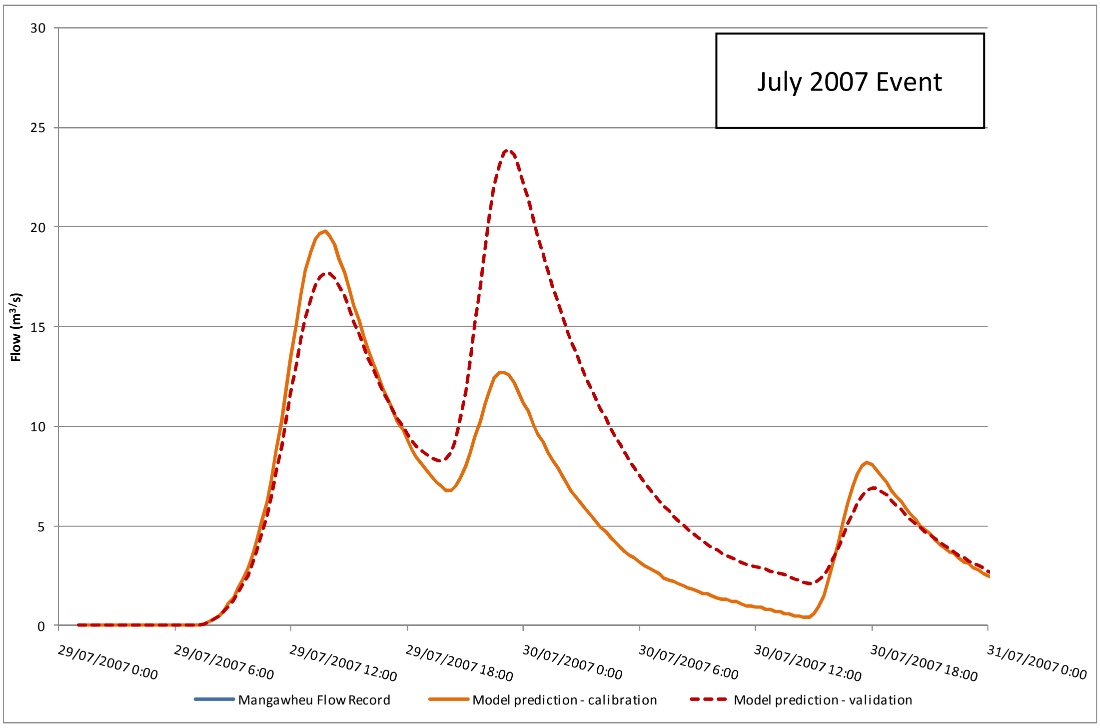
Appendix E: Hydrological calibration results

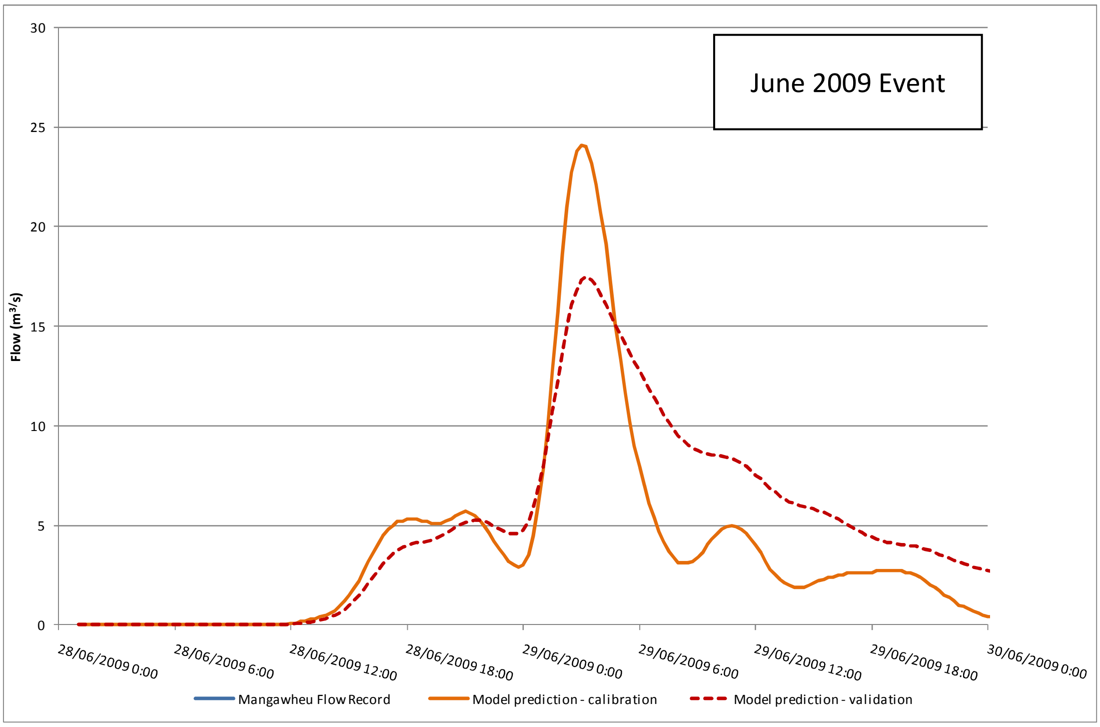
- **E.1 Mangawheu catchment**
- **E.2 Tourist Road catchment**

- **E.1 Mangawheu Calibration results**

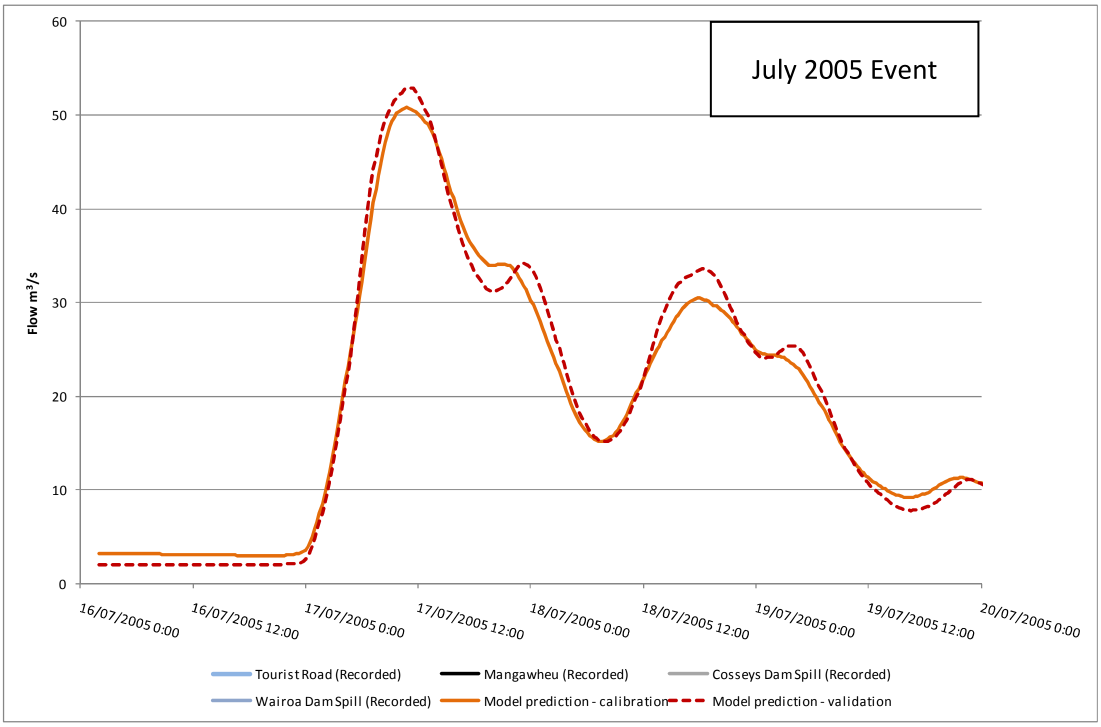


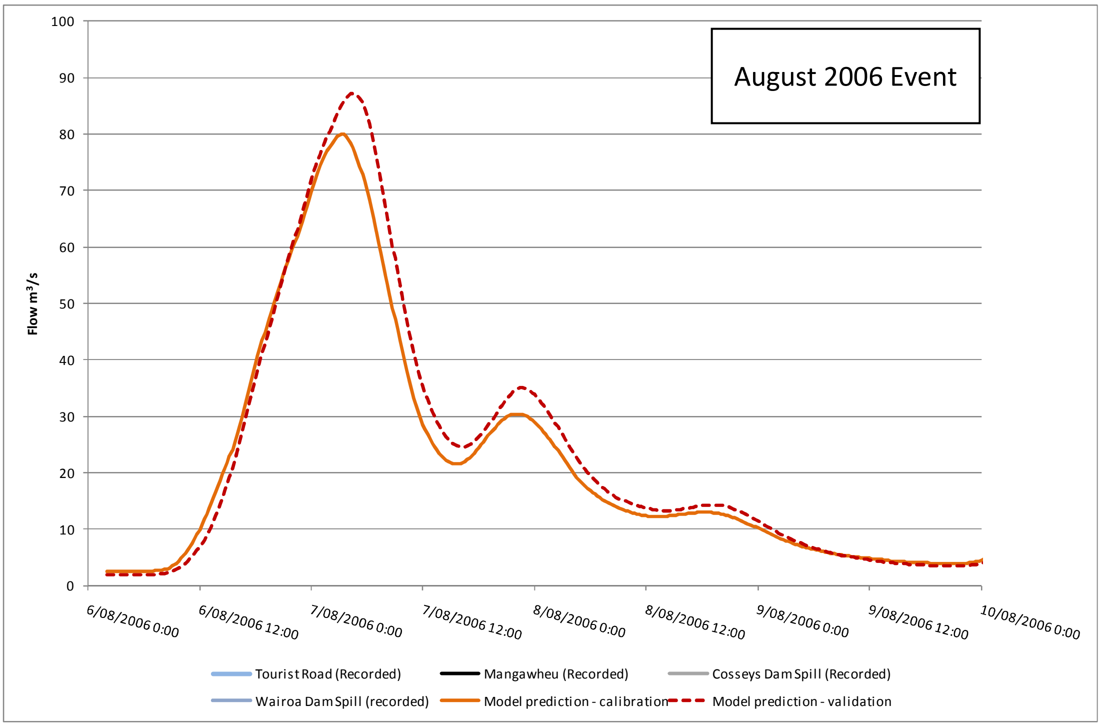


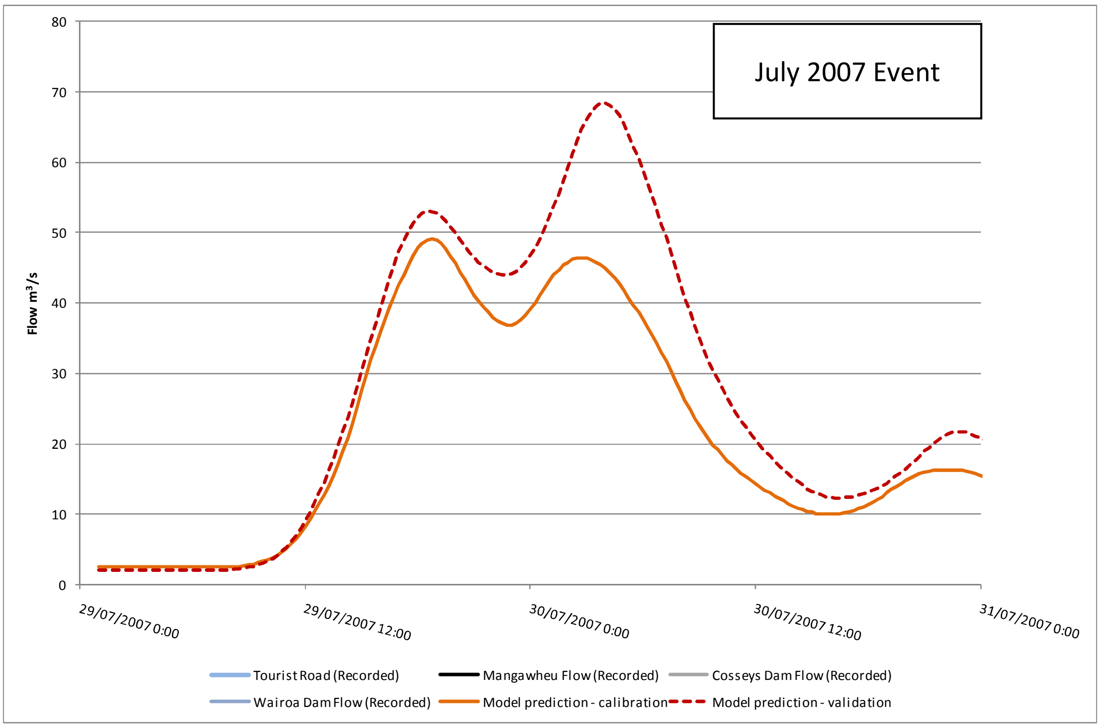

July 2007 Event
Flow (m³/s)
30
25
20
15
10
5
0
29/07/2007 0:00
29/07/2007 6:00
29/07/2007 12:00
29/07/2007 18:00
30/07/2007 0:00
30/07/2007 6:00
30/07/2007 12:00
30/07/2007 18:00
31/07/2007 0:00
Mangawheu Flow Record
Model prediction - calibration
Model prediction - validation

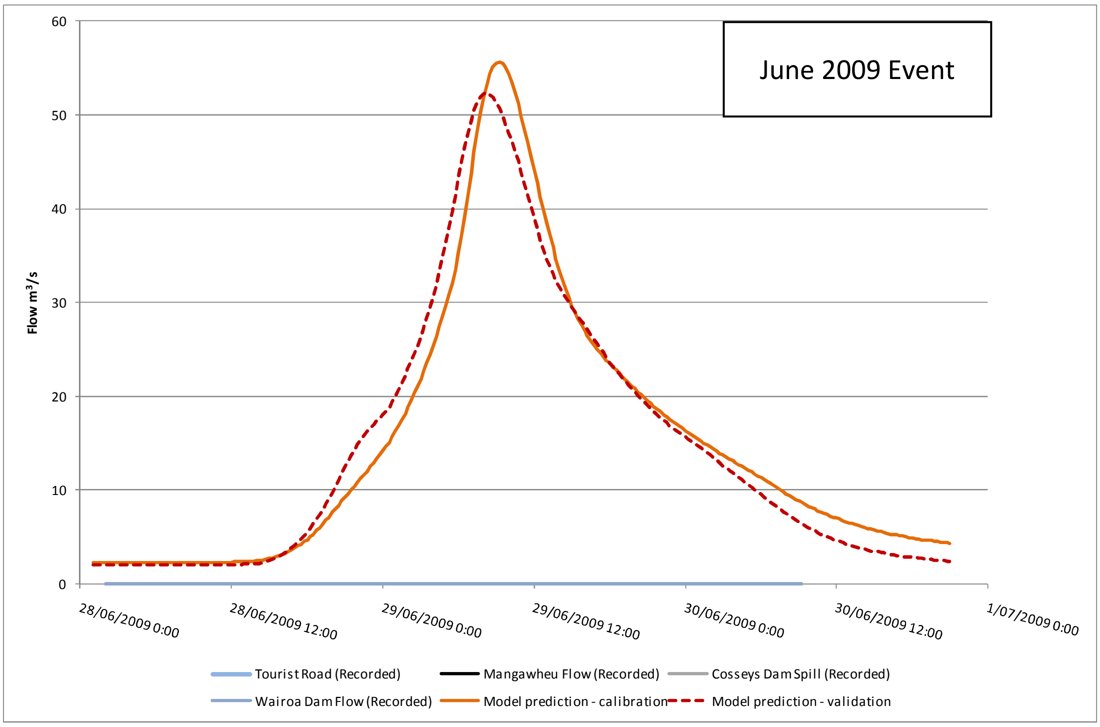

June 2009 Event
Flow (m³/s)
30
25
20
15
10
5
0
28/06/2009 0:00
28/06/2009 6:00
28/06/2009 12:00
28/06/2009 18:00
29/06/2009 0:00
29/06/2009 6:00
29/06/2009 12:00
29/06/2009 18:00
30/06/2009 0:00
Mangawheu Flow Record
Model prediction - calibration
Model prediction - validation

- ## E.2 Tourist Road Calibration results






July 2007 Event
Flow m³/s
80
70
60
50
40
30
20
10
0
29/07/2007 0:00
29/07/2007 12:00
30/07/2007 0:00
30/07/2007 12:00
31/07/2007 0:00
Tourist Road (Recorded)
Mangawheu Flow (Recorded)
Cosseys Dam Flow (Recorded)
Wairoa Dam Flow (Recorded)
Model prediction - calibration
Model prediction - validation


June 2009 Event
Flow m³/s
60
50
40
30
20
10
0
28/06/2009 0:00
28/06/2009 12:00
29/06/2009 0:00
29/06/2009 12:00
30/06/2009 0:00
30/06/2009 12:00
1/07/2009 0:00
Tourist Road (Recorded)
Mangawheu Flow (Recorded)
Cosseys Dam Spill (Recorded)
Wairoa Dam Flow (Recorded)
Model prediction - calibration
Model prediction - validation

Appendix F: Spillway Rating Curves for Cosseys and Wairoa Dam

(Source T&T, 2005)

- ## Cosseys Dam

1) Type: Large diameter circular bellmouth spillway, with ungated overflow crest with a non-standard weir profile.

2) Spillway crest diameter:	38.40 m, with 8 piers (fins) 0.46 m thick
3) Design head:	Not applicable
4) Weir discharge coefficient:	1.705 $m^{0.5}/s$ (broadcrested weir)
5) Lowest spillway crest level:	158.459 m RL
6) Maximum spillway crest level:	158.482 m RL
7) RL of local gauge datum:	129.81 m RL
8) Nominal dam crest level:	161.53 m RL (WCS, 1993)
9) Low range rating data:	0 to 0.15 m head
10) Full range rating data:	0 to 1.80 m head
11) Probable maximum flood (PMF) estimate:	366 m^3/s (WCS, 1993)
12) Dam overtopped in PMF:	No (WCS, 1993)

Note that the spillway barrel chokes above a head of about 1.78 m. The highest rated flow in the data is 469 m^3/s at a head of 1.80 m, which is well below the dam crest.

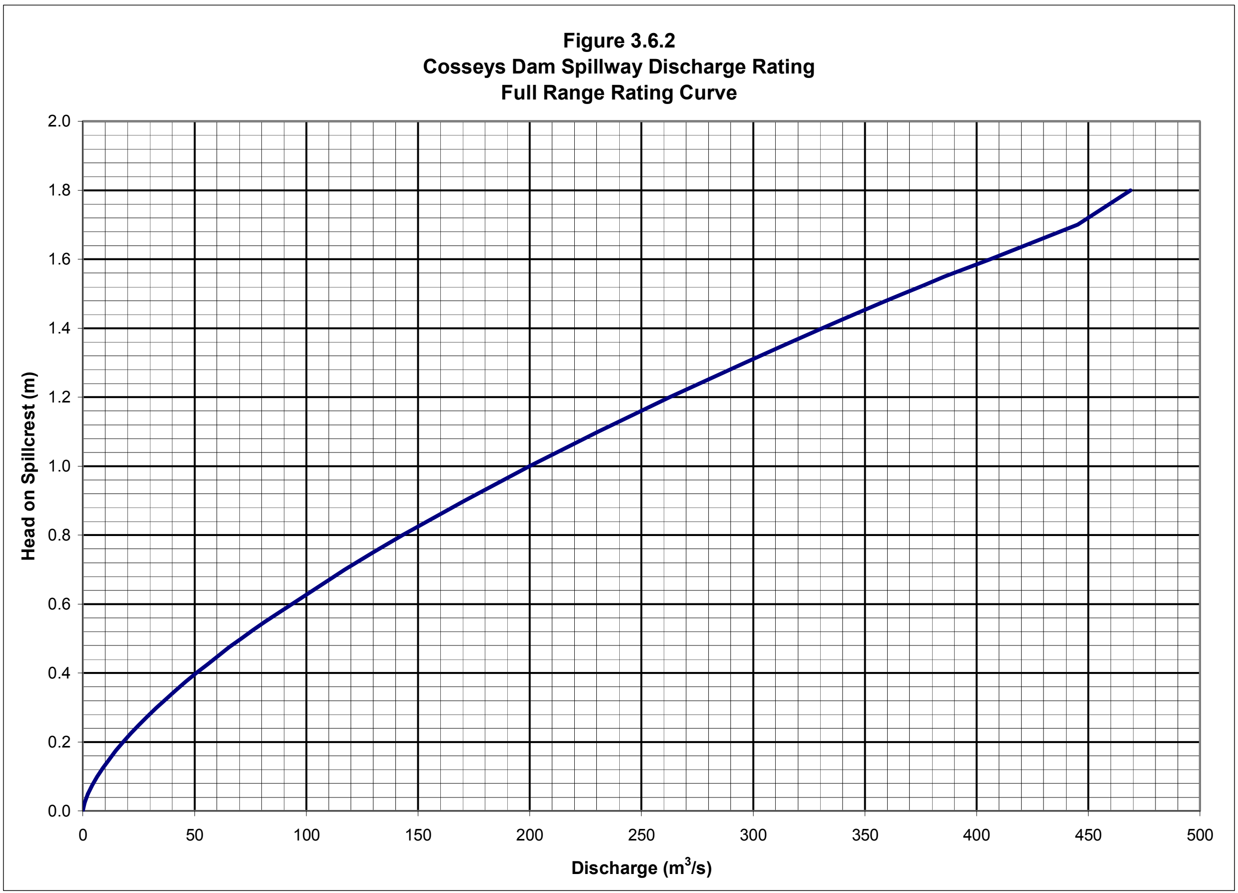


Figure 3.6.2
Cosseys Dam Spillway Discharge Rating
Full Range Rating Curve
Head on Spillcrest (m)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
350
400
450
500
Discharge (m3/s)

- **Wairoa Dam**

1) Type: Circular bellmouth spillway, with ungated overflow crest with an ogee weir profile.
2) Spillway diameter (outside): 7.01 m, with 5 piers (fins) 0.305 m thick
3) Design head: 2.18 m inferred from drawings
4) Apparent discharge coefficient range: 1.60 to 1.67 $m^{0.5}/s$
5) Lowest spillway crest level: 174.953 m RL
6) Maximum spillway crest level: 174.961 m RL
7) RL of local gauge datum: 139.843 m RL
8) Nominal dam crest level: 178.453 m RL (WCS, 1993)
9) Low range rating data: 0 to 0.30 m head
10) Full range rating data: 0 to 3.00 m head
11) Probable maximum flood (PMF) estimate: 136 m^3/s (WCS, 1993)
12) Dam overtopped in PMF: No (WCS, 1993) – see note below

Note that the spillway barrel chokes above a head of about 2.45 m (131 m^3/s), while the auxiliary spillway operates above a head of 2.6 m. The highest rated flow in the data is 162 m^3/s at a head of 3.0 m, which is below the dam crest, and includes the auxiliary spillflow.

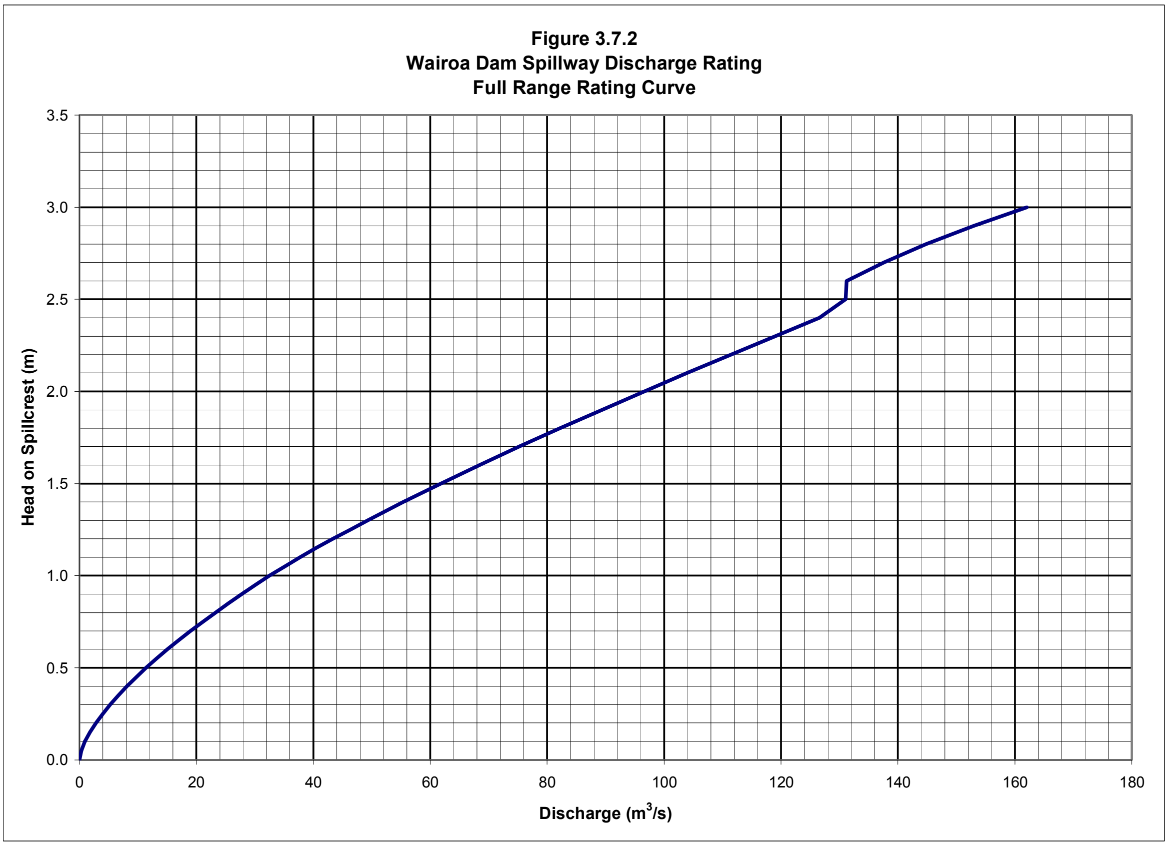
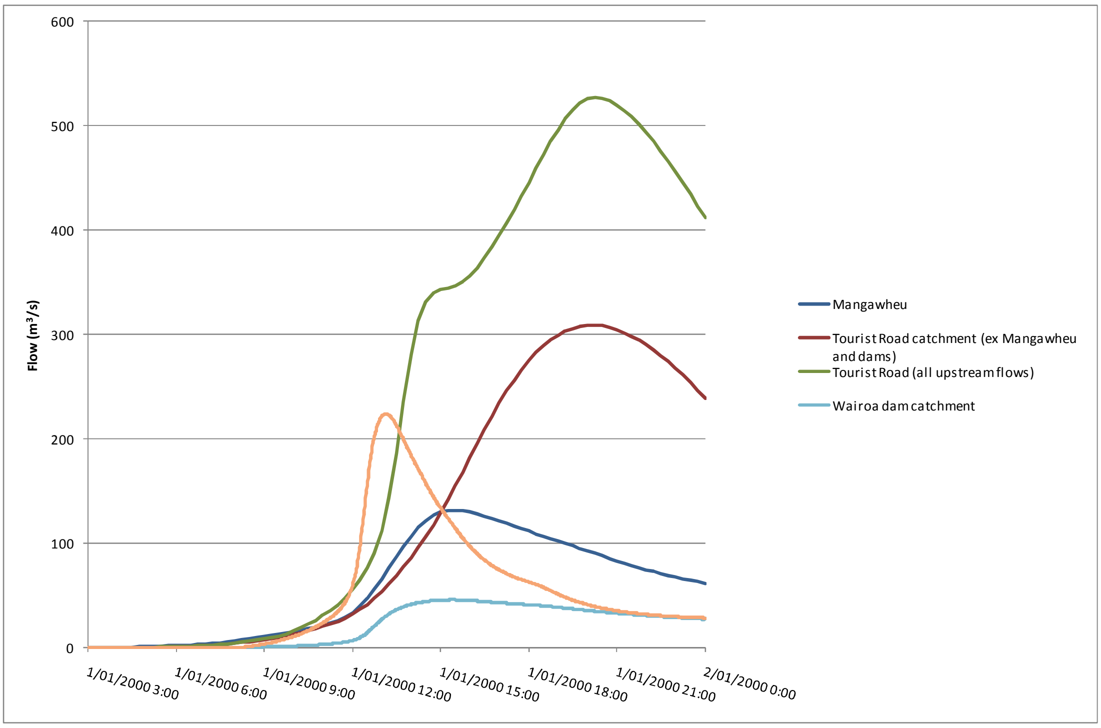


Figure 3.7.2
Wairoa Dam Spillway Discharge Rating
Full Range Rating Curve
Head on Spillcrest (m)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
20
40
60
80
100
120
140
160
180
Discharge (m3/s)

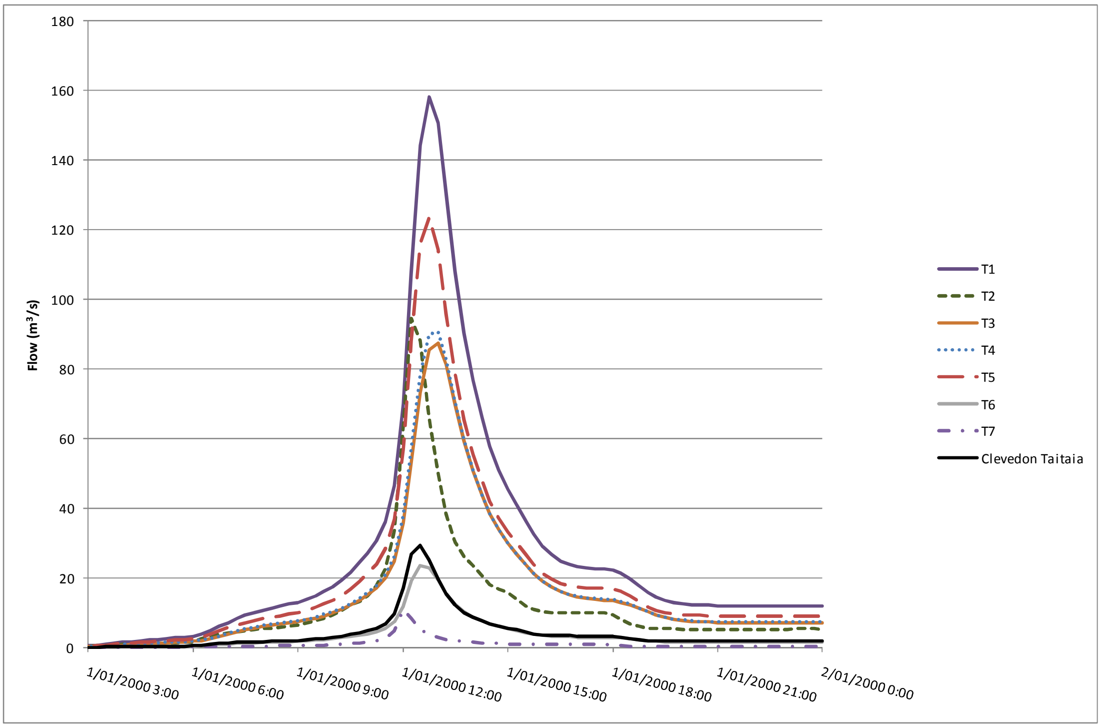
Appendix G: Sub-catchment 100yr ARI design hydrographs

- G.1 Catchments upstream of Tourist Road
- G.2 Taitaia Stream catchments
- G.3 Clevedon township catchments, and downstream

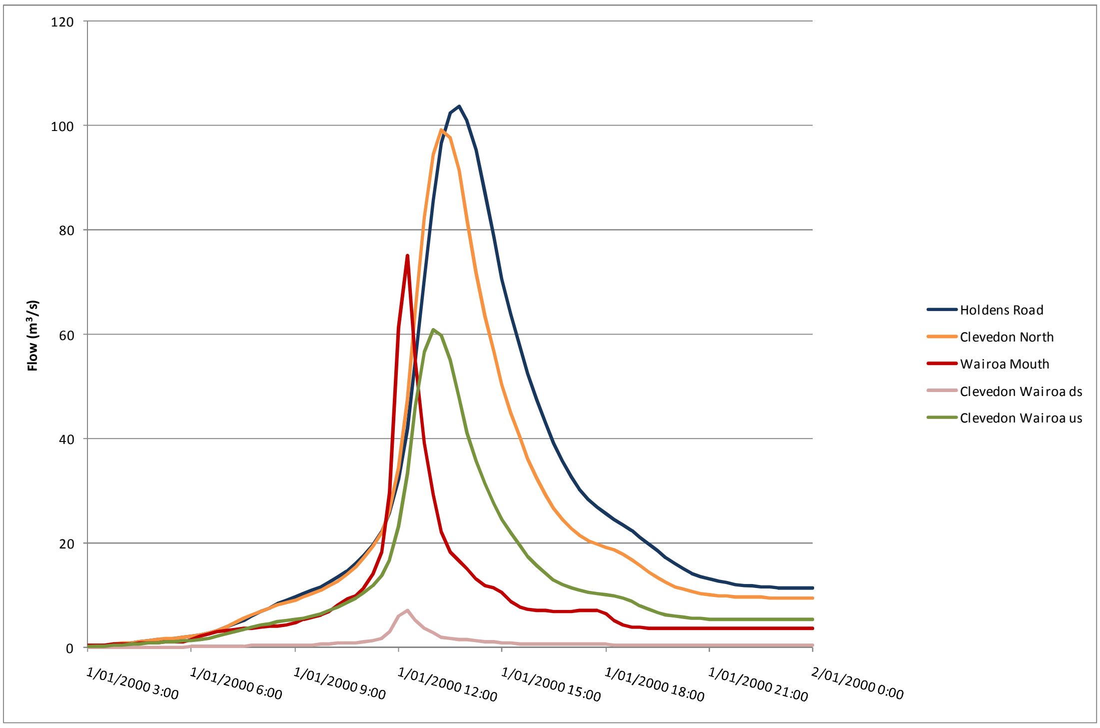
- **Catchments upstream of Tourist Road – Wairoa River (see Table 4.3)**



- **Taitaia Stream catchments – Taitaia Stream (see Table 4.3)**



- **Clevedon township catchments, and downstream (see Table 4.3)**

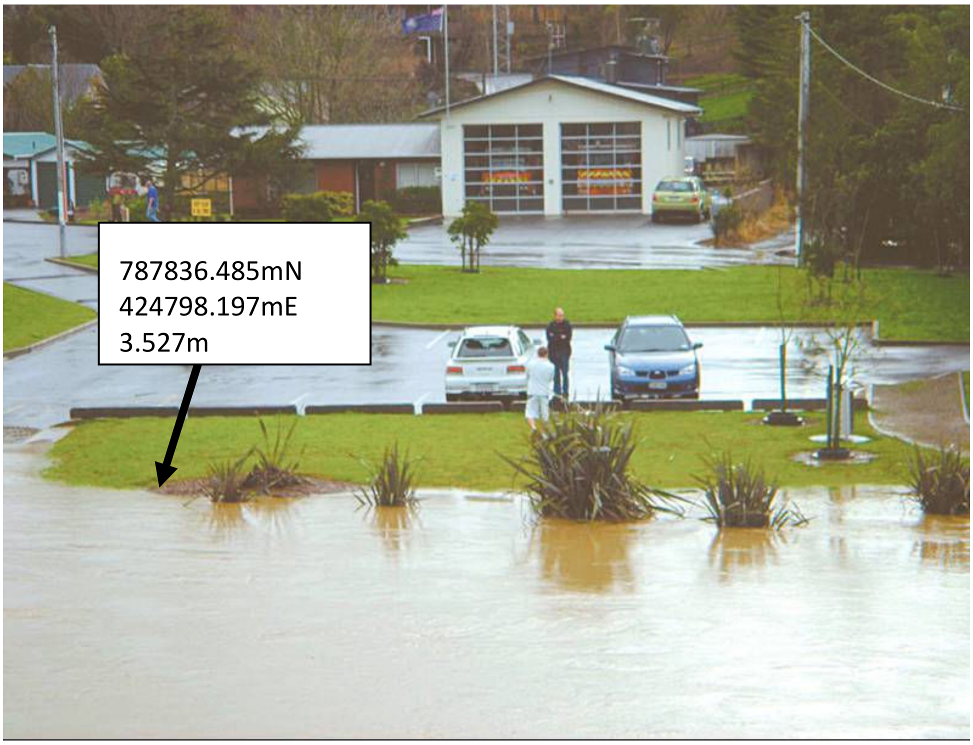


- **Date: 30/7/08**

Location: Polo Grounds (Clevedon - Kawakawa Road)

Source: Murray Helm

Location: Fire Station (Clevedon-Kawakawa Road (left hand side before McNichol Rd)

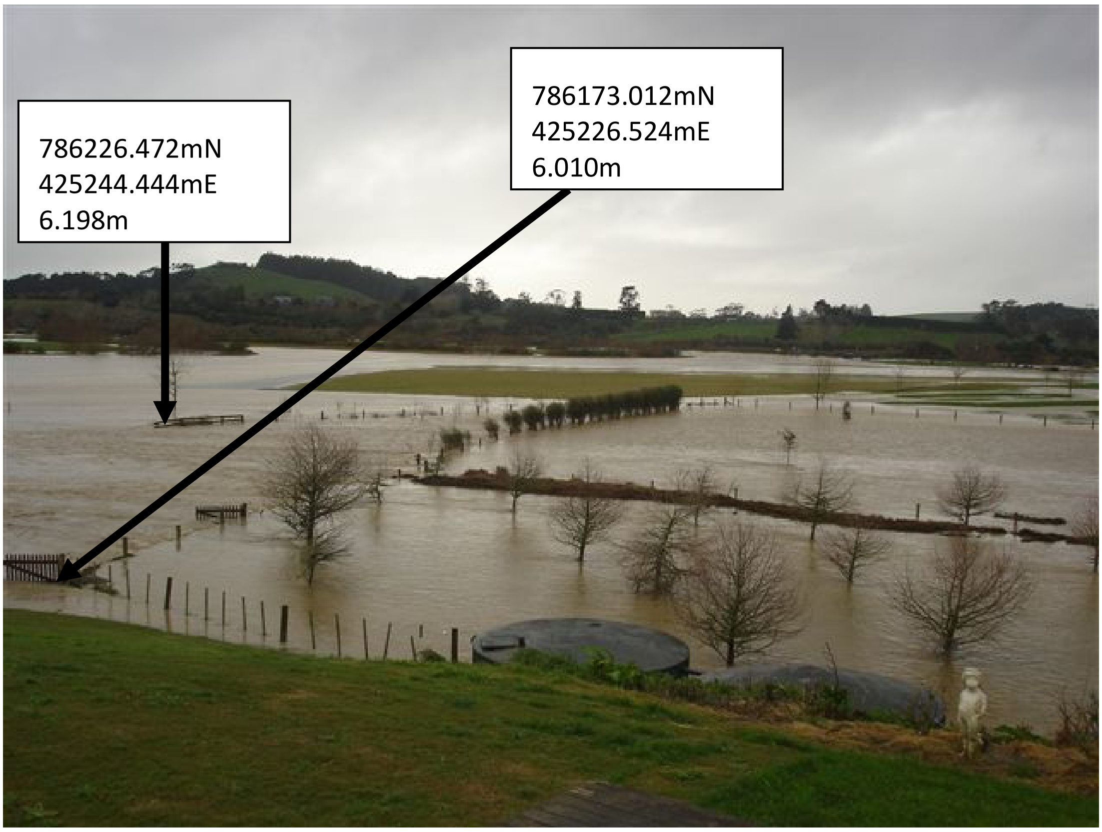


Source: Murray Helm

Location: Tourist Road

Source: Murray Helm

Location: 116 Monument Road



Source: Josephine Elworthy

Appendix H: Historical flood photographs

Location: Camp Sladdin

Source: Josh Page

Location: Camp Sladdin Footbridge

Source: Josh Page

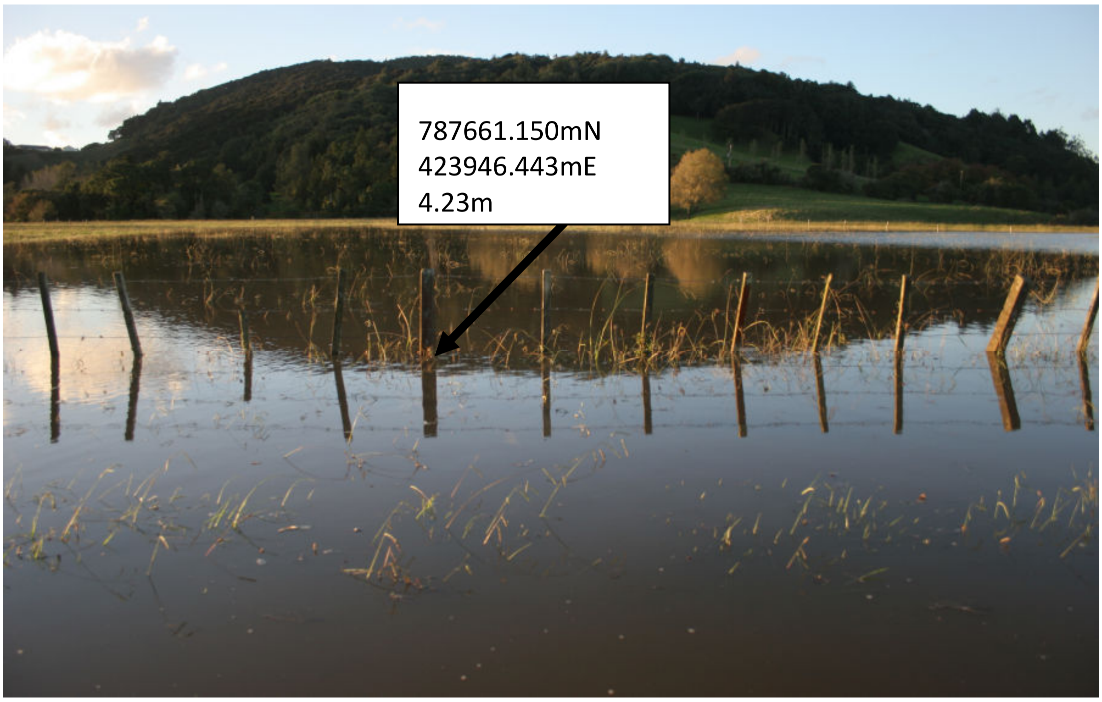
Source: Pohutakawa Coast Times

Location: Polo club on Clevedon – Kawakawa Road (just before cnr with Holdens Road)

Source: Josephine Elworthy

- **Date: 25/4/06**

Location: Twilight Road (Papakura – Clevedon Road end)



Source: Murray Helm

- **1/3/1966 All photographs sourced from local Historical Society**

Location: Wairoa River Flood Old Bridge

Location: approx Clevedon Hotel entrance

Location : Bridge on Kawakawa Bay Road below Homestead

Appendix I: Watercourse photographs

Location: intertidal area at downstream end of Wairoa River

Location: Wairoa River near Clevedon – Kawakawa Road Bridge

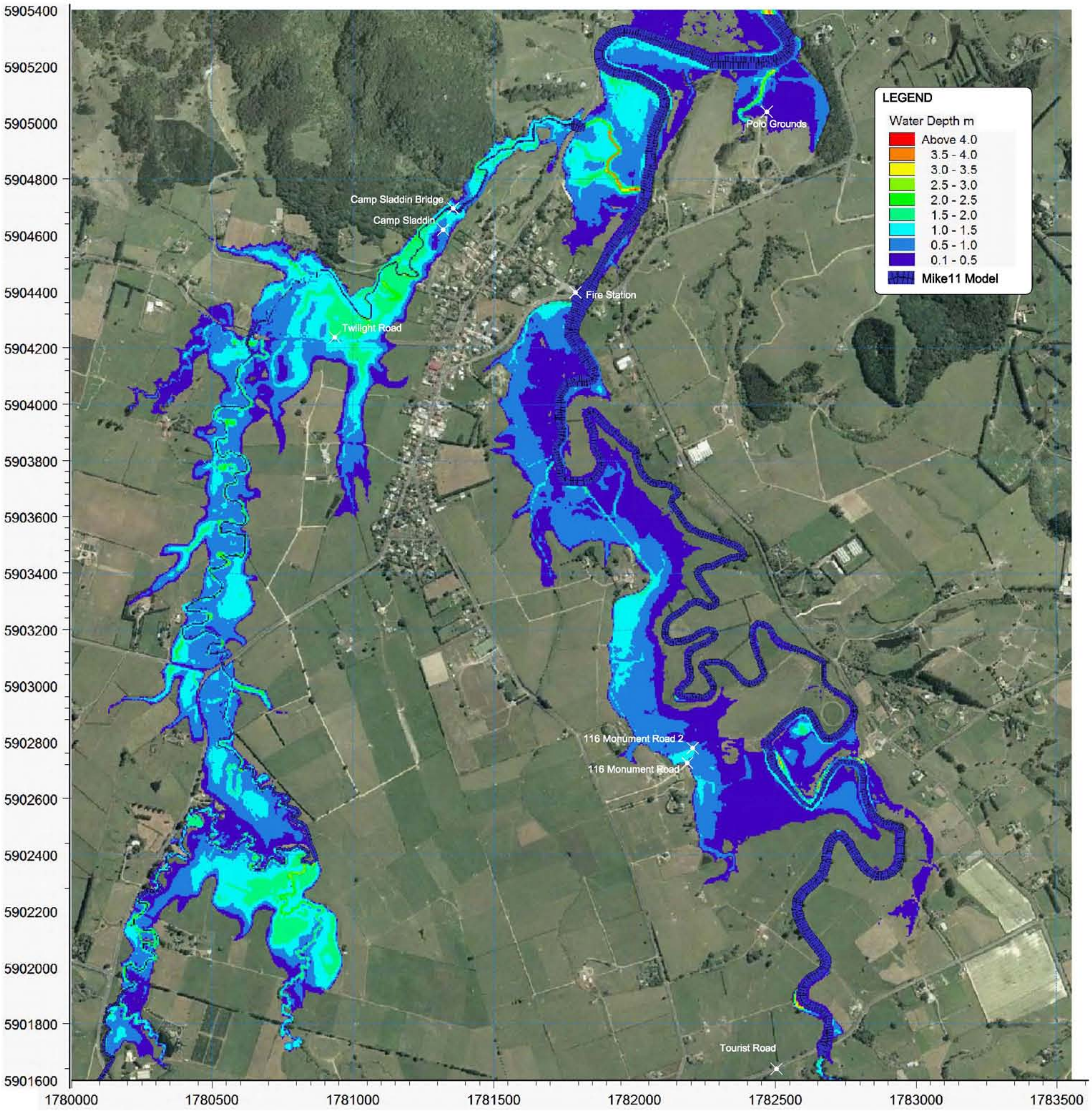
Location: Wairoa River near Tourist Road

Location: Taitaia Stream near confluence with Wairoa River

Location: Taitaia Stream near Camp Sladdin

Location: Taitaia Stream near Ryburns Culvert

Appendix J: Hydraulic model calibration results Storm of July 2008



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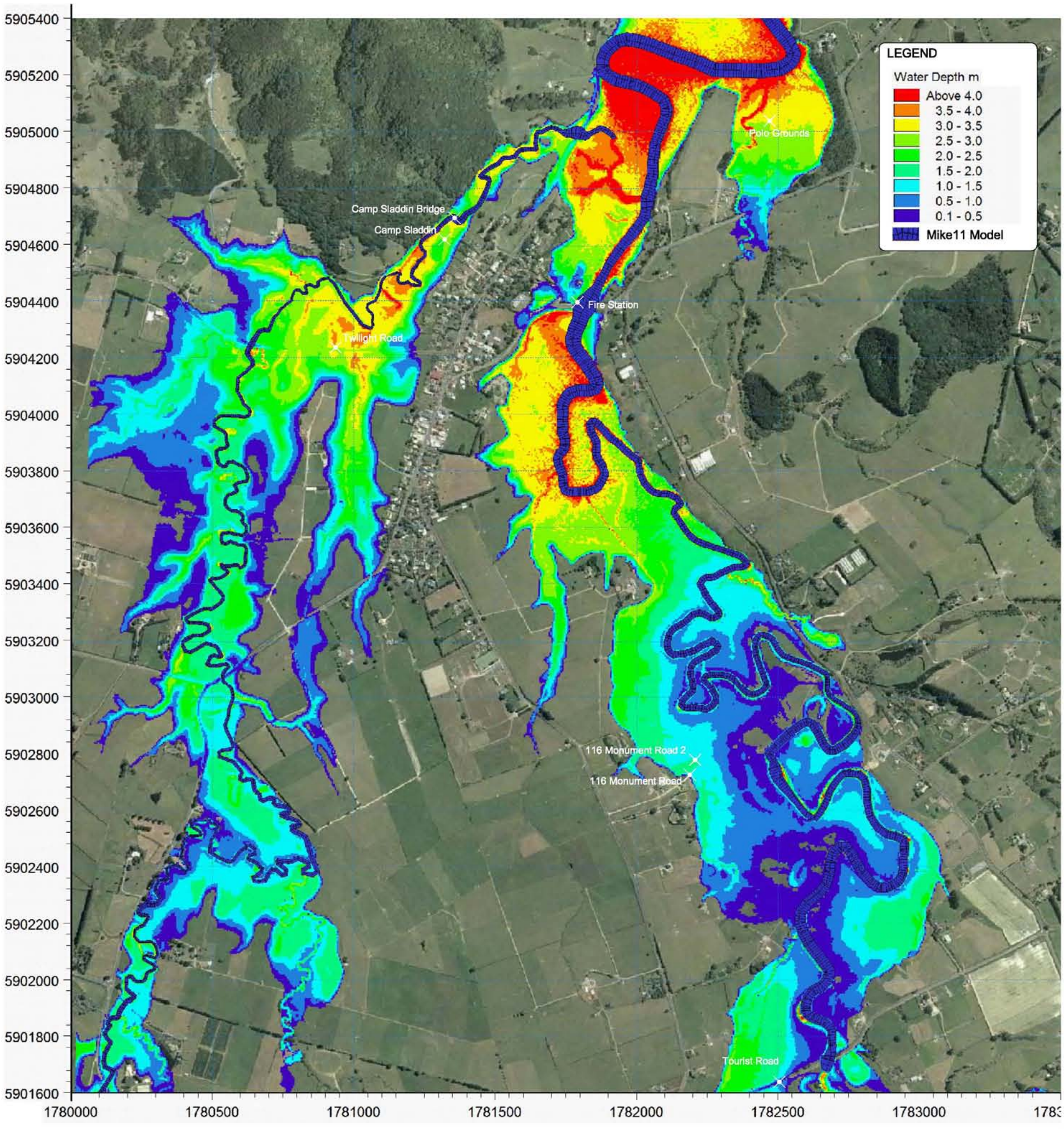
MANUKAU CITY COUNCIL
CLEVEDON FLOOD HAZARD MAPPING
CONTRACT NO. 4518
Storm Event 30 July 2008

FIG. No. Appendix J

REV. 0

**Appendix K:	100 year ARI Floodplain**



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CLEVEDON FLOOD HAZARD MAPPING
CONTRACT NO. 4518
100yr ARI Floodplain Water Depths

FIG. No. Appendix K.1

REV. 0

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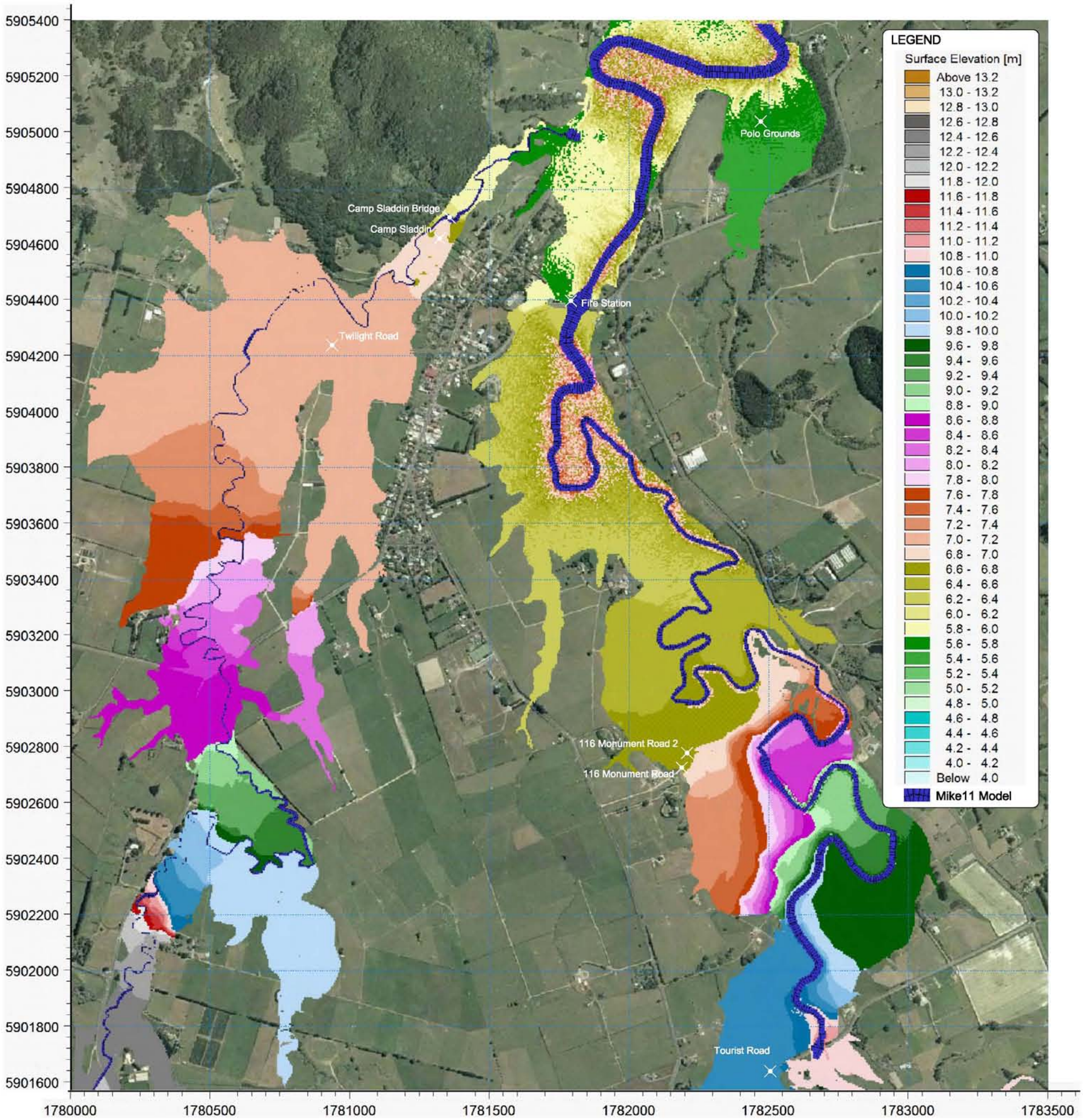

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CLEVEDON FLOOD HAZARD MAPPING
CONTRACT NO. 4518
100yr ARI Floodplain Water Levels

FIG. No. Appendix K.2

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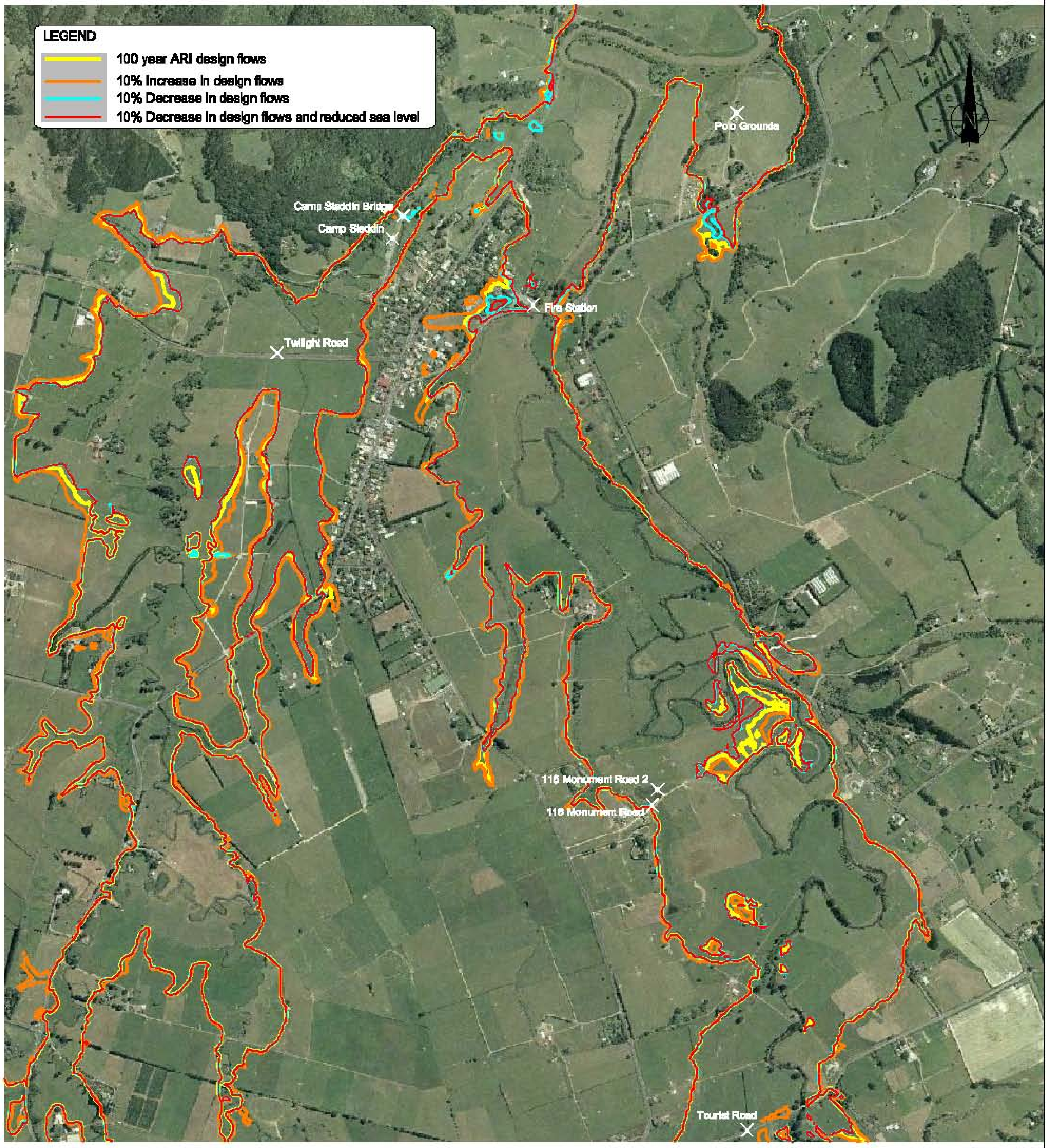
Appendix L: 100 year ARI Sensitivity Assessment



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PROJECT No. 27067.100		

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CLEVEDON FLOOD HAZARD MAPPING

CONTRACT NO. 4518

100yr ARI Floodplain Sensitivity Assessment

FIG. No. Appendix L

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