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Tongariro River flood protection scheme
Service level review

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Abstract

The Tongariro River Flood Protection Scheme was designed and constructed during 2004-2007. The intention of the scheme is to provide flood protection to Turangi to the design standard for floods in the Tongariro River up to a 1%AEP event. To ensure service level delivery the assets and works are monitored and surveyed and their performance assessed regularly. This study reassesses the service level based on review of the catchment hydrology, hydraulic modelling based on 2016 channel cross-sections, and comparison with 2014 asset crest survey data.

Executive summary

The Waikato Regional Council (WRC) manages the flood protection and river management assets (e.g. stopbanks, floodwalls, floodgates, rock revetments and associated river structures and works) along the Tongariro River. Together, these assets and works are designed to provide protection against floods up to a 1%AEP event. To ensure service level delivery the assets and works are monitored and surveyed and their performance assessed regularly.

The works incorporate some elements that were historically built and upgraded by the Taupo District Council while the majority of the flood defences (stopbanks and floodwalls) were designed and constructed during 2004-2007. This report provides a review of the service level afforded by the flood protection scheme within Turangi.

The key review findings include the following:

1. The scheme is delivering the intended service level of 1%AEP flood protection with an estimated flow of 1500m^3/s.

2. The stopbanks and floodwalls are above the level of service with regard to design flood levels.

3. A freeboard allowance is added to the design flood level to give a design crest level for the scheme assets. This is 300mm upstream of the State Highway 1 Bridge, and 500mm downstream. There are shortfalls in freeboard over approximately 190m in various parts of the scheme, primarily the Crescent Reserve Stopbank (133m) and upstream of the SH1 Bridge. These should be scheduled for survey and remediation. Remediation may take the form of asset works or gravel extraction/vegetation management and should employ the Design Waterway method devised by Tonkin + Taylor (2010).

4. The freeboard allowances of 300mm and 500mm are considered low given the dynamic nature of the river, i.e.: large sediment and debris load, high velocities, wave action and super-elevation effects on water levels. Whilst the hydraulic modelling has indicated locations where there are freeboard shortfalls, there is a large element of uncertainty associated with river dynamics during extreme flood events. Application of the Design Waterway method including gravel removal and management will provide for elements of the uncertainty, in particular the risk of deposition, and should be undertaken following this service level review.

5. The Awamate Stopbank is a remnant of earlier flood works. Construction of the Awamate Stopbank extension was never completed as part of the scheme due to landowner agreement issues. The modelling indicates that this area could be outflanked or overtopped during a 1%AEP event. This reach of the river below Turangi urban and the main flood protection scheme requires further investigation and consideration.

The following recommendations are made based on the findings of this service level review:

1. Undertake survey and schedule works as necessary to rectify shortfalls in freeboard within the flood protection scheme. This may take the form of asset works or gravel extraction / vegetation management.

2. Awamate Stopbank – survey and analysis required of existing embankment.

3. Further investigation required into the possibility of breakouts in the lower delta.

1 Introduction

1.1 Purpose

The purpose of this report is to undertake a service level review of the flood protection scheme assets on the Tongariro River at Turangi. The review includes reassessment of catchment hydrology and hydraulic modelling incorporating recent ground survey and LIDAR data. This information is used to determine if the flood protection scheme is meeting the agreed service level and identify any issues or areas where mitigation is required.

1.2 Background

The Lower Tongariro Flood Protection Scheme was initially designed on flood levels based on estimated flood flows routed through a 1-dimensional hydraulic model - Danish Hydraulic Institute's (DHI) MIKE11. This software is used widely in the industry and is currently used by WRC to determine design flood levels for its various flood protection schemes. The following provides a brief timeline of the Tongariro Scheme development:

- 1997 and 2001 – Tonkin + Taylor model (MIKE11) the lower Tongariro River.
- 2002 - WRC commission Tonkin + Taylor to undertake preliminary design, costing and assessment of environmental effects for the proposed scheme.
- September 2003 – resource consent applications submitted.
- October 2003 – Tonkin + Taylor commissioned to complete detailed design drawings.
- January 2004 – detailed design complete.
- 29 February 2004 – major flood ~Q_p1420m^{3}s.
- 2004 - Following the February flood some of the design flood control works were built under emergency works provision, and initiation of a comprehensive design review including resurvey/remodelling (MIKE11) in context of recent flood data.
- 2005-2008 - Construction of scheme works completed in stages.
- 2009 - Taupo District Council (TDC) and WRC commissioned OPUS International Consultants to develop a 2-dimensional (2D) hydraulic model using DHI's MIKE21 for the purposes of a larger Taupo District Flood Hazard Study (OPUS, 2009). The results indicated that some sections of the scheme assets would be overtopped suggesting that the scheme was not meeting its level of service, contrary to the modelling undertaken for the design works in 2004. This 2D model was reviewed in more detail in a secondary report (OPUS, 2011).
- 2009 - As an independent exercise WRC commissioned a new comprehensive cross-section survey of the river and updated the Tonkin + Taylor MIKE11 model.
- 2010 - Tonkin + Taylor (2010) model the hydraulic regime of the river under flood flows, and investigate the requirements for ongoing gravel extraction and vegetation management to maintain the design flood protection of the scheme.
- 2011 – Survey of additional cross-sections and full scheme asset crests.
- 2014 – WRC undertook a service level review with consideration of both the MIKE11 and MIKE21 models described above. In brief the two model types developed (MIKE11 and MIKE21) were adopted for two different purposes and provided varying results due to the different modelling techniques, each with its benefits and shortfalls. The study reassessed both models and compared the results against a 2011 scheme crest survey.

This 2017 service level review utilises a comprehensive cross-section survey of the main channel (September 2016) and utilises LIDAR data (October 2016) to assess the flood protection scheme and identify areas requiring remediation.

2 Flood protection scheme

The flood protection scheme is comprised of various components with an agreed service level equivalent to the 1%AEP design discharge. Freeboard allowances are 300mm upstream of the State Highway 1 Bridge and 500mm downstream. The scheme assets are shown in Figure 1 and described below:

Scheme assets upstream of State Highway 1 - Upstream of the State Highway to Kutai Street the left bank is protected by a variety of scheme assets including stopbanks, timber and concrete floodwalls, and natural high ground. These features are approximately 2250m in length and are listed from the downstream extent:

- SH1 Bridge to Te Aho Reserve Stopbank (564m)
- Natural high ground (140m)
- Te Aho Road to Poto Street Stopbank Section 1 (190m)
- Te Aho Road to Poto Street Floodwall Section 1 (71m)
- Te Aho Road to Poto Street Stopbank Section 2 (70m)
- Te Aho Road to Poto Street Floodwall Section 2 (27m)
- Te Aho Road to Poto Street Floodwall Section 3 (58m)
- Te Aho Road to Poto Street Stopbank Section 3 (40m)
- Te Aho Road to Poto Street Floodwall Section 4 (40m)
- Te Aho Road to Poto Street Stopbank Section 4 (124m)
- Te Aho Road to Poto Street Floodwall Section 5 (45m)
- DOC Access Stopbank (10m)
- Kokopu Street Concrete Wall (49m)
- Kokopu Street Floodwall (47m)
- Kokopu Street Stopbank (17m)
- Kokopu to Koura Street Floodwall (67m)
- Kokopu to Koura Street Stopbank (152m)
- Tahawai Street Timber Floodwall (28m)
- Tahawai Street Stopbank (510m)

Left bank scheme assets downstream of State Highway 1 - The left bank immediately downstream of SH1 is protected by the Bridge Lodge Stopbank (267m). At SH1 the stopbank ties into the bridge approach embankment, and at the downstream extent into high ground. Approximately 800m downstream of SH1 the Crescent Reserve Stopbank (135m) provides protection to the Tautahanga Road area. Further downstream a remnant of earlier flood works, the Awamate Stopbank, protects the Turangi sewerage treatment plant. The Awamate Stopbank was not upgraded as part of the scheme works in the early 2000's due to unresolved landowner and access issues.

Right bank scheme assets downstream of State Highway 1 – These assets form a defence between the right bank bridge approach and Grace Road protecting the Te Herekiekie Street and Tongariro Lodge areas. The stopbanks and floodwalls are approximately 1265m in length and from the bridge are:

- Grace Road to SH1 Section 3 Stopbank (286m)
- Herekiekie Street Timber Floodwall (33m)
- Grace Road to SH1 Section 2 Stopbank (401m)
- Tongariro Lodge Timber Floodwall (87m)
- Grace Road to SH1 Section 1 Stopbank (458m)

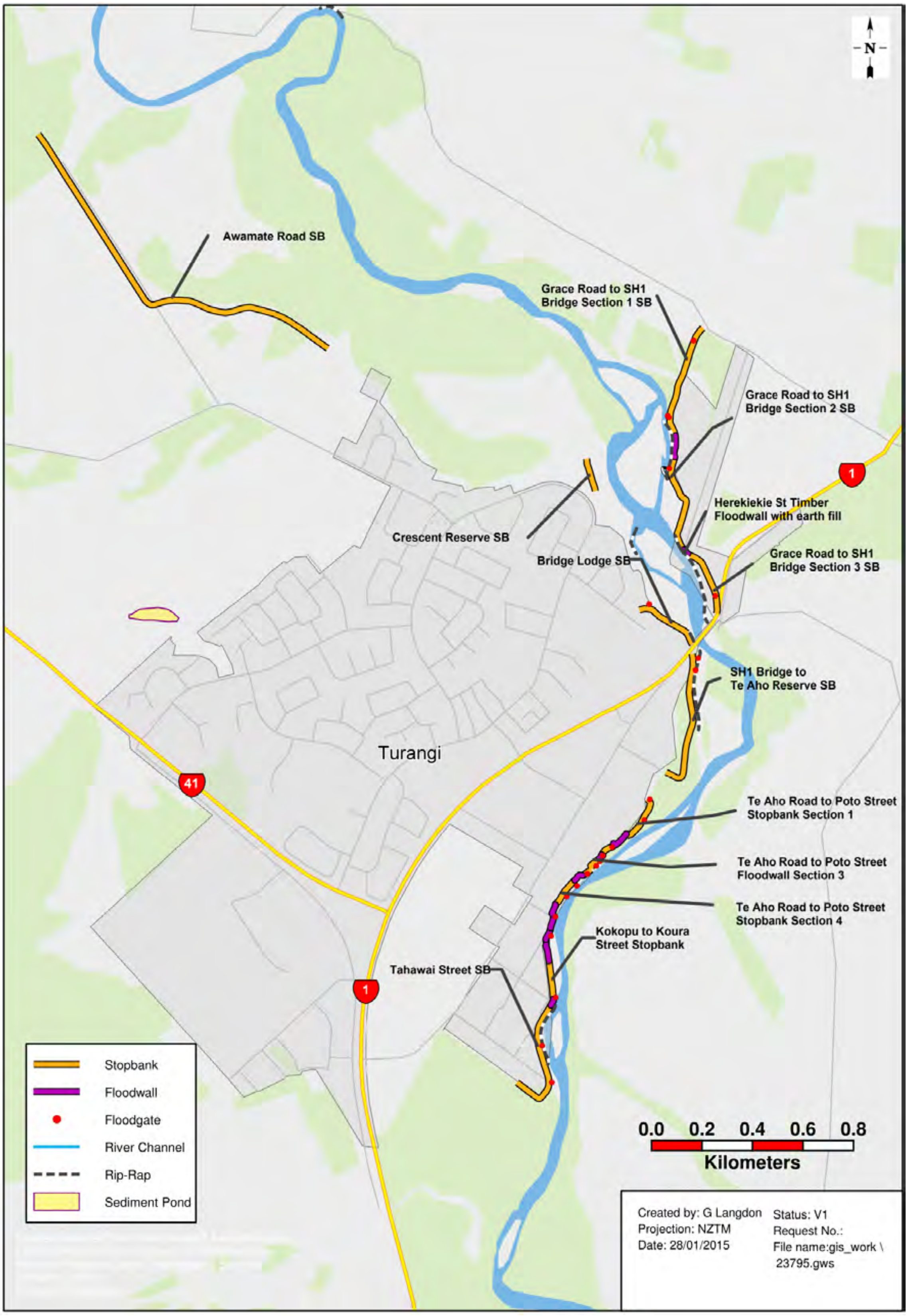

Figure 1 **Flood protection scheme assets along the Tongariro River at Turangi.**

3 Survey

3.1 LIDAR 2016

WRC commissioned AAM NZ Limited to capture a site specific LIDAR survey in the Taupo Zone, including both the Tauranga-Taupo and Tongariro Rivers. The LIDAR was captured on 10 and 17 October 2016 with the coverage shown in Figure 2.

The LIDAR has been used in the development of both 1-dimensional (1D) and 2-dimensional (2D) hydraulic models to assess flooding characteristics and the level of service provided by the flood protection scheme.

The data used in this study is in terms of Moturiki Vertical Datum 1953 (MVD-53) and the horizontal projection is New Zealand Transverse Mercator. Project specification for accuracy was vertical <=0.15m RMS, and horizontal 0.5m RMS. Accuracy estimates for terrain modelling refer to the terrain definition on clear ground. Ground definition in vegetated terrain may contain localised areas with systematic errors or outliers which fall outside this accuracy estimate. The definition of the ground may be less accurate in isolated pockets of dissimilar terrain/vegetation combinations.

3.2 Channel survey

WRC commissioned Discovery Marine Limited to undertake a channel cross-section survey captured 4-10 September 2016 (Discovery Marine, 2016). This includes 30 transects over a 6.25km reach adjacent to the flood protection scheme (Figure 8).

The cross-section data has been used to develop a 1D hydraulic model of this reach, and used to predict flood levels and assess the level of service provided by the scheme (Section 5.1).

The cross-section alignment is typically along that of earlier surveys which has also allowed analysis of changes in river cross-section and profile at these locations (Section 7).

3.3 Scheme asset crest survey

WRC commissioned a crest survey of the flood protection scheme assets which was undertaken in 2011 by Harrison and Grierson (Harrison Grierson, 2012). This provides a detailed profile of all the asset crests and any high ground between or adjacent to the scheme. This information has been used to improve hydraulic model detail and assess the service level provided by the scheme.

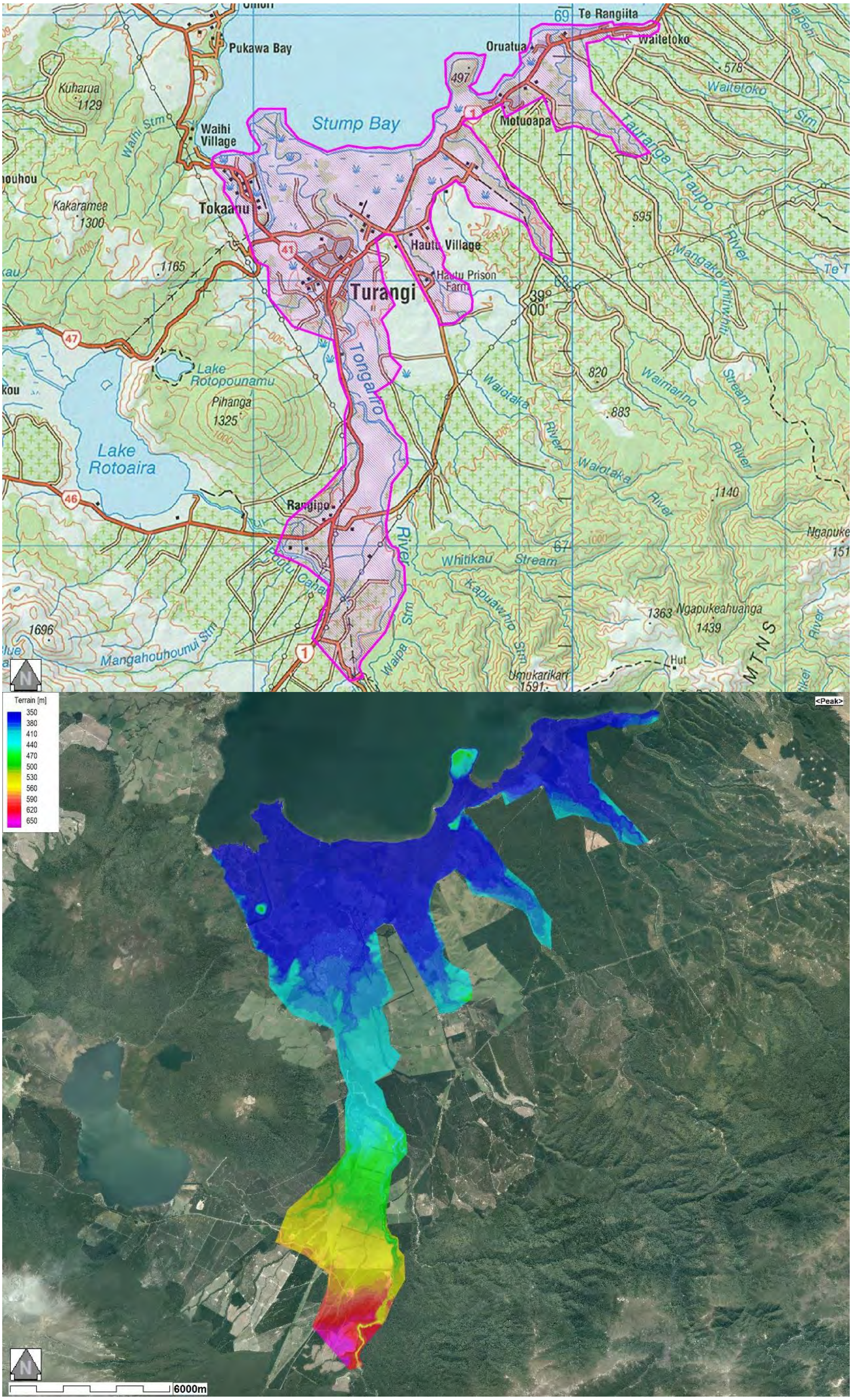

Figure 2 Extent of 2016 LIDAR coverage.

4 Hydrology

4.1 Flow record

Flows on the Tongariro River have been measured at the Turangi Cableway (NIWA gauge) since 1957 (Figure 3). The gauge site has an upstream catchment area of 772km^2 with no significant tributaries downstream.

The flow record provides a good dataset for undertaking flood frequency analyses and assessing flow hydrographs for the flood protection scheme. The flow data of almost 60 years is shown in Figure 4, with ranked annual maxima for the inclusive period 1957-2017 in Table 1, and the full annual maxima record in Table 2.

Figure 3 Location of Turangi Cableway.

Table 1 Ranked annual maxima of Turangi Cableway (NIWA gauge) for the period inclusive 1957-2016.

Rank	Year	Peak discharge (m^3/s)
1	1958	1470
2	2004	1439
3	1964	1038
4	1998	913
5	1986	810
6	1967	774
7	2015	748
8	2003	725
9	1995	718
10	2000	670

Table 2 **Annual maxima of Turangi Cableway (NIWA gauge) for the period inclusive 1957-2016.**

Year	Peak discharge (m^3/s)	Year	Peak discharge (m^3/s)	Year	Peak discharge (m^3/s)
1957	270	1978	441	1999	667
1958	1470	1979	321	2000	670
1959	257	1980	249	2001	504
1960	294	1981	148	2002	329
1961	287	1982	405	2003	725
1962	352	1983	211	2004	1439
1963	306	1984	166	2005	128
1964	1038	1985	254	2006	397
1965	563	1986	810	2007	202
1966	441	1987	272	2008	546
1967	774	1988	282	2009	398
1968	316	1989	494	2010	409
1969	310	1990	653	2011	665
1970	462	1991	417	2012	602
1971	391	1992	131	2013	657
1972	426	1993	436	2014	443
1973	229	1994	438	2015	748
1974	332	1995	718	2016	321
1975	255	1996	322	2017*	485*
1976	466	1997	309	*year 2017 incomplete to 1/11/2017	
1977	387	1998	913		

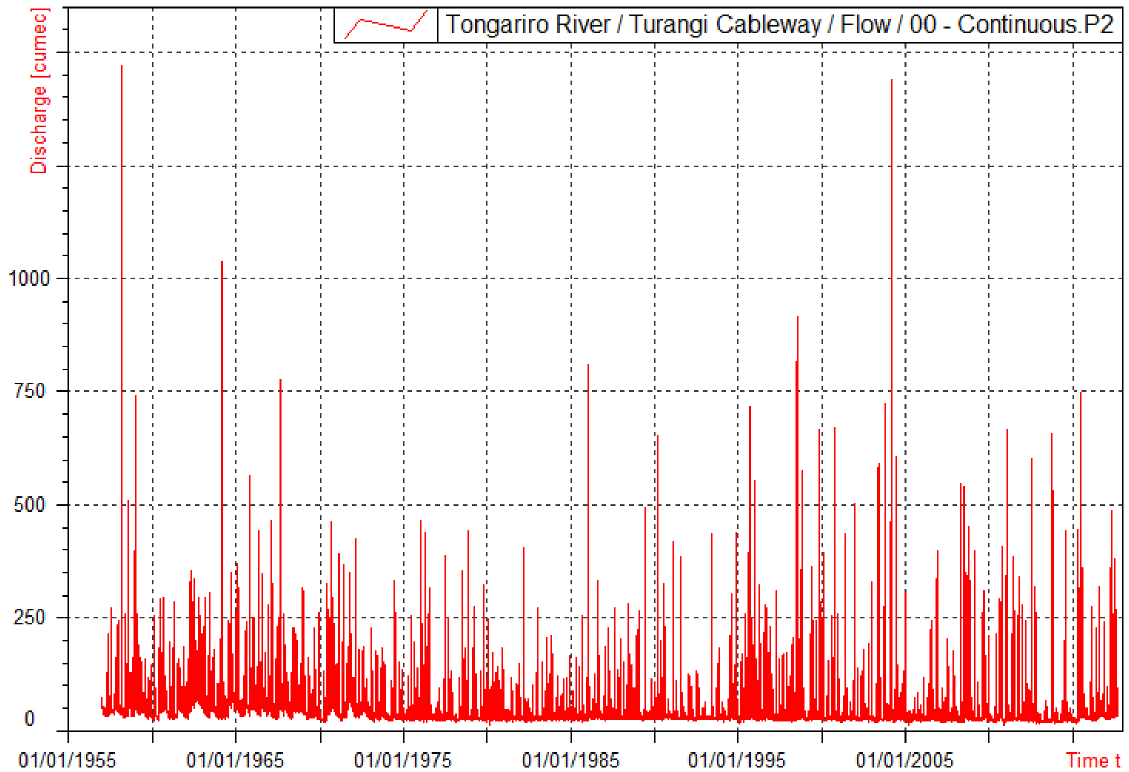

Figure 4 **Flow record for the Tongariro River at Turangi Cableway.**

4.2 Design discharge

Following the February 2004 flood Tonkin + Taylor (2004b) assessed the flow record including the 2004 peak discharge of 1420m^3/s. Various methods and techniques gave a range of estimates for the 1%AEP (Q100) between 1280m^3/s and 1700m^3/s. It was noted that given the length of record (48 years at the time) and nature of sample any extreme analysis is subject to error. The record length would give an estimate of the Q100 with an error of up to +/-25%, and even a 115 year record would give a +/-10% error. Any estimate will have confidence limits and Tonkin + Taylor indicated that the standard error is about 200m^3/s at the Q100. Recommendations included a Q100 of 1500m^3/s, and given the range and standard error in the analyses, scheme freeboard should allow for 1700m^3/s without overtopping.

Opus (2011) assessed the flow record as part of a flood hazard study for the Tongariro River. A flood frequency analysis using a PE3 statistical distribution was used to analyse two periods, 1957-2005 and 1957-2010, giving Q100's of 1534m^3/s and 1451m^3/s respectively. The later period being lower as no significant events had occurred since the 2004 event up to 2010.

As part of this investigation a further flood frequency analysis has been undertaken including the additional 7 years of data to 2017 (Table 2). L-moments suggest the best distribution to use for the dataset is GEV, which has been adopted and compared with the Gumbel and PE3 distributions in Table 3. Estimates have also been provided for both the Q200 and Q500 but given the 60 year dataset, extrapolation to these intervals is not considered appropriate.

Table 3 Flood frequency analysis for Tongariro River at Turangi (1957-2017).

Event	Annual recurrence interval (ARI years)	Annual exceedance probability (%AEP)	Distribution		
			Gumbel	PE3	GEV
Q2	2	50%	464	432	**433**
Q5	5	20%	646	636	**612**
Q10	10	10%	793	815	**783**
Q20	20	5%	935	992	**972**
Q50	50	2%	1118	1222	**1258**
Q100	100	1%	1255	1394	**1508**
Q200*	200*	0.5%*	1391*	1566*	**1793***
Q500*	500*	0.2%*	1572*	1792*	**2230***

**Given length of data set at 60 years extrapolation to these intervals is not considered appropriate.*

The GEV estimate for the Q100 of 1508m^3/s is very similar to that of the scheme design at 1500m^3/s. With consideration of the above, the scheme design Q100 peak flow estimate of 1500m^3/s has been retained for this service level review. Similarly the allowance for uncertainty in the Q100 design discharge (1700m^3/s) has also been modelled to check if it is contained within the freeboard.

An additional model run of 1800m^3/s has been tested in the model as the Q100 climate change event. This closely approximates the Opus (2011) estimate and adopts the same approach (Q100x1.2). The method assumes an increase in rainfall as a result of climate change will produce and equal and corresponding increase in runoff, which likely gives a conservative estimate of runoff.

MfE (2010) gives a percentage adjustment per 1°C warming to apply to extreme rainfall which is 8% at the Q100 for all storm durations. For the Waikato Region the expected changes in annual mean temperature for 2090 from the five IPCC scenarios were on average 2.1°C (range 1.4-3.0°C) with lower and upper limits in the range 0.6-5.5 °C.

MfE (2016) updated the temperature increase for various 'representative concentration pathway's (RCP's) of increasing radiative forcing by greenhouse gases. The projected changes in annual mean temperature for the Waikato Region at 2090 for the various RCP's are 0.7-3.1°C, and to 2100 0.7-3.8°C. Mid-range values for these future dates are 1.8 and 1.9°C.

The Q100 has been increased for climate change as described above, compared against MfE (2010) at 2.1°C to 2090 gives 16.8%, and MfE (2016) at 8% per 1°C to 2090 gives 5.6-24.8%, and to 2100 gives 5.6-30.4%.

Ideally a hydrological model would be developed which gives a present day Q100 hydrograph and peak discharge close to that derived from the flood frequency analysis. The hydrological model could then be reassessed with the future rainfall intensities to give climate change hydrographs and peak flows. At present there is insufficient scope for this work, and the design events described above are to be modelled as detailed in Table 4.

Table 4 Peak discharge for various design events.

Design event	Peak discharge (m^3/s)
100 year ARI (1%AEP) present day	1500 (Q_p1500)
100 year ARI (1%AEP) with allowance for uncertainty	1700 (Q_p1700)
100 year ARI (1%AEP) with allowance for climate change	1800 (Q_p1800)

4.3 Design hydrograph

The hydrographs for various historical events were considered in order to determine a design hydrograph for use in the hydraulic modelling.

Hydrograph shape for the 7 highest ranked events in Table 1 have been peak centred for comparison and shown in Figure 5. The 7 events are all events above approximately a Q10 event, and also includes the recent 2015 event for which there is some peak flood level data for model calibration purposes.

The ranked annual maxima (Table 1) show two large historical events which are close to the Q100 design event, 1958 and 2004 at 1470m^3/s and 1439m^3/s respectively. The 2004 hydrograph shape was used previously as the design event, it has a similar main peak shape to the 1958 event, but the 1958 event has spot readings whilst the 2004 has good telemetry data. For the purposes of this service level review, the 2004 event hydrograph has been smoothed and adjusted in the vertical to the required design discharge (Figure 6).

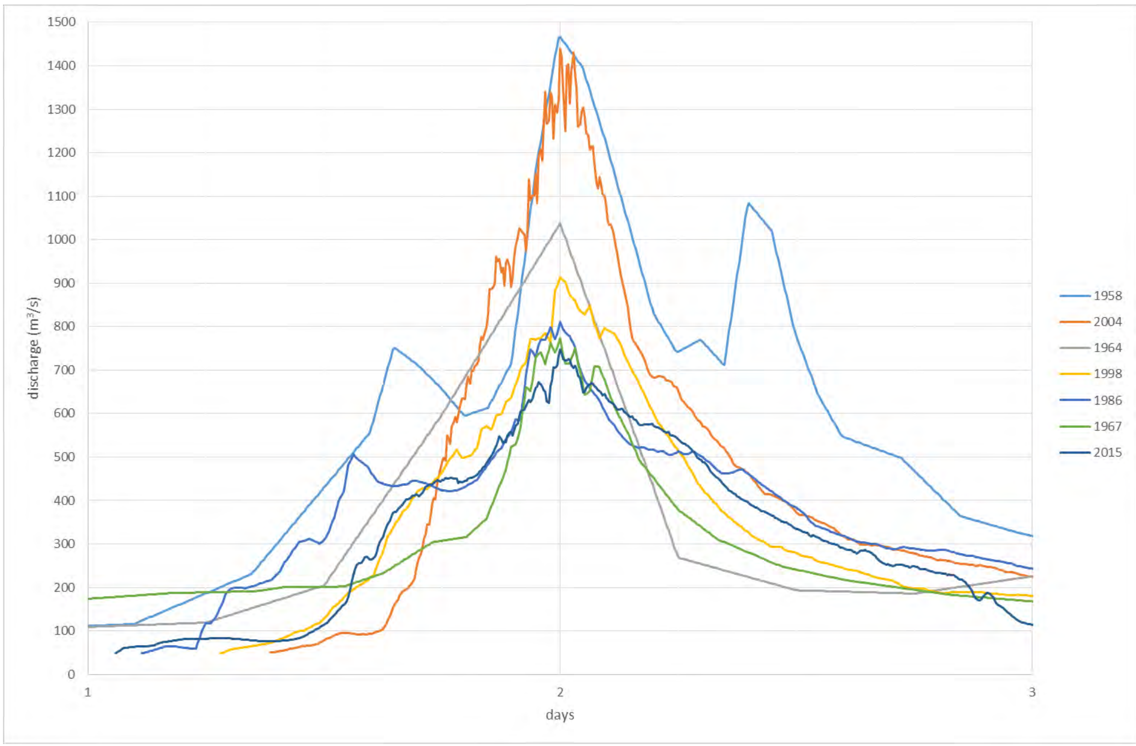

Figure 5 **Peak centered flood hydrographs for the 7 largest events on record for the Turangi Cableway (NIWA gauge).**

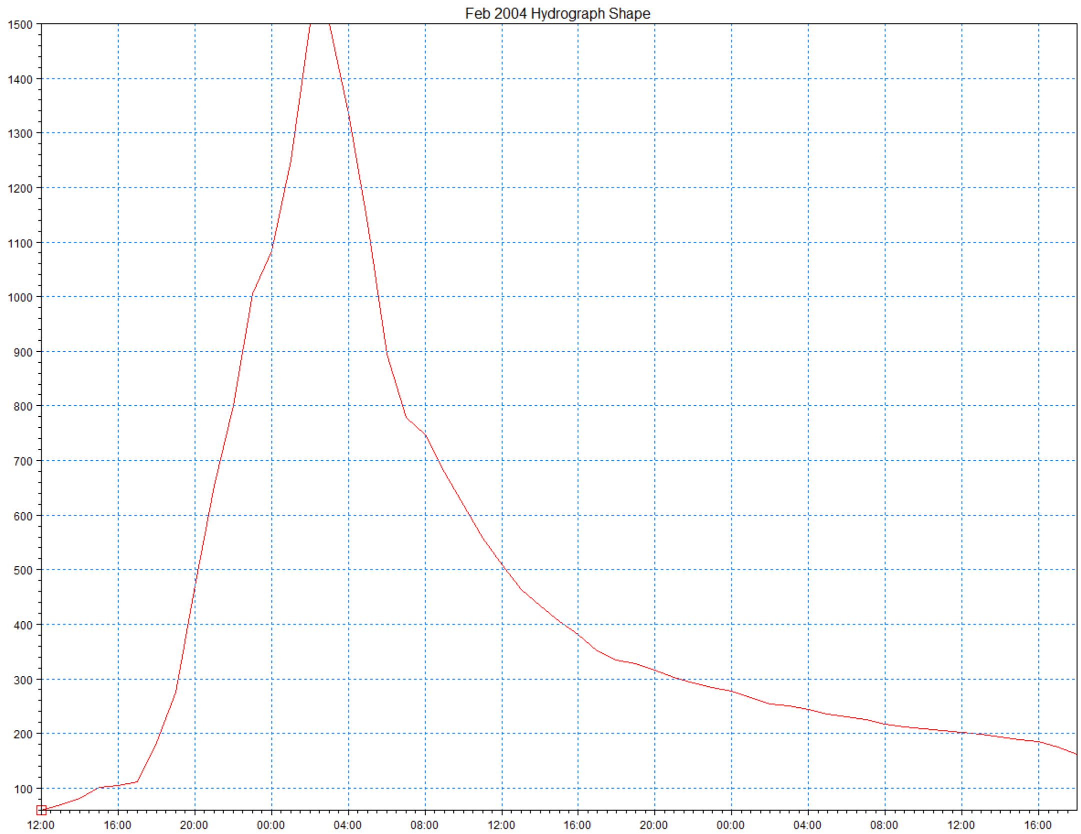

Figure 6 **Design hydrograph shape used in hydraulic modelling - derived from smoothed 2004 event data and adjusted in the vertical to required design discharge.**

4.4 Lake levels

The Acacia Bay record dating back to 1905 indicates an average lake level of RL 356.72m. Opus (2011) provides lake levels for various events including:

- Q2.33 RL357.17
- Q100 RL357.50
- Q100 RL357.79 (static water level including climate change and seiche effect)

For this study lake levels during design events have typically been modelled at RL 357.0m, with the exception of the Q100 climate change event run at RL 357.8m. A level of RL 357.0m for the current climate Q100 design event is considered reasonable given the joint probability of both high lake and flood flows occurring simultaneously is well in excess of 100 years. It is also noted that the effect of lake levels on the flood protection assets is insignificant given the fall in elevation between the lower assets and the lake. However, increased lake levels have a significant impact on flood inundation in the lower river delta and Tokaanu Tailrace area. The inundation between various lake levels is shown in Figure 7.

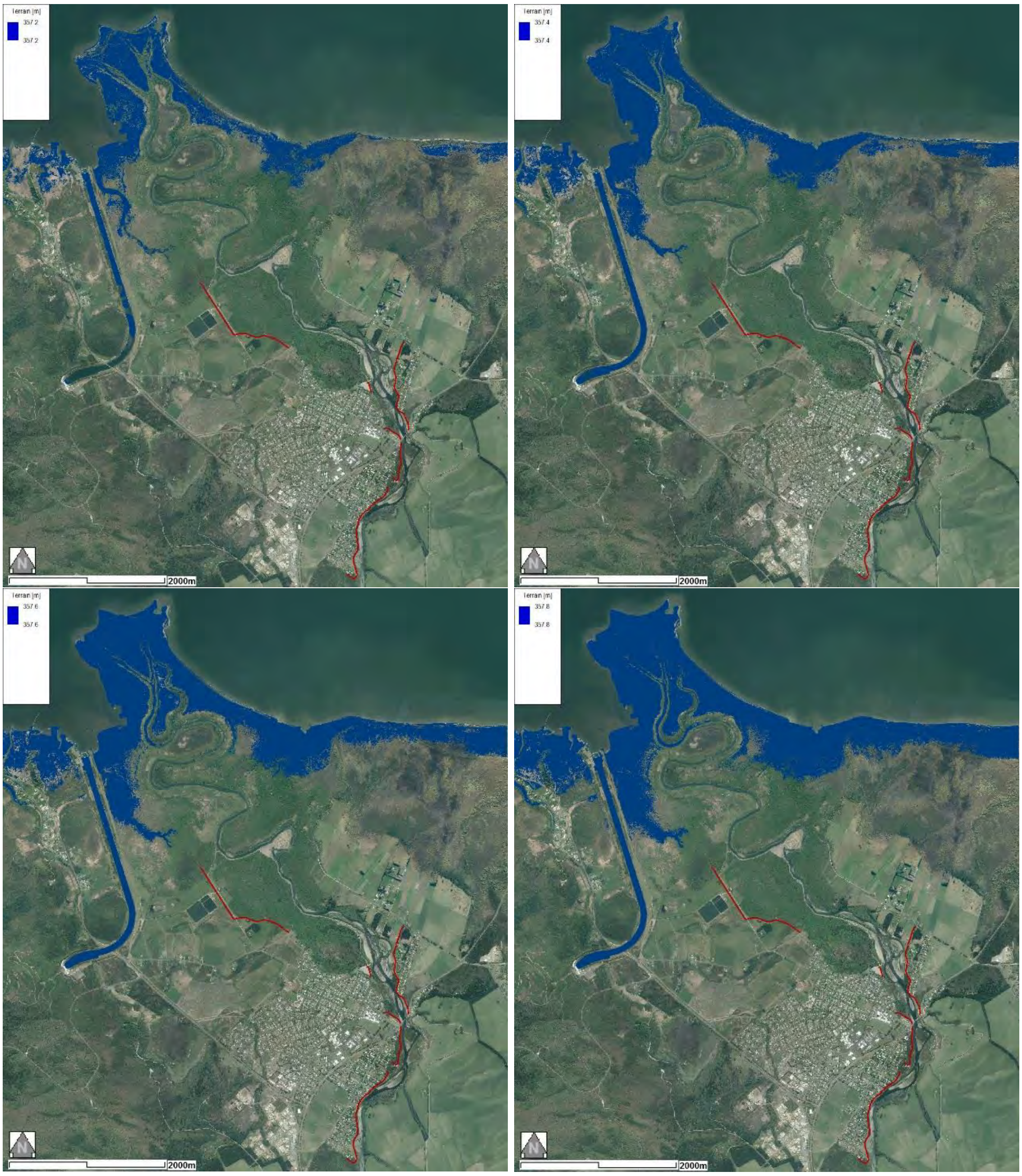

Figure 7 Lake water level inundation on 2016 LIDAR surface at RL 357.2m, 357.4m, 357.6m and 357.8m.

5 Hydraulics

Hydraulic models have been developed to provide estimates of flood characteristics and assess the service level delivered by the flood protection scheme. Two types of model have been configured, MIKE11 (1D) and MIKE21 (2D) developed by the Danish Hydraulic Institute (DHI).

The possibility of a coupled MIKEFLOOD model was investigated, in which the main channel is represented by the 1D component, and the floodplain by the 2D component. Whilst feasible the upper river upper above SH1 is relatively contained primarily within a single channel (asset crest on the left bank, to high ground on the right bank) and would be fully represented by the 1D component apart from any asset overtopping flow paths. Downstream of SH1 a coupled model may have been of use, at least to the lower extent of the scheme assets, but downstream of this point there is limited cross-section data to incorporate this technique through the lower reaches and delta. The original scheme design and indeed the majority of scheme assets within the Waikato Region have all been successfully designed, assessed and flood verified with 1D models. This gives good confidence in using MIKE11 in this service level review. In any case both 1D and 2D models have been developed in a similar manner attempting to calibrate the models to the recent 2015 event.

5.1 MIKE11 model

A MIKE11 1D model has been developed for the relevant reach of river proximal to the flood protection scheme and Turangi urban area.

5.1.1 MIKE11 model development

5.1.1.1 Model network domain and datum

The MIKE11 model network (Figure 8) covers a river reach of 6.25km between surveyed cross-sections. The model domain extends from a southwest origin at NZTM 1839000 5678000 to a northeast corner at NZTM 1845500 5687500 (6.5km x 9.5km). This is a similar domain to the MIKE21 model described in Section 5.2, although the MIKE21 model extends a further 2km south. The model vertical datum is as per the 2016 LIDAR and cross-section survey, and 2011 scheme asset survey, being MVD-53.

5.1.1.2 Model cross-sections

The river cross-sections were surveyed 4-10 September 2016 by Discovery Marine Limited (2016) and include 30 transects over a 6.25km reach (Figure 8). The cross-sections are typically bank-to-bank including any asset crest or to high ground. In wider parts of the floodplain or in heavier vegetation the full extent of the cross-section has not always been surveyed and in this case LIDAR has been used to extend/supplement the data in the model.

Model cross-sections were set to Radius Type – Resistance Radius. Transversal distribution of Manning's 'n' values was either set to high/low flow zones or varied dependent on the number of river channels and vegetation types through the cross-section. Manning's 'n' values were typically 0.030 in-channel and dependent on vegetation type/density were assigned various values (approximately 0.04, 0.05, 0.06, 0.07, 0.08).

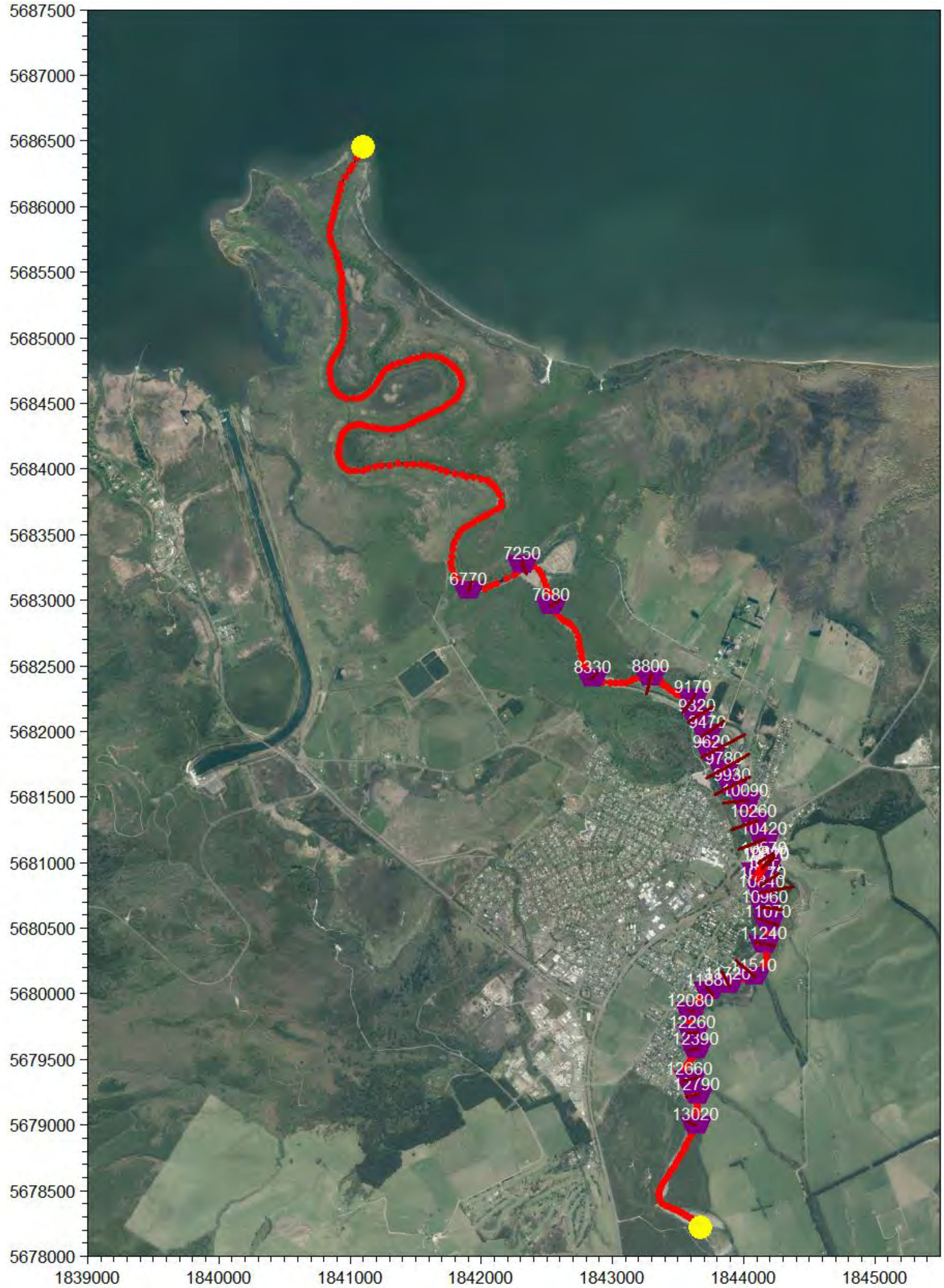

Figure 8 **MIKE11 network showing location of various cross-sections.**

5.1.1.3 Model representation of SH1 Bridge

The SH1 Bridge has been included in the model using the FHWA WSPRO method with allowance for submergence, overflow, piers and blockage. The bridge is modelled to have a waterway length of 10m, an assumed soffit level at RL 373.5m, and piers/debris forming 20% blockage of the waterway opening. The model includes an overtopping height above the handrail assumed to be RL 376.0m, although this level is not reached in the design events modelled given the left bank overflow described below.

On the left bank immediately upstream of the bridge, the scheme asset 'Te Aho Reserve SH1 Bridge Stopbank' ties into the bridge approach. This asset has a design standard with freeboard (1%AEP + 300mm) but in events exceeding this standard the left bank can be overtopped and provide some relief on the bridge structure. Overtopping of this asset can result in ponding in the low terrain between the asset and SH1 (minimum ground levels approx. RL 372.0m), and SH1 will overtop at approximately RL 373.2m. Any overtopping of SH1 at this left bank approach will enter the Bridge Lodge area and be bound by low ground between SH1 and the downstream stopbank (Bridge Lodge Stopbank). The model includes allowance for this overtopping of the upstream asset and any flows are redirected to the main channel immediately downstream of the bridge. Whilst not strictly correct this method is conservative as it still allows for the full flow in-channel as it passes the assets downstream of the bridge.

5.1.1.4 Model representation of scheme asset crests

Cross-sections adjacent to any of the flood protection scheme assets have typically been surveyed to the asset crest where appropriate markers have been placed at the crest. If this is not the case, cross-sections have been supplemented with asset crest survey data or LIDAR data to high ground. Comparison between modelled flood levels and the entire asset crest length is described in more detail in the model results (Section 5.1.2).

5.1.1.5 MIKE11 model boundaries

Inflow hydrographs were applied at the upstream extent of the model at the Waikare Scenic Reserve approximately 1km upstream of the upper flood protection scheme. The hydrographs used for each of the design events and the recent 2015 flood event have been described in Section 4.

Lake boundaries relevant to the scenario were applied as described in Section 4.4. For the reach between the surveyed cross-sections and adjacent to the scheme assets, the effects of lake level has no influence on predicted flood levels. This is due to the hydraulic grade between these locations.

5.1.1.6 Other MIKE11 model variables

Within the HD file, default values were used except:

- Wave approximation was set to Higher Order Fully Dynamic
- Computation scheme delta value set to 0.6.

5.1.2 MIKE11 model results

5.1.2.1 Modelling June 2015 event

The 20 June 2015 event is estimated to be approximately a Q9 event peaking at 748m^3/s. Peak flood level data is available for this event for calibration purposes. Information for larger and earlier events is considered outdated when comparing river channel data in this dynamic system.

Modelling of the June 2015 event was undertaken using the recorded hydrograph from the event, acknowledging that the event precedes the channel survey by more than a year. Model results have been compared with the peak flood level data recorded in the field (Table 5). Whilst the flood data is limited, the model results indicate predictions typically within +/- 0.2-0.4m of observed levels during the 2015 event with the exception being XS7 (Te Herekiekie Street) giving an over-prediction of 0.76m. Whilst not an extensive calibration it gives a degree of confidence in the model results for an event of this magnitude (Q9) with an average of +80mm between actual and modelled flood levels.

5.1.2.2 Modelling of design events

The design events detailed in Table 4 were run through the MIKE11 model. Water levels for each of the design events were extracted at each of the model cross-section locations (Table 6). In order to obtain flood levels at any location within the model reach (i.e.: adjacent to all asset survey points and WRC scheme asset 'embankment points'), the model results have been taken into the software WaterRIDE and a flood surface interpolated between cross-sections. A raster dataset was then generated and flood levels extracted at locations relevant to the assets.

The modelled flood profiles adjacent to the assets have been compared in Figure 9 to Figure 12 and detailed in Table 10 to Table 13 of Appendix A.

The results indicate that the service level of the flood protection scheme is largely met (i.e.: 1%AEP modelled flood levels are below the asset crest) although there are shortfalls in freeboard. Freeboard requirements are 300mm upstream of the SH1 Bridge, and 500mm downstream. Areas with a shortfall in freeboard include approximately 190m, and should be resurveyed and scheduled for remediation if required:

- 40-140mm over 50m in the 70m upstream of SH1 Bridge.
- 40mm over 3-4m between Tongariro Lodge Timber Floodwall and downstream Grace Road to SH1 Section 1 Stopbank.
- 50-450mm over the length (133m) of the Crescent Reserve Stopbank. Some earthworks and stockpiling has occurred around this bank since the asset crest survey in 2011 and levels may have been altered, although 2016 LIDAR levels are fairly close to 2011 levels.

Modelling of the Q_p1700 (allowance for uncertainty in the 1%AEP) confirms that flood levels for this event are typically within the freeboard. Downstream of SH1 the Q_p1700 is well within the 500mm freeboard, whilst upstream of the bridge the Q_p1700 closely approximates the freeboard of 300mm. The exception to this is upstream of the SH1 Bridge given the way the bridge has been modelled as described below.

Modelling of the SH1 Bridge includes an allowance for 20% waterway opening loss for blockage by piers and debris. In the modelled events of Q_p1700 and Q_p1800, which are greater the scheme design standard, the modelling indicates that floodwater levels reach the bridge soffit. This generates a backwater effect modelled as greater than the freeboard allowance and results in overtopping of the left bank asset upstream of the bridge (Figure 9). Left bank overtopping peak discharges in each of the over-design events were: Q_p1700 – $68m^3/s$ and Q_p1800 – $93m^3/s$. As described in Section 5.1.1.3 this can result in flooding and ponding between the assets and SH1 in areas which contain residential and commercial property.

Further downstream the Awamate Road Stopbank extension is incomplete since the development of the flood protection scheme due to landowner agreement issues. Similarly access issues prevented survey during the 2011 scheme asset survey. The modelling in the lower river utilises LIDAR to extend the model cross-sections and suggests that the Awamate Stopbank could possibly be overtopped or outflanked in a Q_p1500 event. This reach of the river below Turangi urban and the main flood protection scheme requires further investigation and consideration as previous studies also suggest the possibility of a breakout towards the Tokaanu Tailrace along this reach i.e.: Smart (2005, 2011), Tonkin + Taylor (2016).

Table 5 Comparison of modelled (MIKE11) and recorded peak flood levels at various locations for the June 2015 event.

XS ID, bank and chainage	Location	Crest level (RL m)	Height - WL below crest (m)	Estimated WL (RL m)	Modelled MIKE11 WL (RL m)	Difference (m)
XSZ LB (ch.8330)	Awamate Road bank	364.8*	n/a	364.5*	364.17	-0.33
XS4 RB (ch.9780)	Tongariro Lodge	368.60	1.70	366.91	367.33	0.42
XS5 RB (ch.9930)	Tongariro Lodge	369.70	2.44	367.27	368.03	0.76
XS7 RB (ch.10260)	Herekiekie Street	371.35	1.49	369.86	369.48	-0.38
XS21 LB (ch.12390)	Swing Bridge	381.90	2.21	379.69	379.47	-0.22
XS23 LB (ch.12790)	Kutai Street	373.70	2.46	381.25	381.48	0.23

*Observations at low point in Awamate bank crest where access track off Hirangi Road heads northeast to meet bank.

Table 6 MIKE11 model water levels at cross-section locations for various events.

Cross-section ID	Cross-section ch. (m)	Location	Modelled water level (m)			
			June 2015 flood event (Q_p748)	100y ARI design event (Q_p1500)	100y ARI uncertainty (Q_p1700)	100y ARI climate change (Q_p1800)
W	6770	Downs Pool	363.00	363.95	364.17	364.27
X	7250	DS DeLatours	363.05	364.01	364.23	364.33
Y	7680	US DeLatours	363.20	364.14	364.35	364.46
Z	8330		364.17	365.11	365.28	365.37
1	8800		365.05	365.97	366.15	366.24
2	9170		365.86	366.75	366.93	367.02
2A	9320		366.25	367.11	367.29	367.37
2B	9470	DS scheme	366.41	367.29	367.48	367.56
3A	9620	Tongariro Lodge	366.72	367.53	367.70	367.78
4	9780	Tongariro Lodge	367.33	367.99	368.13	368.20
5	9930	Tongariro Lodge	368.03	368.66	368.80	368.86
6	10090		368.72	369.50	369.66	369.74
7	10260	Te Herekiekie St	369.48	370.42	370.60	370.69
8	10420		370.47	371.46	371.66	371.76
9A	10570	Bridge Lodge	371.11	372.06	372.35	372.37
n/a	10610	DS Bridge	371.21	372.21	372.45	372.50
10	10620	US Bridge	371.88	373.39	374.52	374.68
11	10770	Lower 'island'	372.15	373.74	374.78	374.94
12	10840	Mid 'island'	372.18	373.86	374.88	375.06
13	10960	Upper 'island'	372.77	374.03	374.89	375.06
14	11070	US 'island'	373.44	374.48	375.07	375.23
15	11240	Te Aho Rd	374.36	375.31	375.63	375.75
16	11510	Taupahi Reserve	375.91	376.86	377.07	377.18
17	11720		376.99	377.99	378.21	378.31
18	11880		377.67	378.83	379.09	379.19
19	12080	Poto St	378.31	379.85	380.15	380.28
20	12260	Kokopu - Koura St	379.00	380.60	380.91	381.05
21	12390	Swing Bridge	379.47	381.12	381.46	381.61
22	12660	Tahawai St	380.80	382.24	382.54	382.68
23	12790	Kutai St	381.48	382.85	383.15	383.29
24	13020	US scheme	382.73	384.16	384.47	384.61

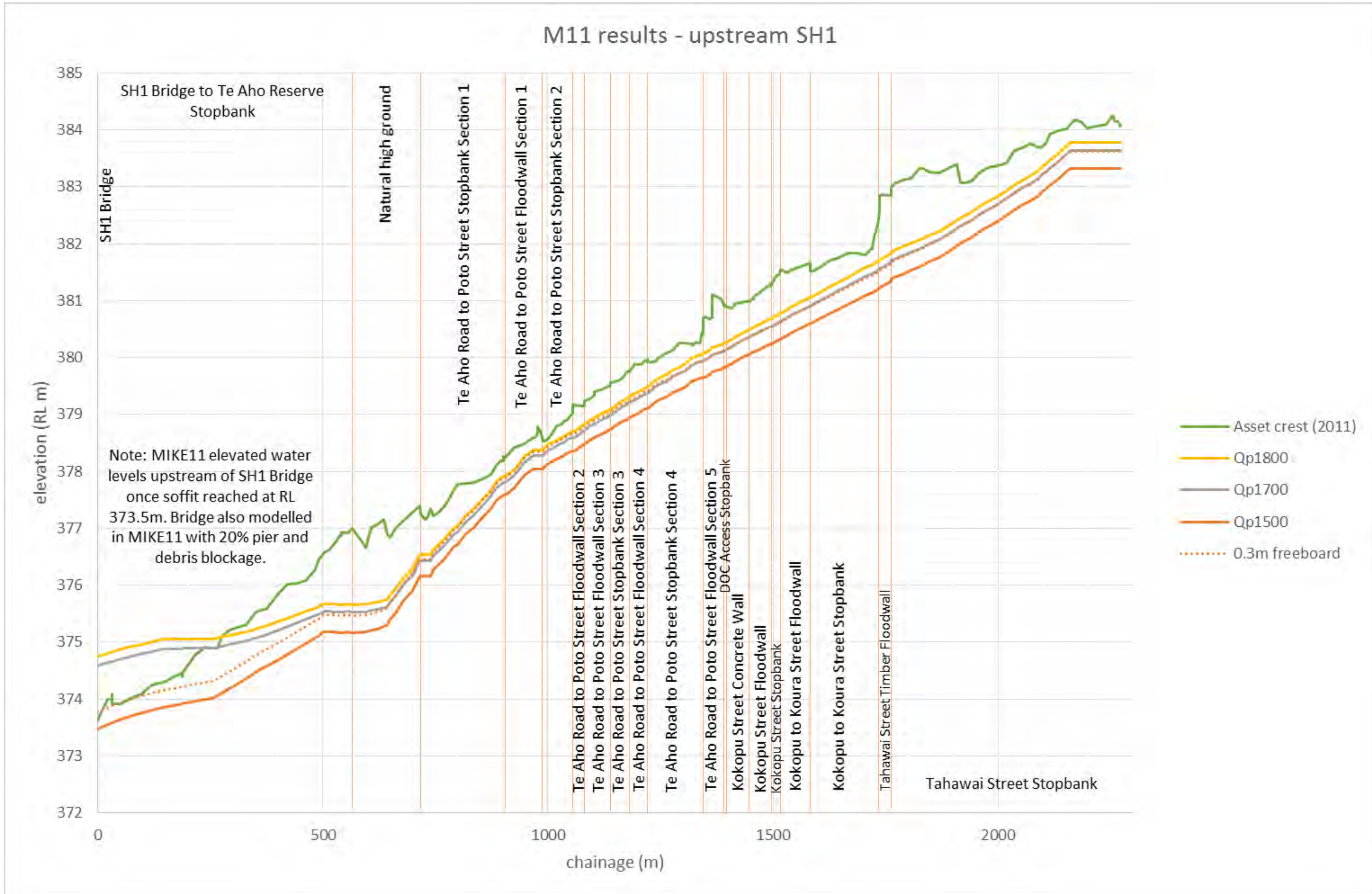

Figure 9 MIKE11 modelled water levels for various discharges compared against left bank flood protection scheme assets upstream of SH1.

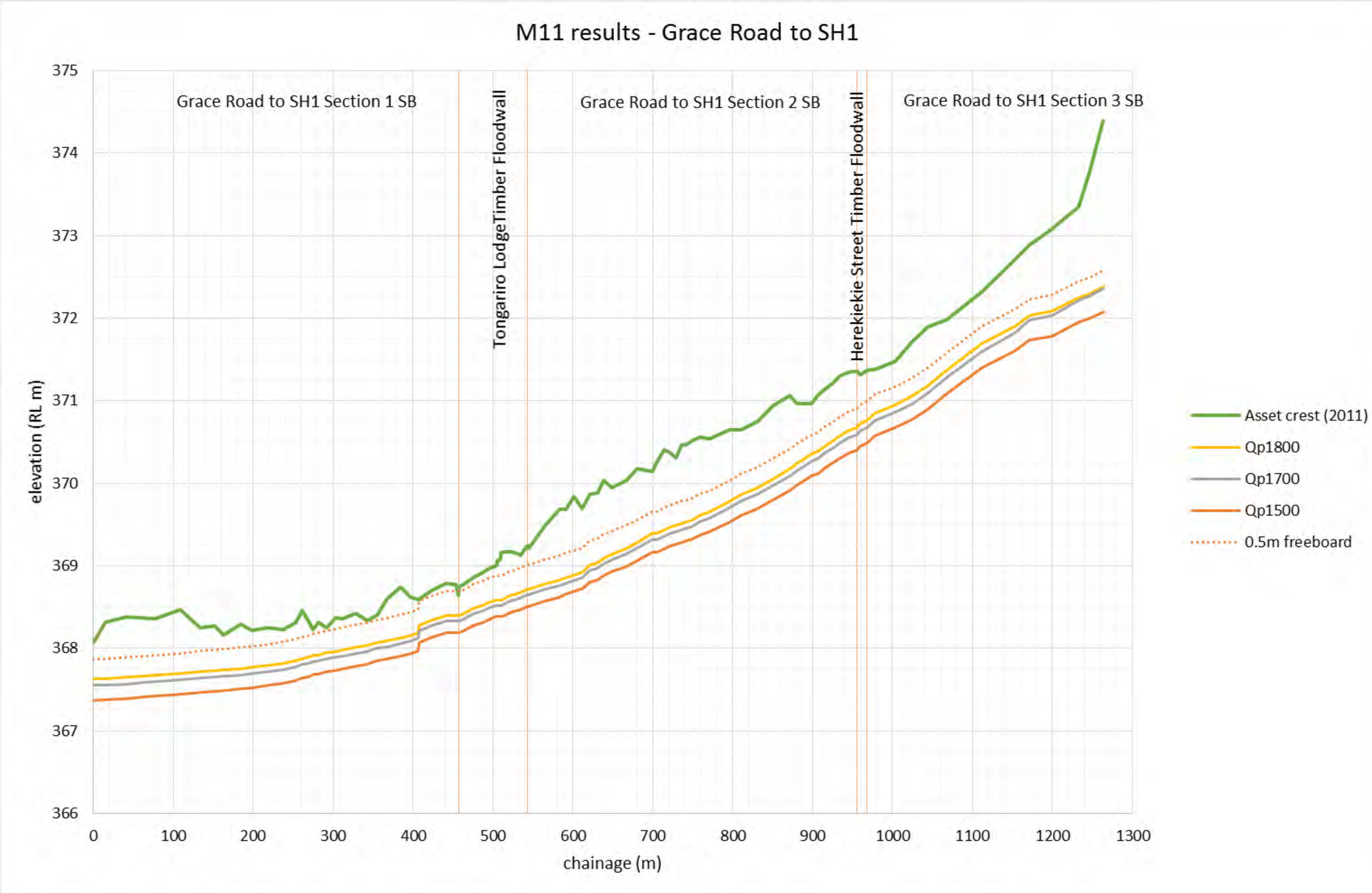

Figure 10 **MIKE11 modelled water levels for various discharges compared against right bank flood protection scheme assets between Grace Road and SH1.**

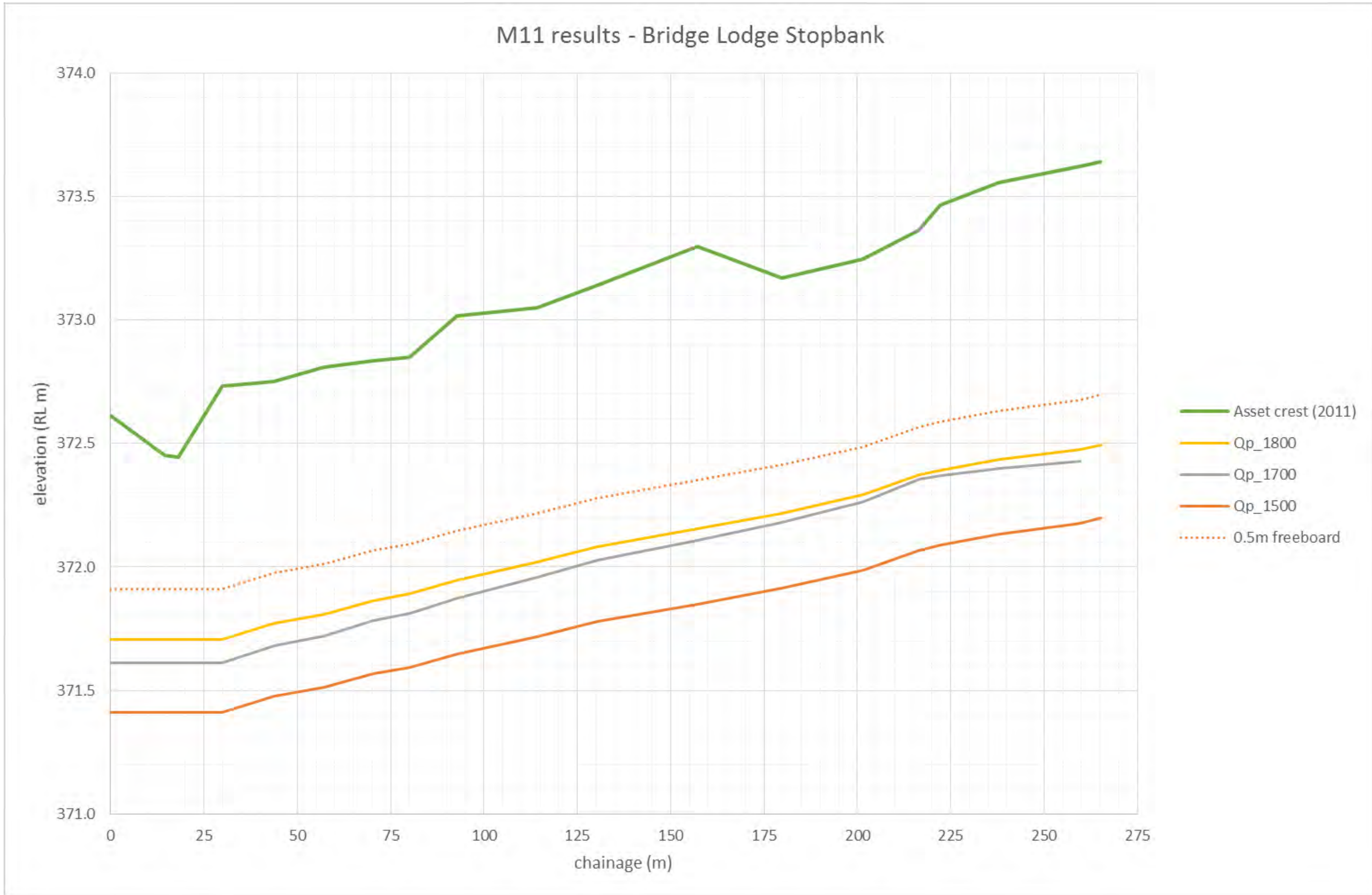

Figure 11 MIKE11 modelled water levels for various discharges compared against the left bank flood protection scheme asset Bridge Lodge Stopbank.

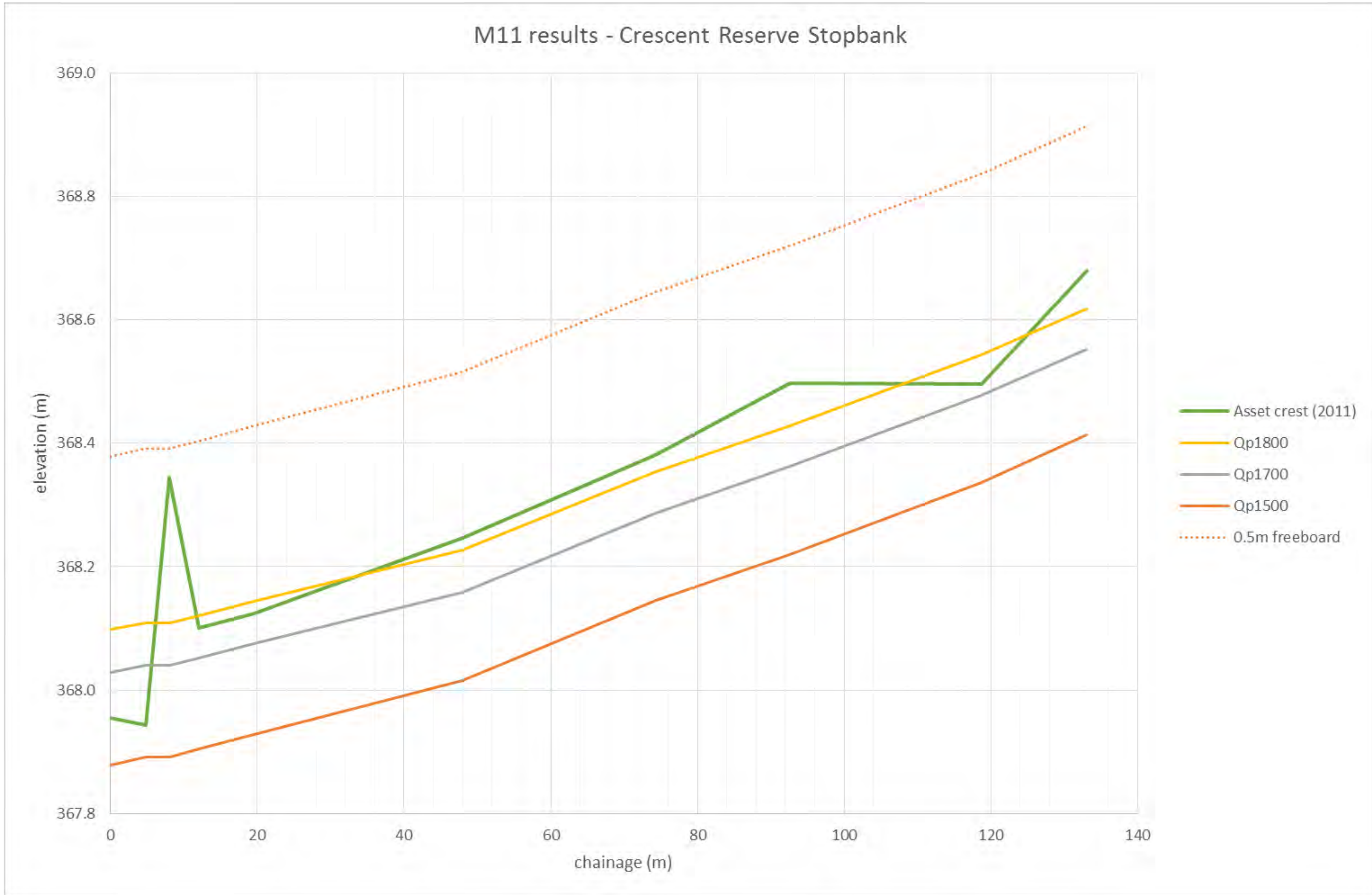

Figure 12 MIKE11 modelled water levels for various discharges compared against the left bank flood protection scheme asset Crescent Reserve Stopbank.

5.2 MIKE21 2D model

A MIKE21 2D model has also been developed of the Lower Tongariro River.

5.2.1 MIKE21 model development

5.2.1.1 Model domain and datum

The model domain (Figure 13) covers an area of 74.75km^2 extending from a southwest origin at NZTM 1839000 5676000 to a northeast corner at NZTM 1845500 5687500 (6.5km x 11.5km). Model bathymetry is a rectangular grid with a resolution of 5m, giving a grid 1300 x 2300 cells. The model vertical datum is as per the 2016 LIDAR and ground survey, and 2011 scheme asset survey, being MVD-53.

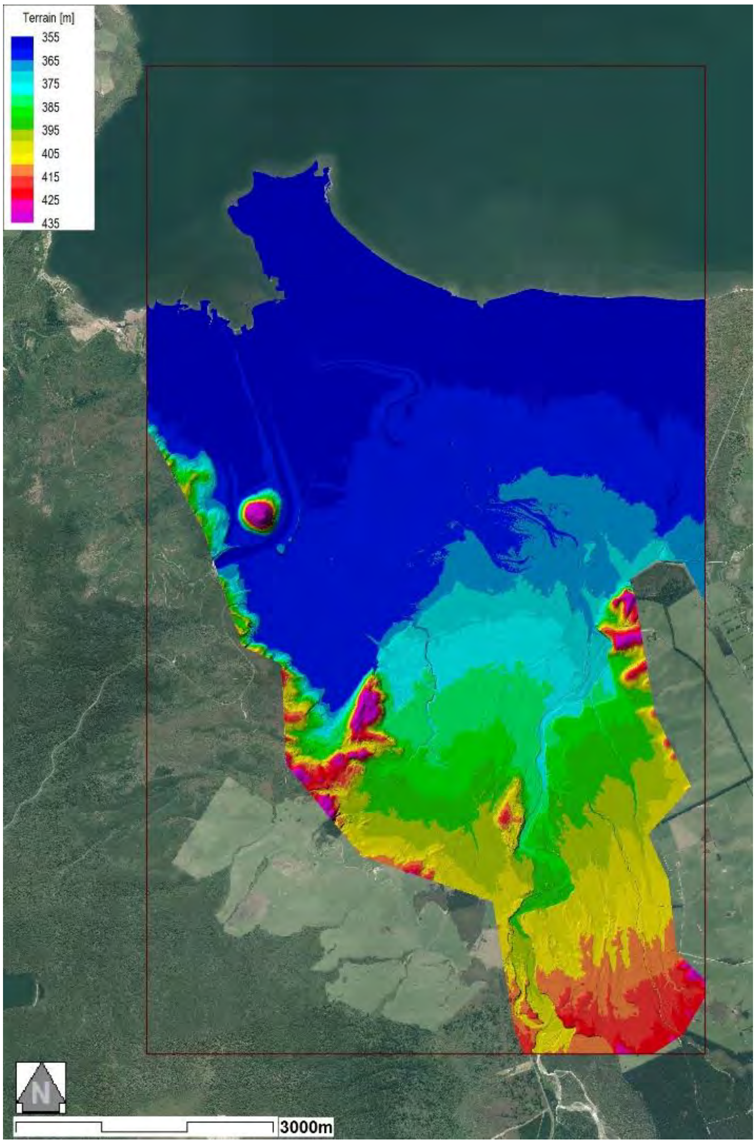

Figure 13 2016 LIDAR coverage within MIKE21 model domain.

5.2.1.2 Bathymetry

The 5m bathymetry was created by undertaking a number of steps as follows. The 2016 LIDAR 1m DEM was used to regenerate a grid of 5m resolution in order to give manageable model run times. Land areas outside the LIDAR coverage were assigned a 'land value' higher than all LIDAR values in the domain of RL 500m. Bed levels on Lake Taupo beyond the extent of the LIDAR (shoreline) were assigned a value of RL 356m, lake levels at the time of the LIDAR survey (10 and 17 October 2017) were approximately RL 357.1m. Scheme asset crest features were represented at a 5m resolution utilising the 2011 asset crest survey data, this was used to adjust the LIDAR grid along the alignment of assets to accurately reflect their height. These asset features in the bathymetry were then manually checked against the survey data to ensure good representation of the asset crests.

Potential issues with using LIDAR based bathymetries include inaccuracies in the vertical, errors associated with the presence of heavy vegetation, and non-penetration of water bodies. In addition, the reduction in resolution of LIDAR data to a 5m grid may result in the loss of some features less than the grid size. Accuracy of the LIDAR is referred to in Section 3.1. Where water is present (i.e. within the river and lower floodplain) the DEM surface typically reflects the water level at the time of data collection, i.e.: the bed level of the lower river channel is not fully represented. However, in this case the Tongariro was flowing at approximately 40m^3/s and the design flood flows to be modelled are 1500-1800m^3/s. The loss of channel representation in the model is likely not a significant issue given flows at the time of survey were 2-3% of the design flows, and 5% for the calibration event. However, there may be an issue in areas with low grades or pools where there is potentially a larger unrepresented channel which is wetted during LIDAR collection.

5.2.1.3 Simulation period, time step and outputs

Time step was reduced to 0.5s for model stability. The design events were run for over 54 hours with arbitrary dates and results saved at 5 minute intervals. The June 2015 flood was run with dates and flows relevant to the event.

5.2.1.4 MIKE21 model boundaries

Inflow hydrographs were applied at the upstream extent of the model several hundred meters upstream of the Tongariro National Trout Centre. The design hydrographs used have been described in Section 4.

Open boundaries were applied on the western, northern and eastern model boundaries of the lake with levels relevant to the simulation as described in Section 4.

5.2.1.5 Other MIKE21 variables

Flooding and drying were set to 20mm and 30mm respectively.

Eddy viscosity was set to a constant based value of 1m^2/s based on the grid size and time step (constant eddy = 0.02 Δx Δy / Δt) as per recommendations by the software developer DHI.

A resistance map was generated based on the difference between the DEM and DSM LIDAR datasets. Whilst not perfect the method allows for a rapid assessment of vegetation heights and other features such as buildings. Roughness values have then be applied based on an estimate of likely vegetation types/densities, whilst giving an increased resistance for the presence of building and other structures. Typically this gave Manning's M values of 31.25 for the main channel and/or open areas with minimal vegetation (e.g.: grass, roads, etc.). M values were applied for the following h range, M=25: <0.1m, M=20: 0.1-0.3m, M=17: 0.3-1m, M=7: 1-2m, M=5: 2-5m, M=8: 5-10m, and M=10: >10m.

5.2.2 MIKE21 model scenarios

Various flood events were modelled as per the MIKE11 modelling. These events include:

- The 20 June 2015 flood with a peak flow of Q_p748 estimated at a Q9 event. This is the largest event since the 2004 flood and was modelled as a calibration event to see if observations could be replicated.

- 100 year ARI event (Q_p1500)
- 100 year ARI event with allowance for uncertainty (Q_p1700)
- 100 year ARI climate change event (Q_p1800)

5.2.3 MIKE21 model results

5.2.3.1 Modelling June 2015 event

Modelling of the June 2015 event was intended as a calibration event, however difficulties in reducing the predicted flood levels to near observed levels was not possible.

In the first instance the model was run with the determined Manning's roughness values (section 5.2.1.5) giving flood levels on average +1.29m higher than observed (range +0.70-2.03m) as shown in Table 7. Trialling of various uniform roughness values was then undertaken from M=32 ('n'=0.03125) down a value of M=60 ('n'=0.0167). Under these roughness values the model was still consistently over-predicting on average by +0.92m (range +0.54-1.30m) and by +0.48m (range +0.09-0.83m) respectively. The roughness values described above and used to reduce the flood levels are considered quite unrealistic for this watercourse.

Given the modelled reach has very high velocities a 10m grid was also trialled but similar over-prediction issues were encountered: original Manning's values +1.59 (range +0.95-2.36m), M=32 ('n'=0.03125) average +0.96m (range +0.66-1.45m), M=80 ('n'=0.0125) average +0.44m (range 0.07-0.71m). Again the roughness values used to reduce the flood levels are unrealistic and do not reduce water levels sufficiently for calibration.

Possible reasons for the overestimation of flood levels include: the loss of the lower channel from the LIDAR data due to non-penetration of waterbodies but as previously described this represents less than 5% of the flood flow; changes in bed level between June 2015 event and survey in September 2016, although MIKE11 more closely resembled the observed flood levels under the same conditions described with more realistic roughness values.

Table 7 Comparison of modelled (MIKE21) and recorded peak flood levels at various locations for the June 2015 event.

XS ID, bank and chainage	Location	Crest level (RL m)	Height - WL below crest (m)	Estimated WL (RL m)	Modelled MIKE21 WL (RL m)	Difference (m)
XSZ LB (ch.8330)	Awamate Road bank	364.8*	n/a	364.5*	365.2	+0.70
XS4 RB (ch.9780)	Tongariro Lodge	368.60	1.70	366.91	368.03	+1.12
XS5 RB (ch.9930)	Tongariro Lodge	369.70	2.44	367.27	368.24	+0.97
XS7 RB (ch.10260)	Herekiekie Street	371.35	1.49	369.86	371.00	+1.14
XS21 LB (ch.12390)	Swing Bridge	381.90	2.21	379.69	381.72	+2.03
XS23 LB (ch.12790)	Kutai Street	373.70	2.46	381.25	383.06	+1.81

*Observations at low point in Awamate bank crest where access track off Hirangi Road heads northeast to meet bank.

5.2.3.2 Abandonment of MIKE21 modelling for assessing service level

Modelling of the June 2015 event (Q9) showed significant over-prediction of flood levels. Adjustment of roughness values to unrealistic values still could not reduce flood levels similar to those observed. The modelling showed significant overtopping of the flood protection scheme and inundation of the local floodplain which did not occur in reality for a relatively minor event.

It is well known that MIKE21 is susceptible to high velocities, and most models to super-critical flow, although it is considered that MIKE11 handles super-critical flows better than MIKE21. Given the difficulties in achieving a reasonable calibration with the June 2015 event (section 5.1.2.1) use of the MIKE21 model for assessing the design events was abandoned. Subsequently the results of the MIKE11 model have used to assess the service level of the flood protection scheme.

6 Service level review of flood protection assets

A service level review of the flood protection assets has been undertaken based on the results of the MIKE11 model and the 1%AEP (Q100) design flood condition of 1500m^3/s. Freeboard allowance has been assessed based 300mm upstream of the SH1 Bridge, and 500mm downstream.

The flood profiles from these design events were plotted against the scheme asset crests in Figure 9 to Figure 12. Table 8 below gives revised design flood levels, design crest levels and performance grades at each of the scheme 'embankment points'. Performance grades are assessed based on the percentage of available freeboard as shown in Figure 14.

The performance grades highlight the deficiencies in the Crescent Reserve Stopbank (performance grades 3 and 4), and smaller shortfalls (performance grade 2) in short sections of the assets immediately upstream of the SH1 Bridge, and downstream of the SH on the right bank. Appendix A gives a more detailed understanding of the shortfalls by comparing modelled flood levels at surveyed crest levels.

In total there is a linear length of 3786m of scheme stopbanks and floodwalls with:

- 75.8% performance grade 1 (2869m)
- 20.7% performance grade 2 (784m)
- 0.9% performance grade 3 (33m)
- 2.6% performance grade 4 (100m)
- Nil performance grade 5

Note that this method is conservative in that minimum actual crest (and hence performance grade) is based on the minimum surveyed level between 'embankment points' (up to 100m apart) and therefore compares a flood level with crests up to 100m upstream. The results may therefore indicate poor performance grades, with crest levels below design flood level when compared to those modelled (Figure 9 and Figure 12). Where this resulted in performance grade, further analysis was undertaken to determine the true performance at these discrete locations.

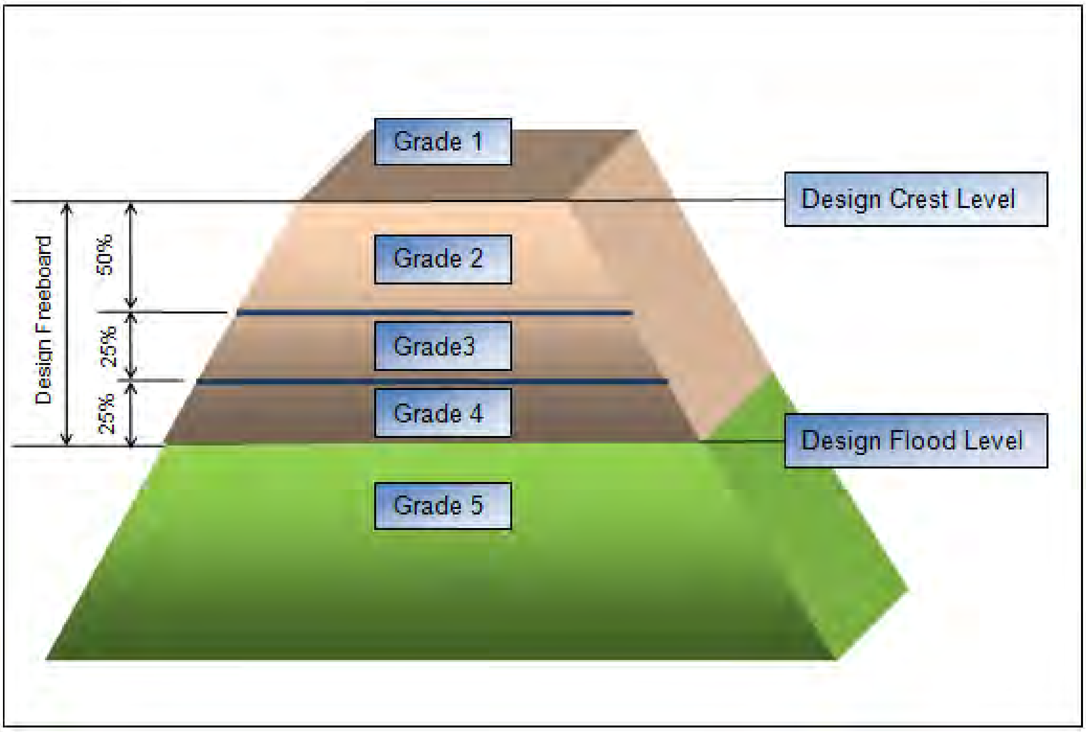

Figure 14 Diagrammatic representation of stopbank performance grades.

Table 8 Revised design flood level, design crest level and performance grades for flood protection scheme 'embankment points'.

Note: Minimum actual crest (and hence performance grade) is based on minimum surveyed level between embankment points (up to 100m apart) and is therefore conservative as it compares a flood level with crests up to 100m upstream.

Parent asset ID	Asset ID	Description	Asset chainage (m)	Free-board (m)	Current design flood level (RL m)	Revised design flood level (RL m)	Current design crest level (RL m)	Revised design crest level (RL m)	Min actual crest level (RL m)	Perform-ance grade
Crescent Reserve Stopbank:										
31251	59729	Crescent Reserve SB 00	0	0.5	368.70	367.88	369.20	368.38	367.96	n/a
31251	31252	Crescent Reserve SB 01	100	0.5	368.90	368.26	369.40	368.76	367.94[1]	4
31251	31253	Crescent Reserve SB 02	133	0.5	368.99	368.41	369.49	368.91	368.50[1]	3
Bridge Lodge Stopbank :										
35364	59743	Bridge Lodge SB 00	0	0.5	371.59	371.51	372.09	372.01	372.61	n/a
35364	46280	Bridge Lodge SB 01	100	0.5	372.03	371.68	372.53	372.18	372.45	1
35364	46281	Bridge Lodge SB 02	200	0.5	372.18	371.99	372.68	372.49	373.05	1
35364	46282	Bridge Lodge SB 03	267	0.5	372.27	372.72	372.77	373.22	373.25	1
State Highway 1 Bridge to Tahawai Street:										
31239	59819	Te Aho Reserve SH1 Bridge SB 00	0	0.3	372.97	373.48	373.27	373.78	373.64	n/a
31239	31240	Te Aho Reserve SH1 Bridge SB 01	100	0.3	373.61	373.77	373.91	374.07	373.64[1]	2
31239	31241	Te Aho Reserve SH1 Bridge SB 02	200	0.3	373.76	373.93	374.06	374.23	374.26	1
31239	31242	Te Aho Reserve SH1 Bridge SB 03	300	0.3	374.01	374.21	374.31	374.51	374.78	1
31239	31243	Te Aho Reserve SH1 Bridge SB 04	400	0.3	374.66	374.69	374.96	374.99	375.27	1
31239	31244	Te Aho Reserve SH1 Bridge SB 05	500	0.3	375.56	375.18	375.86	375.48	375.86	1
31239	31245	Te Aho Reserve SH1 Bridge SB 06	565	0.3	375.60	375.18	375.90	375.48	376.59	1
35495	68234	Te Aho Road to Poto Street Stopbank Section 1 00	0	0.3	376.23	376.17	376.53	376.47	377.40	-
35495	43556	Te Aho Road to Poto Street Stopbank Section 1 01	100	0.3	377.74	376.90	378.04	377.20	377.16	2
35495	35497	Te Aho Road to Poto Street Stopbank Section 1 02	190	0.3	377.96	377.59	378.26	377.89	377.78	2
68125	73735	Te Aho Road to Poto Street Floodwall Section 1 00	0	0.3	377.96	377.59	378.26	377.89	378.25	-
68125	68126	Te Aho Road to Poto Street Floodwall Section 1 01	73	0.3	378.22	378.05	378.52	378.35	378.25	2
68127	76608	Te Aho Road to Poto Street SB Section 2 00	0	0.3	378.22	378.05	378.52	378.35	378.78	-
68127	68129	Te Aho Road to Poto Street SB Section 2 01	76	0.3	378.50	378.39	378.80	378.69	378.54	2

[1] Minimum actual crest level in 'embankment link' compared with design flood level at same location.

Parent asset ID	Asset ID	Description	Asset chainage (m)	Free-board (m)	Current design flood level (RL m)	Revised design flood level (RL m)	Current design crest level (RL m)	Revised design crest level (RL m)	Min actual crest level (RL m)	Perform-ance grade
73745	73746	Te Aho Road to Poto Street Concrete & Timber Floodwall Section 2 00	0	0.3	378.50	378.39	378.80	378.69	379.17	-
73745	73747	Te Aho Road to Poto Street Concrete & Timber Floodwall Section 2 01	27	0.3	378.58	378.49	378.88	378.79	379.15	1
68130	73736	Te Aho Road to Poto Street Floodwall Section 3 00	0	0.3	378.58	378.49	378.88	378.79	379.24	-
68130	68131	Te Aho Road to Poto Street Floodwall Section 3 01	58	0.3	378.78	378.73	379.08	380.03	379.24	1
68135	70531	Te Aho Road to Poto Street SB Section 3 00	0	0.3	378.78	378.73	379.08	380.03	379.57	-
68135	68136	Te Aho Road to Poto Street SB Section 3 01	42	0.3	378.97	378.95	379.27	379.25	379.57	1
68139	73737	Te Aho Road to Poto Street Floodwall Section 3 00	0	0.3	378.97	378.95	379.27	379.25	379.75	-
68139	68140	Te Aho Road to Poto Street Floodwall Section 3 01	40	0.3	379.10	379.12	379.40	379.42	379.75	1
68141	70530	Te Aho Road to Poto Street SB Section 4 00	0	0.3	379.10	379.12	379.40	379.42	379.93	-
68141	68142	Te Aho Road to Poto Street SB Section 4 01	100	0.3	379.50	379.58	379.80	379.88	379.93	1
68141	70529	Te Aho Road to Poto Street SB Section 4 02	125	0.3	379.61	379.66	379.91	379.96	380.21	1
73748	73749	Te Aho Road to Poto Street Floodwall Section 5 00	0	0.3	379.61	379.66	379.91	379.96	380.69	-
73748	73750	Te Aho Road to Poto Street Floodwall Section 5 01	20	0.3	379.68	379.73	379.98	380.03	380.69	1
73748	73751	Te Aho Road to Poto Street Timber Floodwall Section 5 01	45	0.3	379.77	379.80	380.07	380.10	380.94	1
70273	70274	DOC Access Stopbank 00	0	0.3	379.77	379.80	380.07	380.10	380.94	-
70273	70275	DOC Access Stopbank 01	7	0.3	379.79	379.84	380.09	380.14	380.88	1
68053	73738	Kokopu Street Concrete Wall - 00	0	0.3	379.79	379.84	380.09	380.14	380.87	-
68053	68054	Kokopu Street Concrete Wall - 01	49	0.3	380.00	380.05	380.30	380.35	380.87	1
68113	73739	Kokopu Street Floodwall 00	0	0.3	380.00	380.05	380.30	380.35	380.98	-
68113	68114	Kokopu Street Floodwall 01	50	0.3	380.18	380.24	380.48	380.54	380.98	1
68116	76609	Kokopu Street SB 00	0	0.3	380.18	380.24	380.48	380.54	381.30	-
68116	68117	Kokopu Street SB 01	19	0.3	380.27	380.32	380.57	380.62	381.30	1
68118	73740	Kokopu to Koura Street Floodwall 00	0	0.3	380.27	380.32	380.57	380.62	381.55	-
68118	68119	Kokopu to Koura Street Floodwall 01	66	0.3	380.51	380.60	380.81	380.90	381.49	1
68122	76611	Kokopu to Koura Street SB 00	0	0.3	380.51	380.60	380.81	380.90	381.66	-
68122	38961	Kokopu to Koura Street SB 01	100	0.3	381.06	380.99	381.36	381.29	381.51	1
68122	68253	Kokopu to Koura Street SB 02	152	0.3	381.30	381.23	381.60	381.53	381.81	1
35404	73741	Tahawai Street Timber Floodwall 00	0	0.3	381.30	381.23	381.60	381.53	382.43	-
35404	35405	Tahawai Street Timber Floodwall 01	28	0.3	381.45	381.35	381.75	381.65	382.43	1
31219	59815	Tahawai Street SB 00	0	0.3	381.45	381.35	381.75	381.65	382.98	-
31219	31220	Tahawai Street SB 01	100	0.3	381.86	381.76	382.16	382.06	382.98	1
31219	31221	Tahawai Street SB 02	200	0.3	382.45	382.23	382.75	382.53	383.06	1

Parent asset ID	Asset ID	Description	Asset chainage (m)	Free-board (m)	Current design flood level (RL m)	Revised design flood level (RL m)	Current design crest level (RL m)	Revised design crest level (RL m)	Min actual crest level (RL m)	Perform-ance grade
31219	31222	Tahawai Street SB 03	300	0.3	382.65	382.72	382.95	383.02	383.34	1
31219	31223	Tahawai Street SB 04	400	0.3	383.23	383.29	383.53	383.59	383.68	1
31219	31224	Tahawai Street SB 05	500	0.3	383.23	383.29	383.53	383.59	384.04	1
31219	31225	Tahawai Street SB 06	510	0.3	383.23	383.29	383.53	383.59	383.96	1
Grace Road to State Highway 1 Bridge:										
35817	59624	Grace Road to State Highway 1 Section 1 SB 00	0	0.5	367.84	367.37	368.34	367.87	368.08	-
35817	46707	Grace Road to State Highway 1 Section 1 SB 01	100	0.5	367.90	367.44	368.40	367.94	368.08	1
35817	46708	Grace Road to State Highway 1 Section 1 SB 02	200	0.5	367.91	367.53	368.41	368.03	368.16	1
35817	46709	Grace Road to State Highway 1 Section 1 SB 03	300	0.5	367.99	367.72	368.49	368.22	368.23	1
35817	46710	Grace Road to State Highway 1 Section 1 SB 04	400	0.5	368.13	367.95	368.63	368.45	368.34	2
35817	35487	Grace Road to State Highway 1 Section 1 SB 05	458	0.5	368.20	368.19	368.70	368.69	368.59	2
35499	73742	Tongariro Lodge Timber Floodwall 00	0	0.5	368.20	368.19	368.70	368.69	368.75	-
35499	35500	Tongariro Lodge Timber Floodwall 01	87	0.5	368.29	368.51	368.79	369.01	368.75	2[2]
35483	59822	Grace Road to State Highway 1 Section 2 SB 00	0	0.5	368.29	368.51	368.79	369.01	369.21	-
35483	35484	Grace Road to State Highway 1 Section 2 SB 01	100	0.5	369.78	368.91	370.28	369.41	369.21	2
35483	35485	Grace Road to State Highway 1 Section 2 SB 02	200	0.5	369.87	369.30	370.37	369.80	369.95	1
35483	46672	Grace Road to State Highway 1 Section 2 SB 03	300	0.5	370.07	369.79	370.57	370.29	370.52	1
35483	46673	Grace Road to State Highway 1 Section 2 SB 04	400	0.5	370.37	370.34	370.87	370.84	370.94	1
35483	46674	Grace Road to State Highway 1 Section 2 SB 05	401	0.5	370.43	370.34	370.93	370.84	371.35	1
70415	70416	Herekiekie St Timber Floodwall with earth fill 00	0	0.5	370.48	370.44	370.98	370.94	371.35	-
70415	70417	Herekiekie St Timber Floodwall with earth fill 01	33	0.5	370.57	370.58	371.07	371.08	371.32	1
31247	59820	Grace Road to State Highway 1 Section 3 SB 00	0	0.5	370.57	370.58	371.07	371.08	371.38	-
31247	31248	Grace Road to State Highway 1 Section 3 SB 01	100	0.5	370.88	371.15	371.38	371.65	371.98[1]	1
31247	31249	Grace Road to State Highway 1 Section 3 SB 02	200	0.5	371.19	371.73	371.69	372.23	372.32	1
31247	31250	Grace Road to State Highway 1 Section 3 SB 03	285	0.5	372.17	372.08	372.67	372.58	373.08	1

[2] Minimum actual crest level in 'embankment link' compared with design flood level at same location.

7 Analysis of channel survey data

Channel cross-sections within the reach covered by the flood protection scheme were surveyed in 2009 and 2016. Cross-sections sharing the same alignment and benchmarks have been compared for minimum inverts and changes in cross-sectional area, i.e.: bed aggradation or degradation. Comparable cross-sections are plotted in Appendix B Figure 16 to Figure 38, with cross-section locations shown in Figure 15.

Changes in cross-sectional area (about common xyz points) can provide an indication of bed changes at each channel 'slice', and possible channel profile trends between slices. It is noted that even small flood events can significantly change river morphology and the following is a quick analysis of two periods in time. The data indicates the following changes in cross-sectional area between 2009 and 2016:

- Sediment aggradation between XS-24 and XS-18 (upstream of scheme to downstream of Poto Street), with a reduction in cross-sectional area of 1-4%.
- No significant change at XS-17 (upstream of Taupahi Reserve).
- Degradation between XS-16 and XS-13 (Taupahi Reserve to upper 'island'), typically increases in cross-sectional area are small (~1%), although XS-15 has an increase in area of 7.5%.
- At the 'island' upstream of SH1 Bridge, the true left channel has become the dominant channel as opposed to the true right bank in 2009. Subsequently the left bank channel has degraded and the right bank channel aggraded. Overall the channel cross-sectional area has been reduced (aggraded) through this area by 2-3%.
- SH1 Bridge to downstream of Grace Road stopbank, the cross-sectional area is similar or decreased (aggradation) by 1-4%.
- Degradation at XS-1 and XS-2 of 6-10%. Channel and vegetation clearance was undertaken here circa 2012. A cut-off occurred at DeLatours Bend circa 2013, shortening the river reach by 800m approximately 1200m downstream of XS-1. This may possibly result in some degradation upstream of the cut-off as the river grade adjusts.
- Note that channel invert levels and profile are not necessarily reflective of changes in cross-sectional area.

Table 9 gives the channel cross-sectional area and change in cross-sectional area between 2009 and 2016. Note the area is calculated and compared for a common level at each cross-section and comparing areas along the reach is not recommended.

In summary, the general trend between the 2009 and 2016 cross-sections are:

- Aggradation upstream of 'Te Aho Road to Poto Street Stopbank Section 3' (XS-24 to XS-18).
- Degradation between Taupahi Reserve and the 'island' upstream of SH1 (XS-17 toXS-13).
- Aggradation between upstream SH1 ('island') to downstream of Tongariro Lodge.
- Degradation at XS-1 and XS-2 associated with channel and vegetation clearance, and possibly recent downstream DeLatours cut-off.

In order to maintain freeboard and the design flood protection standard, the requirements for gravel extraction and vegetation management need to be considered in terms of the Design Waterway method devised for the Tongariro by Tonkin +Taylor (2010). This will be undertaken following completion of this service level review.

Table 9 Channel cross-section changes between 2009 and 2016.

Note: area is calculated and compared for a common level at each cross-section and comparing areas along the reach is not recommended. Channel invert and profile not necessarily reflective of changes in cross-sectional area.

XS	Model chainage (m)	Location	Common RL (m)	XS area 2009 (m²)	XS area 2016 (m²)	Change ratio	Trend (2009 vs. 2016)	Change in invert (m)
1	8800		365.64	291.6	310.1	0.940 -6.0%	degrading	-0.90
2	9170		366.25	216.0	240.7	0.898 -10.2%	degrading	-0.77
2a	9320	DS Scheme	366.69	467.6	465.2	1.005 +0.5%	aggrading	-0.89
4	9780	Tongariro Lodge	368.35	686.0	687.2	0.998 -0.2%	no signif. change	0.34
5	9930	Tongariro Lodge	370.03	861.9	838.3	1.028 +2.8%	aggrading	0.23
6	10090		369.87	445.9	447.7	0.996 -0.4%	no signif. change	-0.46
7	10260	Herekiekie Street	371.88	747.6	718.1	1.041 +4.1%	aggrading	0.49
8	10420	DS Bridge Lodge	372.79	761.4	741.8	1.027 +2.7%	aggrading	0.03
10	10620	US Bridge	373.85	521.3	509.8	1.022 +2.2%	aggrading	0.19
11-LBC	10770	Lower 'island' Left bank channel	374.16	287.5	304.4	0.944 -5.6%	Left channel degrading	n/a
11-RBC	10770	Lower 'island' Right bank channel	371.21	88.2	80.4	1.097 +9.7%	Right channel aggrading	n/a
11-both channel	10770	Lower 'island' both channels	n/a	375.7	384.8	1.021 +2.1%	overall aggrading	0.05
12-LBC	10840	Mid 'island' Left bank channel	374.36	238.1	255.0	0.934 -6.6%	degrading	n/a
12-RBC	10840	Mid 'island' Right bank channel	372.75	170.4	150.4	1.133 13.3%	aggrading	n/a
12-both channel	10840	Mid 'island' both channels	n/a	408.506	405.387	1.033 3.3%	overall aggrading	-0.09
13	10960	Upper 'island'	374.86	502.4	508.4	0.988 -1.2%	degrading	0.67
14	11070	US 'island'	375.50	480.8	481.0	0.999 -0.1%	no signif. change	-0.12
15	11240	Te Aho Road	375.02	275.5	297.7	0.925 -7.5%	degrading	0.13
16	11510	Taupahi Reserve	377.74	578.9	586.2	0.988 -1.2%	degrading	-0.02
17	11720		377.40	217.7	218.3	0.997 -0.3%	no signif. change	-0.28
18	11880		379.53	308.9	304.8	1.014 +1.4%	aggrading	-0.09
19	12080	Poto St	380.85	277.0	269.5	1.028 +2.8%	aggrading	-0.15
20	12260	Kokopu – Koura St	381.45	325.2	319.5	1.018 +1.8%	aggrading	0.30
21	12390	Swing Bridge	381.89	291.9	286.2	1.020 +2.0%	aggrading	-0.03
22	12660	Tahawai Street	383.28	440.3	447.9	0.983 -1.7%	degrading	0.03
23	12790	Kutai Street	383.63	361.1	357.4	1.010 +1.0%	aggrading	0.35
24	13020	US Scheme	384.50	275.4	264.8	1.040 +4.0%	aggrading	0.28

8 Conclusions

A service level review has been undertaken of the Tongariro River Flood Protection Scheme at Turangi:

1. The previous review was undertaken in 2014, this 2017 review incorporates recent ground and aerial survey (September-October 2016) to give full representation of the river channel and floodplain. An extensive asset crest survey from 2011 was also utilised with the levels unlikely to have changed significantly.

2. Hydrology has been reassessed based on a flood frequency analysis of the gauge record from Turangi Cableway. This includes the 60 year period from 1957-2017 and confirms the 1%AEP design flow at $1500 m^3/s$.

3. A MIKE11 1D model of the river has been fully revised inclusive of the above survey data. The model has been run with the recent 2015 Q9 flood event with predicted flood levels checked against surveyed peak flood levels providing confidence in the model results. Design events were then modelled and a comparison made between peak water levels and scheme asset crest levels.

4. A MIKE21 2D model was also developed but this proved to consistently over-predict flood levels for the 2015 event and was subsequently not used for the design events. Model variables were adjusted to unrealistic values and still could not replicate observed flood levels. The MIKE11 model was subsequently adopted as the preferred model to assess the service level of the scheme.

5. The modelling confirms that the flood protection scheme is delivering the service level for the design discharge of $1500 m^3/s$ (i.e.: 1%AEP modelled flood levels are less than the asset crest) although there are shortfalls in freeboard. Freeboard requirements are 300mm upstream of the SH1 Bridge, and 500mm downstream. Areas with a shortfall in freeboard include a linear length of approximately 190m and should be resurveyed and scheduled for remediation as required. Remediation may take the form of asset works or gravel extraction/vegetation management. These areas are primarily at the Crescent Reserve Stopbank, and immediately upstream of the SH1 Bridge.

6. The Design Waterway method devised by Tonkin + Taylor (2010) specifically for the Tongariro should be used to assess the extent of gravel and vegetation management in order to maintain freeboard and the design flood protection standard. This work should be scheduled following completion of this service level review.

7. The Awamate Road Stopbank extension is incomplete since the development of the flood protection scheme due to landowner agreement issues. Similarly access issues prevented survey during the 2011 scheme asset survey. The modelling in the lower river utilises LIDAR to extend the model cross-sections and suggests that the Awamate Stopbank is likely to be overtopped or outflanked in a Q_p1500 event. This reach of the river below Turangi urban and the main flood protection scheme requires further investigation and consideration as previous studies also suggest the possibility of a breakout towards the Tokaanu Tailrace along this reach.

9 Recommendations

The following recommendations are made based on the findings of this service level review:

1. Undertake survey and schedule works as necessary to rectify shortfalls in freeboard within the flood protection scheme. This may take the form of asset works or gravel extraction / vegetation management.

2. Awamate Stopbank – survey and analysis required of existing embankment.

3. Further investigation required into the possibility of breakouts in the lower delta.

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Appendix A – Modelled MIKE11 water levels vs. flood protection scheme asset crest levels.

Table 10 MIKE11 model results interpolated adjacent to assets – Crescent Reserve Stopbank. Freeboard is 500mm in this reach, red shading denotes overtopping, orange shading less than 500mm freeboard.

Ch. (m)	Asset Crest Level (m)	Modelled water levels and free boards for various design events:					
		Q_p1500	Free-board (m)	Q_p1700	Free-board (m)	Q_p1800	Free-board (m)
Crescent Road Stopbank:							
0.0	367.96	367.88	0.08	368.03	-0.07	368.10	-0.14
4.7	367.94	367.89	0.05	368.04	-0.10	368.11	-0.17
8.0	368.35	367.89	0.45	368.04	0.31	368.11	0.24
12.0	368.10	367.90	0.20	368.05	0.05	368.12	-0.02
19.5	368.12	367.93	0.20	368.08	0.05	368.14	-0.02
48.0	368.25	368.02	0.23	368.16	0.09	368.23	0.02
74.3	368.38	368.15	0.24	368.29	0.09	368.35	0.03
92.6	368.50	368.22	0.28	368.36	0.13	368.43	0.07
118.7	368.50	368.34	0.16	368.48	0.02	368.54	-0.05
133.1	368.68	368.41	0.27	368.55	0.13	368.62	0.06

Table 11 MIKE11 model results interpolated adjacent to assets – Bridge Lodge Stopbank. Freeboard is 500mm in this reach, red shading denotes overtopping, orange shading less than 500mm freeboard.

Ch. (m)	Asset Crest Level (m)	Modelled water levels and free boards for various design events:					
		Q_p1500	Free-board (m)	Q_p1700	Free-board (m)	Q_p1800	Free-board (m)
Bridge Lodge Stopbank:							
0.0	372.61	371.41	1.20	371.61	1.00	371.71	0.91
14.6	372.45	371.41	1.04	371.61	0.84	371.71	0.75
18.1	372.45	371.41	1.03	371.61	0.83	371.71	0.74
29.8	372.73	371.41	1.32	371.61	1.12	371.71	1.03
43.8	372.75	371.48	1.27	371.68	1.07	371.77	0.98
57.2	372.81	371.51	1.30	371.72	1.09	371.81	1.00
70.2	372.84	371.57	1.27	371.78	1.05	371.86	0.97
80.0	372.85	371.59	1.26	371.81	1.04	371.89	0.96
92.8	373.02	371.65	1.37	371.88	1.14	371.95	1.07
114.1	373.05	371.72	1.33	371.96	1.09	372.02	1.03
130.3	373.14	371.78	1.36	372.03	1.11	372.08	1.06
157.1	373.30	371.85	1.45	372.11	1.19	372.15	1.14
179.7	373.17	371.91	1.26	372.18	0.99	372.22	0.95
201.6	373.25	371.99	1.26	372.27	0.98	372.29	0.96
216.5	373.36	372.07	1.30	372.36	1.01	372.37	0.99
222.3	373.47	372.09	1.38	372.37	1.10	372.39	1.07
237.9	373.56	372.13	1.43	372.40	1.16	372.44	1.12
259.6	373.62	372.18	1.45	372.43	1.19	372.48	1.15
265.1	373.64	372.20	1.44	372.44	1.20	372.50	1.14

Table 12 MIKE11 model results interpolated adjacent to assets – Upstream State Highway 1. Freeboard is 300mm in this reach, red shading denotes overtopping, orange shading less than 300mm freeboard.

Ch. (m)	Asset Crest Level (m)	Modelled water levels and free boards for various design events:					
		Q_p1500	Free-board (m)	Q_p1700	Free-board (m)	Q_p1800	Free-board (m)
SH1 Bridge to Te Aho Reserve Stopbank:							
0.00	373.64	373.48	0.16	374.59	-0.95	374.75	-1.11
8.38	373.78	373.51	0.26	374.61	-0.83	374.77	-1.00
21.43	373.99	373.56	0.43	374.64	-0.65	374.80	-0.82
30.96	374.00	373.59	0.41	374.67	-0.67	374.83	-0.83
31.20	374.10	373.59	0.51	374.67	-0.57	374.83	-0.73
32.60	373.91	373.59	0.32	374.67	-0.75	374.83	-0.92
51.48	373.91	373.65	0.26	374.71	-0.80	374.88	-0.96
74.73	374.02	373.72	0.31	374.76	-0.73	374.92	-0.90
97.16	374.10	373.76	0.33	374.79	-0.70	374.96	-0.87
119.72	374.26	373.81	0.44	374.84	-0.58	375.01	-0.75
144.51	374.30	373.86	0.44	374.88	-0.58	375.06	-0.76
151.33	374.31	373.87	0.44	374.88	-0.57	375.06	-0.75
167.56	374.39	373.89	0.50	374.89	-0.50	375.06	-0.67
186.45	374.45	373.92	0.53	374.89	-0.44	375.06	-0.61
188.62	374.39	373.92	0.47	374.89	-0.50	375.06	-0.67
190.12	374.48	373.93	0.56	374.89	-0.41	375.06	-0.58
195.26	374.55	373.93	0.62	374.89	-0.34	375.06	-0.51
216.49	374.78	373.96	0.81	374.89	-0.11	375.06	-0.28
237.20	374.91	373.99	0.92	374.89	0.02	375.06	-0.15
253.15	374.90	374.02	0.89	374.89	0.01	375.06	-0.16
265.95	374.90	374.06	0.84	374.91	-0.01	375.08	-0.17
275.87	375.10	374.11	0.99	374.93	0.17	375.09	0.00
291.75	375.21	374.19	1.02	374.96	0.25	375.12	0.09
309.97	375.27	374.26	1.00	374.99	0.28	375.15	0.12
329.12	375.31	374.36	0.94	375.03	0.28	375.19	0.12
349.69	375.51	374.46	1.05	375.07	0.44	375.22	0.29
356.44	375.54	374.51	1.03	375.09	0.45	375.25	0.29
375.71	375.59	374.58	1.01	375.14	0.45	375.29	0.30
401.02	375.86	374.69	1.17	375.21	0.65	375.36	0.50
420.66	376.01	374.79	1.22	375.28	0.73	375.42	0.59
441.60	376.03	374.88	1.15	375.34	0.69	375.48	0.55
461.38	376.08	374.98	1.10	375.40	0.67	375.54	0.54
480.47	376.26	375.07	1.19	375.46	0.80	375.60	0.66
491.46	376.45	375.12	1.33	375.50	0.96	375.63	0.82
498.50	376.54	375.18	1.36	375.53	1.00	375.66	0.87
504.94	376.59	375.18	1.41	375.54	1.05	375.67	0.92
513.42	376.61	375.19	1.42	375.54	1.07	375.67	0.94
525.35	376.72	375.18	1.55	375.54	1.19	375.67	1.06
539.31	376.89	375.17	1.72	375.53	1.36	375.66	1.23
541.12	376.88	375.17	1.71	375.53	1.35	375.66	1.22
541.75	376.93	375.17	1.76	375.53	1.40	375.66	1.27
556.23	376.91	375.18	1.73	375.54	1.38	375.67	1.25
564.47	377.00	375.16	1.84	375.52	1.47	375.66	1.34
SH1 Bridge to Te Aho Reserve Stopbank ↑							
Higher natural ground:							
595.62	376.66	375.18	1.48	375.53	1.13	375.66	1.00
608.07	377.02	375.20	1.81	375.55	1.46	375.68	1.33
619.14	377.07	375.23	1.83	375.57	1.50	375.70	1.37
634.36	377.15	375.28	1.88	375.60	1.55	375.73	1.43
643.76	376.89	375.31	1.58	375.62	1.27	375.74	1.14

Ch. (m)	Asset Crest Level (m)	Modelled water levels and free boards for various design events:					
		Q_p1500	Free-board (m)	Q_p1700	Free-board (m)	Q_p1800	Free-board (m)
648.28	376.85	375.40	1.45	375.71	1.14	375.83	1.02
660.43	376.99	375.51	1.48	375.81	1.18	375.93	1.06
679.48	377.14	375.73	1.41	376.02	1.12	376.13	1.01
698.67	377.28	375.90	1.38	376.17	1.10	376.29	0.98
Higher natural ground ↑							
Te Aho Road to Poto Street Stopbank Section 1:							
715.21	377.40	376.17	1.23	376.42	0.97	376.54	0.86
717.07	377.26	376.17	1.09	376.42	0.83	376.54	0.72
726.88	377.16	376.17	0.99	376.42	0.74	376.54	0.62
733.99	377.21	376.17	1.04	376.42	0.78	376.54	0.67
739.37	377.34	376.17	1.17	376.42	0.92	376.54	0.80
745.17	377.21	376.27	0.94	376.52	0.69	376.63	0.58
756.81	377.29	376.36	0.93	376.61	0.68	376.72	0.57
758.00	377.28	376.36	0.92	376.61	0.67	376.72	0.56
771.50	377.40	376.48	0.92	376.71	0.69	376.82	0.58
790.26	377.68	376.68	1.00	376.90	0.78	377.01	0.67
799.57	377.78	376.72	1.06	376.94	0.84	377.04	0.74
816.35	377.78	376.90	0.88	377.11	0.67	377.22	0.57
835.35	377.81	377.02	0.79	377.23	0.58	377.34	0.47
859.77	377.88	377.23	0.65	377.45	0.43	377.55	0.33
873.80	377.95	377.35	0.60	377.56	0.39	377.67	0.28
885.93	378.11	377.49	0.61	377.71	0.40	377.82	0.29
894.97	378.18	377.56	0.63	377.77	0.41	377.88	0.30
900.42	378.19	377.59	0.60	377.80	0.39	377.91	0.28
902.08	378.26	377.59	0.68	377.80	0.46	377.91	0.36
Te Aho Road to Poto Street Stopbank Section 1 ↑							
Te Aho Road to Poto Street Floodwall Section 1:							
905.09	378.25	377.59	0.66	377.80	0.44	377.91	0.34
925.39	378.42	377.70	0.71	377.92	0.49	378.03	0.39
946.88	378.48	377.94	0.54	378.16	0.32	378.27	0.21
966.14	378.59	378.05	0.54	378.27	0.32	378.38	0.21
970.63	378.60	378.05	0.55	378.27	0.33	378.38	0.22
976.86	378.67	378.05	0.62	378.27	0.40	378.38	0.29
978.00	378.78	378.05	0.73	378.27	0.51	378.38	0.40
983.61	378.71	378.05	0.66	378.27	0.44	378.38	0.33
986.73	378.60	378.05	0.55	378.27	0.32	378.38	0.22
Te Aho Road to Poto Street Floodwall Section 1 ↑							
Te Aho Road to Poto Street Stopbank Section 2:							
988.7	378.54	378.05	0.49	378.27	0.27	378.38	0.16
993.5	378.54	378.09	0.45	378.31	0.23	378.42	0.12
1001.2	378.58	378.14	0.44	378.37	0.21	378.48	0.10
1011.0	378.69	378.18	0.51	378.41	0.28	378.52	0.17
1019.9	378.81	378.22	0.59	378.45	0.36	378.55	0.25
1030.9	378.83	378.26	0.57	378.49	0.34	378.60	0.23
1034.3	378.87	378.27	0.60	378.51	0.37	378.61	0.26
1042.8	378.92	378.32	0.59	378.56	0.36	378.66	0.25
1052.7	379.01	378.36	0.65	378.59	0.41	378.70	0.31
1054.0	379.02	378.36	0.67	378.59	0.43	378.70	0.32
Te Aho Road to Poto Street Stopbank Section 2 ↑							
Te Aho Road to Poto Street Floodwall Section 2:							
1054.1	379.17	378.36	0.81	378.59	0.58	378.70	0.47
1058.3	379.18	378.36	0.82	378.59	0.59	378.70	0.48

Ch. (m)	Asset Crest Level (m)	Modelled water levels and free boards for various design events:					
		Q_p1500	Free-board (m)	Q_p1700	Free-board (m)	Q_p1800	Free-board (m)
1059.9	379.16	378.36	0.80	378.59	0.57	378.70	0.46
1080.7	379.15	378.48	0.67	378.72	0.43	378.83	0.32
1080.8	379.24	378.48	0.76	378.72	0.52	378.83	0.41
1093.6	379.28	378.55	0.73	378.80	0.49	378.90	0.38
1102.4	379.33	378.59	0.74	378.83	0.50	378.94	0.39
1103.0	379.41	378.59	0.81	378.83	0.57	378.94	0.46
1122.3	379.45	378.68	0.77	378.93	0.53	379.03	0.42
1124.9	379.47	378.68	0.79	378.93	0.55	379.03	0.44
1137.9	379.49	378.73	0.76	378.98	0.51	379.09	0.41
Te Aho Road to Poto Street Floodwall Section 2 ↑							
***Te Aho Road to Poto Street Stopbank Section 3*:**							
1138.7	379.57	378.73	0.84	378.98	0.59	379.09	0.48
1155.2	379.59	378.83	0.77	379.08	0.51	379.19	0.41
1164.5	379.64	378.88	0.75	379.14	0.50	379.24	0.39
1176.3	379.76	378.92	0.85	379.17	0.59	379.28	0.48
1179.3	379.75	378.95	0.80	379.21	0.54	379.32	0.43
Te Aho Road to Poto Street Stopbank Section 3 ↑							
Te Aho Road to Poto Street Floodwall Section 3:							
1180.4	379.75	378.95	0.80	379.21	0.54	379.32	0.43
1192.3	379.89	378.99	0.90	379.26	0.64	379.37	0.53
1200.1	379.88	379.03	0.85	379.29	0.59	379.40	0.48
1208.8	379.89	379.06	0.83	379.33	0.56	379.44	0.45
1215.7	379.93	379.09	0.84	379.36	0.58	379.47	0.46
1220.3	379.96	379.11	0.86	379.38	0.59	379.49	0.48
Te Aho Road to Poto Street Floodwall Section 3 ↑							
Te Aho Road to Poto Street Stopbank Section 4:							
1220.3	379.93	379.11	0.82	379.38	0.55	379.49	0.44
1237.3	379.93	379.21	0.72	379.48	0.45	379.59	0.33
1247.4	380.00	379.26	0.75	379.53	0.48	379.64	0.36
1263.4	380.08	379.30	0.78	379.58	0.50	379.70	0.38
1276.8	380.13	379.39	0.74	379.67	0.46	379.78	0.35
1289.9	380.25	379.43	0.81	379.72	0.53	379.84	0.41
1304.9	380.26	379.48	0.77	379.77	0.49	379.89	0.37
1319.8	380.24	379.59	0.65	379.87	0.37	380.00	0.24
1320.4	380.21	379.59	0.62	379.87	0.34	380.00	0.21
1329.7	380.26	379.61	0.65	379.90	0.36	380.03	0.24
1336.2	380.26	379.64	0.62	379.93	0.33	380.05	0.21
1339.0	380.29	379.64	0.65	379.93	0.36	380.05	0.24
1341.4	380.39	379.64	0.75	379.93	0.46	380.05	0.34
1342.7	380.44	379.64	0.80	379.93	0.51	380.05	0.39
1345.1	380.41	379.66	0.75	379.95	0.46	380.08	0.34
Te Aho Road to Poto Street Stopbank Section 4 ↑							
Private Wall:							
1345.3	380.69	379.66	1.03	379.95	0.74	380.08	0.61
1347.4	380.70	379.66	1.04	379.95	0.75	380.08	0.63
1348.4	380.71	379.66	1.05	379.95	0.76	380.08	0.63
1358.5	380.69	379.70	0.98	380.00	0.69	380.12	0.56
1365.2	380.70	379.75	0.95	380.05	0.66	380.17	0.53
1365.4	381.11	379.75	1.36	380.05	1.06	380.17	0.94
1384.1	381.03	379.80	1.24	380.10	0.94	380.22	0.81
Private Wall ↑							

Ch. (m)	Asset Crest Level (m)	Modelled water levels and free boards for various design events:					
		Q_p1500	Free-board (m)	Q_p1700	Free-board (m)	Q_p1800	Free-board (m)
DOC Access Stopbank:							
1390.0	380.94	379.82	1.12	380.12	0.82	380.25	0.69
1391.7	380.90	379.82	1.08	380.12	0.78	380.25	0.66
1394.4	380.92	379.82	1.10	380.12	0.80	380.25	0.67
DOC Access Stopbank ↑							
Kokopu Street Concrete Wall:							
1397.1	380.88	379.84	1.04	380.14	0.74	380.27	0.61
1409.6	380.87	379.89	0.98	380.19	0.68	380.32	0.55
1416.5	380.95	379.94	1.01	380.24	0.71	380.37	0.58
1439.7	380.98	380.03	0.95	380.33	0.64	380.46	0.51
1446.2	380.98	380.05	0.93	380.35	0.62	380.49	0.49
Kokopu Street Concrete Wall ↑							
Kokopu Street Floodwall:							
1446.3	380.98	380.05	0.93	380.35	0.63	380.49	0.50
1454.0	381.03	380.09	0.94	380.39	0.64	380.53	0.50
1460.5	381.09	380.11	0.97	380.42	0.67	380.55	0.53
1466.0	381.13	380.13	0.99	380.44	0.69	380.57	0.55
1493.5	381.28	380.24	1.04	380.55	0.74	380.68	0.60
1495.4	381.26	380.24	1.02	380.55	0.71	380.68	0.57
Kokopu Street Floodwall ↑							
Kokopu Street Stopbank:							
1496.8	381.30	380.24	1.06	380.55	0.76	380.68	0.62
1506.9	381.42	380.28	1.14	380.59	0.83	380.73	0.69
1513.8	381.47	380.32	1.14	380.63	0.83	380.77	0.70
Kokopu Street Stopbank ↑							
Kokopu to Koura Street Floodwall:							
1516.1	381.55	380.32	1.23	380.63	0.92	380.77	0.78
1519.8	381.53	380.35	1.19	380.65	0.88	380.79	0.74
1530.9	381.49	380.39	1.10	380.70	0.79	380.84	0.65
1539.1	381.53	380.43	1.10	380.74	0.79	380.88	0.65
1582.6	381.66	380.60	1.06	380.91	0.75	380.98	0.68
Kokopu to Koura Street Floodwall ↑							
Kokopu to Koura Street Stopbank:							
1582.6	381.66	380.60	1.06	380.91	0.75	380.98	0.68
1582.8	381.51	380.60	0.91	380.91	0.60	380.98	0.54
1587.9	381.52	380.62	0.90	380.93	0.58	381.08	0.44
1606.5	381.59	380.70	0.89	381.02	0.58	381.16	0.43
1626.6	381.71	380.78	0.93	381.10	0.61	381.24	0.46
1646.1	381.76	380.86	0.90	381.18	0.58	381.33	0.43
1666.4	381.83	380.93	0.90	381.26	0.57	381.41	0.42
1686.0	381.83	381.01	0.82	381.34	0.49	381.50	0.34
1705.3	381.81	381.09	0.72	381.43	0.39	381.58	0.23
1719.7	381.92	381.13	0.79	381.47	0.45	381.62	0.30
1724.7	382.12	381.16	0.96	381.49	0.63	381.65	0.47
1733.3	382.34	381.21	1.13	381.54	0.80	381.69	0.64
Kokopu to Koura Street Stopbank ↑							
Tahawai Street Timber Floodwall:							
1734.6	382.43	381.21	1.23	381.54	0.89	381.69	0.74
1737.1	382.58	381.23	1.35	381.56	1.02	381.72	0.87
1737.2	382.84	381.23	1.61	381.56	1.28	381.72	1.13

Ch. (m)	Asset Crest Level (m)	Modelled water levels and free boards for various design events:					
		Q_p1500	Free-board (m)	Q_p1700	Free-board (m)	Q_p1800	Free-board (m)
1737.3	382.84	381.23	1.62	381.56	1.28	381.72	1.13
1743.2	382.86	381.25	1.61	381.59	1.27	381.74	1.12
1761.8	382.84	381.35	1.49	381.68	1.16	381.83	1.01
Tahawai Street Timber Floodwall ↑							
Tahawai Street Stopbank:							
1762.5	382.98	381.37	1.61	381.70	1.28	381.85	1.13
1771.6	383.07	381.42	1.65	381.75	1.32	381.90	1.17
1787.4	383.12	381.46	1.66	381.79	1.33	381.94	1.18
1806.9	383.15	381.53	1.62	381.85	1.29	382.00	1.14
1827.1	383.33	381.60	1.74	381.92	1.41	382.07	1.27
1847.7	383.25	381.69	1.56	382.01	1.24	382.16	1.10
1868.2	383.24	381.76	1.48	382.08	1.17	382.22	1.02
1887.3	383.32	381.86	1.46	382.17	1.15	382.32	1.01
1907.6	383.40	381.95	1.45	382.27	1.14	382.41	1.00
1911.0	383.31	381.98	1.33	382.29	1.02	382.43	0.88
1916.7	383.06	382.00	1.06	382.31	0.75	382.46	0.61
1926.9	383.07	382.05	1.01	382.36	0.70	382.50	0.56
1940.0	383.10	382.10	1.00	382.41	0.69	382.55	0.55
1958.2	383.25	382.21	1.04	382.51	0.74	382.65	0.60
1977.1	383.34	382.29	1.05	382.59	0.75	382.73	0.61
1997.7	383.38	382.39	0.99	382.69	0.69	382.83	0.55
2017.6	383.42	382.49	0.93	382.80	0.62	382.93	0.49
2036.3	383.64	382.60	1.05	382.90	0.75	383.04	0.61
2057.6	383.71	382.70	1.01	383.00	0.71	383.14	0.57
2071.4	383.76	382.75	1.01	383.05	0.71	383.19	0.57
2089.8	383.68	382.85	0.83	383.15	0.53	383.29	0.39
2099.0	383.71	382.93	0.79	383.22	0.49	383.36	0.35
2106.8	383.77	382.96	0.81	383.26	0.51	383.40	0.37
2113.7	383.92	383.03	0.89	383.33	0.59	383.47	0.45
2133.1	383.98	383.13	0.85	383.43	0.55	383.57	0.41
2152.4	384.02	383.27	0.75	383.57	0.45	383.71	0.31
2160.4	384.09	383.33	0.76	383.63	0.46	383.77	0.32
2169.5	384.18	383.33	0.85	383.63	0.54	383.77	0.40
2183.8	384.15	383.33	0.82	383.63	0.51	383.77	0.37
2198.3	384.04	383.33	0.71	383.63	0.40	383.77	0.26
2218.9	384.06	383.33	0.73	383.63	0.43	383.77	0.29
2239.6	384.09	383.33	0.77	383.63	0.46	383.77	0.32
2254.7	384.25	383.33	0.93	383.63	0.62	383.77	0.48
2258.5	384.15	383.33	0.82	383.63	0.52	383.77	0.38
2266.6	384.15	383.33	0.82	383.63	0.52	383.77	0.38
2272.5	384.06	383.33	0.73	383.63	0.43	383.77	0.29
Tahawai Street Stopbank ↑							

Table 13 MIKE11 model results interpolated adjacent to assets – Grace Road to SH1. Freeboard is 500mm in this reach, red shading denotes overtopping, orange shading less than 500mm freeboard.

Ch. (m)	Asset Crest Level (m)	Modelled water levels and free boards for various design events:					
		Q_p1500	Free-board (m)	Q_p1700	Free-board (m)	Q_p1800	Free-board (m)
Grace Road to SH1 Section 1 Stopbank:							
0.00	368.08	367.37	0.70	367.55	0.53	367.63	0.44
15.38	368.32	367.38	0.94	367.56	0.76	367.64	0.68
41.36	368.38	367.39	0.99	367.57	0.81	367.65	0.73
62.00	368.37	367.41	0.96	367.58	0.79	367.66	0.71
77.73	368.36	367.42	0.94	367.60	0.76	367.68	0.68
109.00	368.47	367.44	1.02	367.62	0.85	367.70	0.77
133.90	368.25	367.47	0.78	367.64	0.61	367.72	0.53
151.57	368.28	367.48	0.80	367.65	0.63	367.73	0.55
163.15	368.16	367.49	0.67	367.66	0.50	367.74	0.42
184.17	368.29	367.51	0.78	367.68	0.61	367.76	0.53
198.30	368.22	367.53	0.69	367.69	0.52	367.77	0.44
218.59	368.26	367.55	0.70	367.72	0.53	367.80	0.46
237.58	368.23	367.58	0.65	367.75	0.48	367.82	0.40
252.96	368.31	367.61	0.70	367.78	0.54	367.85	0.46
260.89	368.46	367.64	0.82	367.80	0.66	367.88	0.58
268.25	368.35	367.66	0.70	367.82	0.54	367.89	0.46
275.28	368.23	367.68	0.55	367.84	0.39	367.92	0.31
281.19	368.31	367.69	0.62	367.85	0.46	367.92	0.39
291.85	368.26	367.72	0.54	367.87	0.38	367.95	0.31
303.09	368.38	367.74	0.64	367.89	0.48	367.97	0.41
311.99	368.36	367.76	0.60	367.91	0.45	367.98	0.37
328.53	368.43	367.79	0.64	367.94	0.48	368.01	0.41
342.65	368.34	367.81	0.53	367.96	0.38	368.03	0.31
354.63	368.41	367.85	0.56	368.00	0.41	368.07	0.34
367.19	368.60	367.87	0.74	368.02	0.59	368.09	0.52
384.23	368.75	367.91	0.84	368.06	0.69	368.13	0.62
397.35	368.62	367.94	0.68	368.09	0.54	368.16	0.47
406.87	368.59	367.98	0.61	368.12	0.47	368.19	0.40
408.15	368.60	368.07	0.53	368.21	0.38	368.28	0.32
423.06	368.70	368.14	0.56	368.28	0.42	368.35	0.36
441.32	368.78	368.19	0.59	368.33	0.45	368.40	0.39
453.86	368.78	368.19	0.59	368.33	0.44	368.40	0.38
457.33	368.65	368.19	0.46	368.33	0.32	368.40	0.25
Grace Road to SH1 Section 1 Stopbank ↑							
Tongariro Lodge Timber Floodwall:							
457.50	368.75	368.19	0.56	368.33	0.42	368.40	0.35
463.53	368.78	368.21	0.57	368.35	0.43	368.42	0.36
475.64	368.87	368.28	0.59	368.42	0.45	368.49	0.38
487.26	368.92	368.32	0.60	368.46	0.46	368.52	0.40
493.75	368.96	368.34	0.62	368.48	0.48	368.55	0.41
503.89	369.01	368.38	0.62	368.52	0.48	368.59	0.42
505.78	369.02	368.38	0.63	368.52	0.49	368.59	0.43
505.84	369.07	368.38	0.68	368.52	0.54	368.59	0.48
506.30	369.06	368.38	0.68	368.52	0.54	368.59	0.48
506.96	369.07	368.38	0.69	368.52	0.55	368.59	0.48
507.55	369.08	368.38	0.69	368.52	0.55	368.59	0.49
508.06	369.07	368.38	0.69	368.52	0.55	368.59	0.48
508.33	369.07	368.38	0.69	368.52	0.55	368.59	0.48
508.38	369.08	368.38	0.70	368.52	0.56	368.59	0.49
509.81	369.10	368.38	0.72	368.52	0.58	368.59	0.51

Ch. (m)	Asset Crest Level (m)	Modelled water levels and free boards for various design events:					
		Q_p1500	Free-board (m)	Q_p1700	Free-board (m)	Q_p1800	Free-board (m)
510.37	369.16	368.38	0.78	368.52	0.64	368.59	0.57
514.72	369.17	368.40	0.77	368.54	0.63	368.61	0.56
518.35	369.17	368.42	0.74	368.56	0.61	368.63	0.54
523.68	369.17	368.44	0.73	368.58	0.59	368.65	0.52
527.28	369.16	368.45	0.71	368.59	0.57	368.66	0.51
531.48	369.15	368.47	0.68	368.61	0.54	368.67	0.47
534.36	369.13	368.47	0.66	368.61	0.52	368.67	0.46
537.59	369.18	368.49	0.70	368.63	0.56	368.69	0.49
543.27	369.25	368.51	0.74	368.65	0.60	368.71	0.54
Tongariro Lodge Timber Floodwall ↑							
Grace Road to SH1 Section 2 Stopbank :							
544.88	369.21	368.51	0.70	368.65	0.56	368.71	0.50
564.77	369.49	368.57	0.91	368.71	0.78	368.78	0.71
583.00	369.69	368.62	1.07	368.76	0.93	368.83	0.86
591.61	369.68	368.66	1.02	368.80	0.89	368.86	0.82
601.90	369.84	368.69	1.15	368.83	1.01	368.90	0.95
611.79	369.70	368.72	0.98	368.86	0.84	368.93	0.77
621.65	369.87	368.81	1.06	368.95	0.92	369.02	0.85
630.24	369.88	368.83	1.06	368.97	0.91	369.04	0.85
638.56	370.03	368.88	1.15	369.02	1.01	369.09	0.94
649.30	369.95	368.93	1.02	369.08	0.87	369.15	0.80
666.48	370.03	368.99	1.04	369.14	0.89	369.21	0.82
680.75	370.17	369.06	1.11	369.21	0.96	369.29	0.89
699.39	370.15	369.16	0.98	369.32	0.83	369.39	0.76
704.50	370.24	369.16	1.08	369.32	0.93	369.39	0.85
714.48	370.40	369.21	1.19	369.37	1.03	369.44	0.96
721.38	370.38	369.24	1.14	369.39	0.98	369.47	0.91
729.23	370.31	369.26	1.05	369.42	0.89	369.50	0.82
736.24	370.46	369.28	1.17	369.44	1.01	369.52	0.94
742.66	370.47	369.30	1.17	369.46	1.01	369.54	0.93
749.52	370.52	369.33	1.19	369.49	1.03	369.56	0.95
759.43	370.56	369.37	1.18	369.53	1.02	369.61	0.94
771.09	370.54	369.41	1.12	369.58	0.96	369.66	0.88
795.58	370.65	369.53	1.12	369.70	0.95	369.78	0.87
810.34	370.65	369.62	1.04	369.78	0.87	369.86	0.79
830.60	370.75	369.69	1.06	369.86	0.88	369.94	0.80
850.67	370.94	369.80	1.14	369.97	0.97	370.06	0.89
870.81	371.06	369.91	1.15	370.09	0.97	370.17	0.89
880.25	370.96	369.97	0.99	370.15	0.81	370.23	0.73
888.82	370.96	370.03	0.93	370.21	0.76	370.29	0.67
898.46	370.97	370.09	0.88	370.27	0.70	370.35	0.61
906.82	371.06	370.12	0.94	370.30	0.76	370.39	0.67
915.32	371.14	370.18	0.96	370.36	0.78	370.45	0.69
925.15	371.22	370.24	0.98	370.43	0.79	370.51	0.71
934.19	371.31	370.31	1.00	370.49	0.82	370.58	0.73
945.51	371.35	370.37	0.98	370.55	0.80	370.64	0.71
955.89	371.36	370.40	0.95	370.59	0.77	370.68	0.68
Grace Road to SH1 Section 2 Stopbank ↑							
Herekiekie St Timber Floodwall with earth fill:							
958.64	371.33	370.44	0.89	370.63	0.70	370.72	0.61
959.39	371.32	370.44	0.87	370.63	0.69	370.72	0.60
968.20	371.37	370.49	0.88	370.63	0.69	370.76	0.61
Herekiekie St Timber Floodwall with earth fill ↑							

Ch. (m)	Asset Crest Level (m)	Modelled water levels and free boards for various design events:					
		Q_p1500	Free-board (m)	Q_p1700	Free-board (m)	Q_p1800	Free-board (m)
Grace Road to SH1 Section 3 Stopbank:							
978.3	371.38	370.58	0.80	370.77	0.61	370.85	0.53
1003.1	371.48	370.67	0.81	370.86	0.62	370.95	0.53
1024.3	371.71	370.77	0.94	370.96	0.75	371.05	0.66
1044.1	371.90	370.90	1.00	371.09	0.81	371.18	0.72
1068.2	371.98	371.09	0.89	371.28	0.70	371.38	0.61
1111.8	372.32	371.40	0.93	371.60	0.73	371.69	0.63
1153.4	372.72	371.61	1.11	371.83	0.89	371.91	0.81
1171.5	372.90	371.73	1.16	371.97	0.92	372.03	0.86
1198.9	373.08	371.78	1.30	372.03	1.05	372.08	1.00
1233.2	373.35	371.95	1.40	372.22	1.13	372.26	1.09
1246.4	373.77	371.99	1.77	372.27	1.49	372.30	1.47
1263.7	374.39	372.08	2.31	372.36	2.02	372.38	2.00
Grace Road to SH1 Section 3 Stopbank ↑							

Appendix B – River channel cross-section comparison - 2009 and 2016 surveys

Note: Not all cross-sections are included – only where alignment is comparable

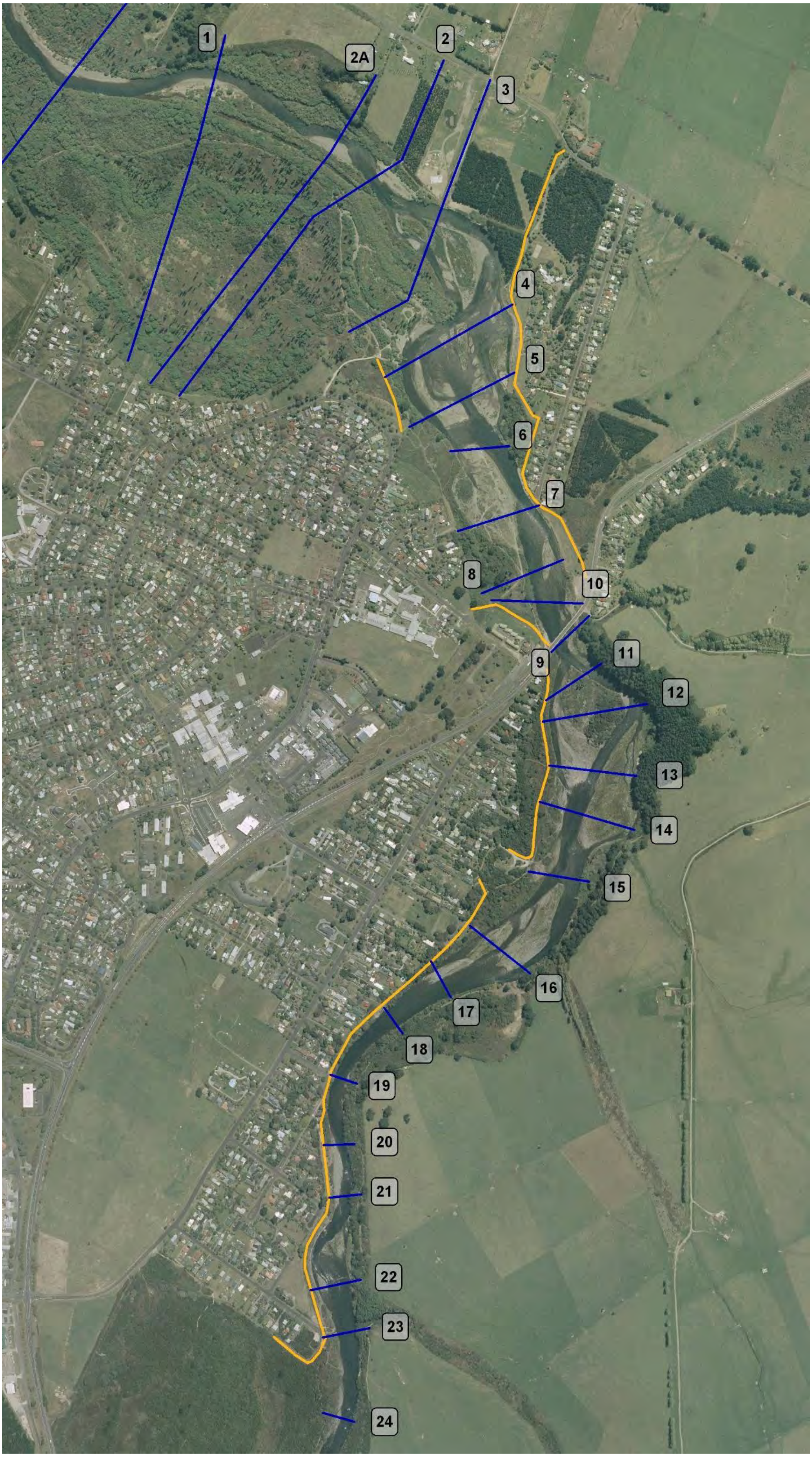

Figure 15 **Cross-section locations.**

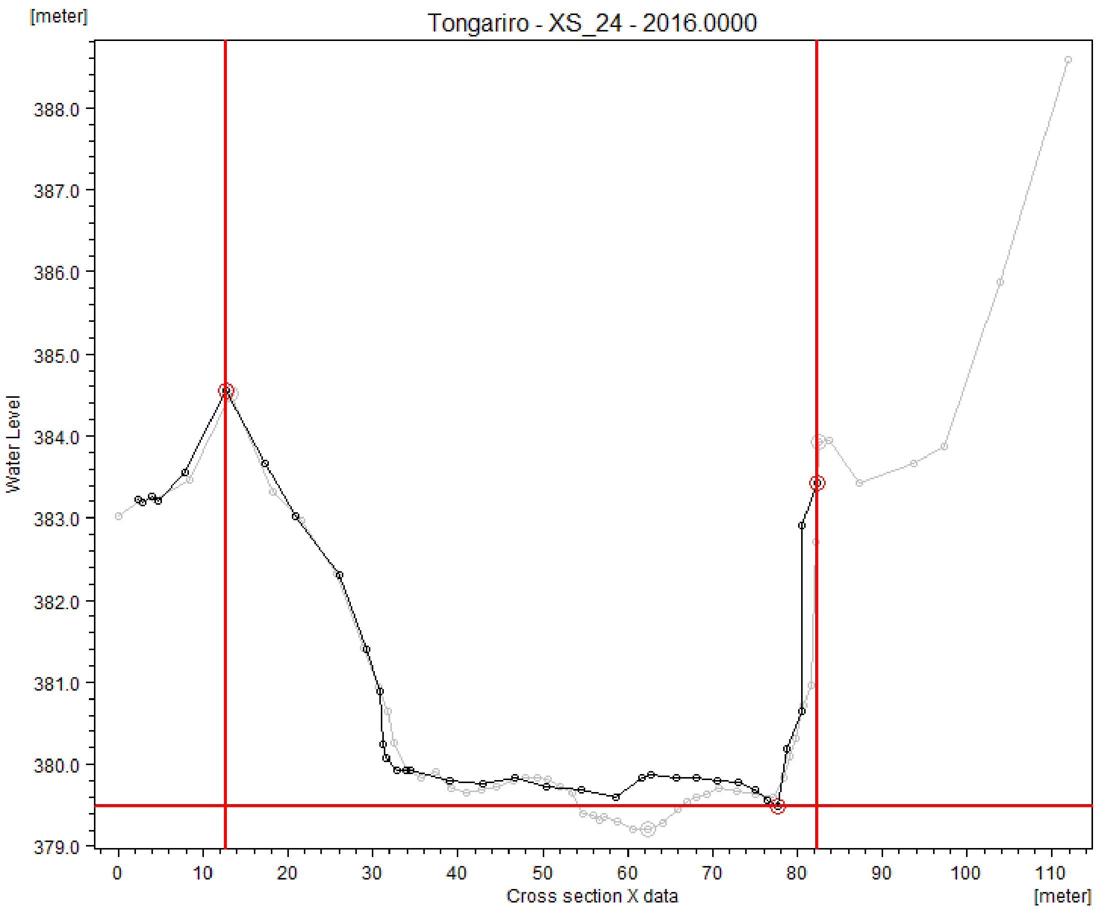

Figure 16 **Cross-section 24 – 2016 (black), 2009 (grey)**

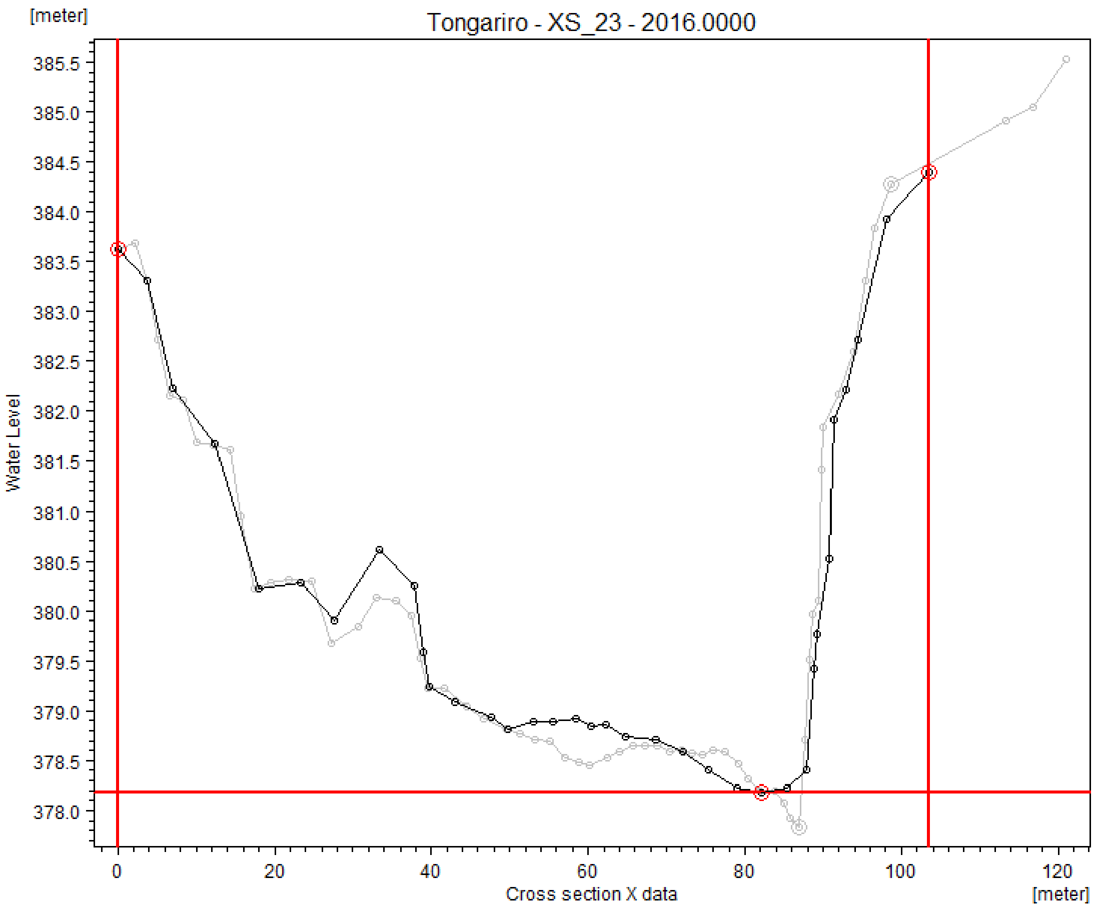

Figure 17 **Cross-section 23 – 2016 (black), 2009 (grey)**

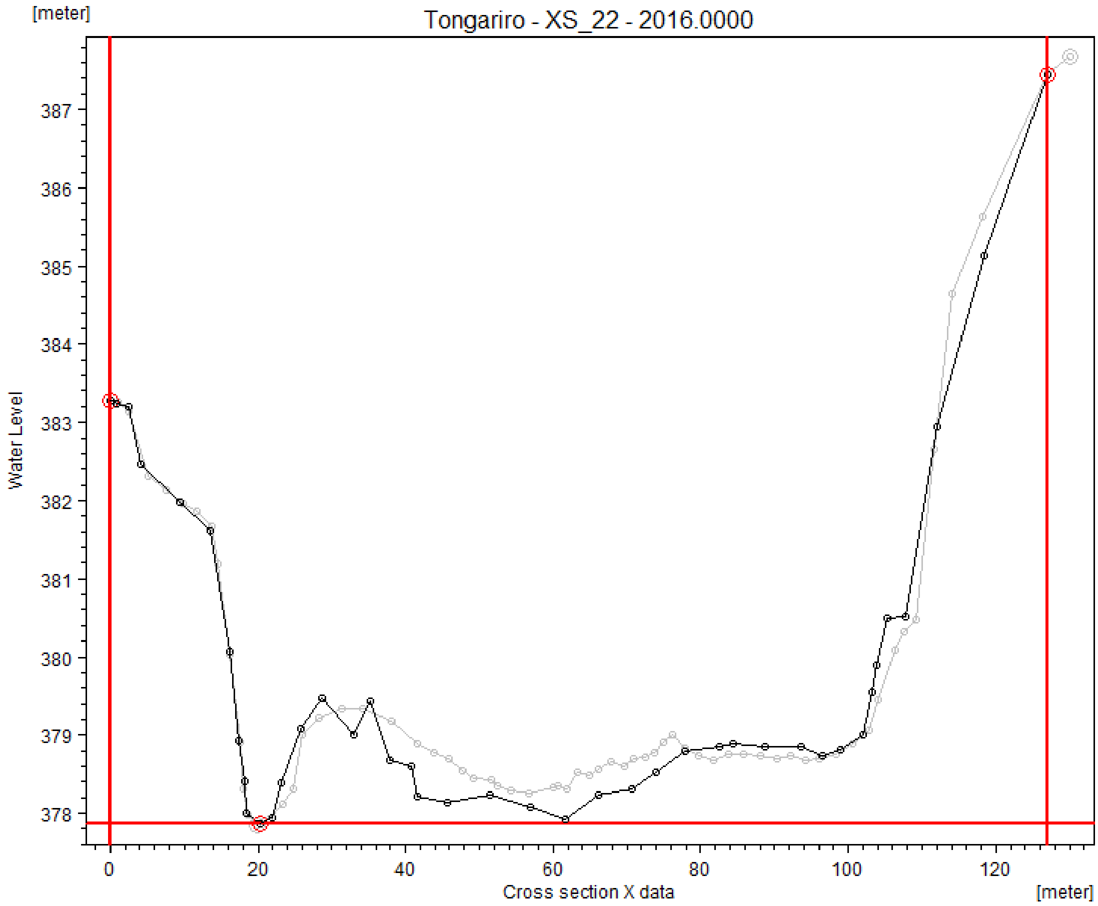

Figure 18 Cross-section 22 – 2016 (black), 2009 (grey)

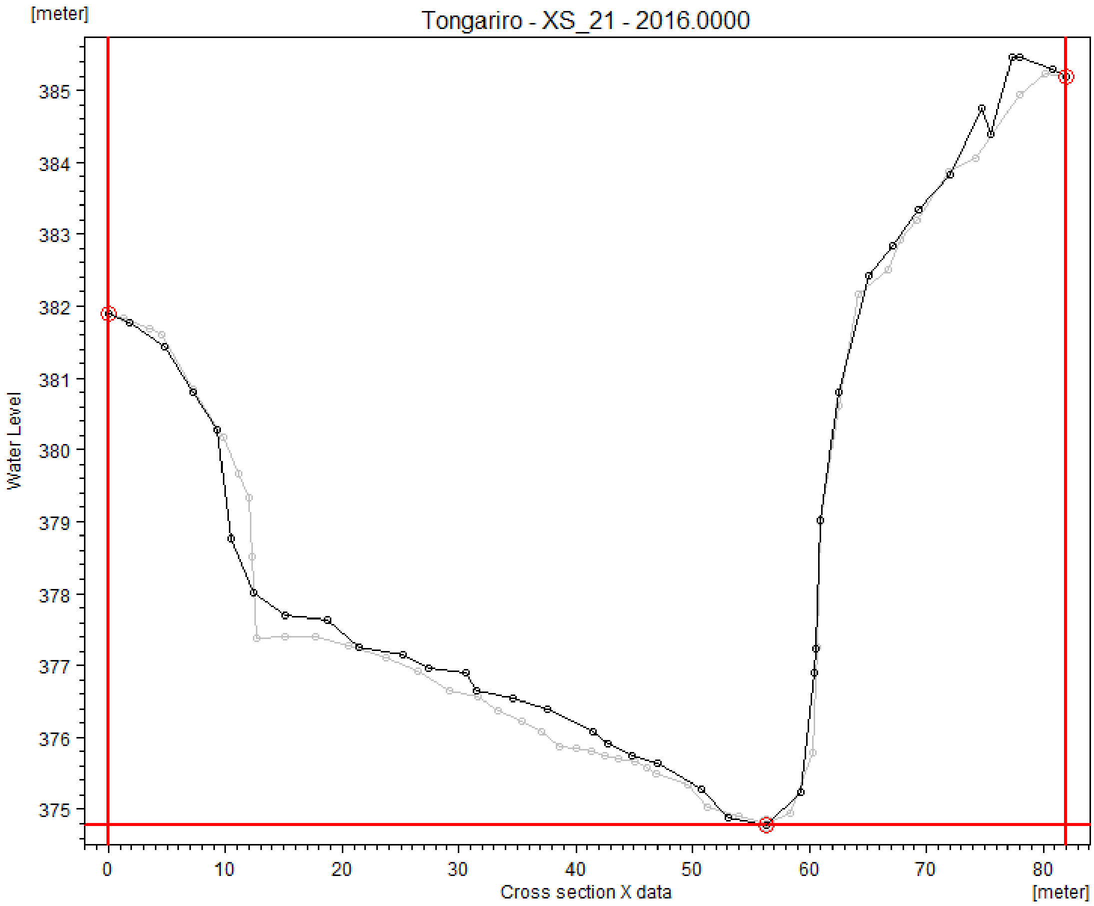

Figure 19 Cross-section 21 – 2016 (black), 2009 (grey)

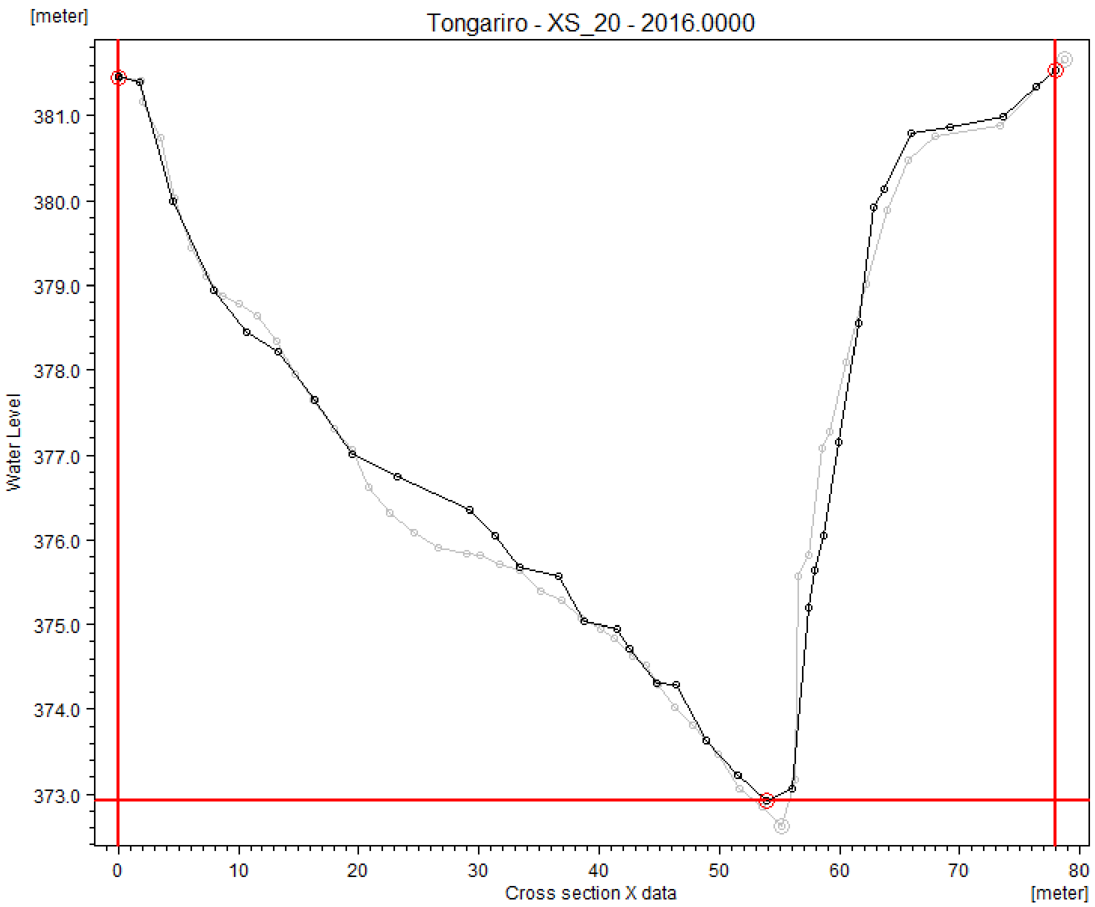

Figure 20 Cross-section 20 – 2016 (black), 2009 (grey)

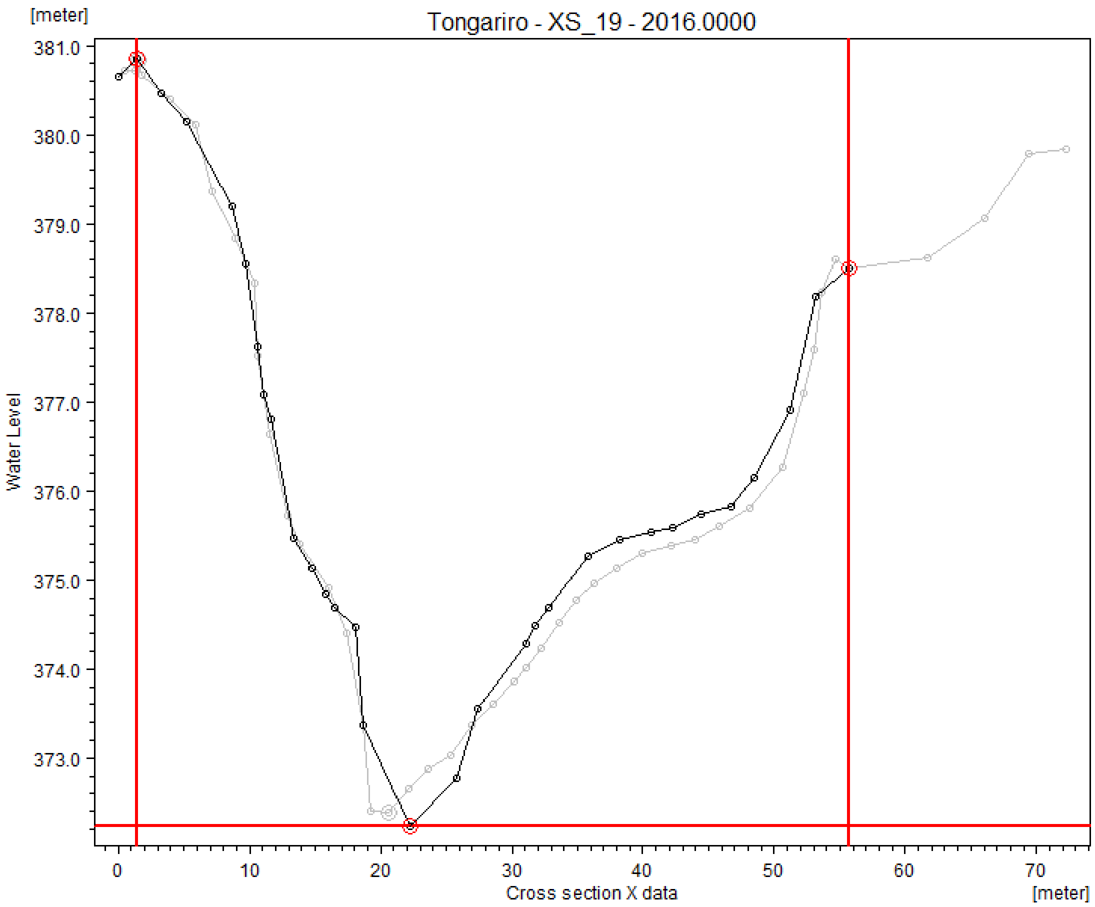

Figure 21 Cross-section 19 – 2016 (black), 2009 (grey)

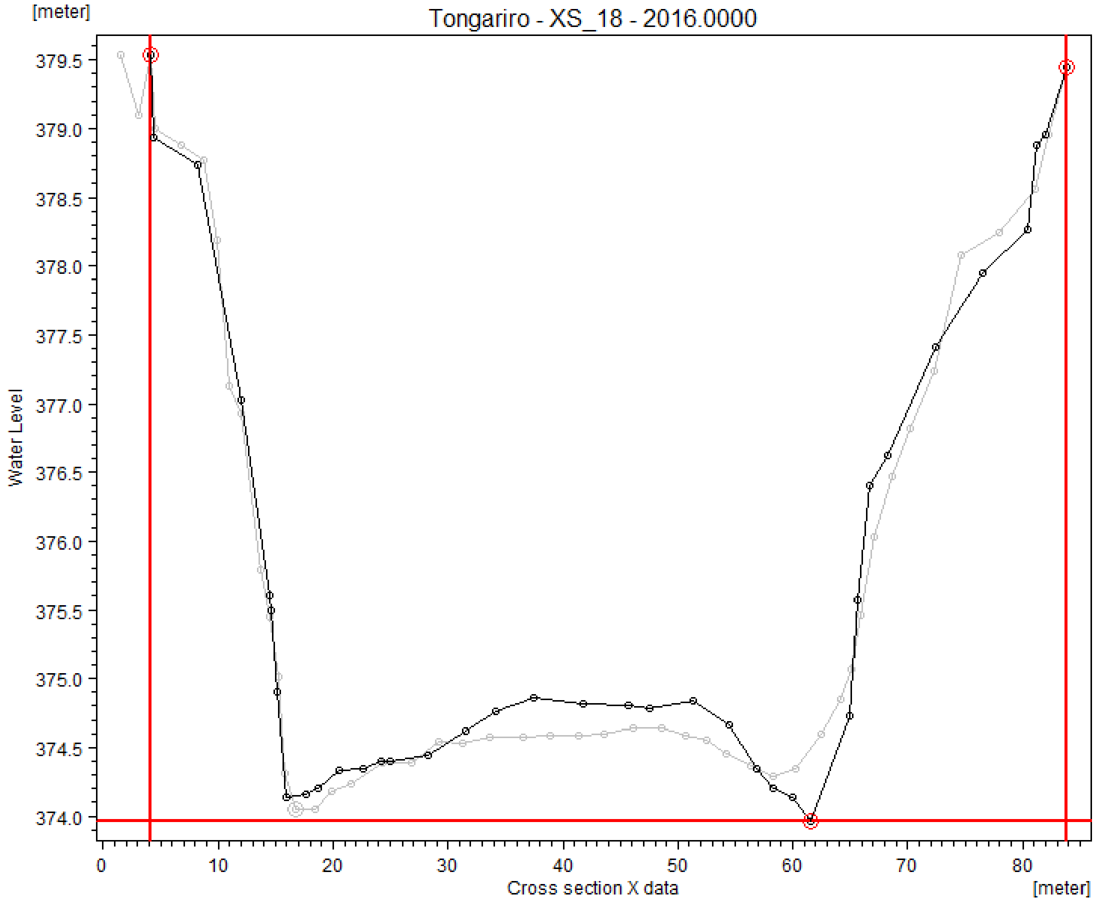

Figure 22 Cross-section 18 – 2016 (black), 2009 (grey)

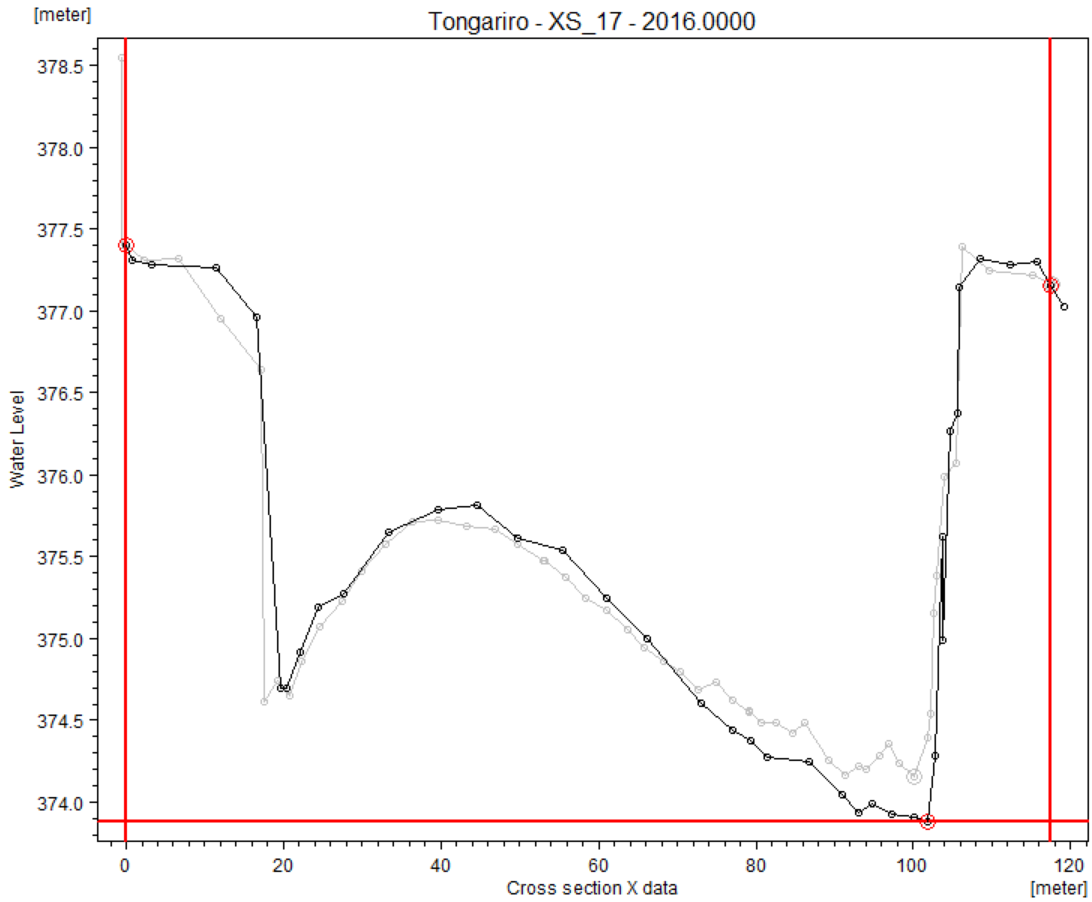

Figure 23 Cross-section 17 – 2016 (black), 2009 (grey)

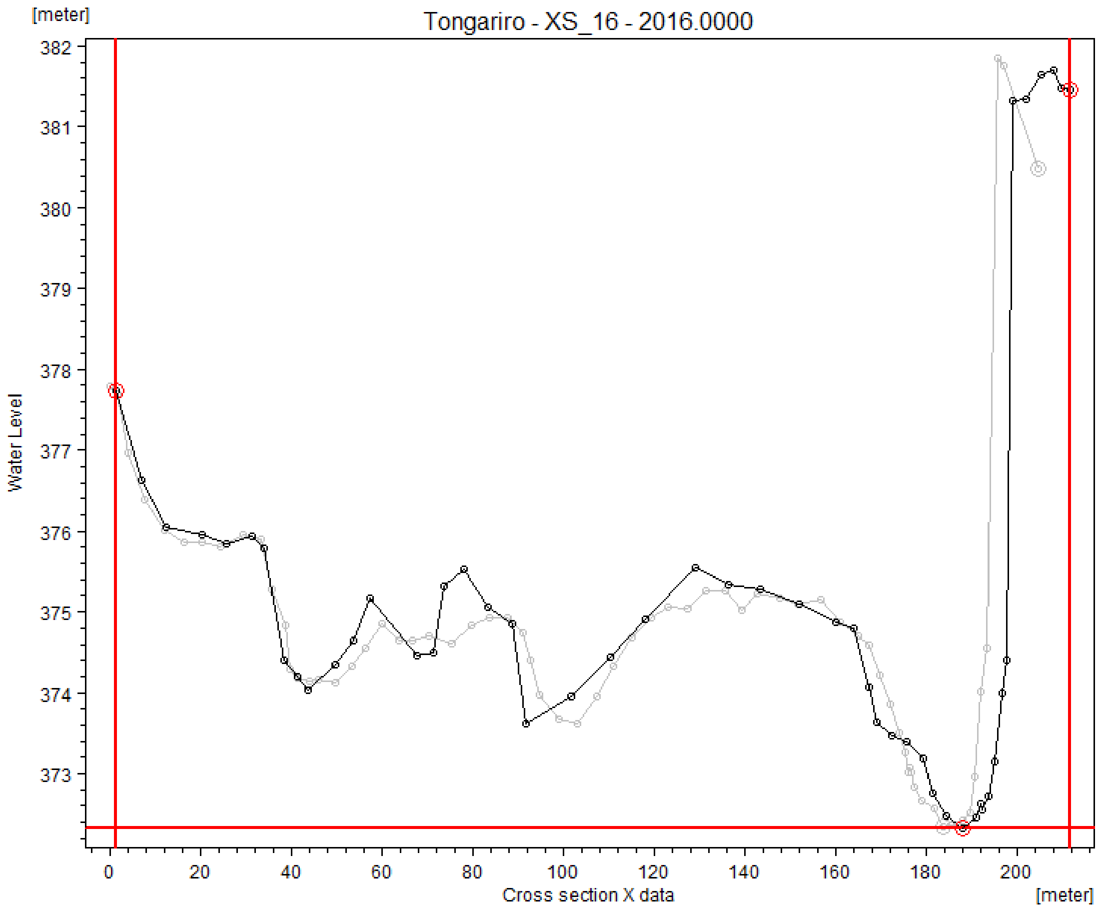

Figure 24 **Cross-section 16 – 2016 (black), 2009 (grey)**

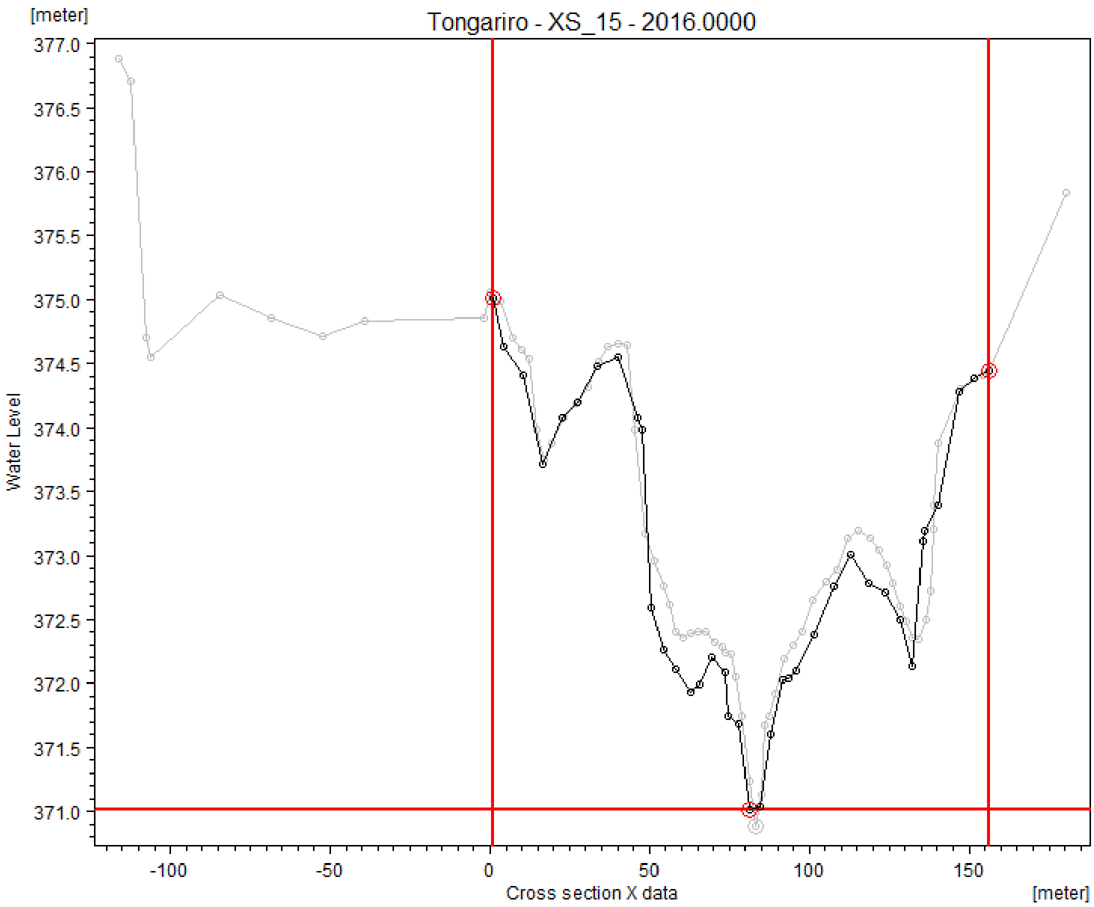

Figure 25 **Cross-section 15 – 2016 (black), 2009 (grey)**

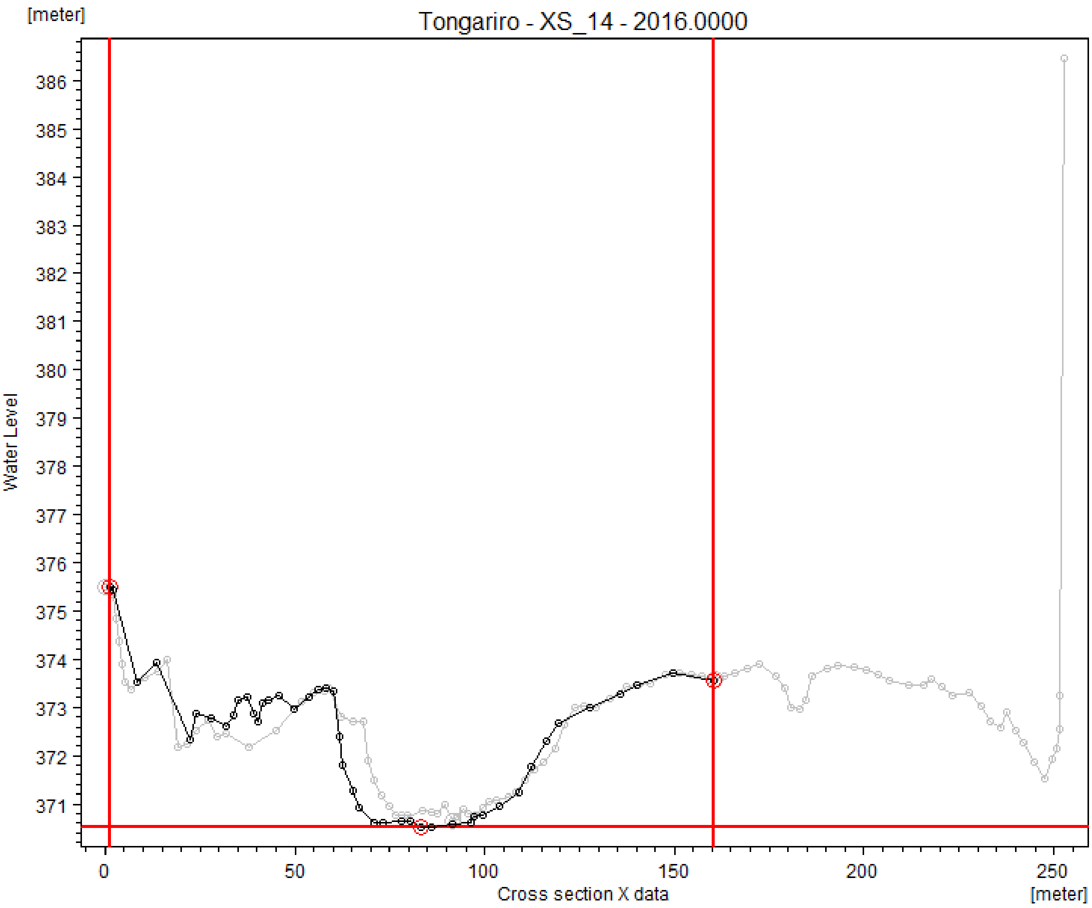

Figure 26 Cross-section 14 – 2016 (black), 2009 (grey)

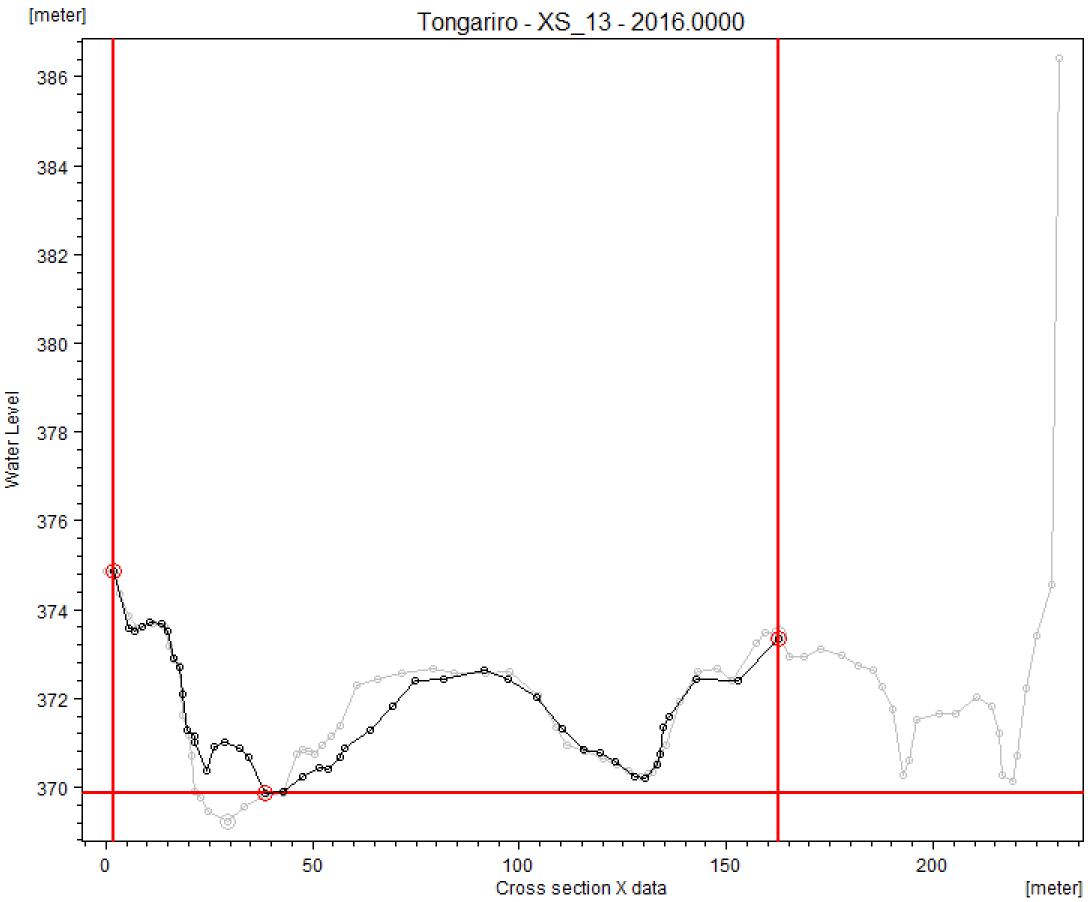

Figure 27 Cross-section 13 – 2016 (black), 2009 (grey)

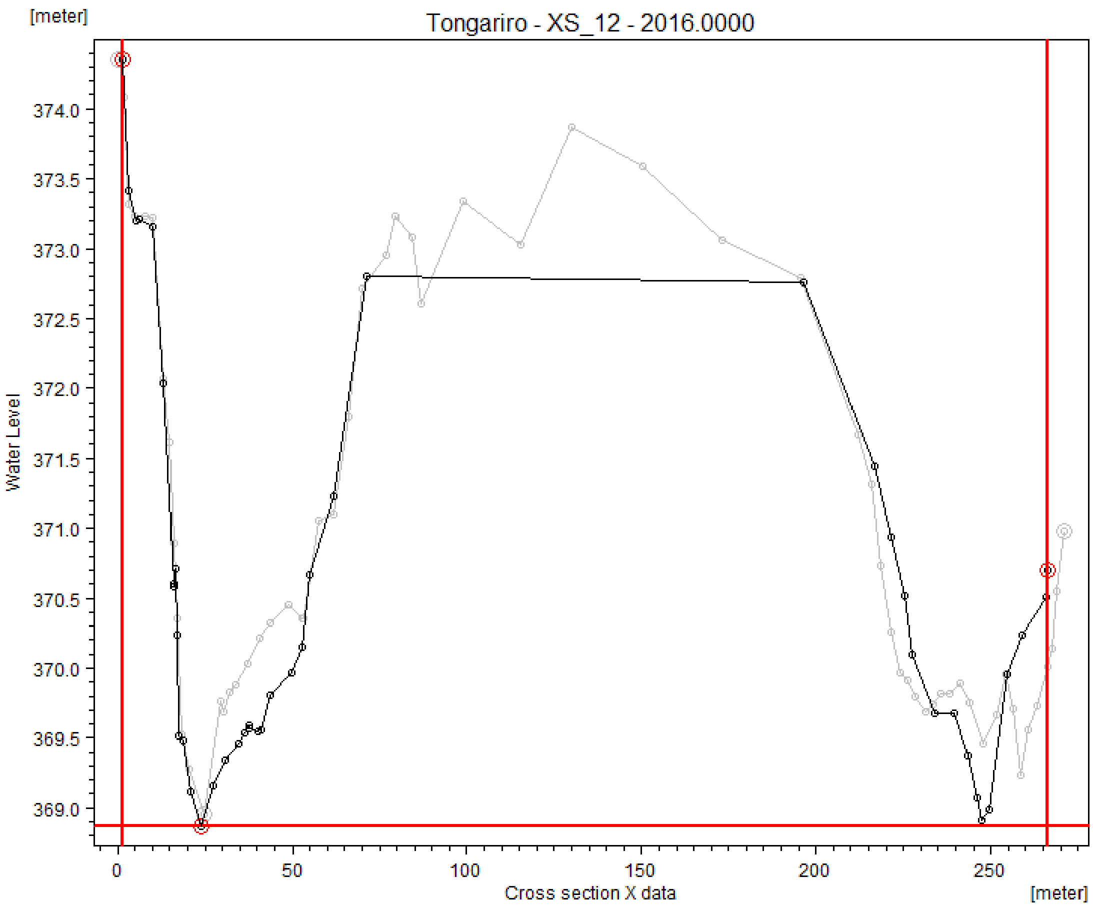

Figure 28 Cross-section 12 – 2016 (black), 2009 (grey), note 'island' not surveyed 2016.

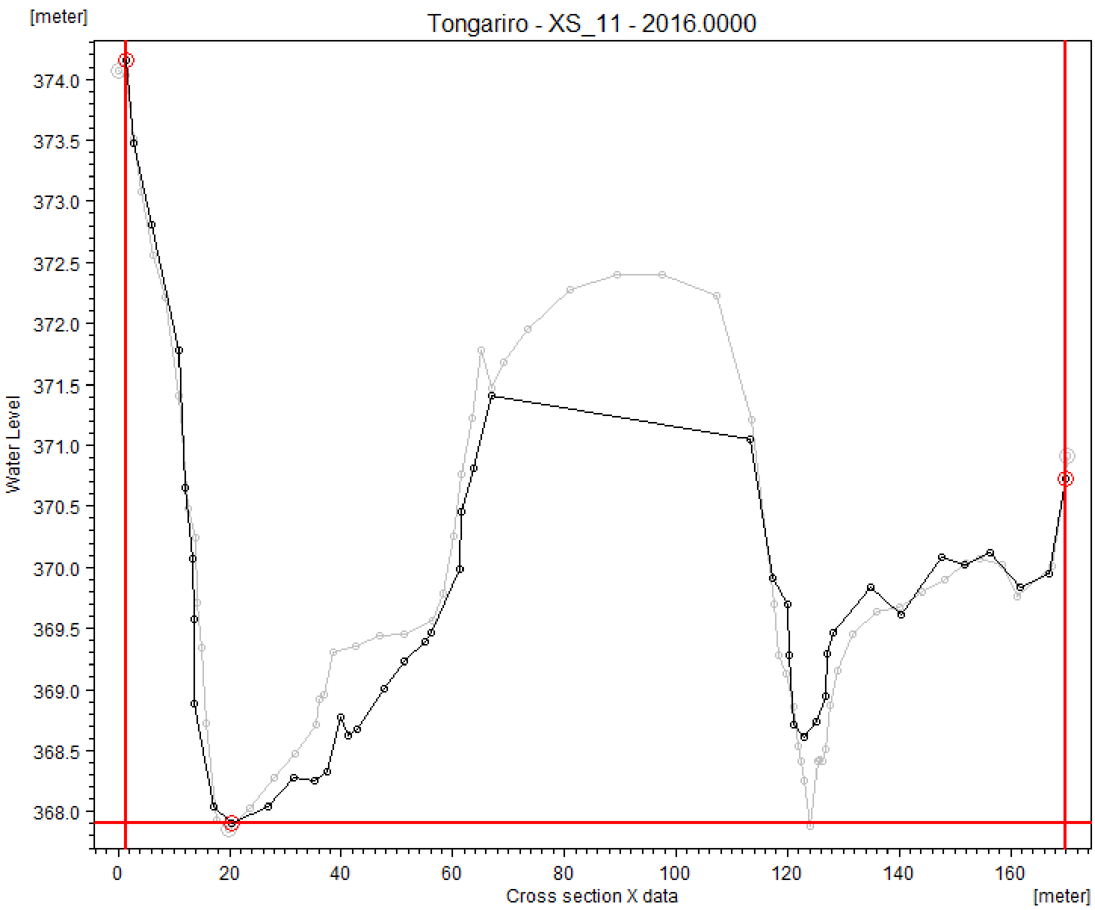

Figure 29 Cross-section 11 – 2016 (black), 2009 (grey), note 'island' not surveyed 2016.

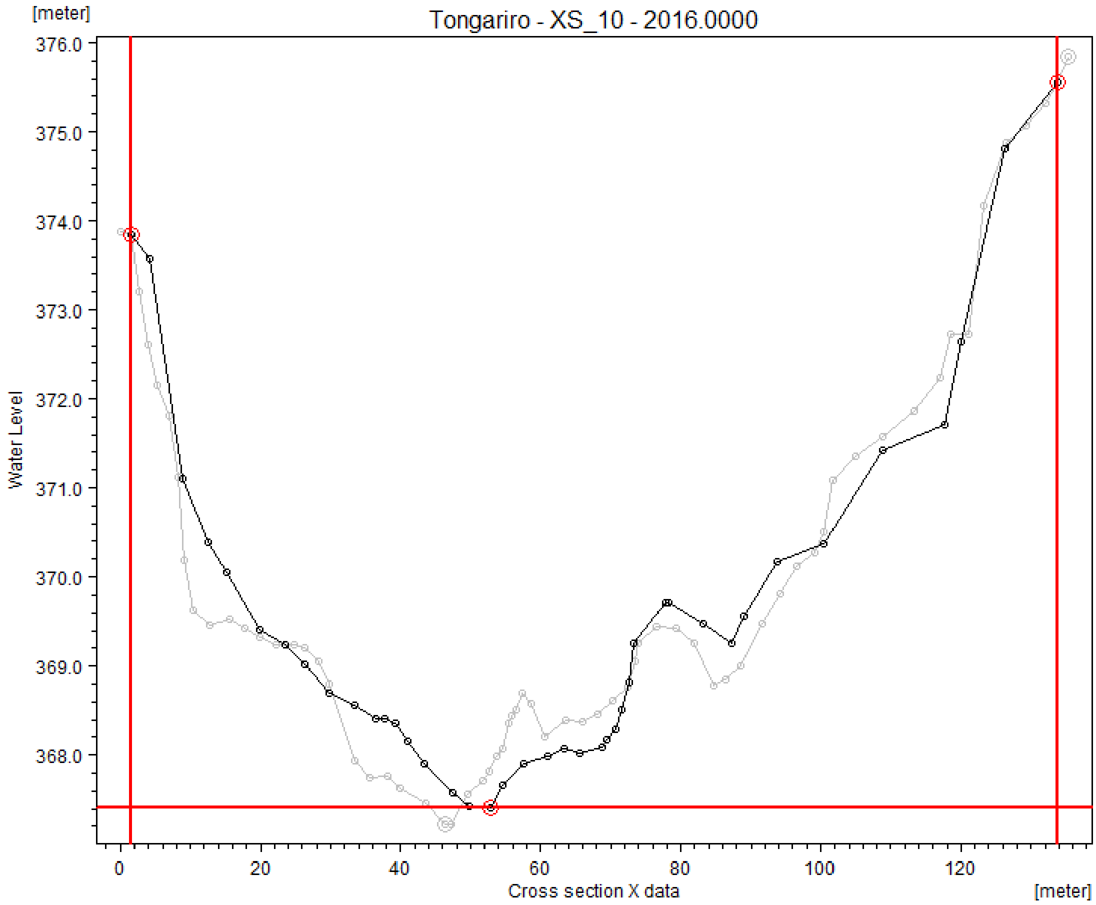

Figure 30 **Cross-section 10 – 2016 (black), 2009 (grey)**

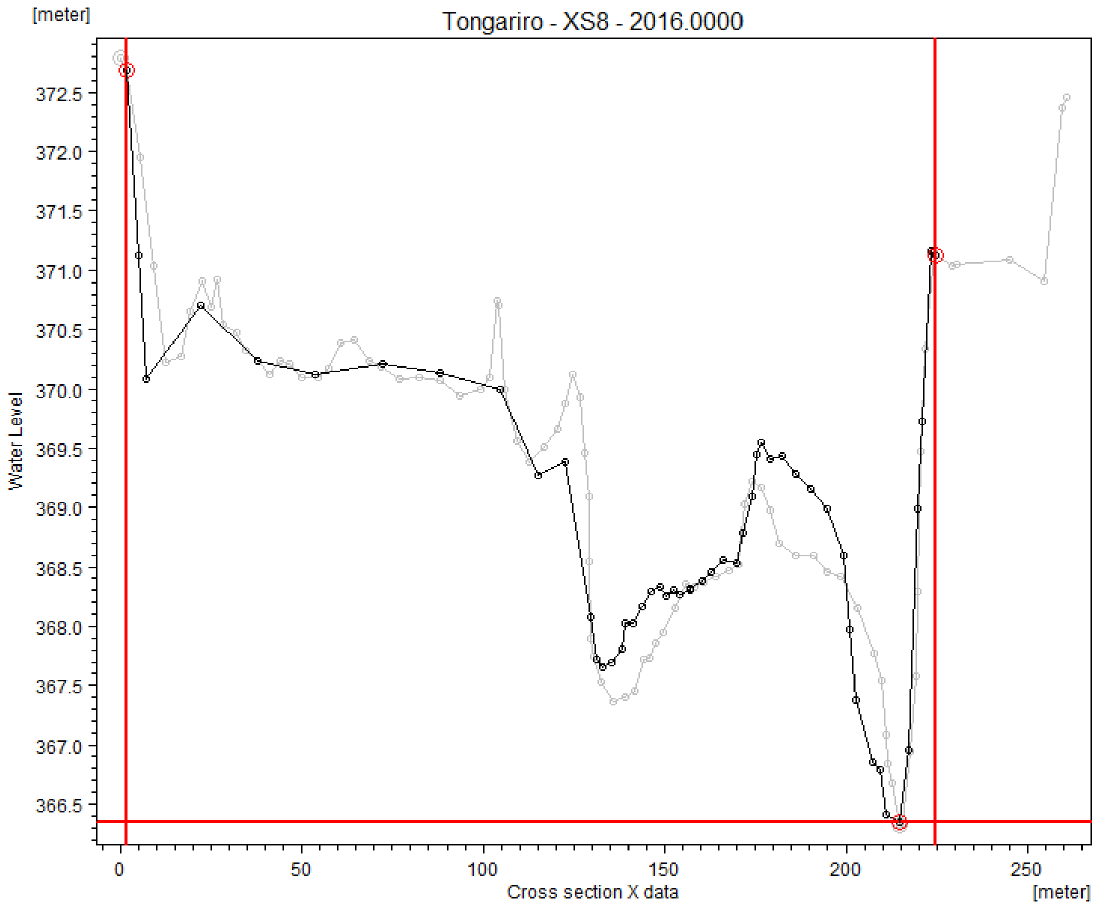

Figure 31 **Cross-section 8 – 2016 (black), 2009 (grey)**

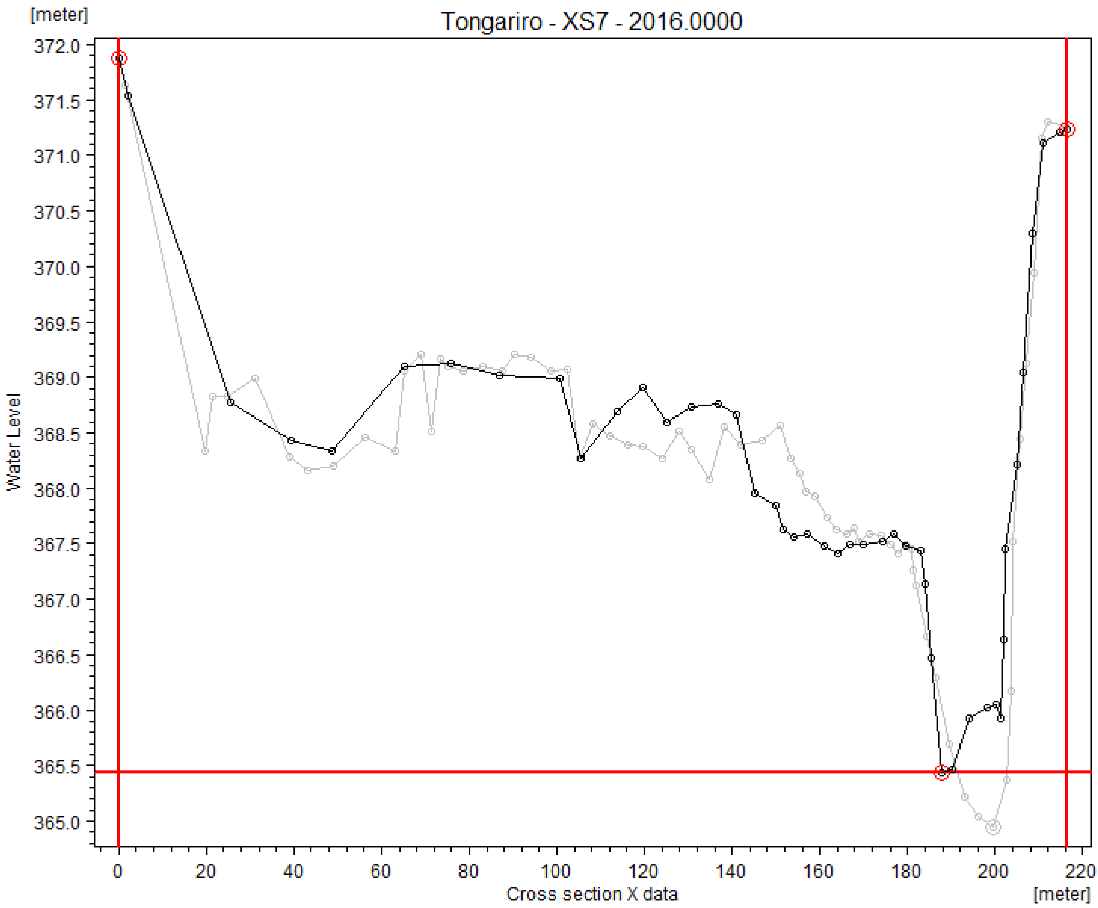

Figure 32 **Cross-section 7 – 2016 (black), 2009 (grey)**

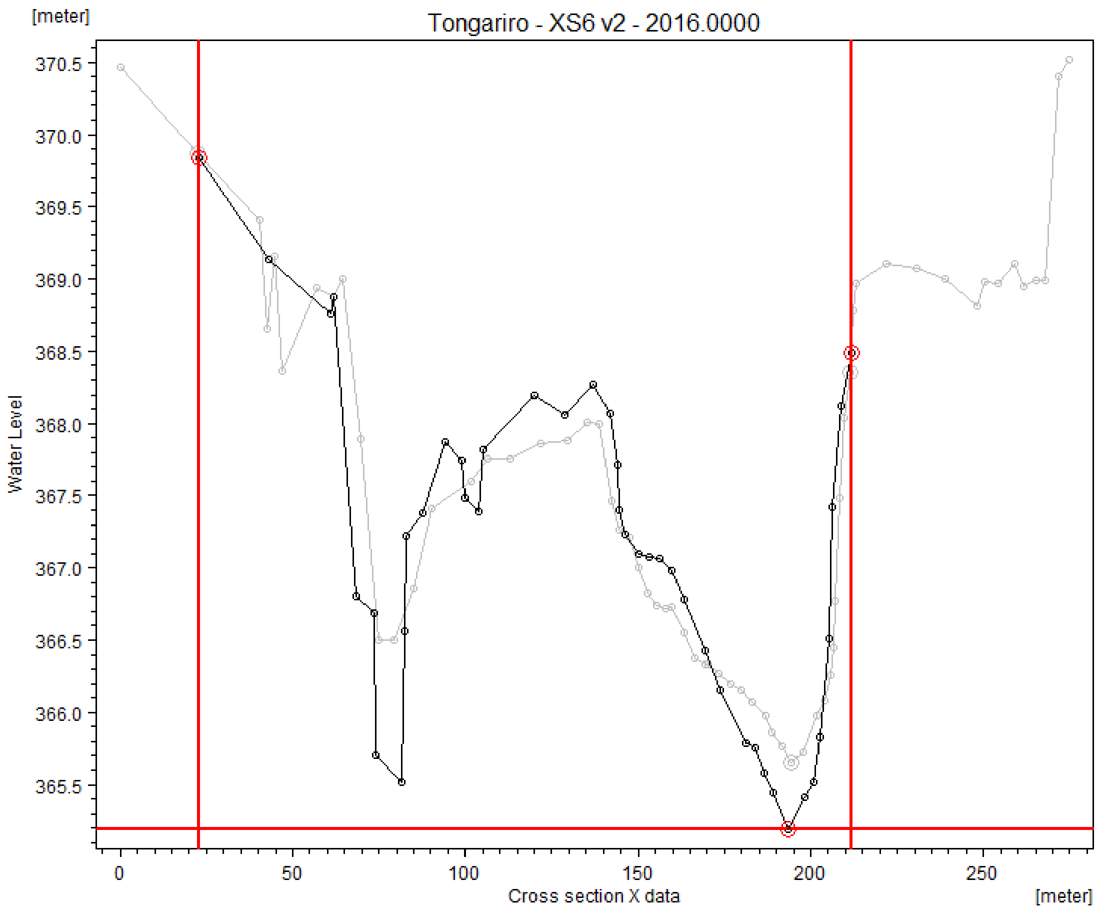

Figure 33 **Cross-section 6 – 2016 (black), 2009 (grey)**

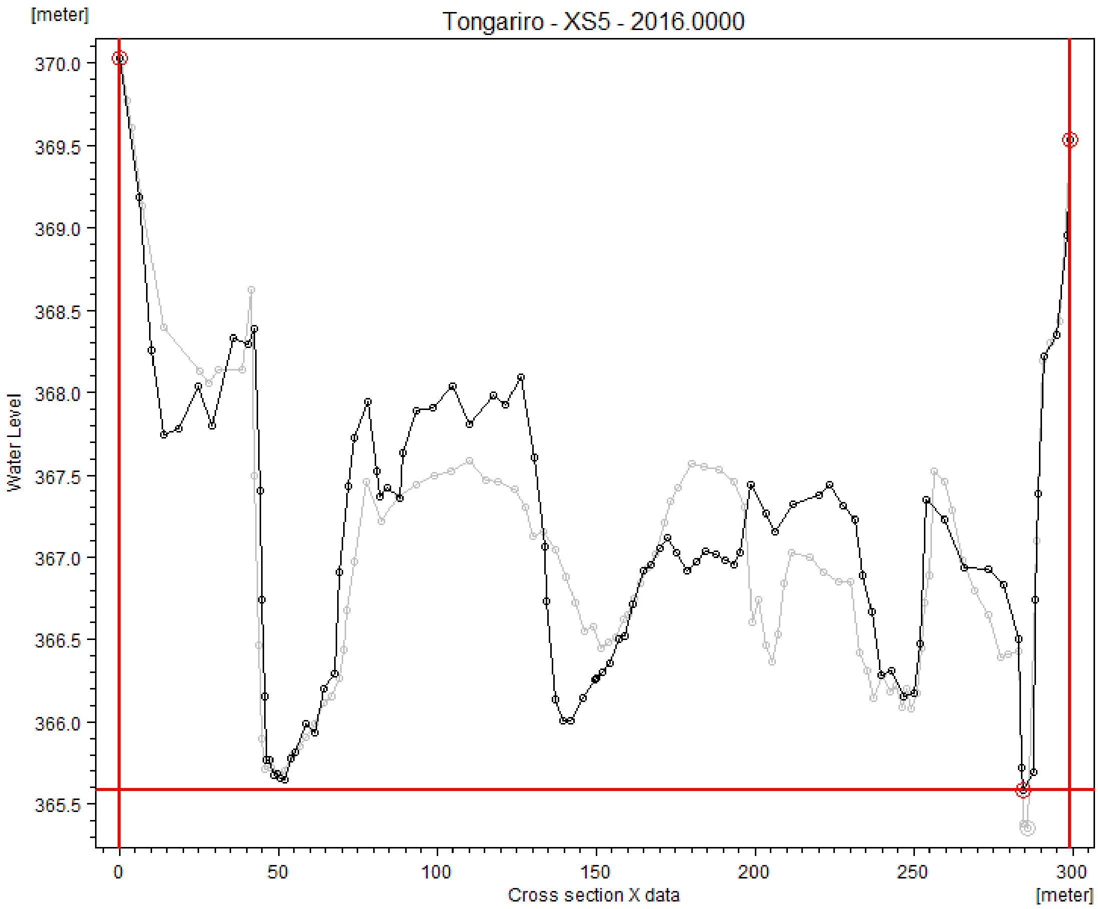

Figure 34 **Cross-section 5 – 2016 (black), 2009 (grey)**

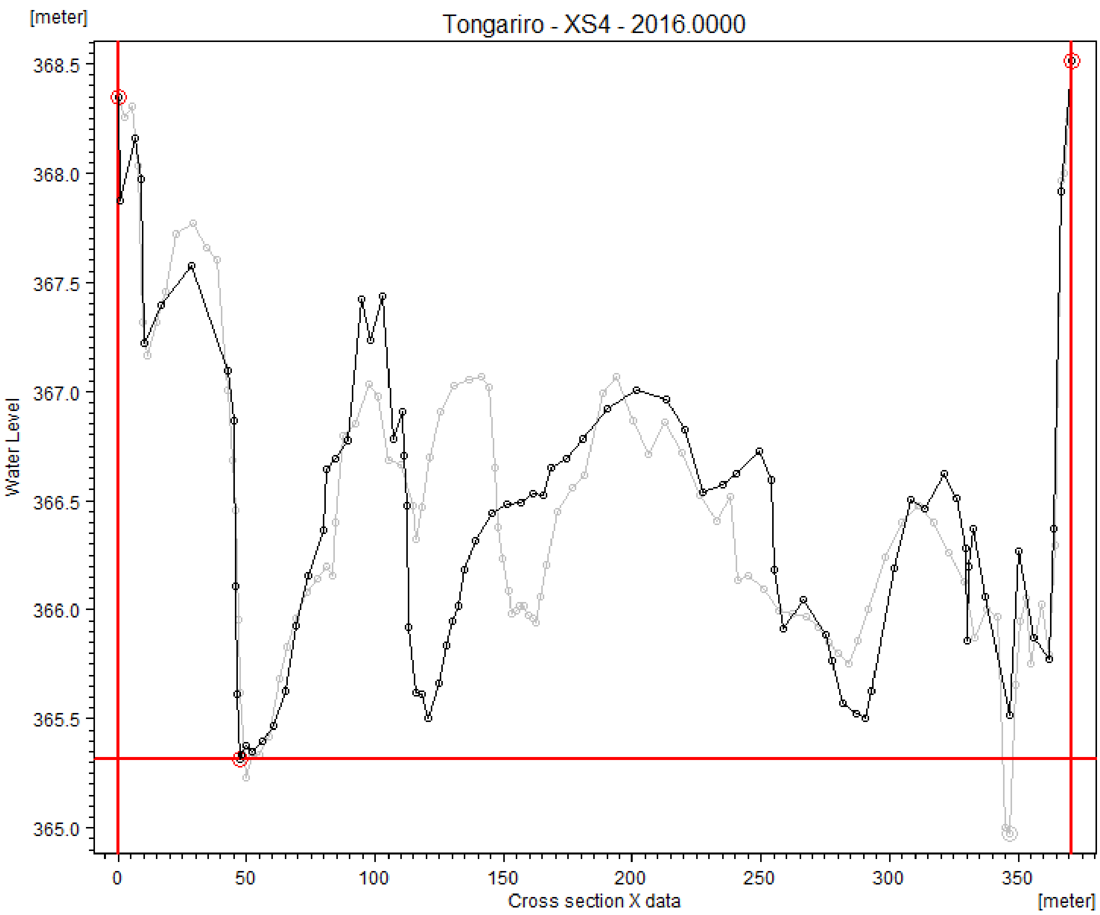

Figure 35 **Cross-section 4 – 2016 (black), 2009 (grey)**

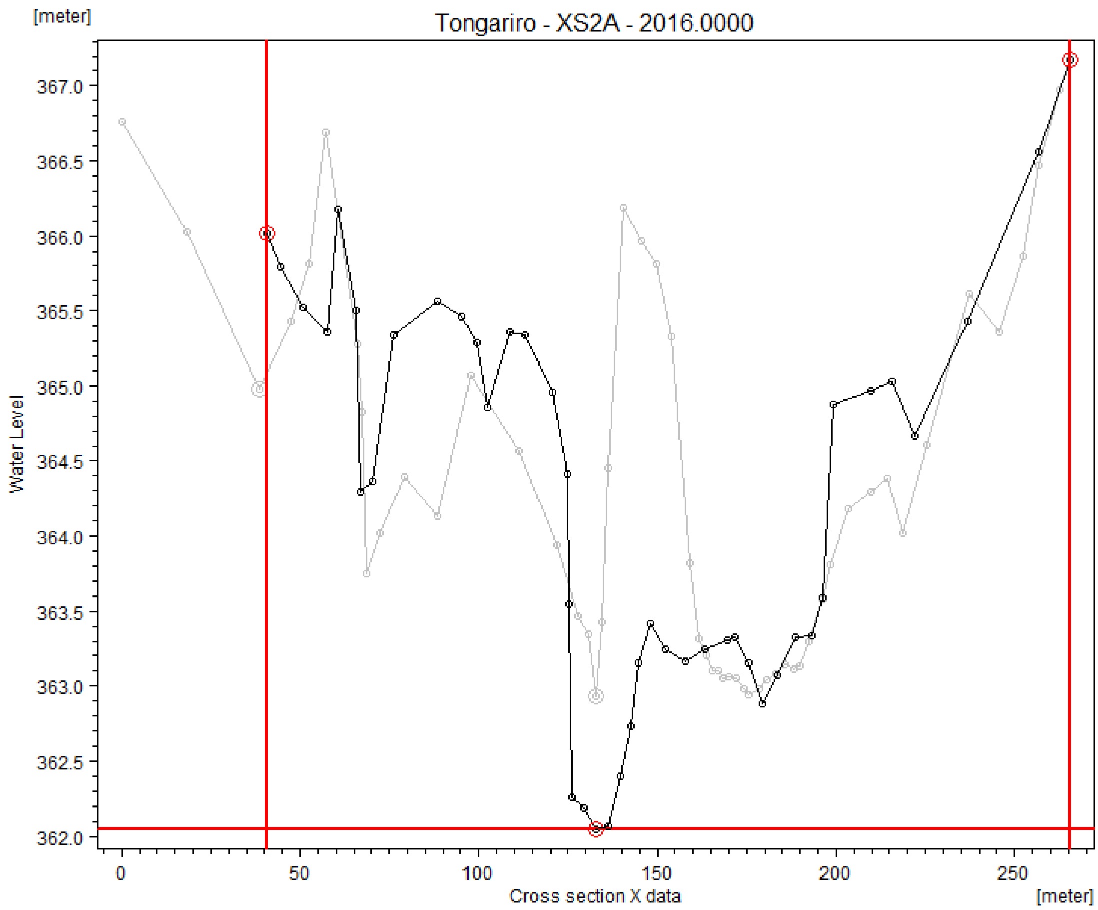

Figure 36 Cross-section 2A – 2016 (black), 2009 (grey)

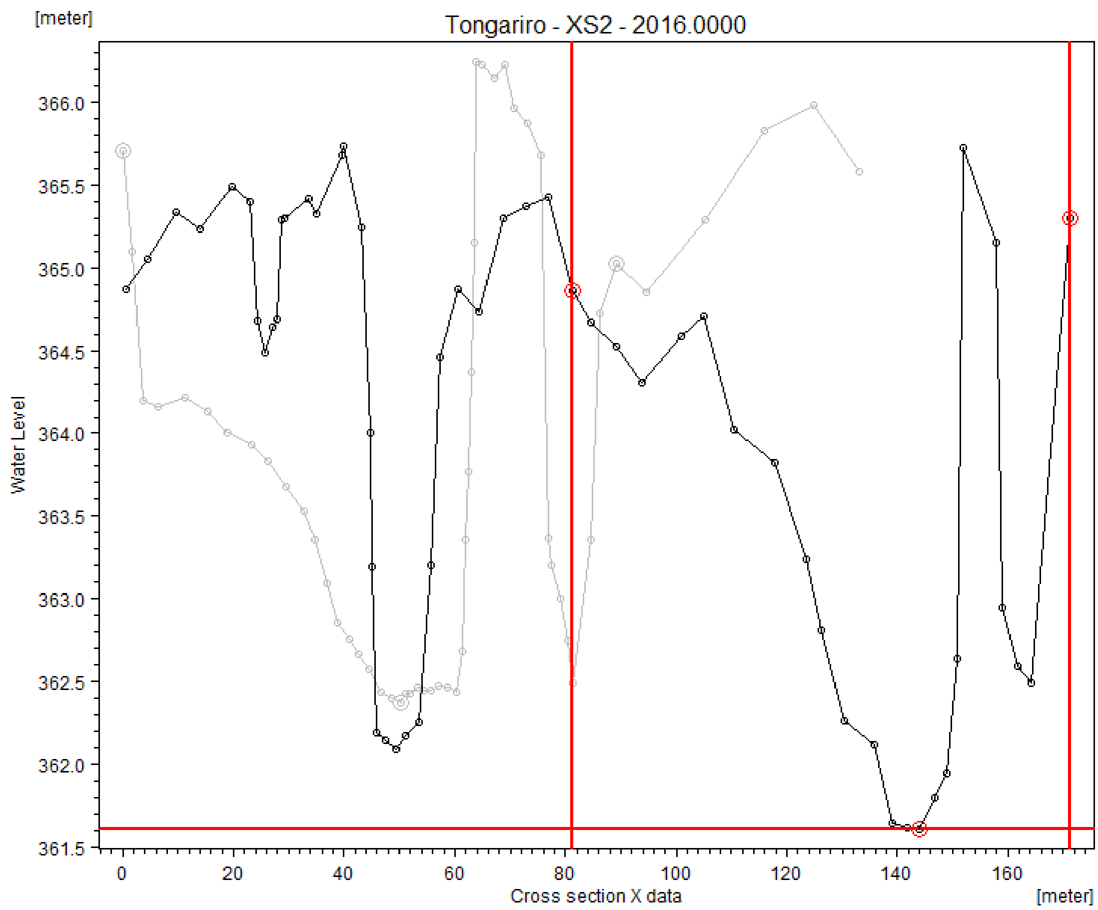

Figure 37 Cross-section 2 – 2016 (black), 2009 (grey)

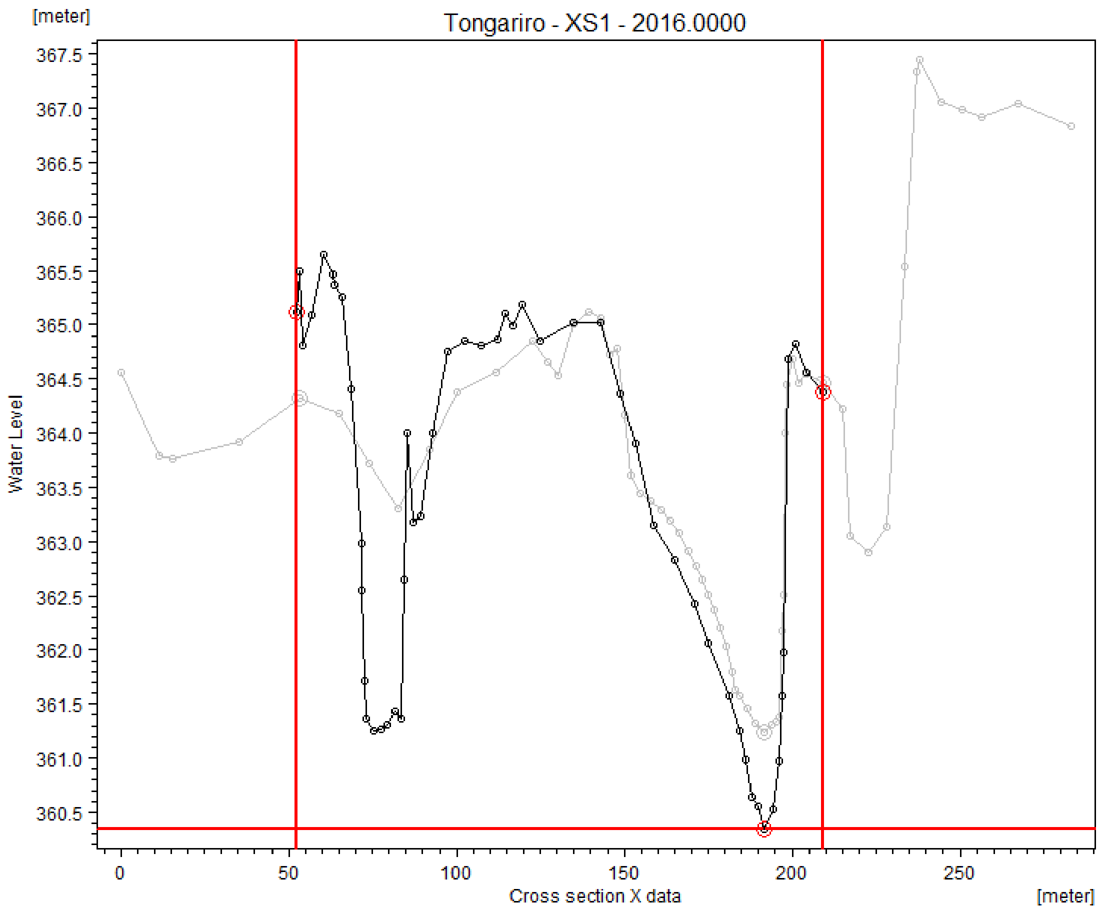

Figure 38 **Cross-section 1 – 2016 (black), 2009 (grey)**