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Te Puru Stream flood protection scheme - service level review

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Abstract

A service level review has been undertaken of the flood protection assets on the Te Puru Stream. The process has included a reassessment of catchment hydrology and design flows, a complete rebuild of hydraulic models based on the available topographic datasets, and a comparison of revised flood profiles against surveyed asset crest levels (stopbanks and floodwalls). The review indicates the scheme can convey the design flow safely although there are some shortfalls in freeboard levels in the lower scheme. The shortfalls are possibly associated with aggradation of sediment in the lower stream channel near the mouth as captured in topographic datasets. Aggradation could result in less in-channel capacity which may increase flood levels. It is recommended that re-survey of the channel cross-sections is undertaken to compare with past records and rerun the hydraulic model to determine appropriate bed levels. Given the fixed nature of the assets (primarily floodwalls or stopbanks within confined areas) the recommended solution to maintain the service level and improve performance in the lower stream is to undertake channel excavation/maintenance to allow sufficient in-channel capacity and freeboard for the design condition.

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 Te Puru Stream. The review includes reassessment of catchment hydrology, and hydraulic modelling of design flood flows incorporating recent ground survey and LIDAR data. This information is used to determine whether the flood protection scheme is meeting the agreed service level and identify any issues or areas where mitigation is required.

1.2 Background

The Te Puru catchment drains predominantly steep and vegetated hill country of 24km^2 in the Coromandel Ranges (Figure 1). Given the geology, terrain, vegetation and aspect the catchment can generate very high flows over short durations.

Figure 1 Location and extent of Te Puru catchment on the Coromandel Peninsula.

The Te Puru community is situated on the alluvial depositional fan formed where the stream meets the coast (Figure 2), and is subsequently at risk from high flood flows and associated debris. In addition, the community is vulnerable to elevated coastal water levels (e.g. king tides and storm surge) and the effects of sea level rise.

Historically, numerous flood events have affected the local community and in particular the severe 2002 event or “Weather Bomb”. This weather event greatly affected the Coromandel Peninsula and in response the Peninsula Project was initiated and adopted by council in 2003/2004. The Peninsula Project addressed river and catchment issues through soil conservation, river management, animal pest control, and flood protection. Te Puru was one of the communities identified as having a very high risk to life and property, requiring actions that addressed these risks. Waikato Regional Council (WRC) and Thames Coromandel District Council (TCDC) worked with the local community to develop a flood mitigation strategy to address the Te Puru Stream flood hazards. Subsequently the flood protection scheme was proposed, designed and constructed with completion around the early 2010's. A Scheme Design Report was issued in 2014 (Wood, 2014).

This current report provides a revision of the hydrology and hydraulics, and the first service level review for the flood protection scheme, which is scheduled every 5 years.

Figure 2 Oblique aerial photo of the Te Puru community situated at the coast on the Te Puru Stream alluvial depositional fan.

2 Hydrology and coastal water levels

2.1 Catchment characteristics

The Te Puru catchment drains predominantly steep and vegetated hill country of 24km^2 rising to 720m in the Coromandel Ranges (Figure 3 to Figure 5). Vegetative cover in the catchment is predominantly native bush and regenerating scrub. Given the, geology, terrain, vegetation and aspect the catchment can generate very high flows over short durations.

Time of concentration in the catchment was estimated as part of the scheme design at 75 minutes. This has been checked using various methods including USSCS, Ramser-Kirpich, and Bransby Williams giving times of 64, 80, and 172 minutes respectively. Given the estimated value of the Ramser-Kirpich method it has been decided to retain the time of concentration of 75 minutes for any requirements associated with this review.

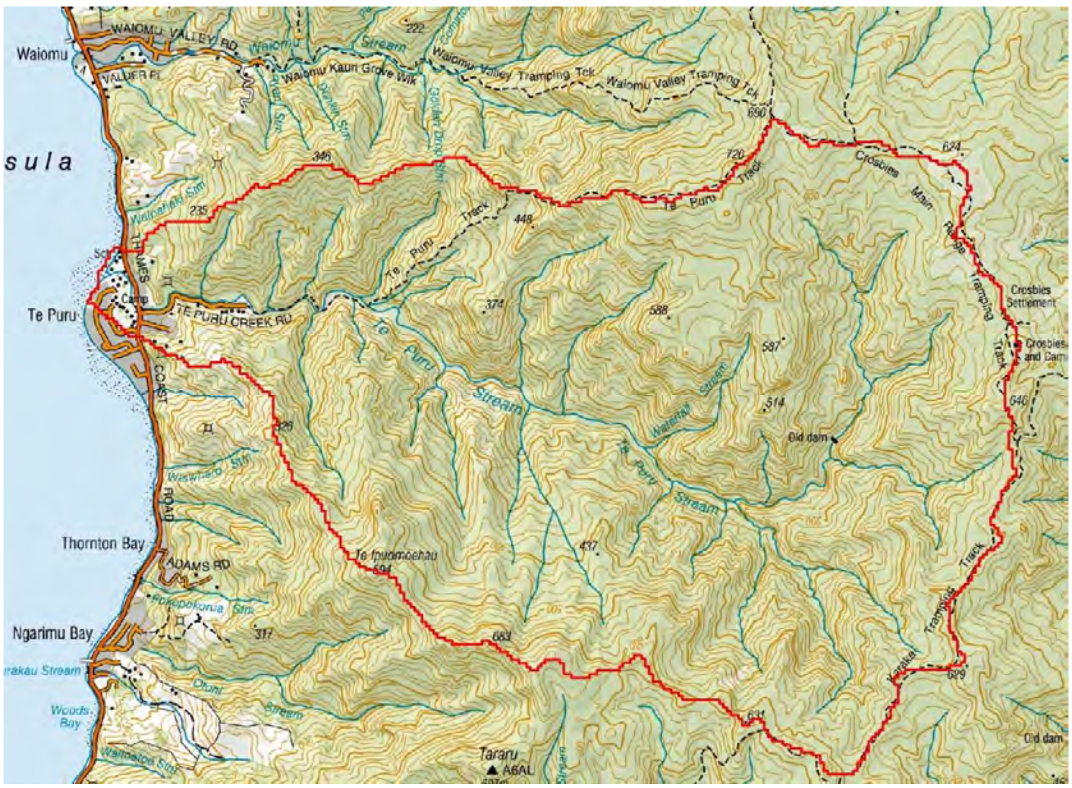

Figure 3 Extent of Te Puru Stream catchment (24km^2).

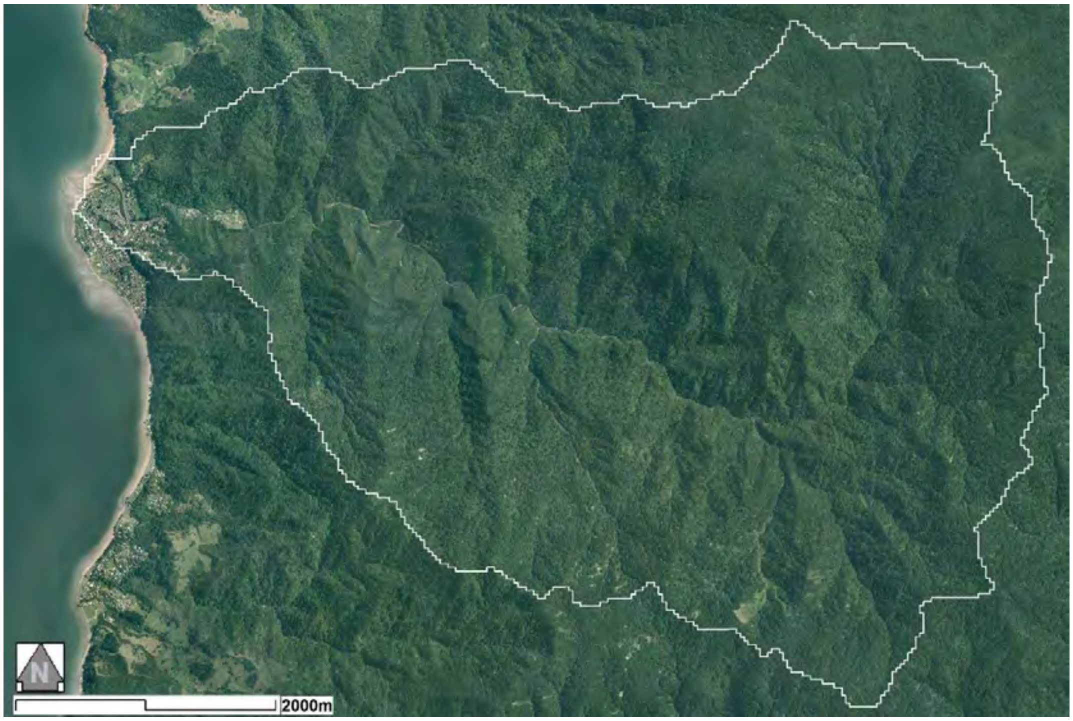

Figure 4 **Vegetative cover of predominantly native forest and regenerating scrub.**

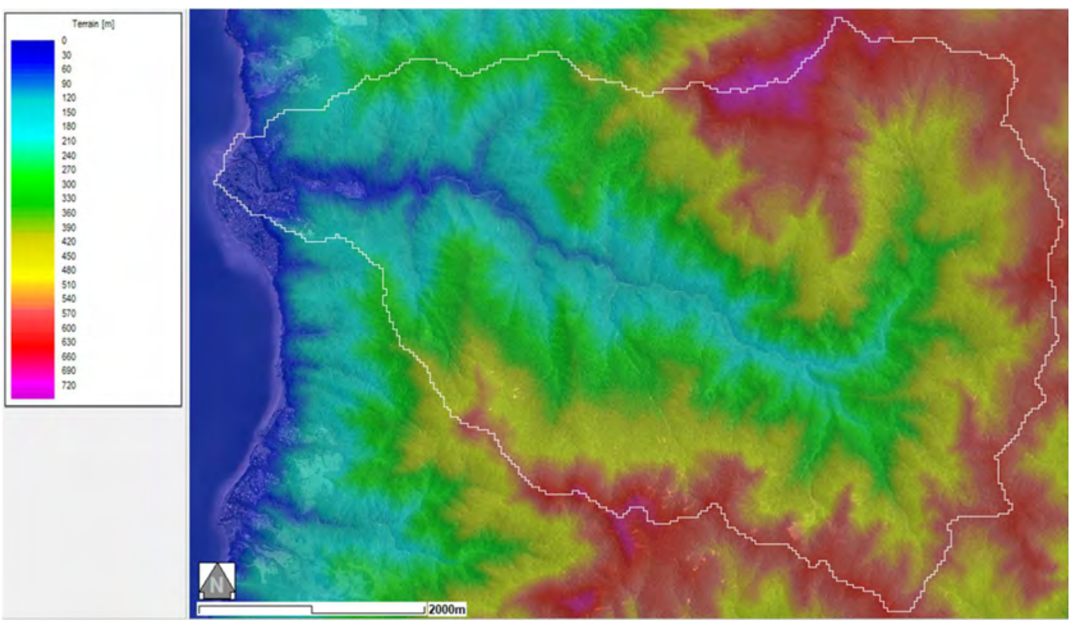

Figure 5 **Terrain from GEOGRAPHX 8m digital terrain model (DTM).**

2.2 Design rainfalls

Design rainfalls used during scheme design were originally sourced from NIWA's HIRDS (V2), but for the purposes of this service level review HIRDS (V4) has been used where applicable. This is described in detail below but unless required the reader is directed at Table 2 for the updated design rainfalls.

During scheme design, design rainfalls applicable at the time were taken from NIWA's HIRDS V2 for both present and future climates to 2080. To obtain the design rainfalls the intensities (mm/hr) for the 1 hour event were multiplied by 1.25 to match the estimated time of concentration in the catchment at 1.25 hours (75 minutes). Conservatively the HIRDS standard error was also added to these values. This was documented in WRC (2004) and WRC doc.

#1189584, and presented in the design report as rainfall intensities (Wood, 2014 – Table 5 and 6). These intensities have been converted to rainfall depths for the 75 minute duration in Table 1 below.

In late 2018, NIWA released HIRDS V4 which provides both present climate design rainfalls (based on historic rainfall data) and future climate scenarios to 2100 based on climate modelling of different possible pathways for the concentration of greenhouse gases. There are a set of four future scenarios, known as representative concentration pathways (RCP). These are identified by their approximate total radiative forcing and are identified as RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5 (see Ministry for the Environment, 2018).

Updated design rainfalls have been sourced from HIRDS V4. These have been conservatively taken for a location towards the head of the Te Puru catchment where design rainfalls are greater than those in the lower catchment (NZTM 1831000 5896000, WGS84 -37.053817° 175.597791°). Rainfall depths for the various %AEP[1] events were interpolated for 75 minutes from the 1 and 2 hour durations. The interpolated figures are shown in Table 2 allowing comparison with those used in the scheme design (Table 1). Increases in the HIRDS V4 1%AEP rainfall depths from the present (based on historical records) to the future climate (2081-2100) are 8%, 16%, 21% and 34% under the four representative concentration pathways (RCP's).

Table 1 Rainfall depths used in scheme design and derived from NIWA HIRDS V2.
(Note: Rainfall depths have since been revised to HIRDS v4 as shown in Table 2. Rainfall depths presented here have been converted from rainfall intensities as shown in the design report.)

	Rainfall depths (mm) for a 75 minute duration					
% Annual Exeedance Probability (%AEP)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
Present	35	43	50	59	73	89
Future 2080	44	54	64	75	94	114

Table 2 Updated rainfall NIWA HIRDS V4 rainfall depths for location at the head of the Te Puru catchment at WGS84 -37.053817° 175.597791°.
(Note: Rainfall depths are interpolated for 75 minutes between 1 and 2 hour depth/duration values.)

	Rainfall depths (mm) for 75 minute duration					
% Annual Exeedance Probability (%AEP)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
Present (historical)	39	51	61	70	84	94
Future 2081-2100 RCP 2.6	42	55	65	76	90	102
Future 2081-2100 RCP 4.5	45	59	70	81	97	109
Future 2081-2100 RCP 6.0	47	62	73	85	102	115
Future 2081-2100 RCP 8.5	51	68	81	94	112	127

2.3 Design discharge

The Te Puru Stream is an ungauged catchment and determination of the 1%AEP design flow is described in the scheme design report (Wood, 2014). During scheme design the 1%AEP peak flow was estimated at 315m^3/s (Q_p315) for the present climate, and Q_p378 for the future (2080) climate. It should be noted that the future climate flow used was a 20% increase in the present climate 1%AEP flow, yet other methods used an increase of up to 29% to Q_p405.

The design discharge has been reassessed here using various methods which are described in the following sections.

[1] Annual Exceedance Probability (AEP) refers to the probability of a flood event occurring in any year. The probability is expressed as a percentage. For example, a large flood which may be calculated to have a 1% chance to occur in any one year, is described as 1%AEP.

2.3.1 Rational method

The rural catchment of 24km^2 is considered too large to be applicable to the Rational Method which cannot account for the effects of catchment storage in attenuating the flood hydrograph. However, this method amongst others was assessed during scheme design using a runoff coefficient of C=0.7 (WRC, 2004). The coefficient value used considered the method outlined in the Ministry of Works and Development (1978) Culvert Manual which takes account of rainfall intensity, catchment relief, surface retention, infiltration, and ground cover. Reapplying this method to the revised HIRDS V4 design rainfalls detailed in Table 2 gives flow estimates for the present and future climate and is shown in Table 3. It is considered that the estimates determined using this method are very conservative. Discharge estimates assuming a lesser value of C=0.6 are also provided in Table 4, which provide similar estimates to the Regional Method and TM61 as described in the following sections.

Table 3 Estimated design discharge considering the Rational Method with runoff coefficient of C=0.7 considering NIWA HIRDS V4 rainfall depths for 75 minute duration.

	Peak discharge estimate (m^3/s)					
% Annual Exeedance Probability (%AEP)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
Present	147	193	228	264	314	355
Future 2081-2100 RCP 2.6	157	207	245	284	339	383
Future 2081-2100 RCP 4.5	168	222	263	306	365	412
Future 2081-2100 RCP 6.0	175	232	276	321	383	432
Future 2081-2100 RCP 8.5	192	256	304	354	423	478

Table 4 Estimated design discharge considering the Rational Method with runoff coefficient of C=0.6 considering NIWA HIRDS V4 rainfall depths for 75 minute duration.

	Peak discharge estimate (m^3/s)					
% Annual Exeedance Probability (%AEP)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
Present	126	165	195	226	270	304
Future 2081-2100 RCP 2.6	136	178	210	245	291	329
Future 2081-2100 RCP 4.5	145	191	226	262	313	352
Future 2081-2100 RCP 6.0	152	200	236	274	329	371
Future 2081-2100 RCP 8.5	165	220	262	304	362	410

2.3.2 TM61

Design flow estimates were made using TM61 and considered saturated soils and a cover characteristic coefficient of 1.0. This cover characteristic is relatively high for a catchment which is predominantly native bush and regenerating scrub, however it was felt that lower values produced lower discharges not in alignment with historic events as detailed in the design report. TM61 was undertaken for the rainfall depths shown in Table 2 for both the present and future climates, with the results shown in Table 5.

Table 5 Peak discharge estimates considering TM61 and NIWA HIRDS V4 rainfall depths for 75 minute duration.
(Note: Assumed saturated soils and cover characteristic coefficient of 1.0.)

	Peak discharge estimate (m^3/s)					
% Annual Exeedance Probability (%AEP)	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
Present	131	172	203	236	281	317
Future 2081-2100 RCP 2.6	140	185	219	254	303	342
Future 2081-2100 RCP 4.5	150	198	235	273	326	368
Future 2081-2100 RCP 6.0	157	208	246	286	342	386
Future 2081-2100 RCP 8.5	172	228	271	316	378	427

2.3.3 Regional method

NIWA's Stream Explorer allows extraction of the regional method considering both McKerchar and Pearson (1989) and McKerchar (1991). These are reproduced below in Figure 6 with determination of the 1%AEP flow at Q_p305-308. The discharge values are in line with previous WRC estimates of current climate 1%AEP flows (WRC, 2004 and 2014). During the time of writing NIWA's Stream Explorer was replaced with New Zealand River Flood Statistics with a revision of the regional method dataset. This gave very similar results at Te Puru for the 1%AEP of Q_p302.

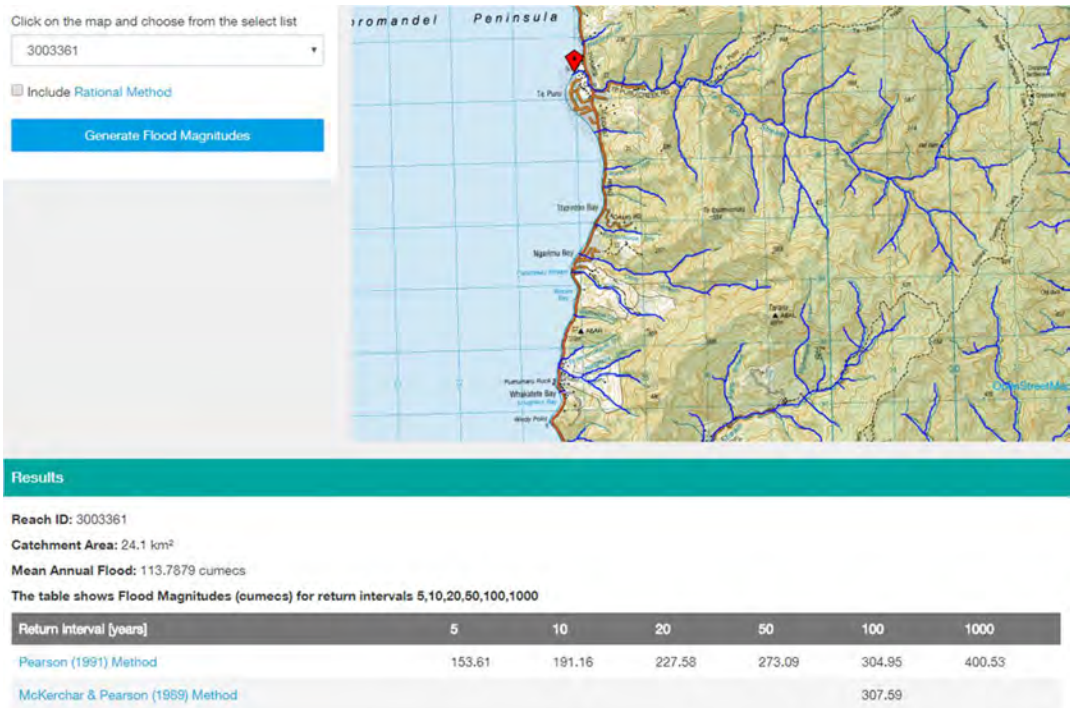

Figure 6 NIWA Stream Explorer regional method discharge estimates for Te Puru Stream.

2.3.4 Flow scaling

WRC operates long term historic flow gauges at locations across the region. Six of these sites are situated on the Coromandel Peninsula with the gauge locations and upstream catchments shown in Figure 7.

Flood frequency analyses (FFA) were undertaken in 2017 by Doug Stewart (WRC doc. #12608436) with the results for the Coromandel sites reproduced in Table 6. Flow record lengths for these sites at the time of analysis range from 27 to 58 years.

The method of flow scaling has been undertaken using the FFA from all six Coromandel gauges sites. The gauged catchments have many similarities to the Te Puru catchment in terms of the geology, hydrology and land use characteristics, however the catchments vary significantly in area and aspect. Flow scaling is calculated using $Q_1/Q_2 = (A_1/A_2)^{0.8}$ and has been applied to the catchments and FFA estimates shown in Table 6 with the results presented in Table 7.

It is noted that the original scheme design applied a similar method in determining the 1%AEP flow (WRC, 2004 and 2014). OPUS (2004) used flow scaling of the Kauaeranga to get the 1%AEP discharge of Q_p315, this was based on the estimate for the Kauaeranga 1%AEP of Q_p1161.

Based on the 2017 FFA of the Kauaeranga (1%AEP Q_p1236) the Te Puru 1%AEP estimate is Q_P344 which is high compared to most of the methods assessed and historic events in the catchment. The Tapu catchment whilst having a very similar catchment gives an estimate at Te Puru considered too low based on historic events. Similarly the estimate based on the east coast catchment of Wharekawa appears too low based on historic events at Te Puru.

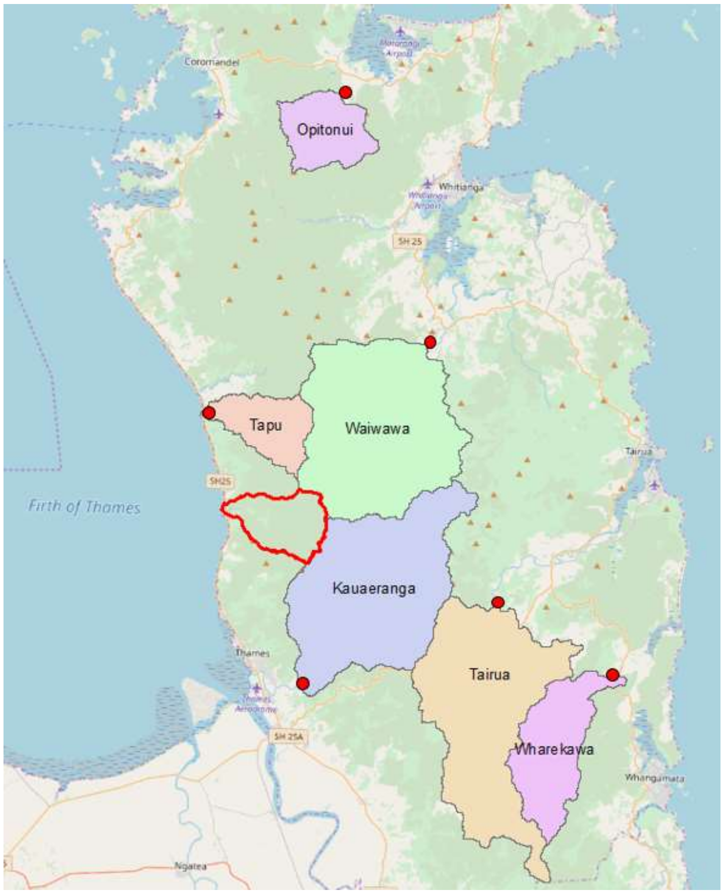

Figure 7 **Coromandel Peninsula WRC flow gauging sites and upstream catchments (Te Puru catchment shown as red polygon).**

Table 6 **Flood frequency analysis for WRC flow gauges sites on the Coromandel Peninsula.**

WRC flow gauge site and catchment area	Location (NZTM)		Peak discharge estimate (m^3/s) %AEP					
	east	north	50%	20%	10%	5%	2%	1%
Kauaeranga (122km^2)	1830040	5884528	465	672	808	940	1109	1236
Tairua (117km^2)	1843320	5890290	352	535	656	772	922	1035
Waiwawa (120km^2)	1838187	5908791	358	544	667	786	938	1053*
Wharekawa (46.5km^2)	1851964	5885309	128	189	230	269	319	357*
Opitonui (29km^2)	1832431	5926826	119	186	231	274	312	330*
Tapu (26.4km^2)	1822967	5904237	56	91	114	136	165	201*

**Extrapolated too far for length of record. Record lengths are Kauaeranga (58 years), Tairua (41 years) and remainder 27 years as at time of analysis (2017).*

Table 7 **Peak discharge estimates based on flow scaling for the Te Puru catchment.**

WRC flow gauge site	A_2 (km^2)	relative ratio*	Peak discharge estimates %AEP					
			50%	20%	10%	5%	2%	1%
Kauaeranga	119.9	0.278	129	187	225	261	308	344
Tairua	117.9	0.282	99	151	185	217	260	292
Waiwawa	121.2	0.276	99	150	184	217	258	290
Wharekawa	46.9	0.589	75	111	135	158	188	210
Opitonui	28.8	0.870	104	162	201	238	271	287
Tapu	26.6	0.927	52	84	106	126	153	186

** Based on Te Puru catchment area (A_1=24.2km^2).*

2.3.5 Direct rainfall modelling

A 'direct rainfall' or 'rain-on-grid' model was also developed of the full catchment using an 8m GEOGRAPHX DTM. Whilst the model involved very basic hydrological assumptions it allowed some testing of peak flows and time to peak under present and future climate rainfall estimates.

The model was run for the five 1%AEP present and future climate scenarios shown in Table 2. These rainfall depths are for the assumed duration of 75 minutes equivalent to the estimated time of concentration. It was also assumed that 0.6 of this rainfall would eventuate in runoff (net rainfall) and was subsequently distributed spatially uniform over the model domain, temporally uniform over the 75 minutes, and routed over the model surface assuming a constant roughness of Manning's M=20. Flows and hydrographs were then extracted from the model in the lower catchment upstream of the State Highway.

The time to peak was approximately 65-75 minutes with peak flows for the various 1%AEP events shown in Table 8.

Table 8 Estimated 1%AEP design discharge for present and future climate considering direct rainfall modelling and associated assumptions.

	Estimated discharge (m^3/s)
% Annual Exeedance Probability (%AEP)	**1%AEP**
Present	300
Future 2081-2100 RCP 2.6	326
Future 2081-2100 RCP 4.5	349
Future 2081-2100 RCP 6.0	367
Future 2081-2100 RCP 8.5	405

2.3.6 Summary of design discharge estimates

Section 2.3 has described various methods in estimating the design discharge. Comparison of the methods for the current climate is shown in Figure 8 with 1%AEP estimates ranging from Q_p287-344. Many of the methods provide similar estimates including TM61, Rational (C=0.6), Regional, direct rainfall modelling, and half of the flow scaling sites. For the current climate 1%AEP these are in the range Q_p287-317, and are aligned with the original scheme design discharge of Q_p315. Given the results described above it has been chosen to retain the original 1%AEP design discharge for the current climate of Q_p315.

In assessing the future climate design discharge we are only able to consider methods which use design rainfall depths (HIRDS V4) for the various RCP scenarios (Section 2.2). This includes TM61, Rational, and the direct rainfall modelling. The estimates for the various future climate RCP scenarios are shown and compared with the present climate 1%AEP event in Table 9. Increases in flow for the future climate scenarios over the present climate 1%AEP event are approximately 8%, 16%, 22% and 35%. The previous future climate design flow was Q_p378 which falls into the flow range determined for the RCP 6.0 scenario. As part of this service level review the two upper future climate scenarios (RCP 6.0 and RCP 8.5) will be investigated. The estimates for each RCP scenario in Table 9 have been averaged to give 1%AEP future climate estimates of Q_p375 (RCP 6.0) and Q_p414 (RCP 8.5). These estimates will be used in assessing the effects of possible future climate 1%AEP flows.

In summary the flows to be used in reassessing the service level of the scheme assets are:

- present climate 1%AEP design discharge is Q_p315
- future climate (RCP 6.0) design discharge is Q_p375
- future climate (RCP 8.5) design discharge is Q_p414

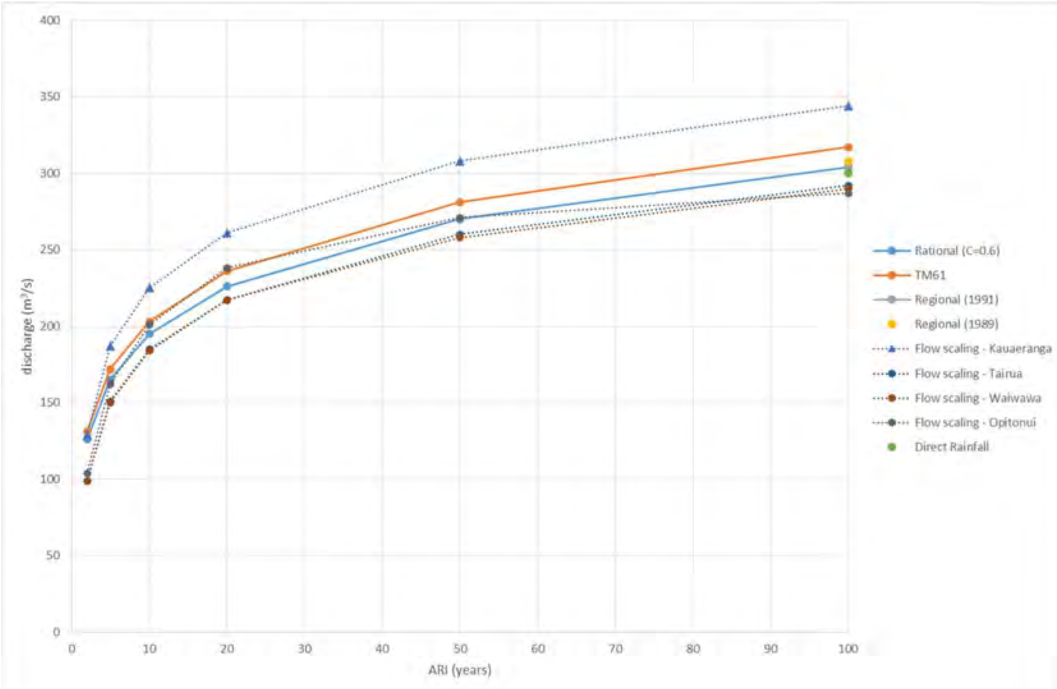

Figure 8 Comparison of various methods for current climate discharge estimates.

Table 9 Flow estimates for the 1%AEP for present climate and various future climate RCP scenarios.

Method	Present climate	Future climate scenarios			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Direct Rainfall	300	326	349	367	405
Rational (C=0.6)	304	329	352	371	410
TM61	317	342	368	386	427

2.4 Design hydrograph

During scheme design a hydrograph was adopted from the adjacent Kauaeranga catchment based on 5 of the larger events on record. The hydrograph was adjusted in both the vertical to the required design peak flow, and temporally shifting the time-to-peak to the estimated time of concentration (75 minutes).

As part of this review the hydrograph was rechecked and also compared with events in the Tapu catchment to the north (Figure 7). Tapu has many similarities to Te Puru, although its flow record is relatively short at 27 years and historically has not received as severe floods. The chosen hydrograph for comparison from the Tapu record was the largest flood on record of Q_p240 (2002 event). All other floods in the catchment were significantly smaller and less than Q_p80.

Both the Kauaeranga and Tapu hydrographs were normalised and the time-to-peak shifted to 75 minutes as shown in Figure 9. The comparison shows that both hydrographs are relatively similar particularly in the rising limb, although Tapu is slightly broader with a higher receding limb. It is considered that either of these hydrographs will be suitable in assessing the flood protection assets, and in this case the Kauaeranga shape will be retained.

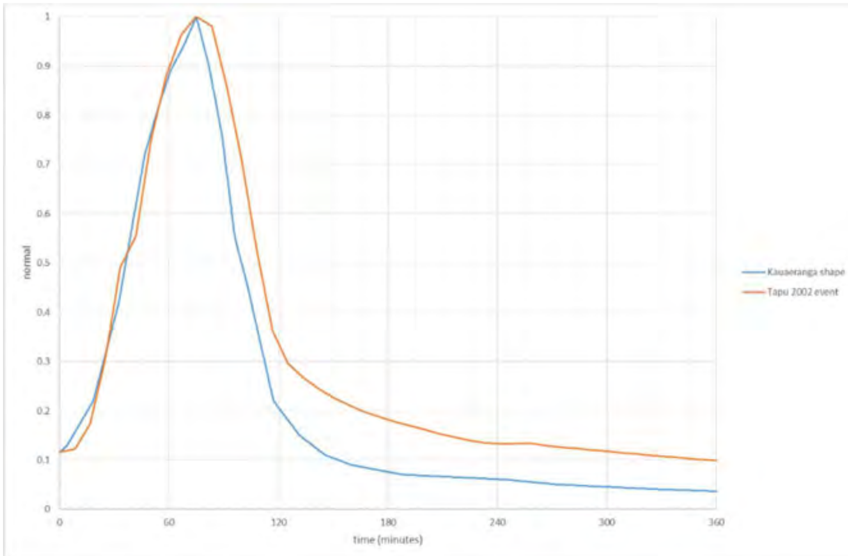

Figure 9 **Comparison of normalised Kauaeranga shape hydrograph and that from the Tapu catchment.**

2.5 Tide levels

Tide levels at Te Puru have been taken from the WRC Coastal Inundation Tool pre-defined water levels derived by NIWA. These levels are to MVD-53 but for reference purposes have been converted to both TVD-52 and AVD-46 as shown in Table 10. The relationship between the three datum is discussed in Section 4.1 and shown in Figure 12.

Various tide levels have been mapped on the 2013 LIDAR (AVD-46) topography as shown in Figure 10. All areas below the specified tide level are shaded blue.

For the present climate the mapping highlights a number of depressions within residential areas which are below the present climate mean high water spring (MHWS) tide, and maximum tide levels. This includes 23 residential properties with some ground levels below the MHWS, and 51 below the maximum tide. During typical tide conditions these depressions are separated from the sea by areas of high ground (i.e.: shoreline deposits both natural and man-made) but inundation can occur from elevated coastal water level conditions such as storms or future climate change. The future climate images in Figure 10 also show significant consequences for the community under sea level rise scenarios.

Table 10 **Tides levels at different datum for present and future climates with consideration for 1m sea level rise.**

Tide	Datum		
	TVD-52 (m)	MVD-53 (m)	AVD-46 (m)
Present:			
MHWS	1.63	1.75	1.76
Maximum tide	1.94	2.06	2.07
Storm tide lower	2.04	2.16	2.17
Storm tide upper	3.05	3.17	3.18
Future 1m SLR:			
MHWS	2.63	2.75	2.76
Maximum tide	2.94	3.06	3.07
Storm tide lower	3.04	3.16	3.17
Storm tide upper	4.05	4.17	4.18

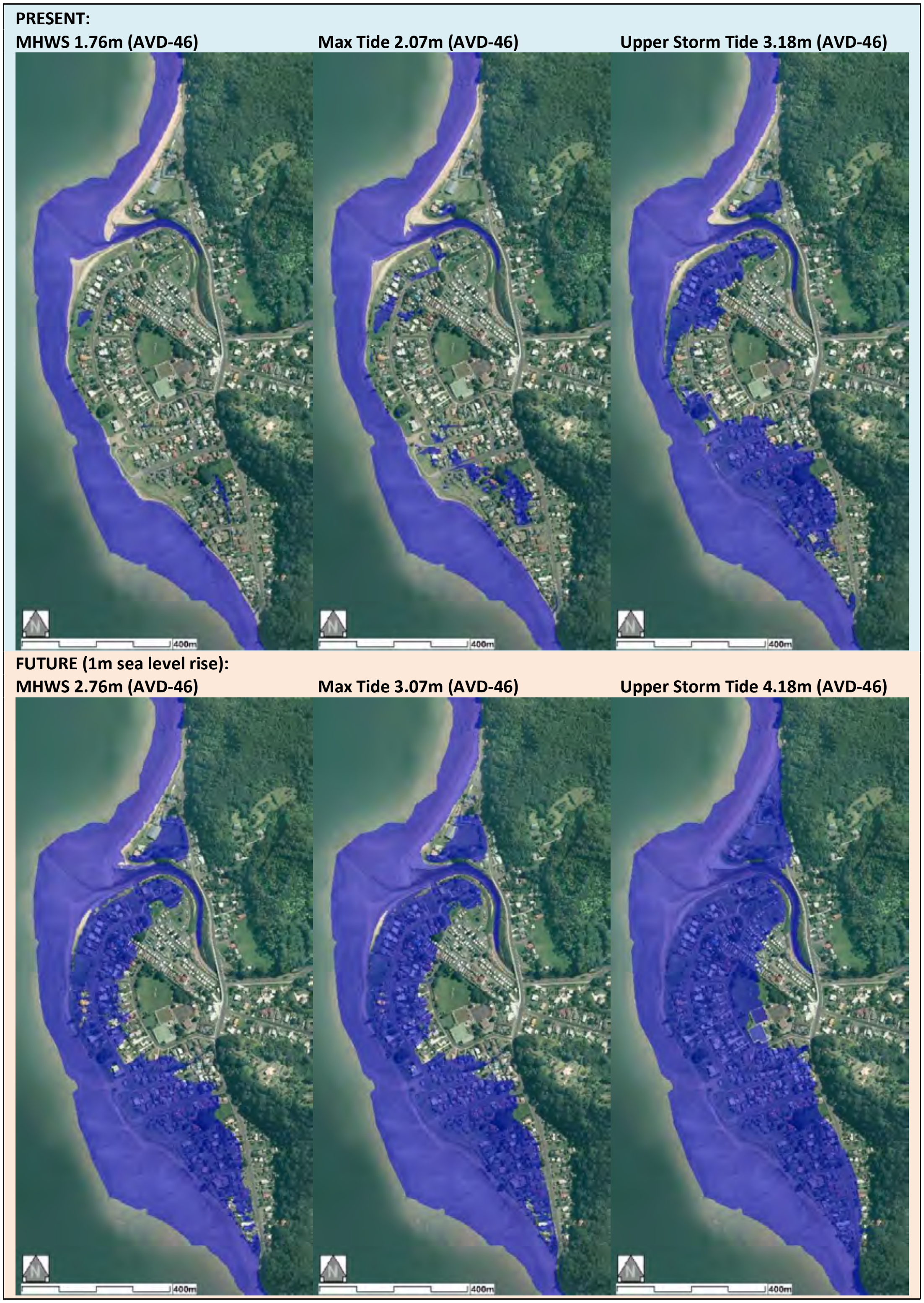

Figure 10 Various coastal water levels on 2013 LIDAR surface (AVD-46). Note: Future water levels include 1.0m of sea level rise.

3 Flood protection scheme

The flood protection scheme is comprised of various components having an agreed service level equivalent to the present climate 1%AEP design discharge. During the design phase the present climate 1%AEP design discharge was estimated at Q_p315, and following reassessment (Section 2.3) is to be retained.

Freeboard allowance at Te Puru is predominantly 600mm but there are exceptions detailed below. Commonly predicted future climate change flows and the associated increase in water levels can be contained within the freeboard but this will be reassessed as part of this analysis. The freeboard allowance also allows for some uncertainty associated with hydrology and hydraulic model uncertainty, super-elevation in water levels, stream wave-action, and mobile debris and bed load.

The scheme assets are comprised of stopbanks and floodwalls with a spillway designed to take some over-design flows in order to protect the bridge structure. The assets are shown in Figure 11 and described below.

The main components of the flood protection scheme are:

Left bank downstream of State Highway

- *Te Puru Left Below State Highway Floodwall* - 463m, 1%AEP, 600mm freeboard

Left bank upstream of State Highway

- *Te Puru Left Above State Highway Floodwall* - 168m, 1%AEP, 600mm freeboard

Right bank downstream of State Highway

- *Te Puru Right Below State Highway Stopbank* – 134m, 1%AEP, 600mm freeboard
- *Te Puru Right Below State Highway Floodwall* – 199m, varying service level[2] :
    - Service level downstream of XS 11 is 1%AEP + 600mm freeboard – 68m
    - Service level upstream of XS 11 (floodwall extension) is future climate 1%AEP + no freeboard – 131m

Right bank upstream of State Highway

- *Te Puru Right Above State Highway Floodwall Spillway* - 62m, 1%AEP, 300mm freeboard[3]

Various other features included in the flood protection scheme include retaining walls, rock rip rap, and floodgates:

Rock rip rap

- *Te Puru Stream LB Rock Rip Rap Upstream of Bridge* (250m)
- *Te Puru Left Rip Rap Below State Highway* (196m)
- *Te Puru Right Below State Highway Rip Rap* (178m)

Floodgates

- *Te Puru Right Floodgate 1* (900mm) downstream State Highway
- *Te Puru Right Floodgate 2* (2 x 375mm) downstream State Highway
- *Te Puru Right Floodgate 3* (1200mm) downstream State Highway

[2] XS 11 is the break point between the standard of service based on doc #1937518. The difference between the two service level profiles determined during this review is 100-200mm.

[3] The scheme design report (Wood, 2014) describes 300mm freeboard and is incorrectly assigned 600mm in the Conquest database.

Retaining walls

- *Te Puru Left Retaining Above State Highway*
- *Te Puru Left Campsite Retaining Wall*

The retaining walls are located at the toe of embankments where insufficient space was available for the full embankment profile. Rock rip rap was used to improve the stability of the channel and protect the other works associated with the flood protection scheme. The floodgates are associated with the SH25 Bridge upgrade and drainage from the road network. These features are inspected at regular intervals associated with river maintenance schedules. Hence the primary focus of this service level review is the comparison of design discharge floodwater levels and scheme asset crest levels.

Figure 11 Location of Te Puru flood protection scheme assets.

4 Survey

4.1 Datum

The horizontal datum used throughout this report is New Zealand Transverse Mercator (NZTM). Several vertical datum are discussed and used in this report. The most relevant datum is the Hauraki Catchment Board Te Puru Local Datum. The 'Local Datum' is relevant to historic ground surveys, including channel cross-sections from various eras and as-built data for the flood protection scheme. The latest of these surveys was undertaken in 2014 following completion of the scheme (Section 4.2).

Three other vertical datum are also commonly used in the area in relation to various data sources. These include Moturiki Vertical Datum 1953 (MVD-53), Tararu Vertical Datum 1952 (TVD-52) and Auckland Vertical Datum 1946 (AVD-46). The relationship between the three datum is shown in Figure 12. The exact offset between the Local Datum and the other three datum has not been determined accurately via survey techniques, although this is discussed in the Section 4.4 and later in this report where applicable.

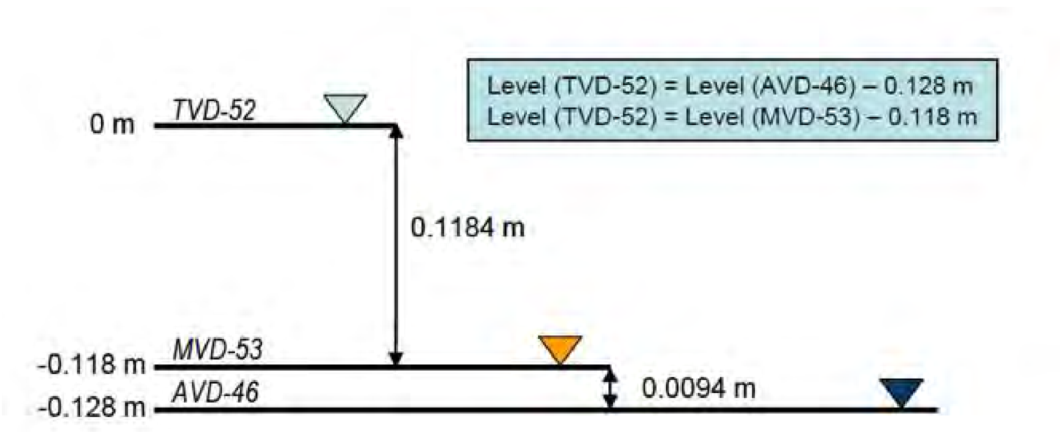

Figure 12 Relationship and conversions between the three local vertical datum of Tararu (TVD-52), Moturiki (MVD-53) and Auckland (AVD-46).
(Source: Goodhue, 2012.)

4.2 Ground survey 2014

After completion of the flood protection scheme WRC engaged Dunwoodie & Green Surveyors Limited to undertake a full survey of both the channel and flood protection scheme and other surrounding features. This survey includes full channel cross-sections of the lower Te Puru Stream and all components of the flood protection scheme. The survey and as-built drawings are dated February 2014 and are in terms of the Local Datum (WRC Plan 1437, WRC Doc. #3159738).

4.3 LIDAR 2013

LIDAR coverage of the Coromandel Peninsula coast was captured between 1 January and 12 March 2013. At Te Puru this data is available in terms of the vertical datum AVD-46. Flood protection works at Te Puru including the new bridge were completed at the time of the LIDAR survey.

Comparison of the 2013 LIDAR surface (AVD-46) was found to be very close in the vertical to Local Datum when compared against the 2014 ground survey data (see Section 4.4). The LIDAR has an accuracy of +/- 0.15m.

The extent of the 2013 LIDAR coverage is shown below in Figure 13.

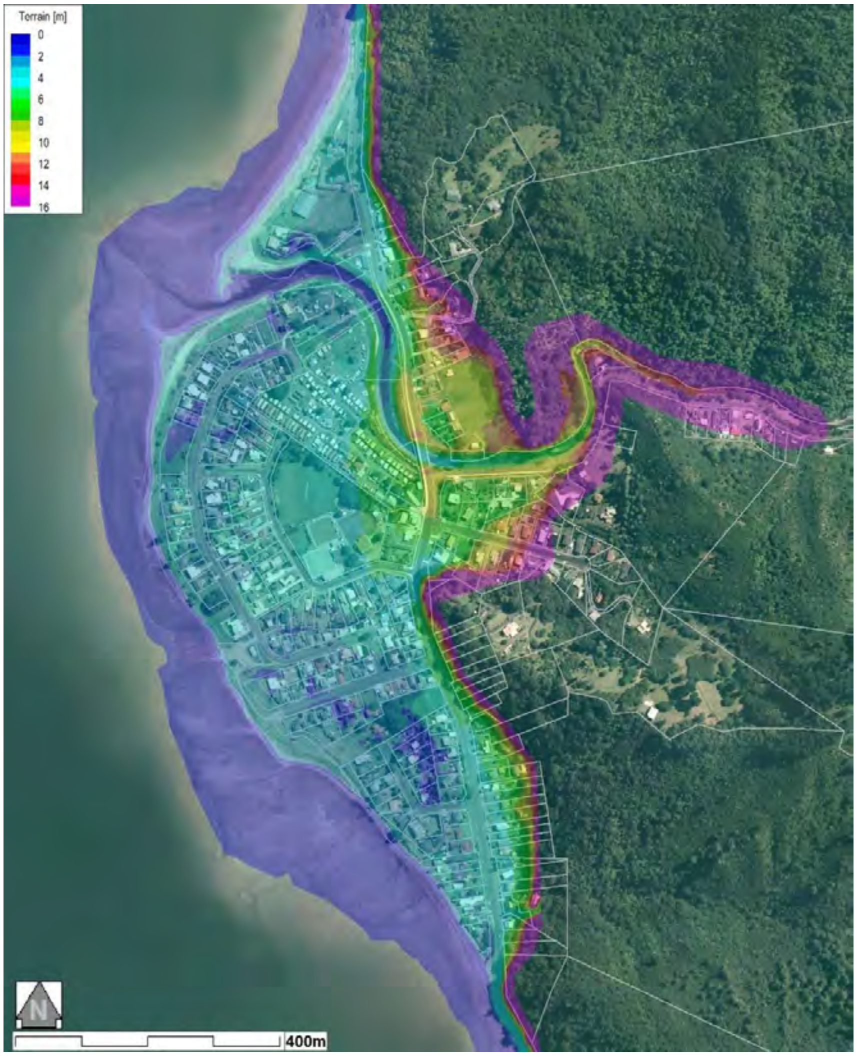

Figure 13 Extent of 2013 LIDAR coverage.

4.4 Te Puru Local Datum offsets

The offset between the Local Datum and the three more widely used datum (Section 4.1) has not been precisely determined. This has not been necessary as construction of the flood protection scheme, historic channel surveys, and as built drawings have all been undertaken on the Local Datum. For the purposes of this report some checks were made on this offset. This was for the purposes of hydraulic modelling with use of recent LIDAR, ground survey and appropriate tide conditions.

The Te Puru Flood Protection Scheme Design Report (Wood, 2014) suggests TVD-52 is +0.2m Local Datum (i.e.: commentary around tide levels describes RL 1.6m (Local Datum) is RL 1.4m (TVD-52).

Survey of high tides (WRC Doc. #1301684) suggests TVD-52 is +0.13m Local Datum although there are possible errors in this method owing to tidal wave amplification (i.e.: the high tide level at Tararu is greater than Te Puru). NIWA's tide forecaster alone without considering other met-ocean effects indicates this difference is approximately 0.05m on the day of the survey.

The 2014 ground survey data (Local Datum) was compared with ground strikes from the 2013 LIDAR (AVD-46). This involved comparing proximal LIDAR ground strikes (within 0-1m horizontal) with surveyed points (1583 points). This suggested that the ground survey surface (Local Datum) was slightly higher than the LIDAR surface (AVD-46). Average vertical differences were 0.03-0.05m where points were within a horizontal distance of 0-0.3m, and average 0.097 between 0-1m horizontal, noting that the vertical accuracy of the LIDAR is +/-0.15m. Whilst not perfect this analysis indicates that the Local Datum is very close to AVD-46. This was further confirmed by comparing ground survey channel cross-sections with slices from the 2013 LIDAR DTM (AVD-46). This is shown in Appendix A with mostly good representation of the channel.

Based on the above and for the purposes of hydraulic modelling it is assumed that the Local Datum is very close to AVD-46. This has allowed the flood protection scheme asset crest data (2014 survey - Local Datum) to be used without vertical adjustment with the 2013 LIDAR (AVD-46), and with tide conditions in AVD-46.

Future survey capture at Te Puru should determine the exact offset between Local Datum and AVD-46, and also place data in WRC's new datum standard NZVD-2016.

5 Hydraulics

Hydraulic models have been configured 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). A MIKEFLOOD (coupled 1D and 2D) model could have been configured, however as no channel overflows were predicted by MIKE11 for the service level design event this would be of limited use.

5.1 MIKE11 model

A MIKE11 1D model has been configured for the relevant reach of river proximal to the flood protection scheme and Te Puru community.

5.1.1 MIKE11 model development

5.1.1.1 Model network domain and datum

The MIKE11 model network covers a river reach of 710m between surveyed cross-sections. The model domain extends from a southwest origin at NZTM 1823600 5896240 to a northeast corner at NZTM 1824900 5897740 (1300m x 1500m) as shown in Figure 14. This is the same domain as the MIKE21 model network described in Section 5.2. The model vertical datum is Te Puru Local Datum which as described in Section 4 is assumed to be very close to AVD-46.

Figure 14 Extent of MIKE11 model network at Te Puru.

5.1.1.2 Model cross-sections

The Te Puru Stream is represented by the cross-sections surveyed in 2014 and detailed in Section 4.2. These cross-sections have also been checked and adjusted to include the asset crest (floodwall or stopbank) as surveyed in 2014. The location and extent of these cross-sections in the model is shown in Figure 15.

Figure 15 Location and extent of 2014 ground survey cross-sections as shown in MIKE11 model. Note model chainage is shown in image but cross-sections are XS 1 (upstream - right) to XS 15 (downstream - left).

5.1.1.3 Model representation of State Highway Bridge, right bank spillway, and asset crests

The State Highway Bridge was replaced in conjunction with the development of the flood protection scheme. The bridge was intended to have a minimum soffit level of RL 10.3m, but owing to issues described in the Scheme Design Report (Wood, 2014) the bridge was constructed with a minimum soffit at RL 9.6m. The report (Appendix 1) provides NZTA’s bridge design assessment and also provides a design flood profile and water levels (page 49) for the 1%AEP event (Q_p315). This gives a peak water level at the bridge of RL 8.5m and hence 1.1m freeboard. Note that the design flood levels tabulated for the bridge assessment, are slightly different from those adopted for the flood protection scheme final construction issue drawings.

The cross-section underneath the bridge (XS 5 – model chainage 202m) was surveyed in 2014 (Figure 16) and is included in this updated model. The bridge structure itself is omitted from the model given it is a single span structure and modelled floodwater levels for the various design events do not reach the soffit.

The scheme design also includes a spillway on the right bank upstream of the bridge as depicted in Figure 17. The spillway provides a relief for the bridge in over-design events, it is approximately 60m in length with a minimum crest height of RL 8.61m. MIKE11 modelling of the various present and future climate flood flows as part of this service level review indicate water levels are either below or just at activation levels. The spillway has therefore not been included in this model either and this is discussed further in the results (Section 5.1.2). The design freeboard for spillway activation was 300mm above the present day 1%AEP, noting that this is incorrectly recorded in the Conquest database as 600mm.

Surveyed cross-sections (2014) were added to the model and adjusted to include the flood protection scheme asset crest features as necessary.

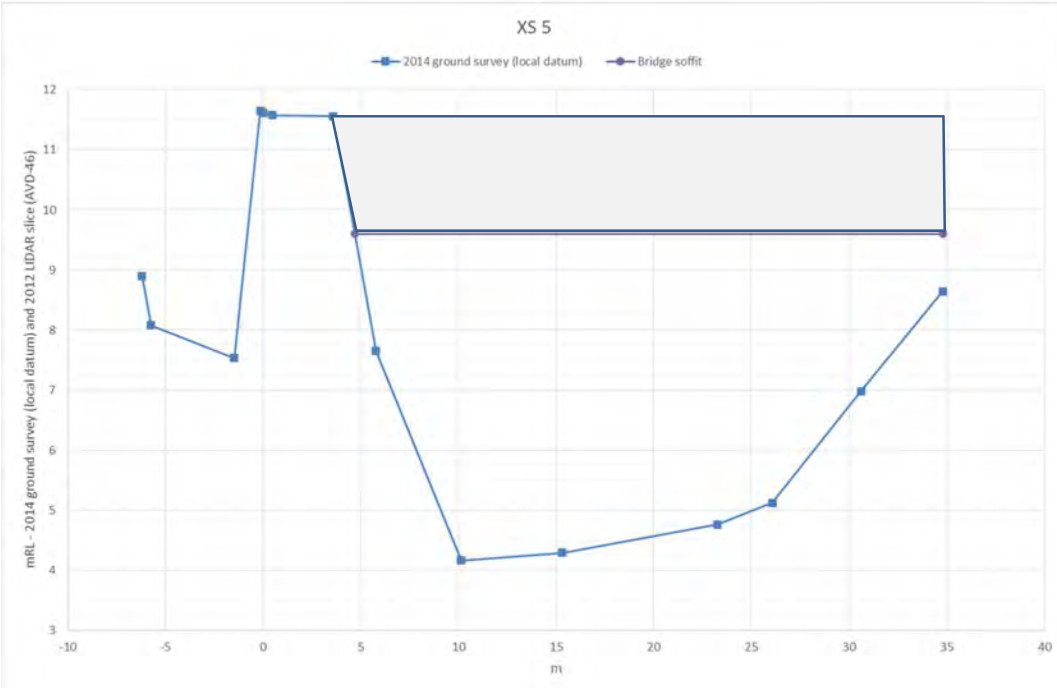

Figure 16 State Highway Bridge cross-section (XS 5) as surveyed in 2014, minimum bridge soffit shown at RL 9.6m, with left bank bridge approach / stopbank adjacent.

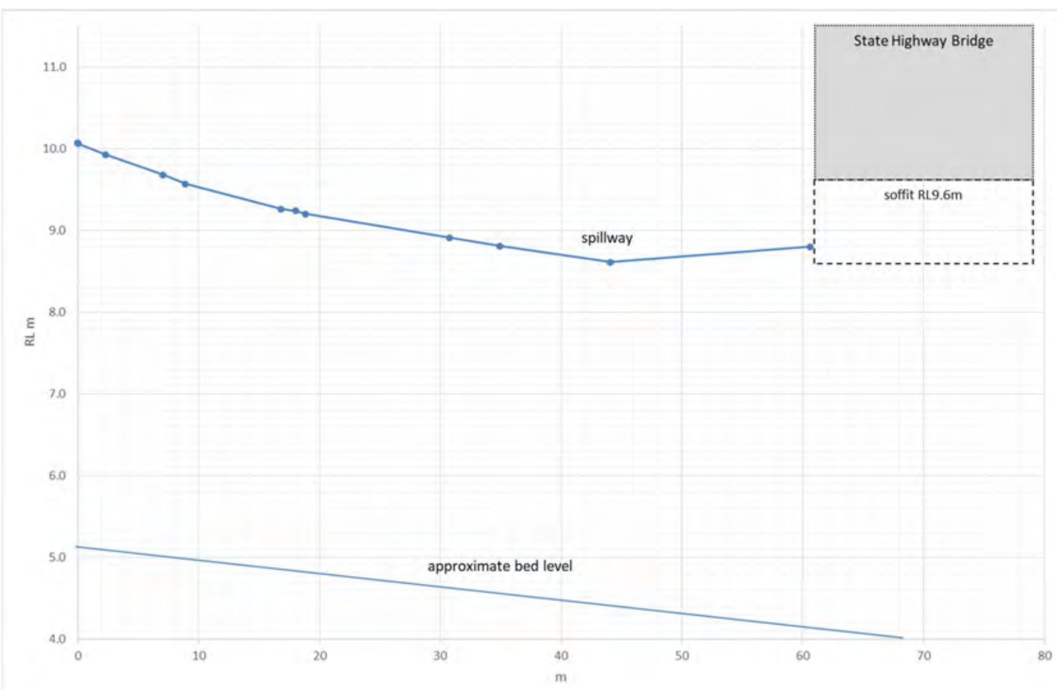

Figure 17 Right bank spillway upstream of State Highway Bridge as surveyed in 2014 (as viewed from right bank). Note bed and bridge are approximated in image.

5.1.1.4 MIKE11 model boundaries

The design discharge estimates (Section 2.3.6) were applied as flood hydrographs (Section 2.4) at the upstream limit of the MIKE11 model approximately 200m upstream of the State Highway Bridge.

At the tidal boundary a static mean high water spring (MHWS) tide (RL 1.76m) was applied for the current climate. Future climate scenarios included 1m of sea level rise to RL 2.76m.

Note the original design model used a conservatively high tidal boundary of RL 2.5m but was applied at the lowest surveyed cross-section (XS 15) just inside the stream mouth. This would have forced modelled water levels down to RL 2.5m at this location.

5.1.1.5 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.
- Manning's roughness was set to a uniform roughness of n=0.05 as per the original design model.
- Maximum dx was set to 10m.

Other model details include:

- Cross-section radius type – resistance radius.
- Simulation timestep 5 seconds.
- Result storing frequency 60 seconds.

5.1.2 MIKE11 model results

Predicted water levels at each of the channel cross-sections have been extracted from the MIKE11 model. This has been undertaken for the present climate 1%AEP design flow (Q_p315), and the two more conservative future climate scenarios (RCP 6.0 and RCP 8.5) having respective peak flows of Q_p375 and Q_p414 plus the effects of 1m sea level rise. The predicted water levels are detailed in Table 11 with flood profiles in Figure 18.

The assumptions include those described in the model build above, and the use of the 2014 cross-sections and associated bed levels recorded at the time. There is no allowance for sediment deposition, debris, blockage, or super-elevation of water levels.

Observations from the MIKE11 modelling, surveys, LIDAR and historical aerial imagery are that:

- The original design flood profile is mostly higher than the revised design flood profile. This is more prevalent upstream of the bridge and reduces downstream to less than the revised flood profile (Figure 18).
- Minimum bed levels have lowered through most of the reach between the 2004 and 2014 cross-section surveys, with the exception of the lower stream closer to the mouth where there has been aggradation.
- Comparison of cross-sectional areas between 2004 and 2014 surveys indicates channel capacity has been increased with the raising of flood defences. Some channel degradation through much of the reach has further increased this capacity, however there is some aggradation in the lower stream near the mouth.
- MIKE11 modelling suggests there is sufficient capacity to contain the present day 1%AEP event through the entire river reach but there is insufficient freeboard (<600mm) in the lower stream near the mouth (i.e. XS 13 to XS 15).
- MIKE11 modelling also suggests that 600mm freeboard would be sufficient to allow for increases in flood level associated with the climate change events, however future climate events would overtop the banks in the lower reach near the mouth.

- The spillway commences activation in the future climate Q_p414 event, but not in the present day 1%AEP event in which approximately 480mm freeboard has been modelled similar to the design freeboard condition of 300mm.

These elements are described in more detail in some of the following sections.

Table 11 MIKE11 model results for the various design events (all levels in terms of Te Puru Local Datum).

XS	Design Report (#3243546)			2014 bed levels:		2018 MIKE11 model results:			
	Model Ch. (m)	2004 bed level (RL m)	1%AEP design flood level (RL m)*	2014 (RL m)	Δ in min. bed level 2004-2014	Model Ch. (m)	Q_p315 (RL m)	Q_p375+ 1mSLR (RL m)	Q_p414+ 1mSLR (RL m)
1	0	6.99	10.92	6.57	-0.42	0	10.27	10.59	10.78
2	50	6.26	10.32	5.97	-0.29	44	9.72	10.03	10.23
3	100	5.82	9.85	5.58	-0.24	94	9.19	9.52	9.72
4	150	5.18	9.06	4.99	-0.19	144	8.56	8.88	9.08
US BRG	200	4.38	8.50	-	-	192	8.03	8.35	8.54
5	210	4.25	8.02	4.16	-0.09	202	7.94	8.26	8.45
DS BRG	220	4.13		-	-	211	7.82	8.13	8.32
6	250	3.82	7.60	3.00	-0.82	249	7.26	7.58	7.78
7	300	3.24	7.01	3.05	-0.19	295	6.79	7.11	7.30
8	350	2.85	6.53	2.32	-0.53	350	6.29	6.60	6.79
9	400	2.18	6.21	1.99	-0.19	402	5.92	6.23	6.42
10	450	1.66	5.52	1.38	-0.28	450	5.37	5.67	5.84
11	500	1.52	5.05	1.02	-0.50	501	4.91	5.19	5.36
12	550	1.11	4.47	1.19	+0.08	551	4.50	4.77	4.93
13	600	0.72	3.92	0.18	-0.54	600	4.08	4.31	4.44
14	650	0.48	3.41	0.64	+0.16	650	3.78	3.99	4.09
15	700	0.52	2.50	0.48	-0.04	710	2.94	3.20	3.27
FIRTH	-	-	-	-	-	800	1.76	2.76	2.76

*Taken from construction issue design drawings in Design Report (Wood, 2014).

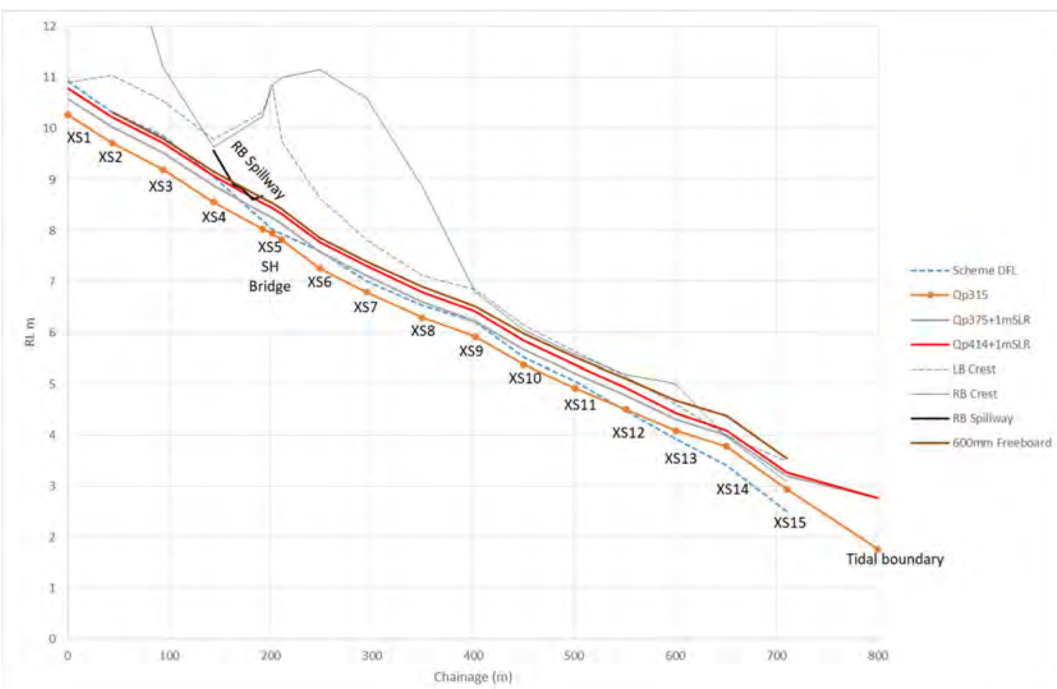

Figure 18 Modelled flood profiles compared with original design flood levels and left and right bank assets.

5.1.2.1 Bed levels

Comparison of the 2004 and 2014 channel cross-sections indicate that the minimum bed level has typically degraded and is on average -0.27m lower (Figure 19). Upstream of the bridge the minimum bed level was -0.19m to -0.42m; immediately downstream of the bridge (XS 6) the bed was degraded by-0.82m; and downstream towards the mouth the average lowering is -0.32m (range -0.04m to -0.54m). However, some increases (+0.08-0.16m) are noted in the lower stream near the mouth.

The degradation in the majority of the stream increases the amount of available freeboard and helps explain the apparent lowering of design flood levels. Conversely, the increases in bed levels in the lower stream suggest aggradation in this area at the time of ground survey (2014). This is also an observation from the LIDAR (2013) and historical aerial imagery (Google Earth) of spit growth at the mouth around this period. More recent imagery suggests the channel at the mouth has opened somewhat since 2013/2014.

Whilst minimum bed level is not necessarily a firm indication of overall bed degradation, comparison of 2004/2014 cross-sections (Appendix B) suggests bed degradation in most of the reach apart from the lower stream towards the mouth where aggradation was recorded.

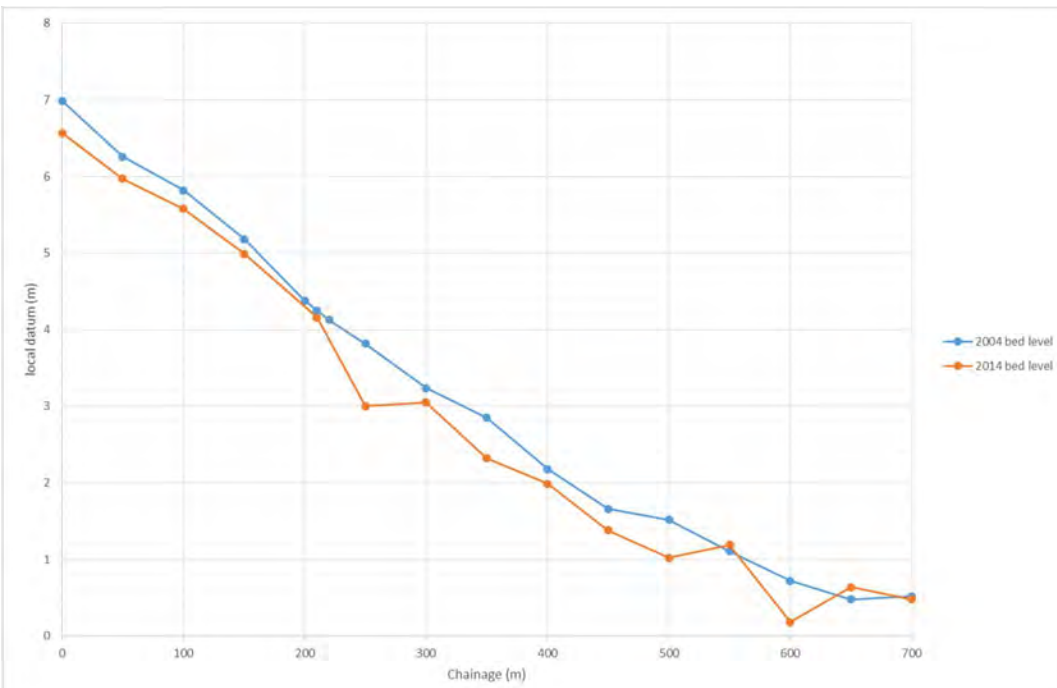

Figure 19 Minimum bed level profiles from 2004 and 2014 channel surveys between XS 1 (upstream) and XS 15 (downstream).

5.1.2.2 Channel capacity

A function of the scheme works is increased channel capacity by raising flood defences. A comparison of channel cross-sectional areas was made between the 2004 and 2014 surveys to the level of overtopping. This indicates that on average channel capacity has increased by a ratio of approximately 1.7 associated with the scheme.

The channel capacity upstream of the bridge has increased by a ratio of 1.8-2.0. At the bridge this is 1.5, downstream of the bridge towards the mouth varies between 1.3-2.8, but at the mouth there was a reduction to 0.9 which aligns with observations described in this report around aggradation at the mouth for this period.

5.1.2.3 Spillway activation

The spillway design is for the 1%AEP event with 300mm freeboard. The modelling suggests there is 480mm freeboard available for the revised MIKE11 model. Modelling of the future climate Q_p414 event estimated that peak water levels would be just high enough to commence spillway activation.

5.1.2.4 Freeboard

The MIKE11 modelling suggests that 600mm freeboard would be sufficient to allow for increases in flood level associated with the climate change events. The increase in flood levels between the present climate and future climate flows are predicted to be less than 300-500mm.

5.1.3 MIKE11 model summary

MIKE11 modelling of Te Puru Stream for the present and future climate 1%AEP floods has been undertaken using the 2014 channel cross-section survey and flood protection scheme as-built data. The results indicate:

- The present day 1%AEP event flood flows are contained within the scheme assets, however, there is less than 600mm freeboard in the lower stream near the mouth (i.e. XS 13 to XS 15).
- Future climate 1%AEP events are likely to overtop the banks in the lower stream near the mouth as above.
- The spillway upstream of the State Highway approximates its design condition of activation in events greater than a 1%AEP event with 300mm freeboard.
- The original design flood profile is mostly higher than the revised design flood profile with the exception of the lower stream near the mouth. This suggests degradation in the upper stream and aggradation in the lower stream near the mouth.
- Analysis of 2004 and 2014 cross-sections confirms bed levels have lowered through most of the reach with the exception of the lower stream near the mouth where some aggradation has occurred.
- Aggradation at the mouth in the form of spit growth is evident in LIDAR capture and aerial imagery in the period around 2011-2013. The mouth appears more open in more recent imagery and site observations.
- Resurvey of the channel cross-sections would be useful in determining current trends in channel morphology. Re-running the model with revised cross-sections is straightforward and would allow re-assessment of flood levels to determine if shortfalls in freeboard in the lower channel remain an issue.

5.2 MIKE21 2D model

A MIKE21 2D model was also developed of the Te Puru Stream as described below.

5.2.1 MIKE21 model development

5.2.1.1 Model domain and datum

The MIKE21 model domain extends from a southwest origin at NZTM 1823600 5896240 to a northeast corner at NZTM 1824900 5897740 (1300m x 1500m) as shown in Figure 20. This is the same domain as the MIKE11 model network described in Section 5.1. The model vertical datum is Te Puru Local Datum which is assumed to be very close to AVD-46 (see Section 4.4).

5.2.1.2 Bathymetry

The MIKE21 model bathymetry (2m grid) is derived primarily from the 2013 LIDAR dataset, but has been supplemented with 2014 ground survey of the flood protection scheme. The flood protection scheme including the new bridge and approaches were completed prior to the 2013 LIDAR. Flood protection asset crest data from the ground survey has been used to modify the model bathymetry so that the assets are accurately represented. A comparison of 2013 LIDAR data (AVD-46) has been found to be very close in the vertical to the 2014 ground survey data (Te Puru Local Datum) as described in Section 4.4.

The model bathymetry used in the MIKE21 modelling is shown in Figure 20.

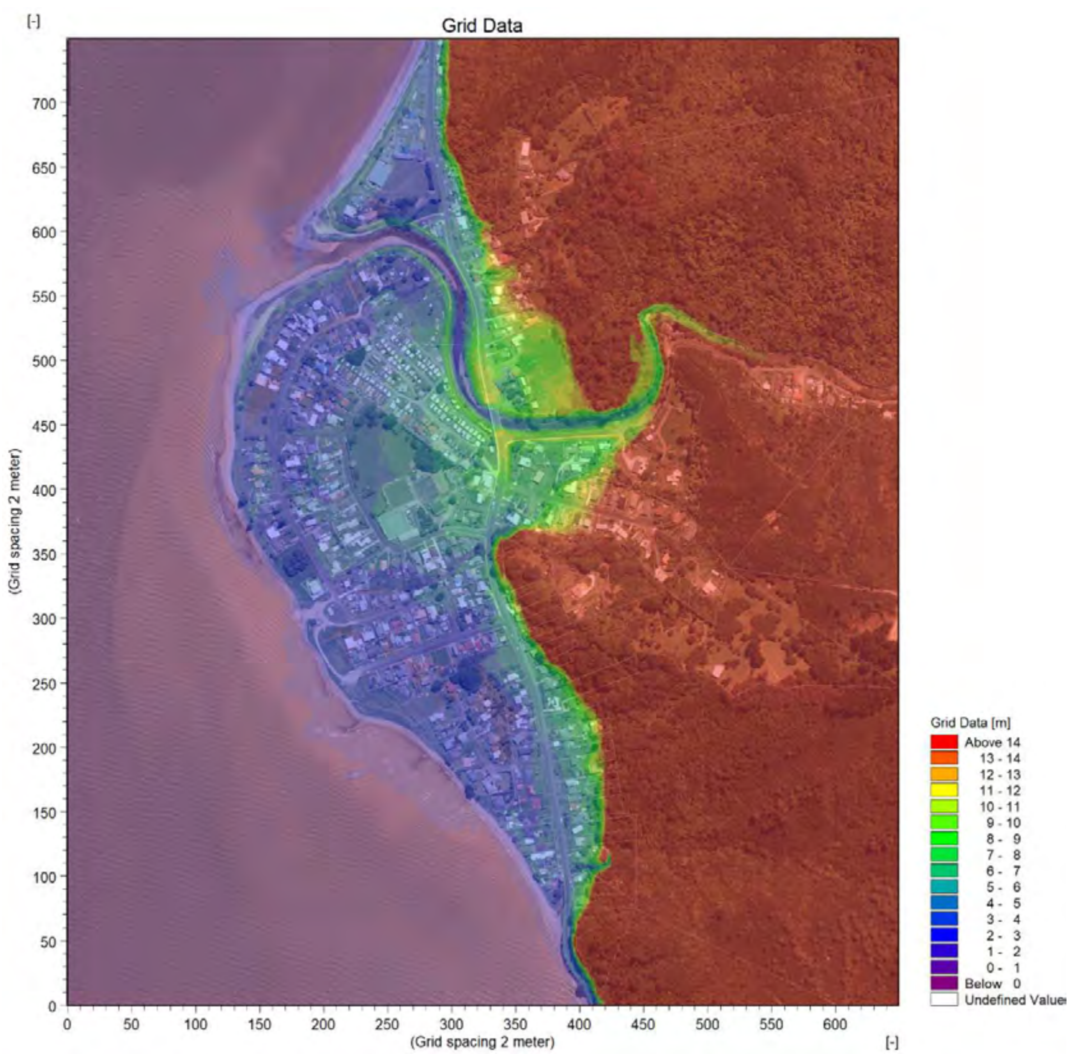

Figure 20 MIKE21 model domain and bathymetry.

5.2.1.3 Simulation period, time step and outputs

Time step was reduced to 0.1 second for model stability. The design events were run for 3 hours with arbitrary dates and results saved at 1 minute intervals. 3 hours is sufficient for the passage of the hydrograph and any overland flows to peak and disperse or pond.

5.2.1.4 MIKE21 model boundaries

The design discharge estimates (Section 2.3.6) were applied as flood hydrographs (Section 2.4) at the eastern extent of the MIKE21 model, approximately 800m upstream of the State Highway Bridge.

Open coastal boundary conditions were applied on the western, northern and southern model boundaries representing the Firth of Thames. At this tidal boundary a static mean high water spring (MHWS) tide was applied for the present climate (RL 1.76m). Future climate scenarios included 1m of sea level rise (RL 2.76m).

5.2.1.5 Other MIKE21 variables

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

Eddy viscosity was set to a constant flux based value of $0.8m^2/s$ based on the grid size and time step (constant eddy = $0.02\ \Delta x\ \Delta y\ /\ \Delta t$) as per recommendations by the software developer DHI.

A surface roughness or resistance map was generated which assigned Manning's values of M=30 (n=0.033) for the channel and open water of the Firth of Thames, M=20 (n=0.050) for the floodplain, and M=10 (n=0.100) for the floodplain where buildings and dense vegetation are present. Areas beyond the LIDAR extent and where no water flows were set to a 'land value' of 50.

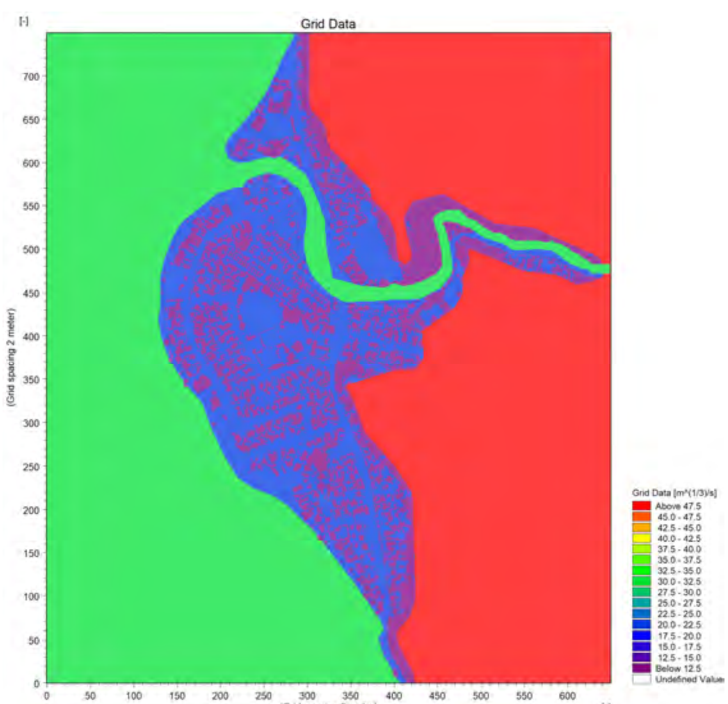

Figure 21 Roughness map used in MIKE21 model.

5.2.2 MIKE21 model scenarios

The MIKE21 model scenarios include various flood events as per the MIKE11 modelling and as described in Section 2.3.6. The modelled event scenarios include:

Present climate:

- 1%AEP discharge (Q_p315) with MHWS tide (RL 1.76m)

Future climate:

- RCP 6.0 1%AEP discharge (Q_p375) with MHWS tide + 1m SLR (RL 2.76m)
- RCP 8.5 1%AEP discharge (Q_p414) with MHWS tide + 1m SLR (RL 2.76m)

5.2.3 MIKE21 model results

The MIKE21 model results saved at 1 minute intervals have been analysed and maximum flood statistics produced for each of the three flood scenarios described above. The estimated maximum flood depths for the three scenarios are shown in Figure 22 to Figure 24. A description of the flooding that is predicted in each of the simulations is described in the following sections. Note the predicted flooding is quite different from that predicted by the MIKE11 model and this is discussed in Section 5.2.3.4.

5.2.3.1 Present climate 1%AEP discharge (Q_p315) with MWHS tide (RL 1.76m)

Conveyance of the majority of the flood flow and volume is contained within the flood protection assets, however overtopping of the channel into the floodplain is modelled in a number of locations:

- Overbank flows initially occur over the lower left bank at the mouth, downstream of the flood protection assets. This is the only left bank overflow location modelled during this event. A flood volume of approximately 1100m^3 flows into the floodplain affecting properties at the northern end of Seaview Avenue.

- Right bank overflows are modelled at two locations:
  - Over the right bank assets just upstream of the mouth *(Asset: Te Puru Right Below State Highway Stopbank).*
  - Over the right bank assets opposite #532 and #540 Thames Coast Road *(Asset: Te Puru Right Below State Highway Floodwall)*.

  The modelled overflows from these locations either directly enter the school and two properties to the north of the mouth, or flow north down the State Highway into these properties.

- The spillway on the right bank upstream of the State Highway is also activated (*Asset: Te Puru Right Above State Highway Floodwall Spillway*). The volume overtopping the spillway is not significant and estimated at approximately 325m^3. This is modelled as being contained within the basin downstream of the spillway. In reality, this area is drained by a 1200mm diameter stormwater culvert which discharges back to the river downstream of the bridge.

It is considered that the results described above for the present day 1%AEP event are likely overestimated for a number of reasons outlined below. These reasons also apply to the future climate scenarios but are most apparent for the present day scenario as it is expected that the flow is contained given the service level for flood protection assets.

- The bathymetry for the MIKE21 model is derived from 2013 LIDAR supplemented with 2014 scheme asset crest data. At the time of the LIDAR capture (1 January to 12 March 2013) a significant spit has formed at the mouth which has narrowed the stream mouth

(Figure 27). This is a function of coastal processes and the frequency of low/high stream flows. A review of aerial imagery in Google Earth at the time of writing shows the changes in the mouth between 2001 and late 2016. The imagery shows periods when the spit is dominant and the mouth is narrow, and other times when the stream channel is relatively open. Between 2011 and 2013 spit accretion is dominant and the mouth is narrow. As the LIDAR was captured during this period the model bathymetry represents a narrow mouth. Whilst a narrow mouth may be present during flood events, such features are also rapidly eroded during high flows. It is therefore likely that modelled flood levels upstream of the mouth are likely overestimated. It is also noted that the previous LIDAR dataset (2006) used during the scheme development had a relatively open stream mouth present.

- LIDAR does not penetrate water bodies. Comparison of recent surveyed cross-sections and LIDAR slices (Appendix A) indicates that channel capacity in the lower reach is under-represented in the LIDAR. This is apparent between XS 13 and XS 15 (location - Figure 15) as shown in Appendix A Figure A13 to Figure A15 where bed levels (or captured water levels) are around RL 1.0m associated with a backwater formed upstream of the pinch formed by the spit. Further upstream of XS 13 the LIDAR penetration does not appear to be an issue.
- The model does not include stormwater networks or floodgates which may reduce the extent and depth of any ponding.

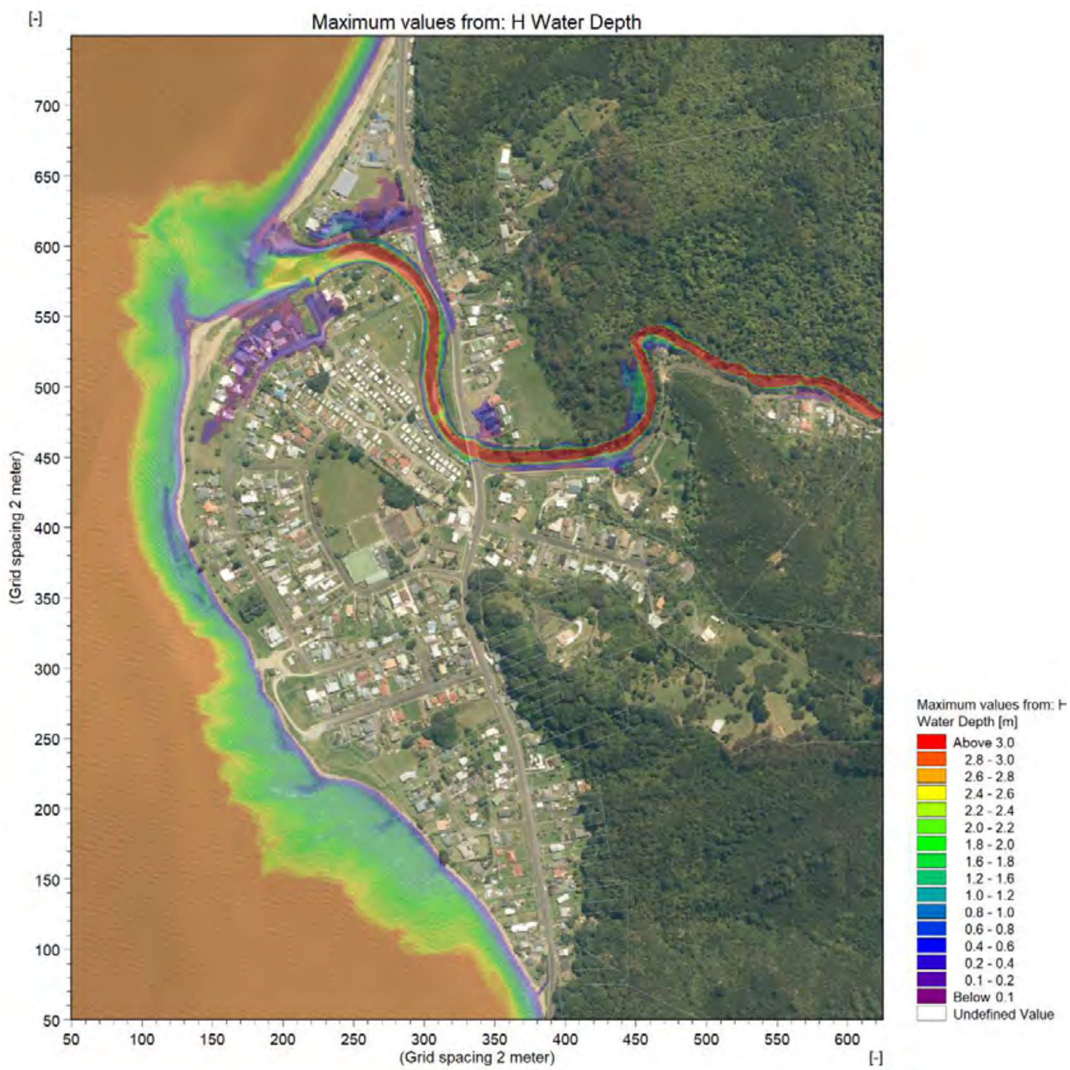

Figure 22 **MIKE21 model estimated maximum depth for present climate 1%AEP design discharge (Q_p315) and MWHS tide (RL 1.76m) considering MIKE21 model.**

5.2.3.2 Future climate 1%AEP discharge (Q_p375) with MWHS tide (RL 2.76m)

Prior to the commencement of the model run, the coastal inundation caused by applying 1m of sea level rise to the MHWS tidal condition is significant. This was shown in Figure 10 (lower left image) and affects approximately 120 properties. This is prior to effects of the modelled flood event.

The initial effects of the fluvial flood event are similar to those described for the present climate 1%AEP event, although these obviously become more severe and other overflows occur. The additional overflow locations are on the left bank at the upstream extent of the scheme assets, and on the left bank immediately downstream of the bridge. The maximum flood depths and extent from this modelled event are shown in Figure 23.

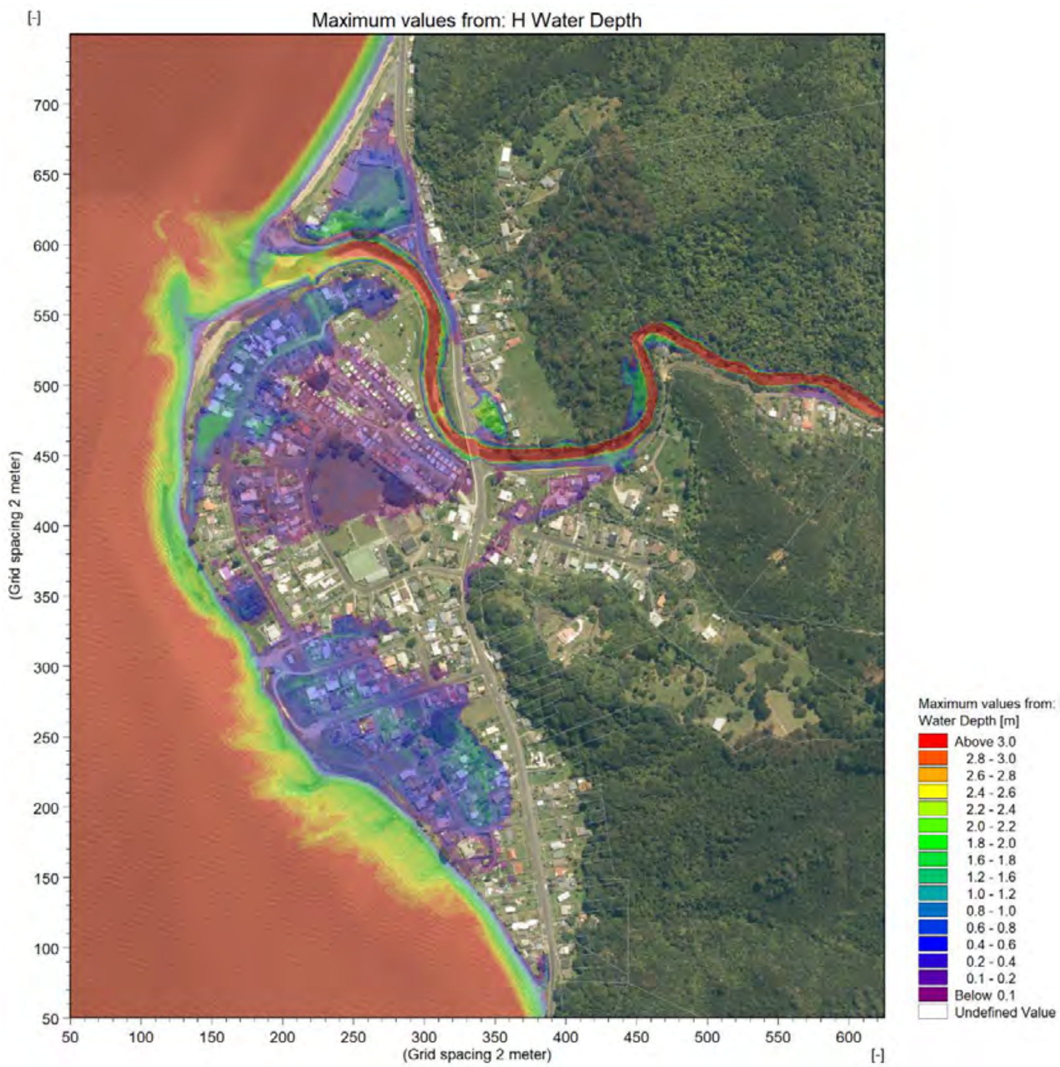

Figure 23 MIKE21 model estimated maximum depth for future climate (RCP 6.0) 1%AEP design discharge (Q_p375) and MWHS tide (RL 2.76m).

5.2.3.3 Future climate 1%AEP discharge (Q_p414) with MWHS tide (RL 2.76m)

Similar to the previous future climate scenario the coastal inundation caused by applying 1m of sea level rise to the MHWS tidal condition is significant affecting approximately 120 properties as shown in Figure 10 (lower left image). This is prior to effects of the modelled flood event.

The modelled flood characteristics are also very similar to the previous climate scenario but are obviously more severe. A greater volume of overtopping occurs at the locations already described and the inundation on the floodplain is more extensive. The maximum flood depths and extent from this modelled event are shown in Figure 24.

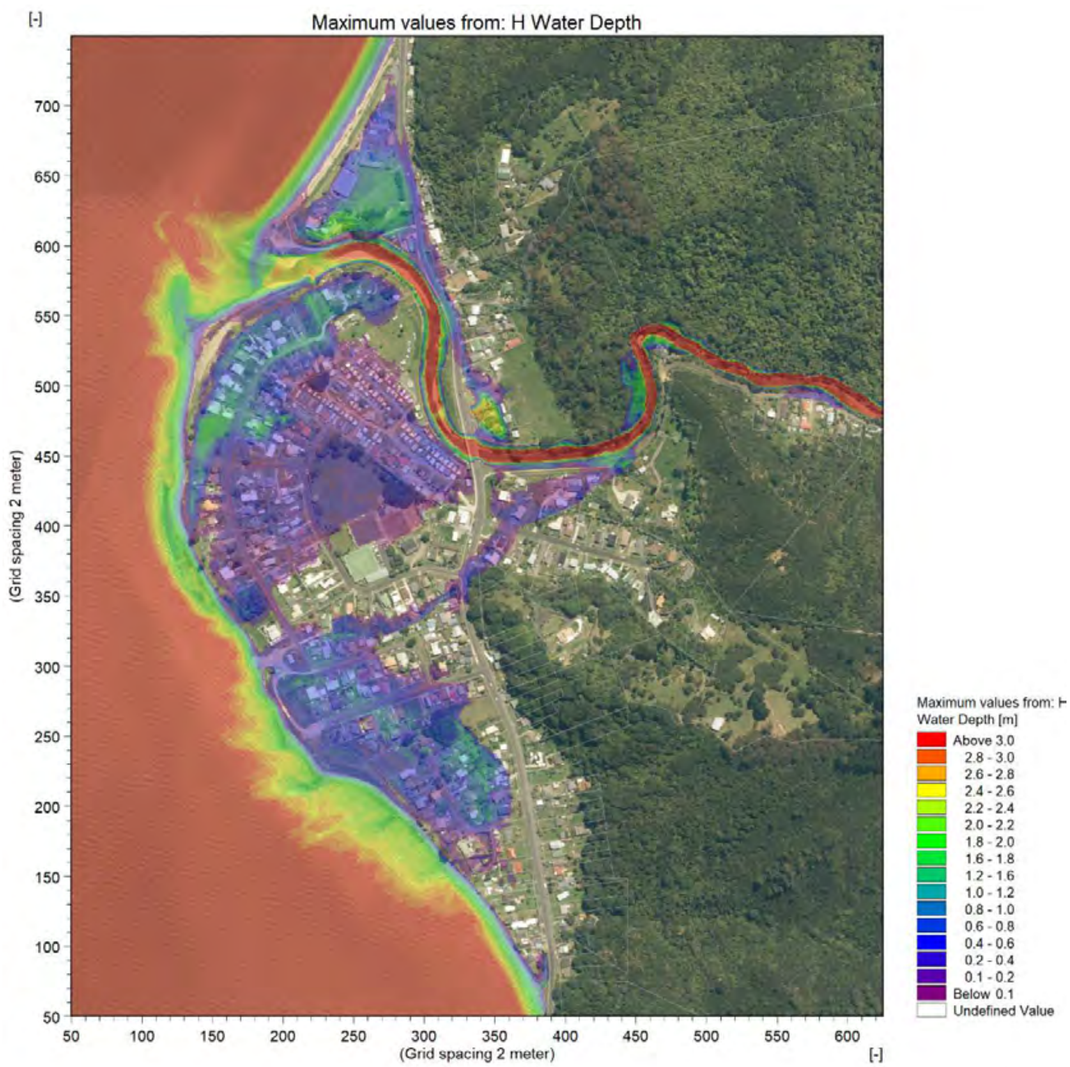

Figure 24 MIKE21 model estimated maximum depth for future climate (RCP 8.5) 1%AEP design discharge (Q_p414) and MWHS tide (RL 2.76m).

5.2.3.4 Comparison between MIKE21 and MIKE11 model results

A comparison of MIKE21 and MIKE11 maximum water levels along the alignment of the channel cross-sections was undertaken. The maximum water level profiles between the present day 1%AEP event (Q_p315) and larger climate change event (Q_p414) is shown in Figure 25. Observations include:

- MIKE21 maximum water levels are on average 0.36-0.45m higher for the various events.
- Actual variation in maximum water levels between the two models along the stream reach vary significantly from approximately -0.3m (lower) to +1.1m (higher).
- The variations between the two models are typically less in the lower reach and greater around and upstream of the bridge.
- The effect of the channel pinch at the mouth as a result of spit formation has a greater influence in MIKE21 given the bathymetry is derived from LIDAR at a time when the channel was narrow (Figure 27).
- Similarly, the hydraulic jump at the bridge may be an exaggerated function of the bed morphology depicted by the LIDAR at this location where the DTM is interpolated beneath the state highway bridge structure.
- MIKE11 has a single maximum water level at each cross-section. Taking a slice from MIKE21 along the cross-section alignment will give significant variations in maximum water level (e.g. effects of bed morphology over grid and super-elevation). These variations across the channel are 0.17-1.15m, and on average 0.5m.
- For reference, comparison of the present day 1%AEP (Q_p315) MIKE11 maximum water levels and MIKE21 minimum and maximum water levels are provided in Figure 26.

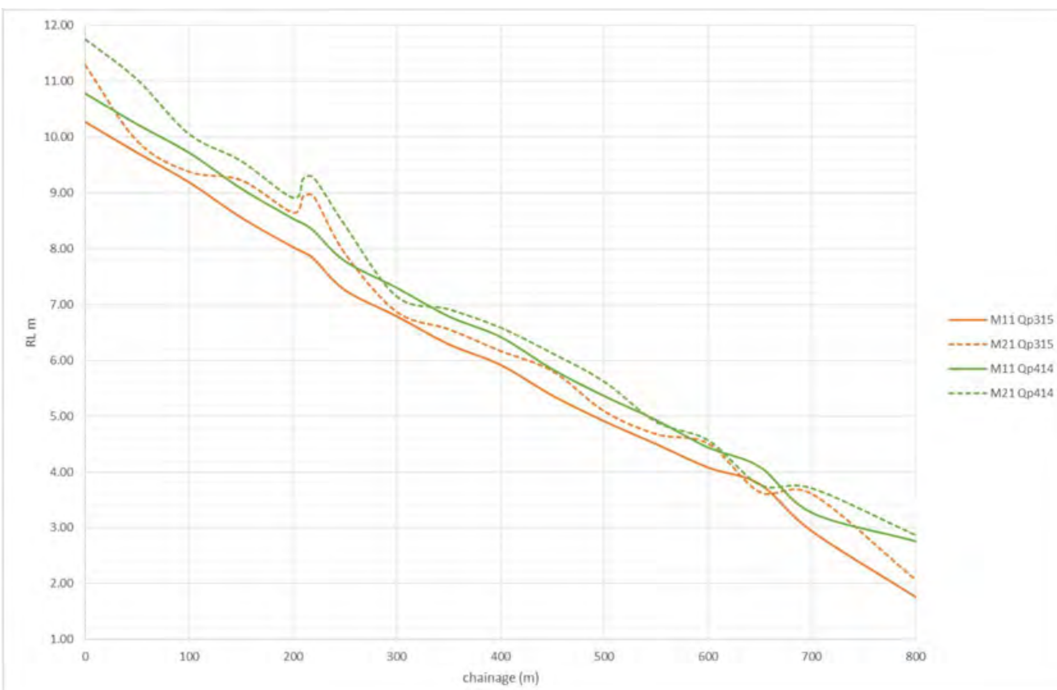

Figure 25 Comparison of MIKE11 and MIKE21 maximum water level results at location of MIKE11 cross-sections for Q_p315 and Q_p414 events.

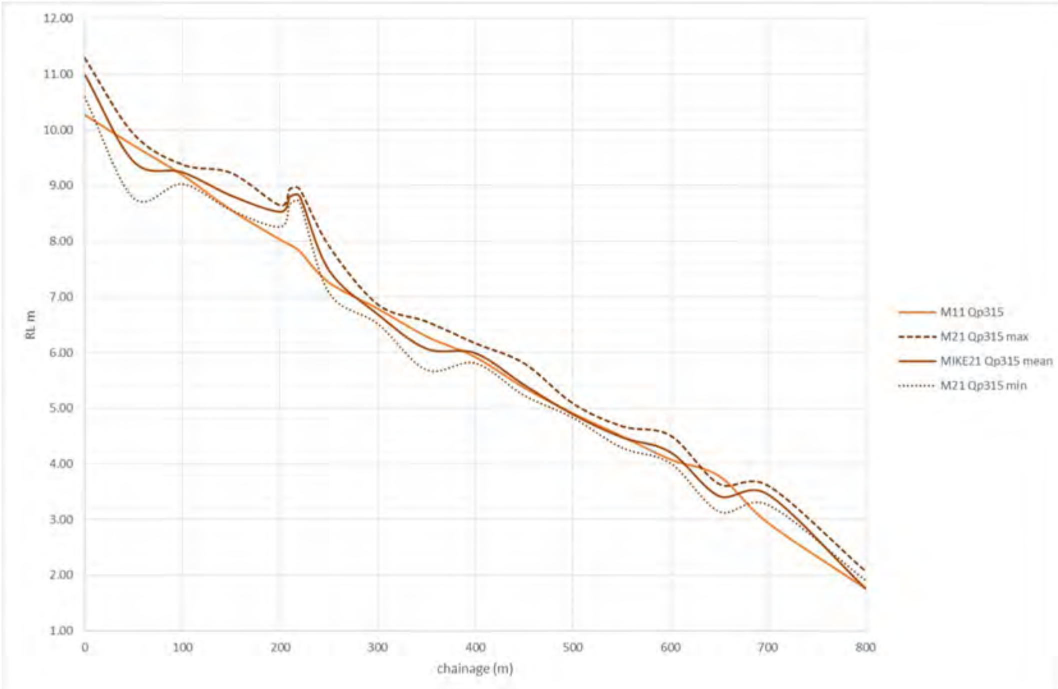

Figure 26 **Comparison of Q_p315 MIKE11 maximum water levels and MIKE21 minimum and maximum water levels at cross-sections alignments.**

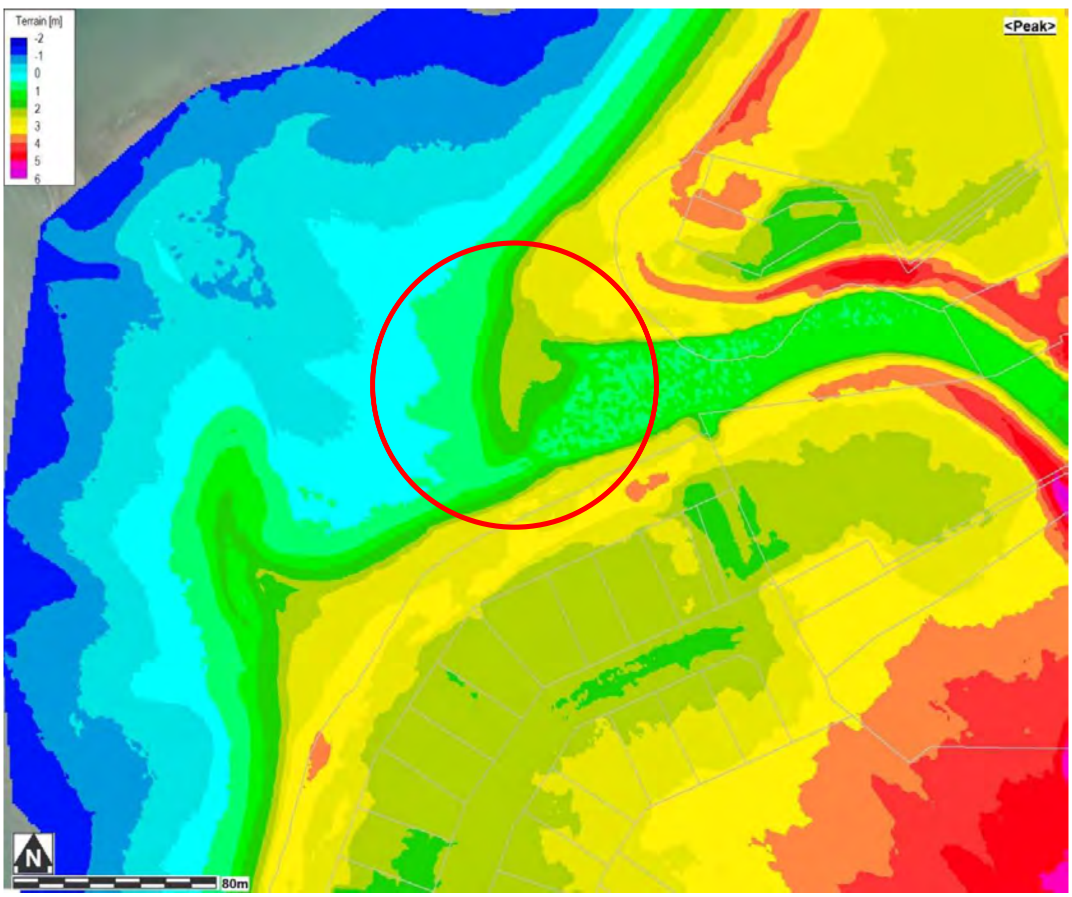

Figure 27 **2013 LIDAR imagery showing narrow channel opening and spit extending from north bank at time of LIDAR capture.**

5.2.4 MIKE21 model summary

Modelling of Te Puru Stream for the present and future climate 1%AEP floods has been undertaken using the 2013 LIDAR supplemented with 2014 flood protection scheme crest data. The results indicate that present day event flood flows are mostly contained within the scheme assets but some overflows are modelled which affect the lower left and right floodplain closer to the mouth between Seaview Avenue and the school to the north. The results also indicate minor activation of the spillway upstream of the bridge.

Predicted water levels from the MIKE21 model are typically greater than those of the MIKE11 model. MIKE11 suggests that the flood flows are contained within the assets whilst MIKE21 indicates a degree of overtopping. A number of reasons have been discussed as to why MIKE21 generates greater water levels, some of which include:

- Sediment deposition around the mouth and spit at the time of LIDAR/survey, noting this is cyclical between erosional/depositional phases associated with coastal events and low/high stream flows.
- Under-representation of the lower channel immediately upstream of the mouth and spit associated with a backwater present at the time of the LIDAR capture.
- LIDAR representation of stream bed under state highway bridge includes some irregularities/features associated with interpolation of the DTM.
- MIKE21 allows modelling of super-elevation which is likely to be significant given the tortuosity and grade of the river. Therefore MIKE21 gives a wide range of water levels across the channel cross-section alignment.

5.3 Modelling discussion

Both MIKE11 (1D) and MIKE21 (2D) modelling have been undertaken as described in Sections 5.1 and 5.2. Both models have their strengths and weaknesses and utilise different modelling techniques subsequently giving varying results. MIKEFLOOD is a coupled model that also could have been used, however the benefits of this approach are limited in this instance as the design flow modelled by the 1D component would remain in-channel, hence give the same result as MIKE11.

MIKE11 indicates that the scheme is able to pass the service level design flow (present day 1%AEP) but there are shortfalls in the 600mm freeboard. These shortfalls are on the left bank in the lower stream downstream of XS 13. Future climate 1%AEP flows were modelled to overtop the left bank in the same location.

MIKE21 indicates more overtopping than MIKE11 on both the left and right banks in the lower reach as discussed in the previous section. This may be partially attributed to the bathymetry in the lower channel as represented by the LIDAR, but is also a function of the fundamental differences between the two modelling techniques.

The cross-section surveys (2004/2014) suggest there is degradation in the upper reach and aggradation in the lower reach near the mouth as at 2014. Further evidence of aggradation in the lower reach appears to align with observations in aerial imagery, LIDAR capture and survey, however, more recent imagery and site observations suggest the channel and mouth may now be more open. Re-survey of the channel cross-sections would be useful in determining current trends in channel morphology, and allow reappraisal of the MIKE11 model results.

The results of the MIKE21 model, whilst possibly overestimating flood levels, still provide a useful flood extent suitable for flood hazard delineation and identifying points of potential overflow.

6 Service level review of flood protection assets

A service level review of the flood protection assets shown in Figure 11 has been undertaken based on the results of the MIKE11 model.

Primarily the service level of the assets is based on the present climate 1%AEP design flood (Q_p315) in conjunction with a MHWS tide (RL 1.76m), and a freeboard allowance of 600mm. There are however exceptions to the service level:

- Te Puru Right Above State Highway Floodwall Spillway
  - 1%AEP flood + 300mm freeboard
- Te Puru Right Below State Highway Floodwall (floodwall extension only - upper 130m)
  - future climate 1%AEP flood and no freeboard (used RCP 8.5 scenario Q_p414)

Profiles have been plotted along each asset crest length showing the actual crest level, revised design crest level and design flood level (Figure 28 to Figure 32). In addition, Table 12 provides full details of the service level data including performance grades at individual survey points along the assets. Performance grades are assessed based on the percentage of available freeboard as shown in Figure 33.

In total there is a linear length of 1026m of scheme floodwalls and stopbanks with:

- 77% performance grade 1 (793m)
- 11% performance grade 2 (112m)
- 7% performance grade 3 (68m)
- 5% performance grade 4 (53m)
- 0% performance grade 5 (0m)

The performance grades highlight that the majority of the scheme is providing the intended service level. The MIKE11 modelling indicates that the main shortfalls in freeboard are primarily in the lower assets within approximately 100m of the downstream extent on both banks. As suggested earlier this may be a function of the timing of the channel surveys in relation to stream mouth morphology or it could indicate aggradation at the time of survey. Re-survey of the channel cross-sections and comparison with the 2014 dataset will help determine if this performance issue still exists under the current morphology. Therefore one of the recommendations of this review is to resurvey the 2014 cross-section alignments.

Service level data is provided for import into the Asset Management Conquest Database in Table 13 (Appendix C – Conquest service level data).

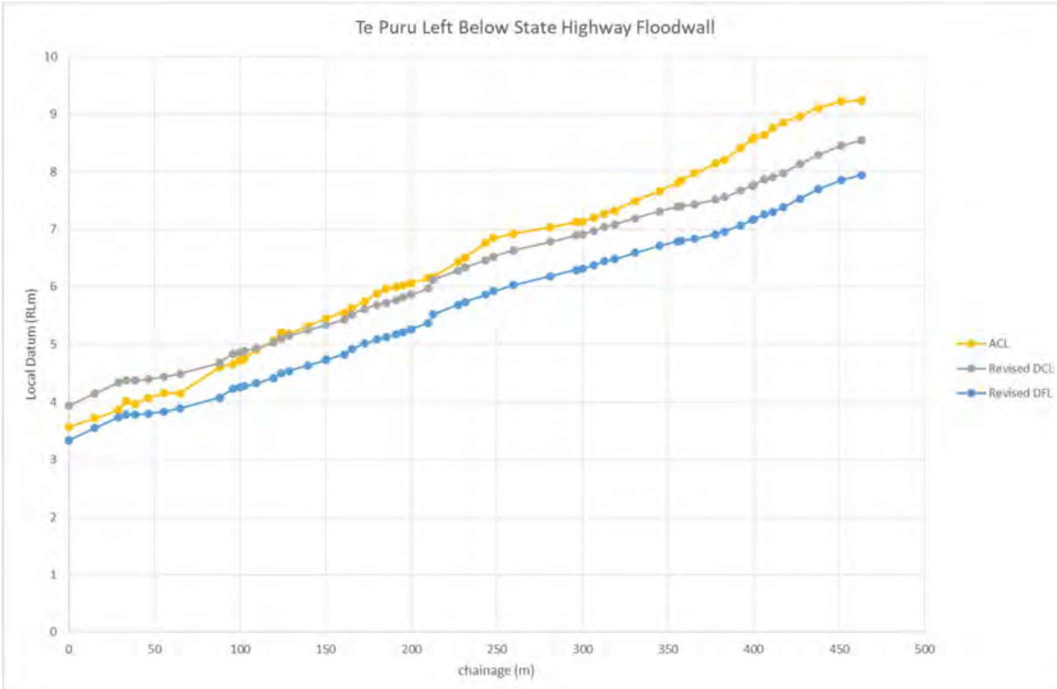

Figure 28 Te Puru Left Below State Highway Floodwall - profiles for actual crest level (ACL) compared to the revised design crest level (DCL) and design flood level (DFL).

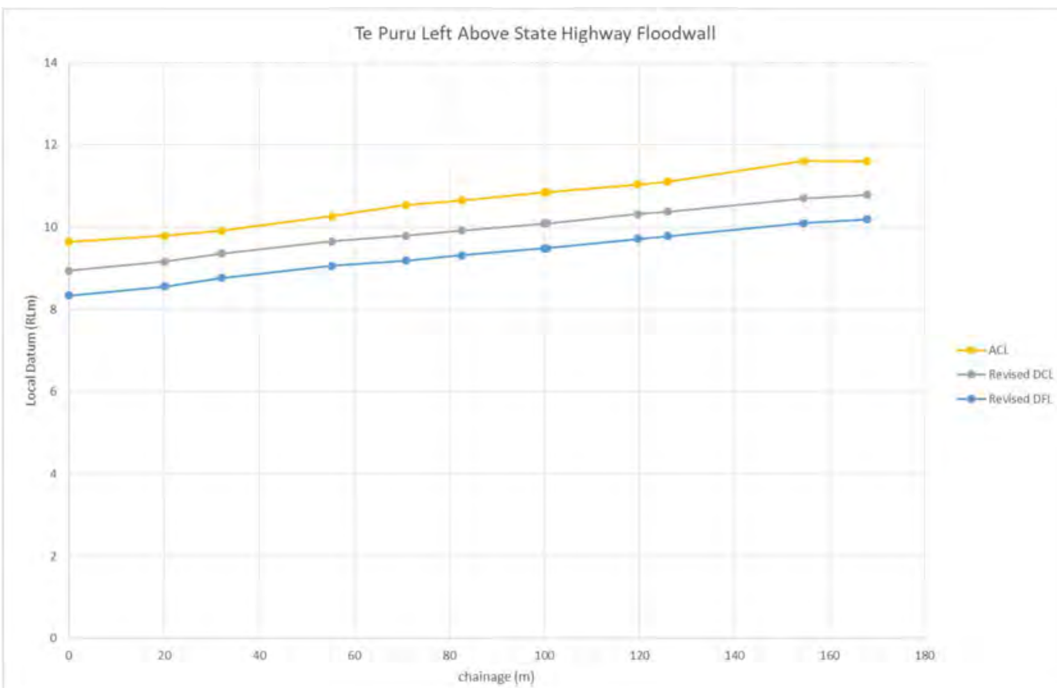

Figure 29 Te Puru Left Above State Highway Floodwall - profiles for actual crest level (ACL) compared to the revised design crest level (DCL) and design flood level (DFL).

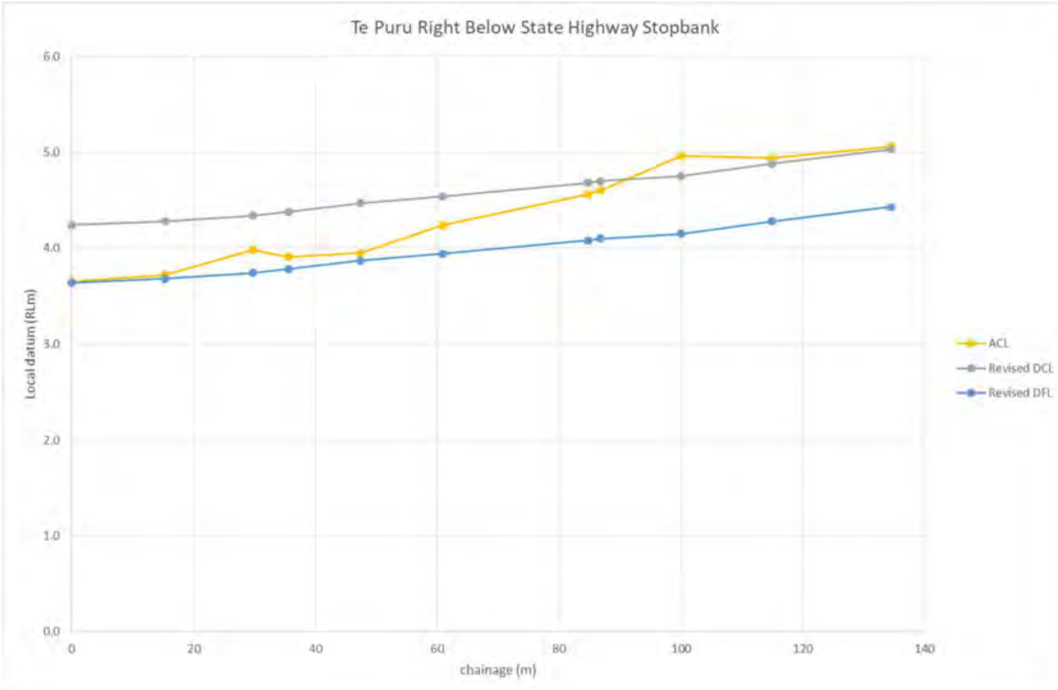

Figure 30 **Te Puru Right Below State Highway Stopbank - profiles for actual crest level (ACL) compared to the revised design crest level (DCL) and design flood level (DFL).**

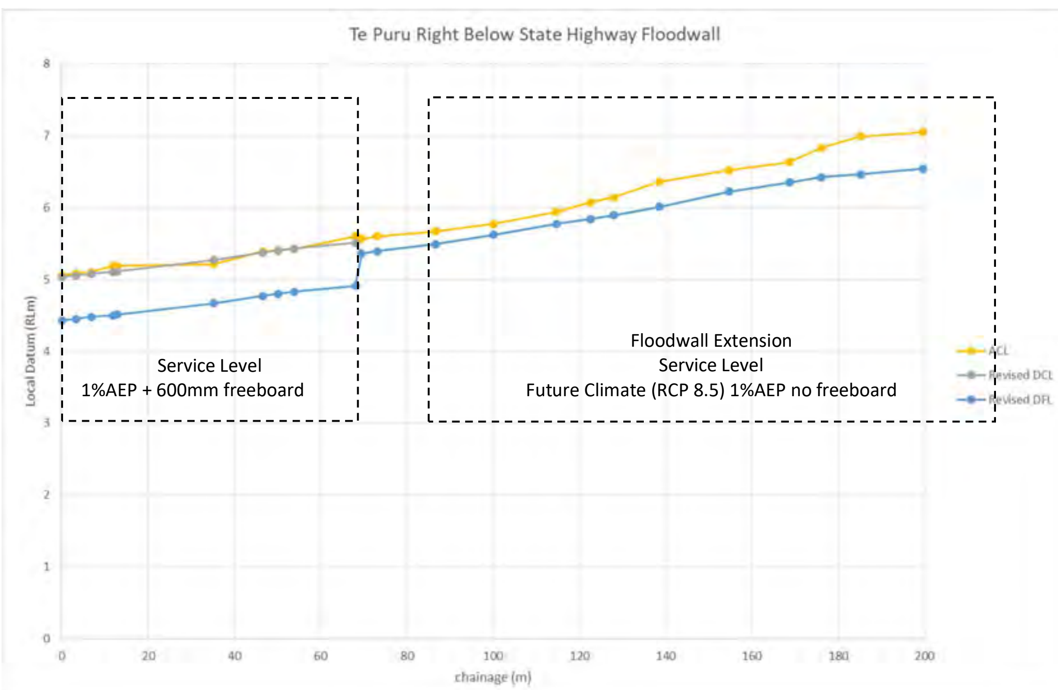

Figure 31 **Te Puru Right Below State Highway Floodwall - profiles for actual crest level (ACL) compared to the revised design crest level (DCL) and design flood level (DFL).**

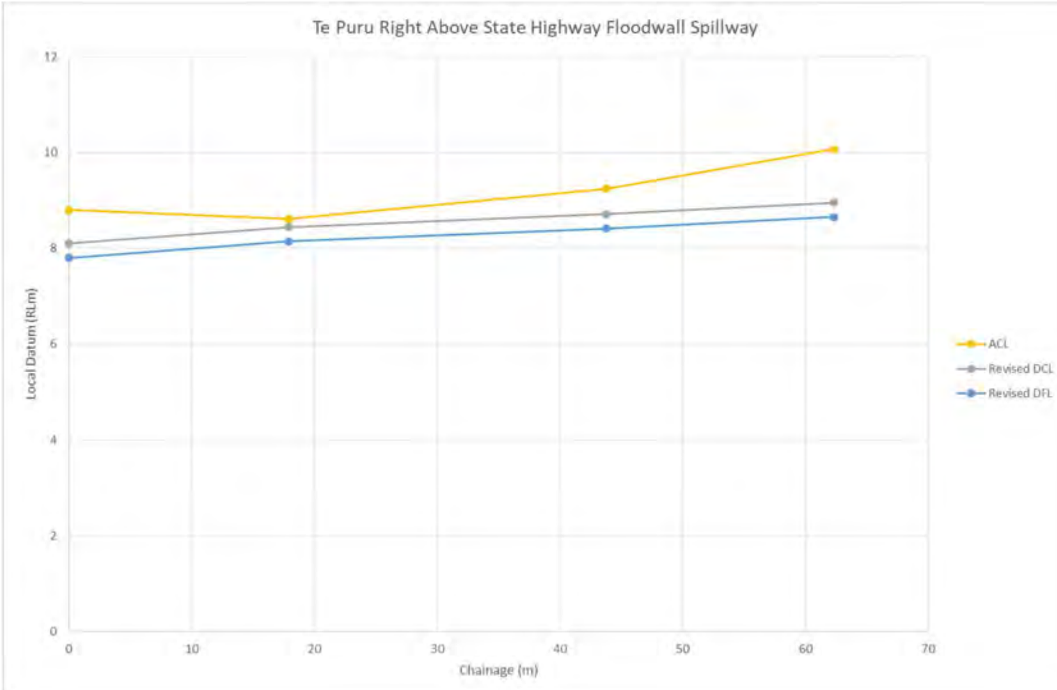

Figure 32 **Te Puru Right Above State Highway Floodwall Spillway - profiles for actual crest level (ACL) compared to the revised design crest level (DCL) and design flood level (DFL).**

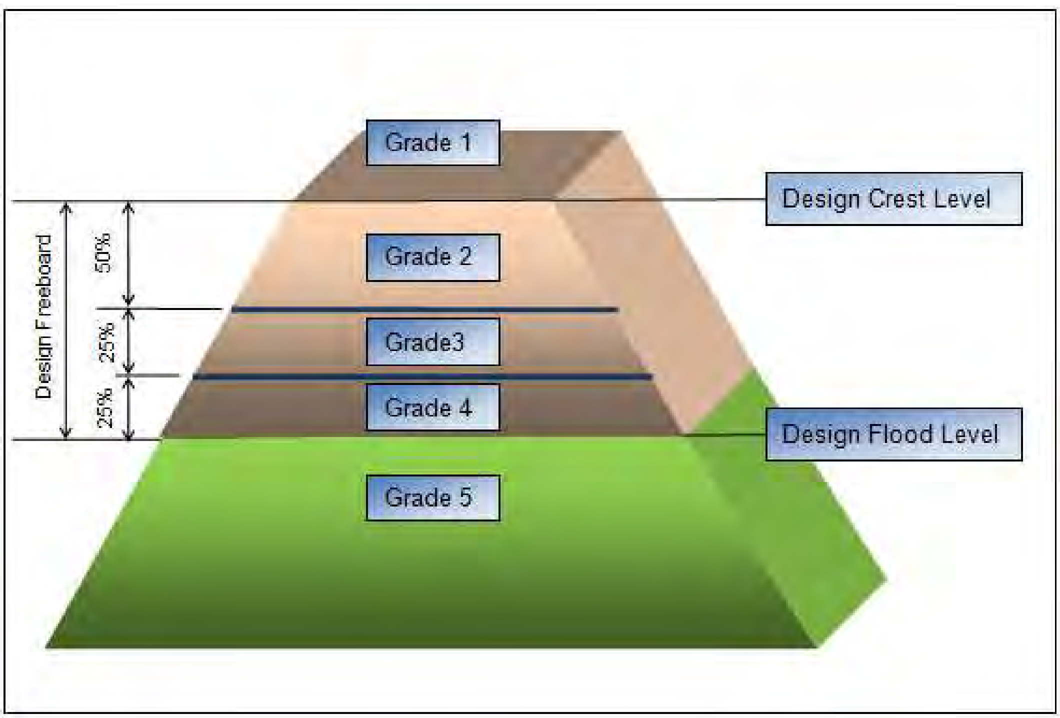

Figure 33 **Diagrammatic representation of stopbank performance grades.**

Table 12 Revised service level review data.

(Note: Performance grades are based on estimated flood level and actual crest level at each surveyed point along 'embankment link.'

Parent asset ID	Asset ID	Description	Asset chainage (m)	Cross-section	Easting (NZTM)	Northing (NZTM)	Revised design flood level (RL m)	Free-board (m)	Revised design crest level (RL m)	Actual crest level (RL m)	Actual free-board (m)	Perf. Grade at point
Te Puru Left Below State Highway Floodwall – 463m ***Service level: 1%AEP + 600mm freeboard***												
76074	76378	TP Left Below SH Floodwall 00	**0**		1824025.41	5897373.06	3.34	0.60	3.94	3.57	0.23	3
76074	76379	TP Left Below SH Floodwall 01	15		1824039.06	5897379.88	3.55	0.60	4.15	3.72	0.17	3
76074	76379	TP Left Below SH Floodwall 01	29		1824052.70	5897382.49	3.74	0.60	4.34	3.87	0.13	4
76074	76379	TP Left Below SH Floodwall 01	34	XS 14	1824054.07	5897386.77	3.78	0.60	4.38	4.02	0.24	3
76074	76379	TP Left Below SH Floodwall 01	39		1824055.66	5897391.52	3.78	0.60	4.38	3.97	0.19	3
76074	76379	TP Left Below SH Floodwall 01	46		1824059.81	5897398.03	3.80	0.60	4.40	4.08	0.28	3
76074	76379	TP Left Below SH Floodwall 01	56		1824068.31	5897401.40	3.84	0.60	4.44	4.16	0.32	2
76074	76379	TP Left Below SH Floodwall 01	65		1824076.67	5897405.63	3.89	0.60	4.49	4.15	0.26	3
76074	76379	TP Left Below SH Floodwall 01	88	XS 13	1824098.74	5897412.48	4.08	0.60	4.68	4.61	0.53	2
76074	76379	TP Left Below SH Floodwall 01	96		1824106.31	5897414.64	4.23	0.60	4.83	4.66	0.43	2
76074	76380	TP Left Below SH Floodwall 02	**100**		1824110.37	5897415.42	4.26	0.60	4.86	4.72	0.46	2
76074	76380	TP Left Below SH Floodwall 02	103		1824112.85	5897415.90	4.28	0.60	4.88	4.76	0.48	2
76074	76380	TP Left Below SH Floodwall 02	110		1824119.90	5897415.42	4.33	0.60	4.93	4.90	0.57	2
76074	76380	TP Left Below SH Floodwall 02	120		1824129.58	5897413.24	4.42	0.60	5.02	5.06	0.64	1
76074	76380	TP Left Below SH Floodwall 02	124	XS 12	1824133.61	5897411.31	4.50	0.60	5.10	5.21	0.71	1
76074	76380	TP Left Below SH Floodwall 02	128		1824137.62	5897409.33	4.54	0.60	5.14	5.18	0.64	1
76074	76380	TP Left Below SH Floodwall 02	140		1824147.69	5897404.71	4.64	0.60	5.24	5.31	0.67	1
76074	76380	TP Left Below SH Floodwall 02	150		1824156.75	5897398.96	4.73	0.60	5.33	5.45	0.72	1
76074	76380	TP Left Below SH Floodwall 02	161		1824165.65	5897393.27	4.82	0.60	5.42	5.55	0.73	1
76074	76380	TP Left Below SH Floodwall 02	165	XS 11	1824168.69	5897390.18	4.91	0.60	5.51	5.63	0.72	1
76074	76380	TP Left Below SH Floodwall 02	173		1824173.89	5897384.97	5.01	0.60	5.61	5.74	0.73	1
76074	76380	TP Left Below SH Floodwall 02	180		1824178.53	5897379.24	5.08	0.60	5.68	5.88	0.80	1
76074	76380	TP Left Below SH Floodwall 02	185		1824181.44	5897374.83	5.12	0.60	5.72	5.96	0.84	1

Parent asset ID	Asset ID	Description	Asset chainage (m)	Cross-section	Easting (NZTM)	Northing (NZTM)	Revised design flood level (RL m)	Free-board (m)	Revised design crest level (RL m)	Actual crest level (RL m)	Actual free-board (m)	Perf. Grade at point
76074	76380	TP Left Below SH Floodwall 02	191		1824185.33	5897370.15	5.17	0.60	5.77	5.99	0.82	1
76074	76380	TP Left Below SH Floodwall 02	195		1824187.27	5897366.80	5.21	0.60	5.81	6.02	0.81	1
76074	76380	TP Left Below SH Floodwall 02	200		1824190.36	5897363.44	5.26	0.60	5.86	6.06	0.80	1
76074	76381	TP Left Below SH Floodwall 03	**200**		1824190.45	5897363.15	5.26	0.60	5.86	6.06	0.80	1
76074	76381	TP Left Below SH Floodwall 03	210	XS 10	1824193.30	5897353.70	5.37	0.60	5.97	6.15	0.78	1
76074	76381	TP Left Below SH Floodwall 03	213		1824194.24	5897350.82	5.52	0.60	6.12	6.17	0.65	1
76074	76381	TP Left Below SH Floodwall 03	227		1824197.77	5897336.86	5.68	0.60	6.28	6.43	0.75	1
76074	76381	TP Left Below SH Floodwall 03	231		1824197.52	5897332.86	5.73	0.60	6.33	6.51	0.78	1
76074	76381	TP Left Below SH Floodwall 03	243		1824196.75	5897320.75	5.86	0.60	6.46	6.76	0.90	1
76074	76381	TP Left Below SH Floodwall 03	248	XS 9	1824196.50	5897316.27	5.92	0.60	6.52	6.84	0.92	1
76074	76381	TP Left Below SH Floodwall 03	260		1824195.70	5897304.37	6.03	0.60	6.63	6.92	0.89	1
76074	76381	TP Left Below SH Floodwall 03	282		1824194.32	5897282.75	6.18	0.60	6.78	7.03	0.85	1
76074	76381	TP Left Below SH Floodwall 03	296	XS 8	1824192.07	5897268.12	6.29	0.60	6.89	7.12	0.83	1
76074	76382	TP Left Below SH Floodwall 04	**300**		1824191.71	5897264.45	6.31	0.60	6.91	7.13	0.82	1
76074	76382	TP Left Below SH Floodwall 04	307		1824190.78	5897257.98	6.37	0.60	6.97	7.20	0.83	1
76074	76382	TP Left Below SH Floodwall 04	313		1824192.35	5897251.83	6.44	0.60	7.04	7.27	0.83	1
76074	76382	TP Left Below SH Floodwall 04	319		1824193.42	5897246.07	6.48	0.60	7.08	7.32	0.84	1
76074	76382	TP Left Below SH Floodwall 04	331		1824194.42	5897234.10	6.59	0.60	7.19	7.49	0.90	1
76074	76382	TP Left Below SH Floodwall 04	345		1824197.51	5897220.24	6.71	0.60	7.31	7.66	0.95	1
76074	76382	TP Left Below SH Floodwall 04	356	XS 7	1824198.76	5897209.55	6.79	0.60	7.39	7.81	1.02	1
76074	76382	TP Left Below SH Floodwall 04	358		1824199.00	5897207.50	6.80	0.60	7.40	7.85	1.05	1
76074	76382	TP Left Below SH Floodwall 04	366		1824201.95	5897200.26	6.83	0.60	7.43	7.97	1.14	1
76074	76382	TP Left Below SH Floodwall 04	378		1824206.17	5897188.74	6.91	0.60	7.51	8.14	1.23	1
76074	76382	TP Left Below SH Floodwall 04	383		1824208.44	5897184.09	6.96	0.60	7.56	8.21	1.25	1
76074	76382	TP Left Below SH Floodwall 04	392		1824213.23	5897176.15	7.07	0.60	7.67	8.41	1.34	1
76074	76382	TP Left Below SH Floodwall 04	399		1824217.70	5897170.70	7.16	0.60	7.76	8.56	1.40	1
76074	76383	TP Left Below SH Floodwall 05	**400**		1824218.13	5897170.24	7.17	0.60	7.77	8.59	1.42	1
76074	76383	TP Left Below SH Floodwall 05	406	XS 6	1824222.50	5897165.50	7.26	0.60	7.86	8.64	1.38	1

Parent asset ID	Asset ID	Description	Asset chainage (m)	Cross-section	Easting (NZTM)	Northing (NZTM)	Revised design flood level (RL m)	Free-board (m)	Revised design crest level (RL m)	Actual crest level (RL m)	Actual free-board (m)	Perf. Grade at point
76074	76383	TP Left Below SH Floodwall 05	411		1824225.82	5897162.04	7.30	0.60	7.90	8.76	1.46	1
76074	76383	TP Left Below SH Floodwall 05	417		1824229.83	5897157.52	7.38	0.60	7.98	8.85	1.47	1
76074	76383	TP Left Below SH Floodwall 05	427		1824237.16	5897151.02	7.53	0.60	8.13	8.96	1.43	1
76074	76383	TP Left Below SH Floodwall 05	438		1824244.47	5897143.55	7.69	0.60	8.29	9.11	1.42	1
76074	76383	TP Left Below SH Floodwall 05	451		1824254.23	5897134.14	7.85	0.60	8.45	9.22	1.37	1
76074	76383	TP Left Below SH Floodwall 05	**463**	XS 5	1824264.60	5897127.85	7.94	0.60	8.54	9.24	1.30	1
Te Puru Left Above State Highway Floodwall – 168m ***Service level: 1%AEP + 600mm freeboard***												
76084	76387	TP Left Above SH Floodwall 01	**0**		1824307.07	5897116.77	8.34	0.60	8.94	9.65	1.31	1
76084	76388	TP Left Above SH Floodwall 02	20	XS 4	1824327.20	5897118.40	8.56	0.60	9.16	9.79	1.23	1
76084	76388	TP Left Above SH Floodwall 02	32		1824338.96	5897119.36	8.76	0.60	9.36	9.91	1.15	1
76084	76388	TP Left Above SH Floodwall 02	55		1824362.23	5897120.98	9.06	0.60	9.66	10.27	1.21	1
76084	76388	TP Left Above SH Floodwall 02	71	XS 3	1824377.80	5897121.40	9.19	0.60	9.79	10.54	1.35	1
76084	76388	TP Left Above SH Floodwall 02	83		1824389.49	5897121.73	9.32	0.60	9.92	10.65	1.33	1
76084	76389	TP Left Above SH Floodwall 03	**100**		1824406.87	5897122.61	9.49	0.60	10.09	10.85	1.36	1
76084	76389	TP Left Above SH Floodwall 03	100		1824407.36	5897122.64	9.49	0.60	10.09	10.85	1.36	1
76084	76389	TP Left Above SH Floodwall 03	120	XS 2	1824426.50	5897124.00	9.72	0.60	10.32	11.04	1.32	1
76084	76389	TP Left Above SH Floodwall 03	126		1824432.81	5897124.51	9.78	0.60	10.38	11.11	1.33	1
76084	76389	TP Left Above SH Floodwall 03	155		1824461.35	5897125.09	10.10	0.60	10.70	11.61	1.51	1
76084	76389	TP Left Above SH Floodwall 03	**168**		1824470.15	5897115.16	10.19	0.60	10.79	11.60	1.41	1
Te Puru Right Below State Highway Stopbank – 134m ***Service level: 1%AEP + 600mm freeboard***												
76076	76392	TP Right Below SH Stopbank 00	**0**		1824012.45	5897460.34	3.64	0.60	4.24	3.65	0.01	4
76076	76393	TP Right Below SH Stopbank 01	15		1824021.41	5897448.01	3.68	0.60	4.28	3.72	0.04	4
76076	76393	TP Right Below SH Stopbank 01	30		1824035.23	5897443.66	3.74	0.60	4.34	3.98	0.24	3
76076	76393	TP Right Below SH Stopbank 01	36	XS 14	1824041.10	5897443.10	3.78	0.60	4.38	3.91	0.13	4
76076	76393	TP Right Below SH Stopbank 01	47		1824052.82	5897441.50	3.87	0.60	4.47	3.95	0.08	4
76076	76393	TP Right Below SH Stopbank 01	61		1824066.12	5897444.04	3.94	0.60	4.54	4.24	0.30	2

Parent asset ID	Asset ID	Description	Asset chainage (m)	Cross-section	Easting (NZTM)	Northing (NZTM)	Revised design flood level (RL m)	Free-board (m)	Revised design crest level (RL m)	Actual crest level (RL m)	Actual free-board (m)	Perf. Grade at point
76076	76393	TP Right Below SH Stopbank 01	85	XS 13	1824088.50	5897452.00	4.08	0.60	4.68	4.56	0.48	2
76076	76393	TP Right Below SH Stopbank 01	87		1824090.45	5897452.45	4.10	0.60	4.70	4.60	0.50	2
76076	76398	TP Right Below SH Stopbank 02	**100**		1824103.67	5897451.31	4.15	0.60	4.75	4.96	0.81	1
76076	76398	TP Right Below SH Stopbank 02	115		1824118.54	5897450.03	4.28	0.60	4.88	4.94	0.66	1
76076	76398	TP Right Below SH Stopbank 02	**134**		1824137.78	5897452.84	4.43	0.60	5.03	5.06	0.63	1
Te Puru Right Below State Highway Floodwall – 199m. ***Service level varied: downstream XS11 - 1%AEP + 600mm freeboard (68m)*** ***upstream XS11 - %AEP (climate change) + no freeboard (131m)***												
76076	76384	TP Right Below SH Floodwall 00	**0**		1824137.78	5897452.84	4.43	0.60	5.03	5.05	0.62	1
76076	76385	TP Right Below SH Floodwall 01	3		1824140.95	5897452.23	4.45	0.60	5.05	5.08	0.63	1
76076	76385	TP Right Below SH Floodwall 01	7		1824144.07	5897450.41	4.48	0.60	5.08	5.10	0.62	1
76076	76385	TP Right Below SH Floodwall 01	12	XS 12	1824148.60	5897448.30	4.50	0.60	5.1	5.19	0.69	1
76076	76385	TP Right Below SH Floodwall 01	13		1824149.52	5897447.81	4.51	0.60	5.11	5.19	0.68	1
76076	76385	TP Right Below SH Floodwall 01	35		1824167.96	5897435.28	4.67	0.60	5.27	5.21	0.54	2
76076	76385	TP Right Below SH Floodwall 01	47		1824177.42	5897428.75	4.77	0.60	5.37	5.39	0.62	1
76076	76385	TP Right Below SH Floodwall 01	50		1824179.34	5897425.87	4.80	0.60	5.4	5.40	0.60	1
76076	76385	TP Right Below SH Floodwall 01	54		1824182.31	5897423.53	4.83	0.60	5.43	5.42	0.59	2
76076	76385	TP Right Below SH Floodwall 01	68	XS 11	1824193.70	5897415.10	4.91	0.60	5.51	5.60	0.69	1
Change in service level as detailed in header												
76076	76385	TP Right Below SH Floodwall 01	69		1824194.81	5897414.28	5.36	0.00	5.36	5.56	0.20	1
76076	76385	TP Right Below SH Floodwall 01	73		1824197.18	5897411.45	5.39	0.00	5.39	5.60	0.21	1
76076	76385	TP Right Below SH Floodwall 01	87		1824201.76	5897398.79	5.49	0.00	5.49	5.67	0.18	1
76076	76386	TP Right Below SH Floodwall 02	**100**		1824208.86	5897387.44	5.62	0.00	5.62	5.77	0.15	1
76076	76386	TP Right Below SH Floodwall 02	115		1824216.65	5897374.99	5.77	0.00	5.77	5.94	0.17	1
76076	76386	TP Right Below SH Floodwall 02	123	XS 10	1824219.80	5897367.80	5.84	0.00	5.84	6.07	0.23	1
76076	76386	TP Right Below SH Floodwall 02	128		1824222.02	5897362.91	5.89	0.00	5.89	6.14	0.25	1
76076	76386	TP Right Below SH Floodwall 02	138		1824225.58	5897353.02	6.01	0.00	6.01	6.36	0.35	1
76076	76386	TP Right Below SH Floodwall 02	155		1824230.58	5897337.45	6.22	0.00	6.22	6.52	0.30	1

Parent asset ID	Asset ID	Description	Asset chainage (m)	Cross-section	Easting (NZTM)	Northing (NZTM)	Revised design flood level (RL m)	Free-board (m)	Revised design crest level (RL m)	Actual crest level (RL m)	Actual free-board (m)	Perf. Grade at point
76076	76386	TP Right Below SH Floodwall 02	169		1824234.44	5897324.15	6.35	0.00	6.35	6.63	0.28	1
76076	76386	TP Right Below SH Floodwall 02	176	XS 9	1824235.10	5897316.70	6.42	0.00	6.42	6.83	0.41	1
76076	76386	TP Right Below SH Floodwall 02	185		1824235.89	5897307.74	6.46	0.00	6.46	6.99	0.53	1
76076	76386	TP Right Below SH Floodwall 02	**199**		1824238.60	5897293.48	6.54	0.00	6.54	7.05	0.51	1
Te Puru Right Above State Highway Floodwall Spillway – 62m ***Service level: 1%AEP + 300mm freeboard***												
76086	76390	TP Right Above SH Floodwall Spillway	**0**	XS 5	1824273.69	5897167.53	7.80	0.30	8.10	8.80	1.00	1
76086	76391	TP Right Above SH Floodwall Spillway	18		1824290.95	5897162.81	8.14	0.30	8.44	8.61	0.47	1
76086	76391	TP Right Above SH Floodwall Spillway	44		1824315.72	5897155.26	8.41	0.30	8.71	9.24	0.83	1
76086	76391	TP Right Above SH Floodwall Spillway	**62**		1824334.10	5897152.83	8.65	0.30	8.95	10.07	1.42	1

7 Conclusions

This report has provided the first service level review of the Te Puru Flood Protection Scheme since it was completed in the early 2010's.

Hydrology for the Te Puru catchment has been reviewed with the original present climate 1%AEP design discharge of Q_p315 retained. The former future climate flow of Q_p378 has been revised based on the latest guidance from MfE (2018). This has included the two upper climate scenarios, RCP6.0 and RCP8.5, giving discharges of Q_p375 and Q_p414 respectively.

Hydraulic modelling has been undertaken using both 1D (MIKE11) and 2D (MIKE21) models. MIKE11 has been used for the service level review component and MIKE21 has been used for flood hazard delineation. A coupled 1D-2D model (MIKEFLOOD) was considered, however as no channel overflows were predicted by MIKE11 for the service level design event this would have been of limited use. The hydraulic modelling has been based on 2014 survey data and 2013 LIDAR data.

The service level review of the flood protection assets indicates that:

- The design 1%AEP event flood is contained within the scheme assets, however, there is less than 600mm freeboard in the lower stream near the mouth.
- Future climate 1%AEP events (i.e.: those greater than design) are likely to overtop the banks in the lower stream near the mouth.
- The spillway upstream of the State Highway approximates its design condition of activation in events greater than a 1%AEP event with 300mm freeboard.
- The original design flood profile is mostly higher than the revised design flood profile with the exception of the lower stream near the mouth. This suggests degradation in the upper stream and aggradation in the lower stream near the mouth.
- Analysis of 2004 and 2014 cross-section data confirms bed levels have lowered through most of the reach, the exception being the lower stream near the mouth where aggradation was measured.
- Aggradation at the mouth in the form of spit growth is evident in both LIDAR capture and aerial imagery in the period around 2011-2013. The mouth appears more open in more recent imagery and site observations.
- Resurvey of the channel cross-sections would be useful in determining current trends in channel morphology. Re-running the model with revised cross-sections would allow re-assessment of flood levels to determine if shortfalls in freeboard in the lower channel remain an issue.
- The flood protection assets are floodwalls or stopbanks within confined areas and are not easily modified. The best solution to maintain the service level and improve performance grades in the lower stream is collect survey, re-model, and undertake as required channel excavation/maintenance to allow sufficient capacity for the determined shortfall in freeboard.

Mapping of various tidal and coastal conditions for the present and future climates indicates significant risk to the community. During present day tide conditions some areas are below tide levels but are separated from the sea by areas of high ground both natural and man-made. This includes approximately 50 properties below the maximum tide. However, during coastal storm conditions and under future sea level rise scenarios the barriers to the sea are exceeded and subsequently there are significant risks for the community under these scenarios.

8 Recommendations

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

- Resurvey channel cross-sections (XS 1 – XS 15) and provide levels in terms of Te Puru Local Datum, AVD-46 and NZVD2016. This will allow:
    - Comparison with 2004 and 2014 cross-section surveys
    - Comparison with 2013 LIDAR dataset
    - Place data in context of revised WRC adopted datum (NZVD-16)
    - Enable assessment of changes in channel morphology between the three periods.
    - Determine whether channel excavation from the lower channel and mouth should be undertaken, and to what level to maintain freeboard in the lower reach. This can be estimated by updating the MIKE11 model with re-surveyed cross-sections.

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Appendix A – Comparison of ground survey cross-sections (2014 – local datum) and LIDAR DTM slices (2012 – AVD-46)

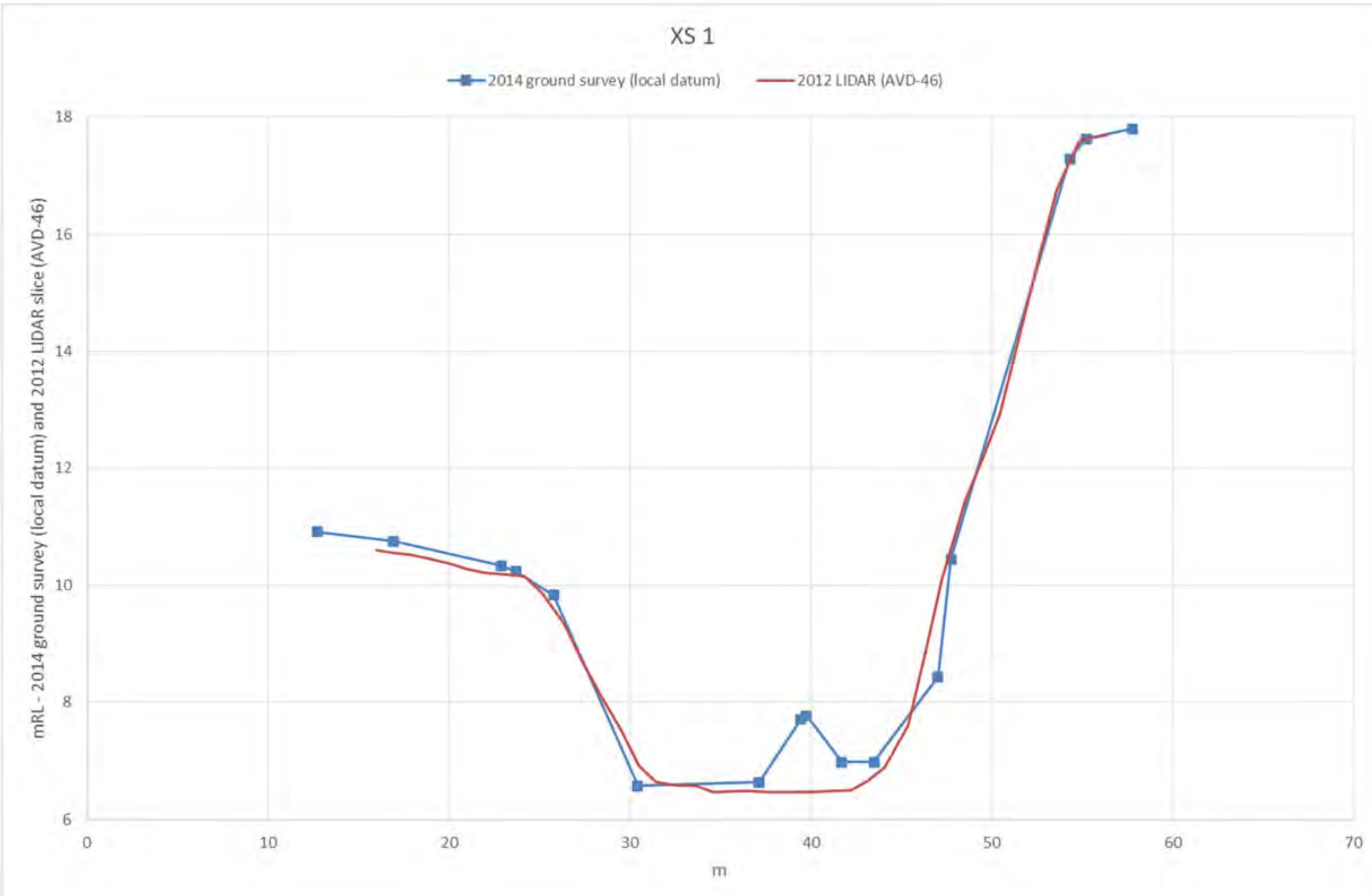

Figure A1 XS 1 (MIKE11 model chainage 0m – location shown in Figure A16)

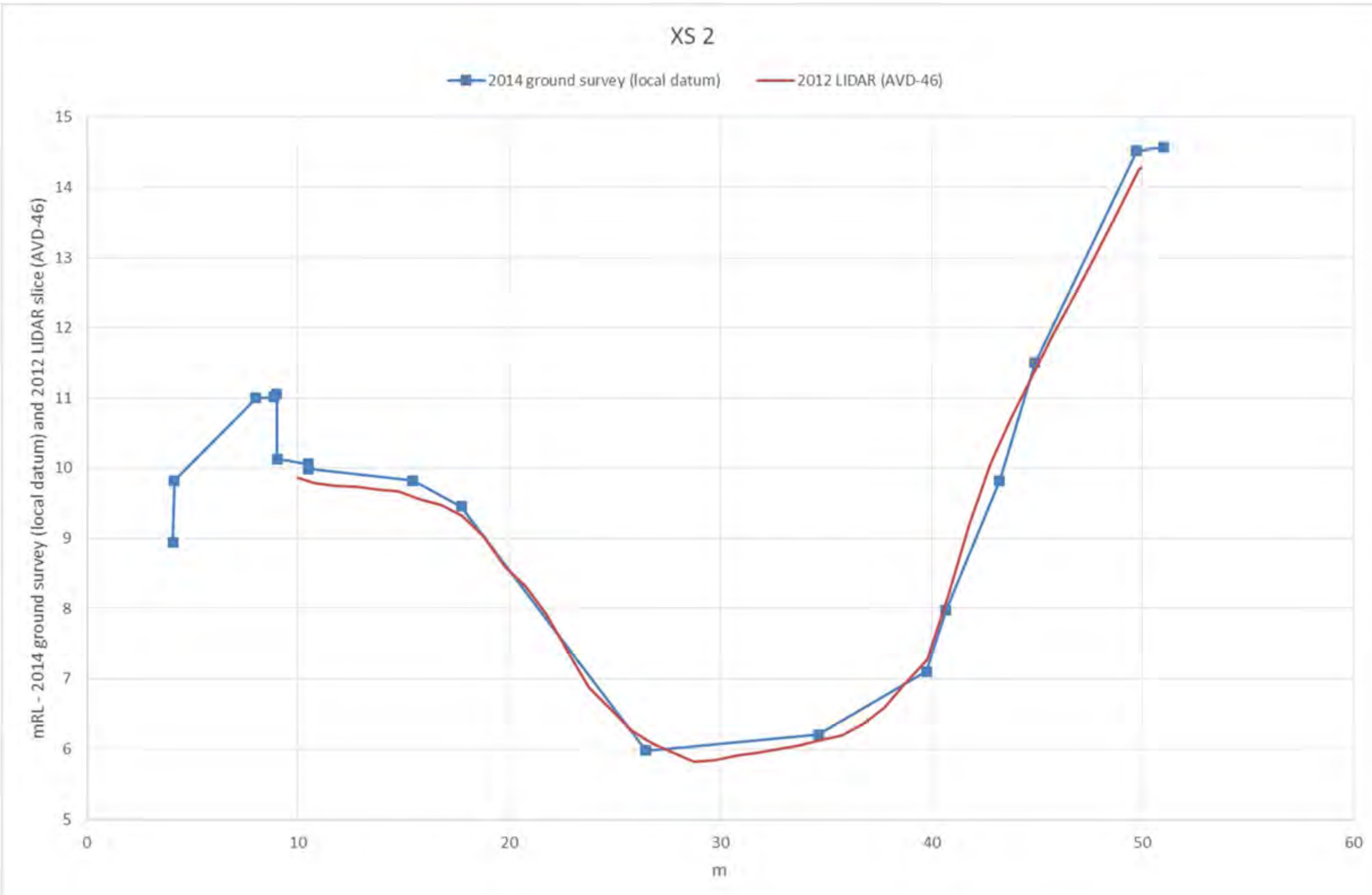

Figure A2 XS 2 (MIKE11 model chainage 44m – location shown in Figure A16)

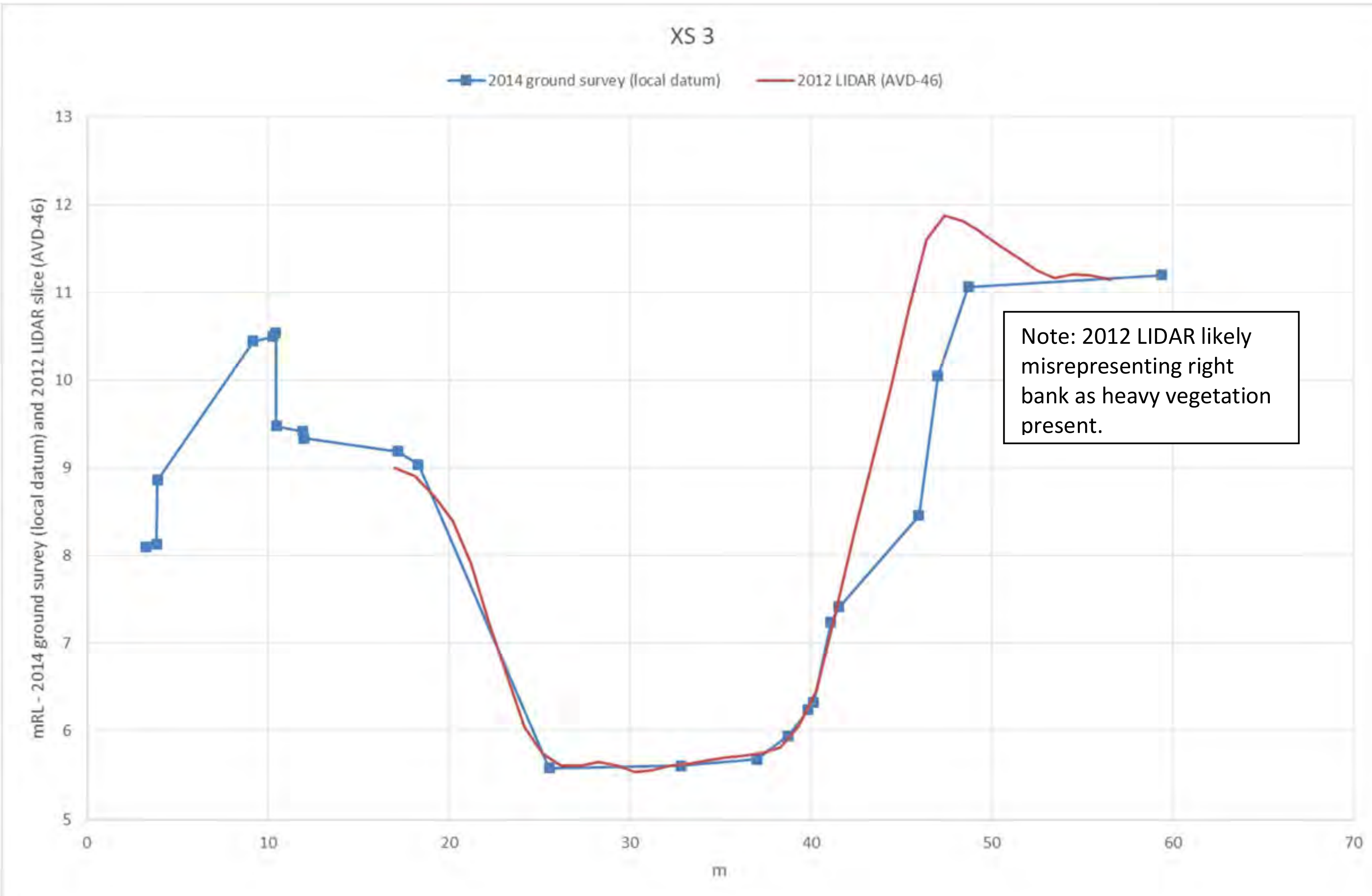

Figure A3 XS 3 (MIKE11 model chainage 94m – location shown in Figure A16)

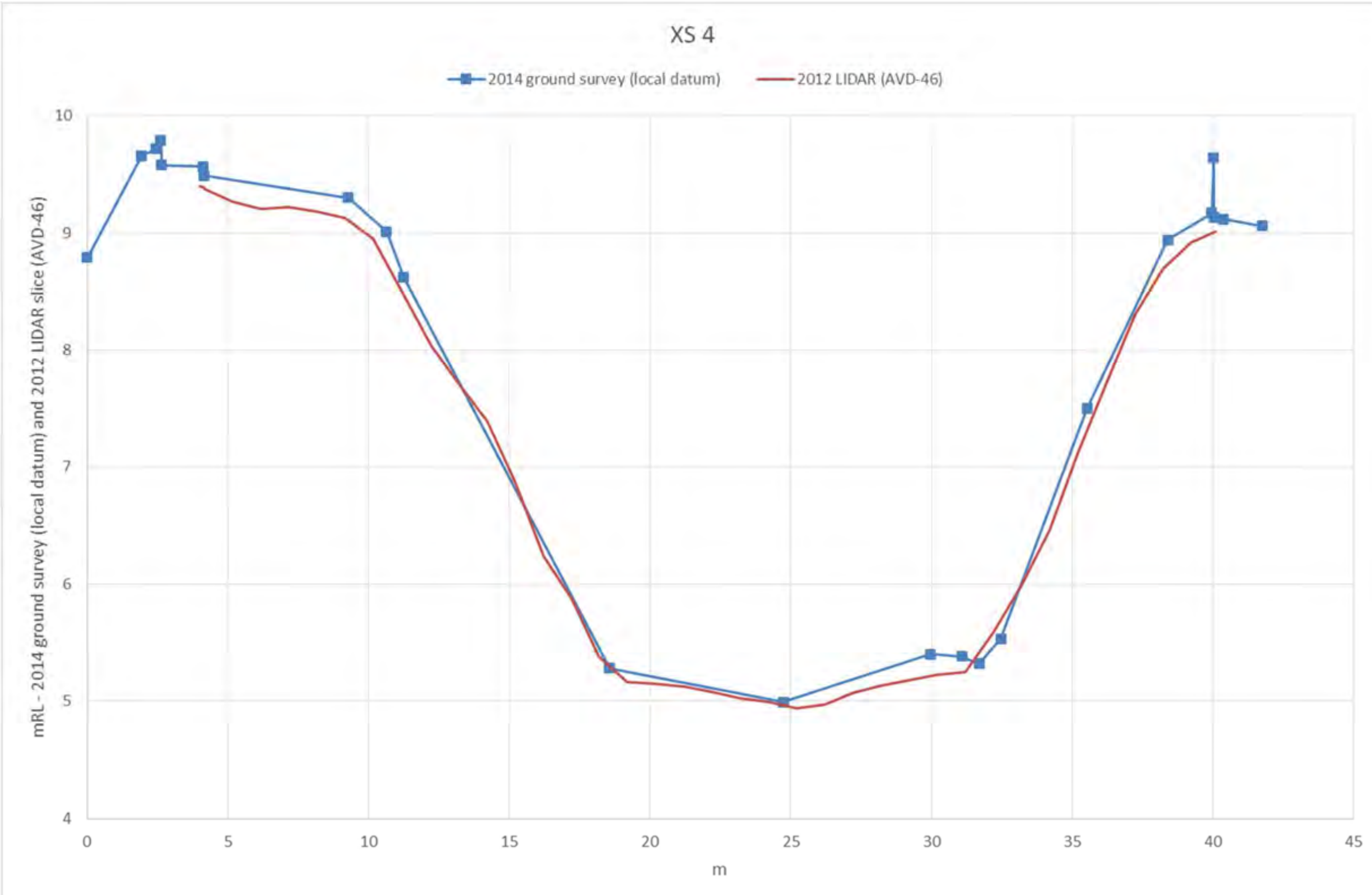

Figure A4 XS 4 (MIKE11 model chainage 144m – location shown in Figure A16)

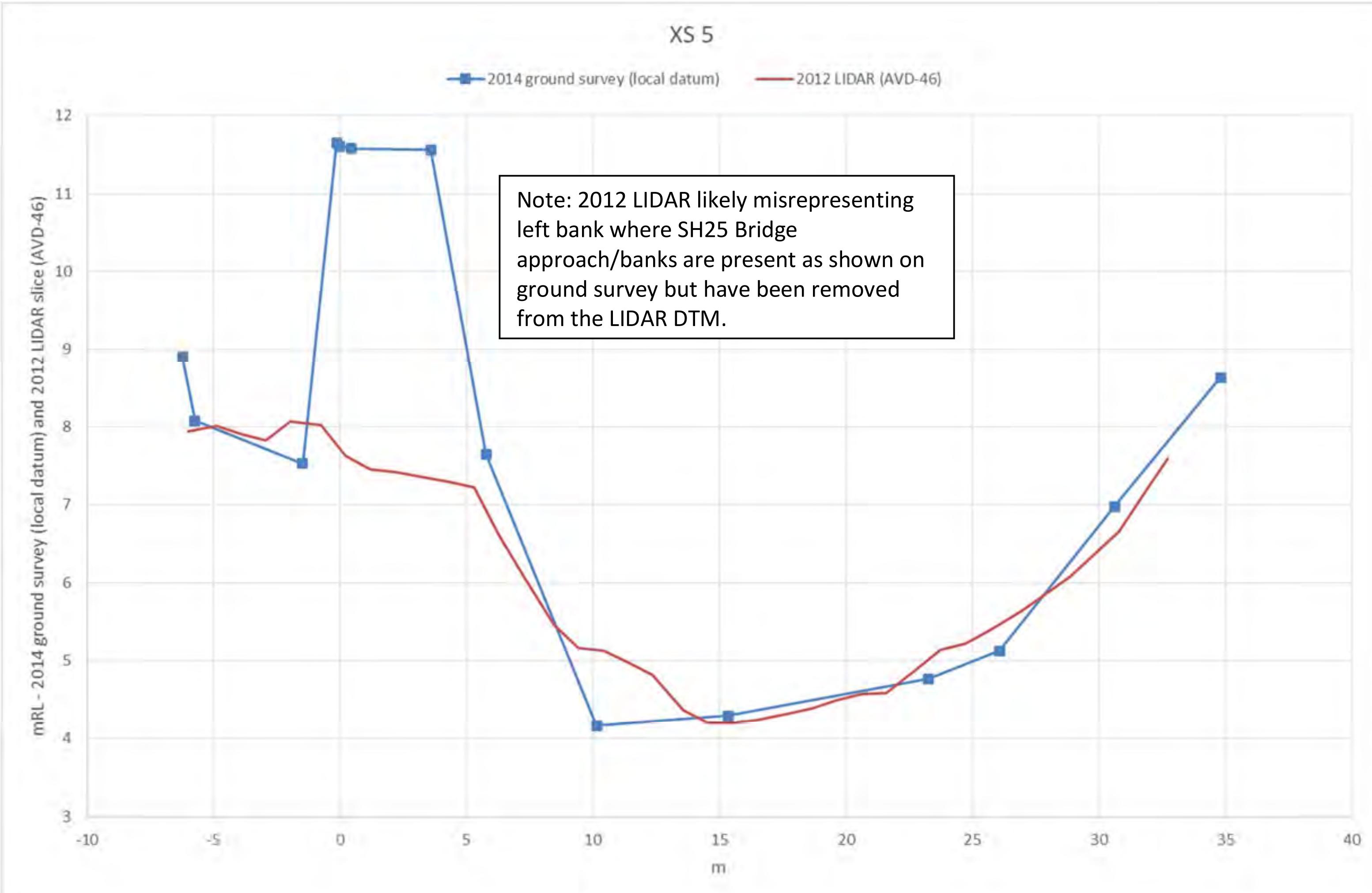

Figure A5 XS 5 (MIKE11 model chainage 202m – location shown in Figure A16)

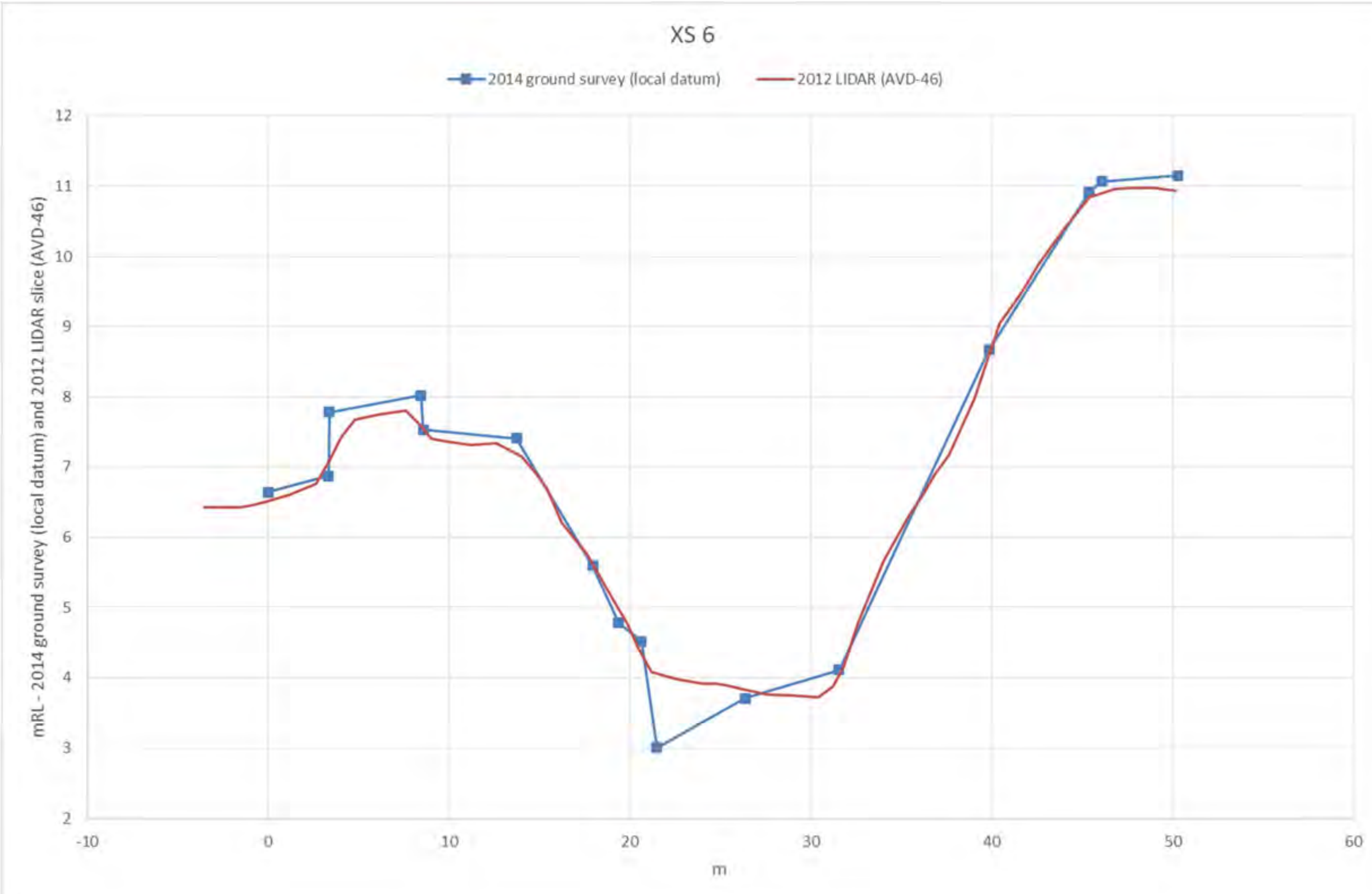

Figure A6 XS 6 (MIKE11 model chainage 249m – location shown in Figure A16)

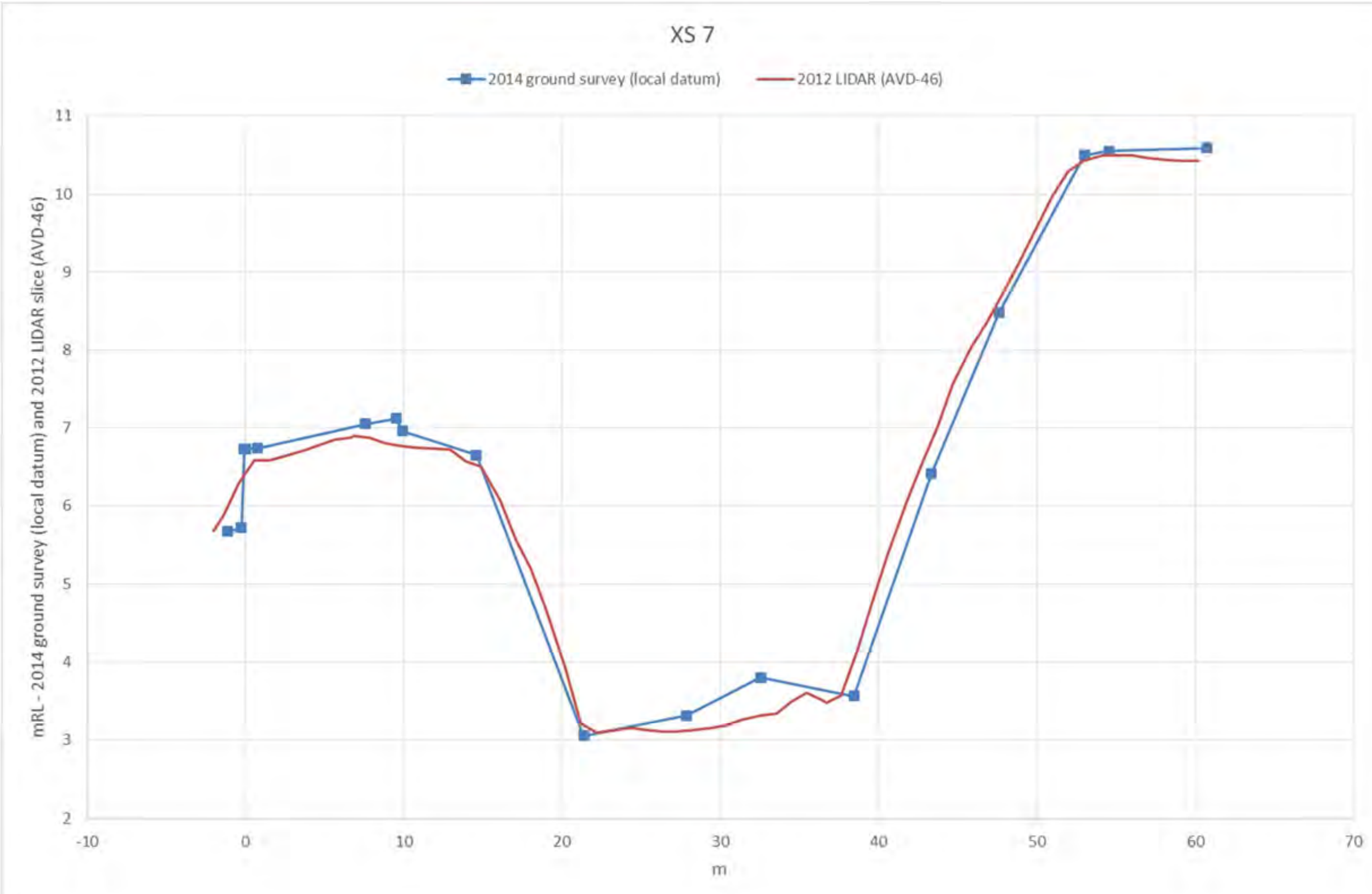

Figure A7 XS 7 (MIKE11 model chainage 295m – location shown in Figure A16)

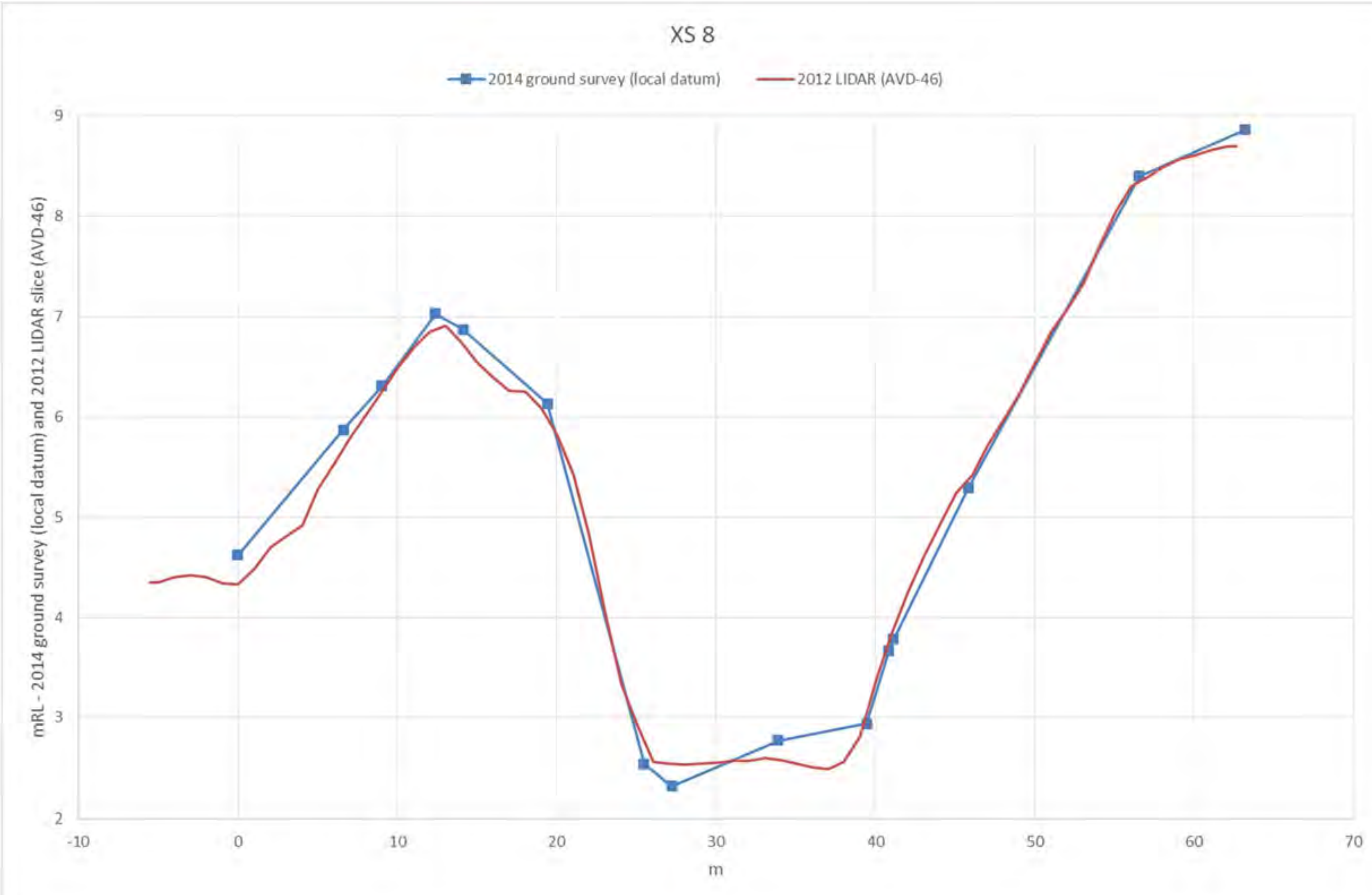

Figure A8 XS 8 (MIKE11 model chainage 350m – location shown in Figure A16)

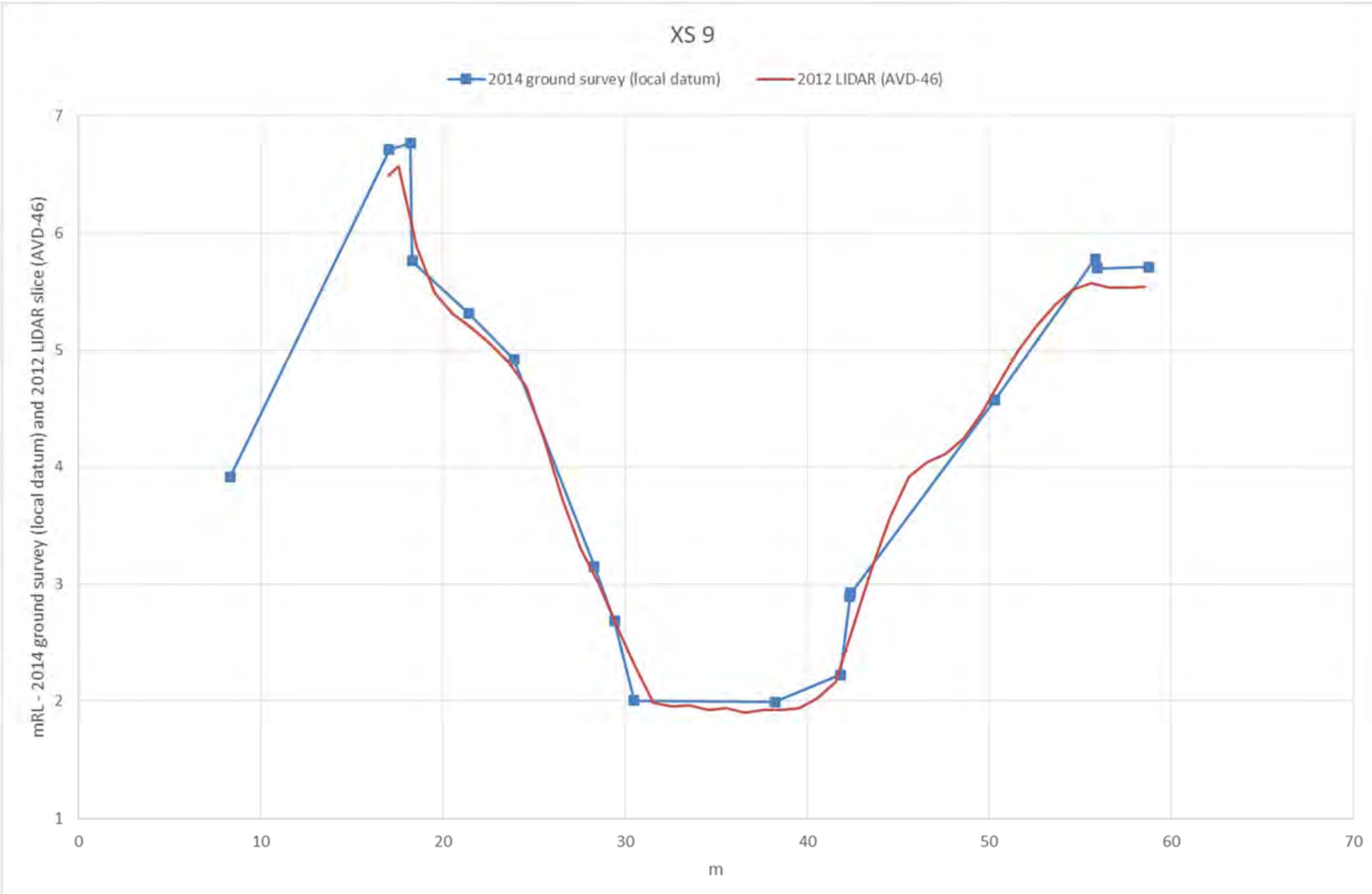

Figure A9 XS 9 (MIKE11 model chainage 402m – location shown in Figure A16)

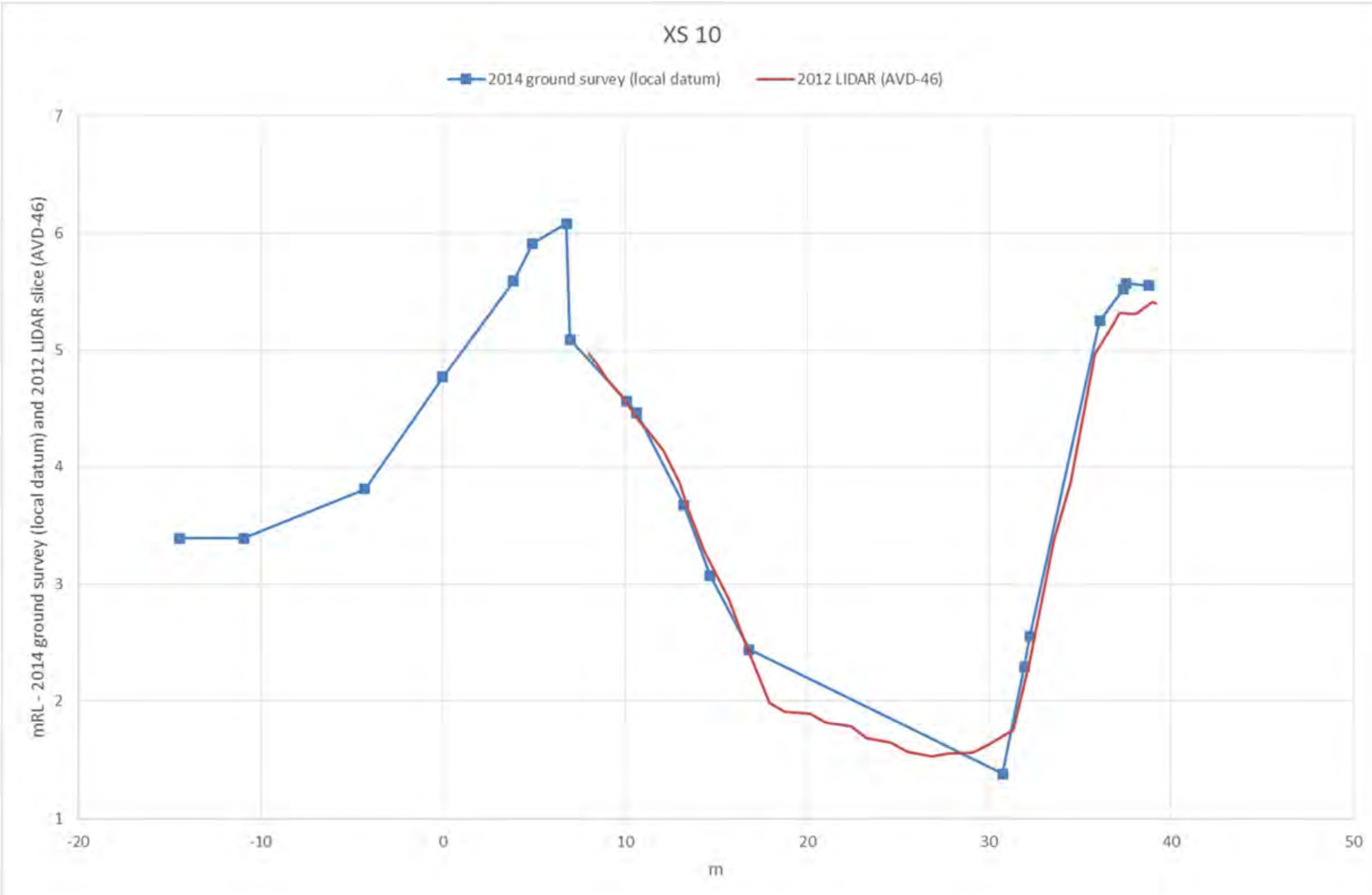

Figure A10 XS 10 (MIKE11 model chainage 450m – location shown in Figure A16)

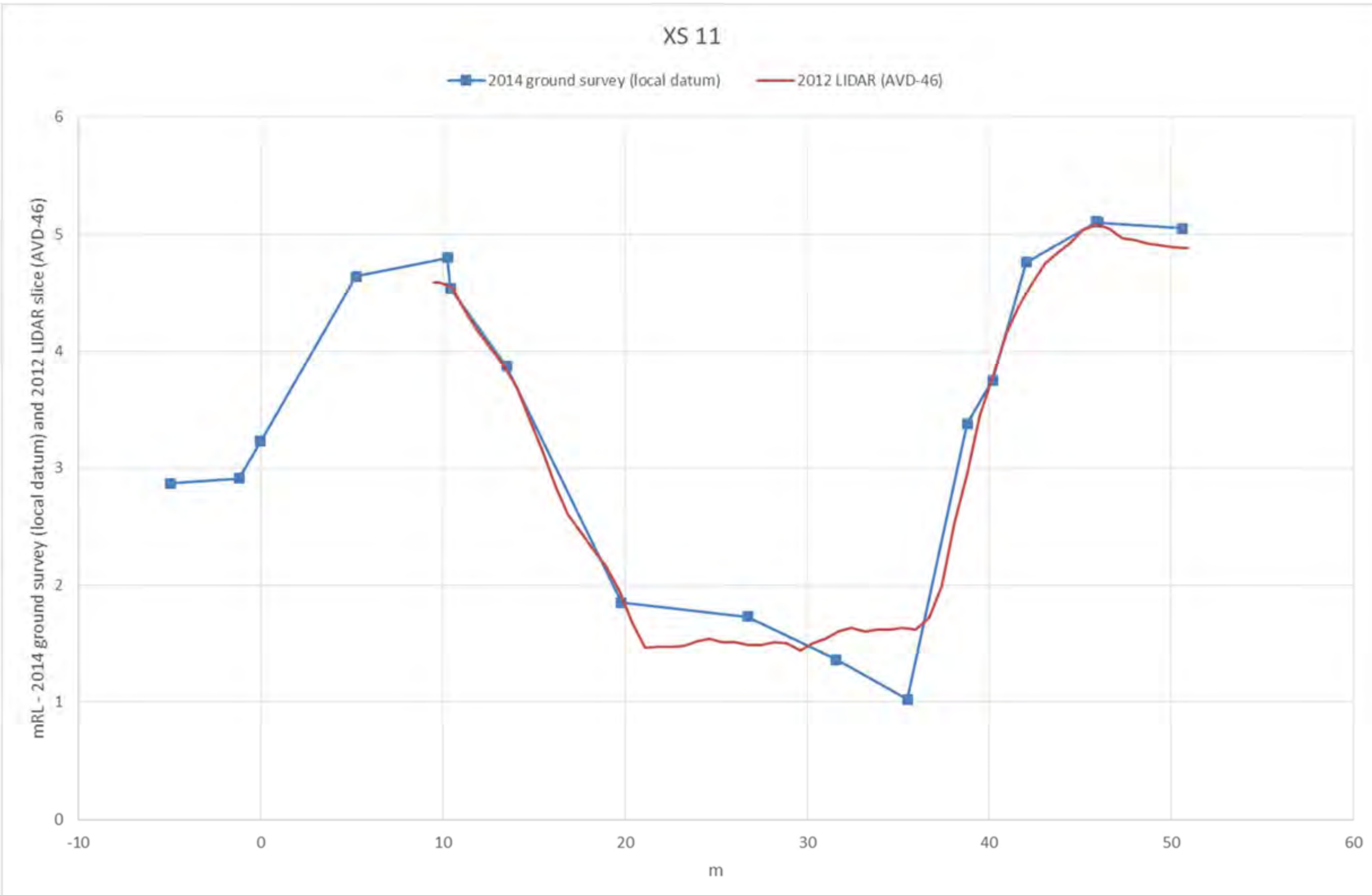

Figure A11 XS 11 (MIKE11 model chainage 501m – location shown in Figure A16)

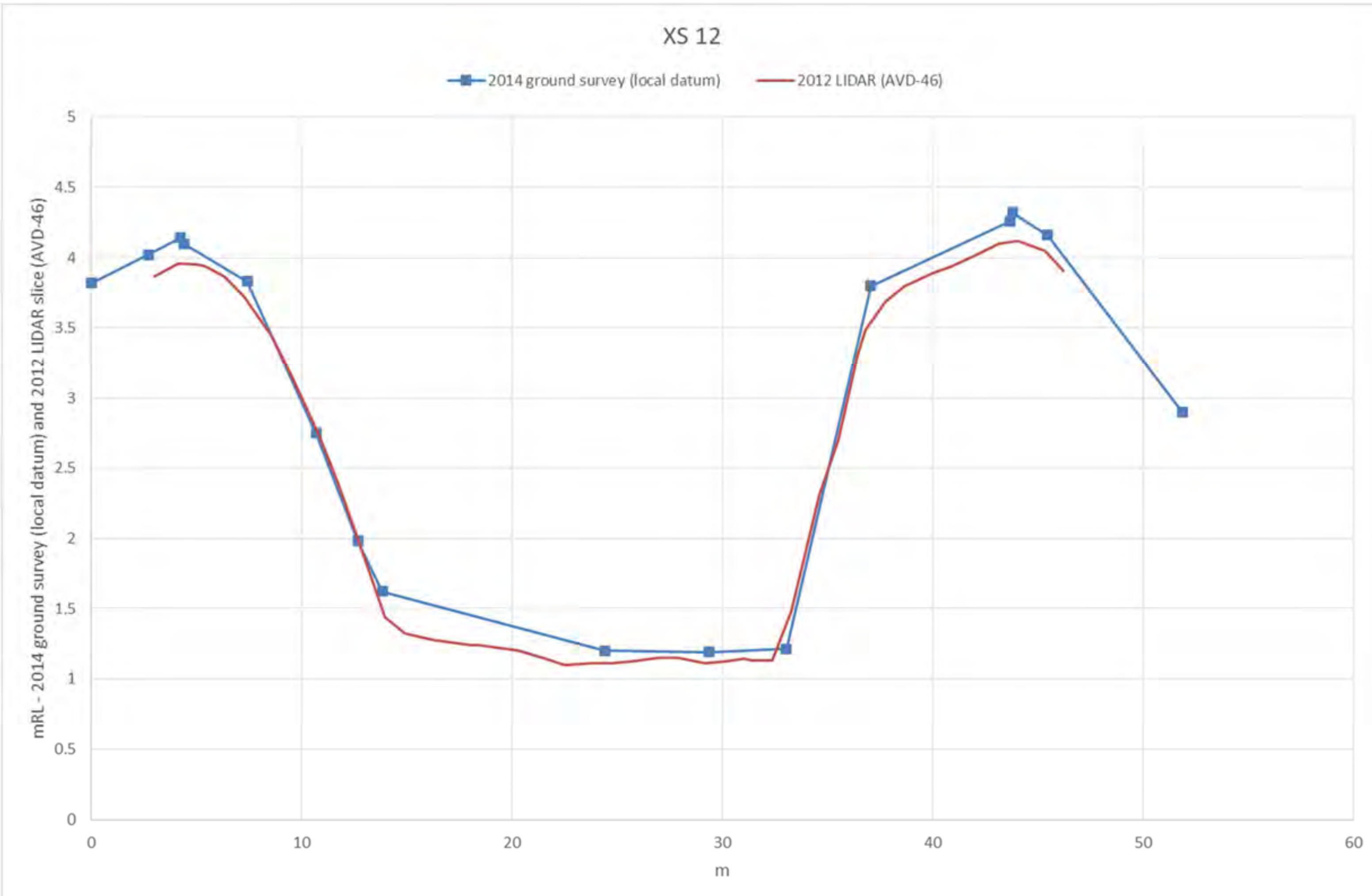

Figure A12 XS 12 (MIKE11 model chainage 551m – location shown in Figure A16)

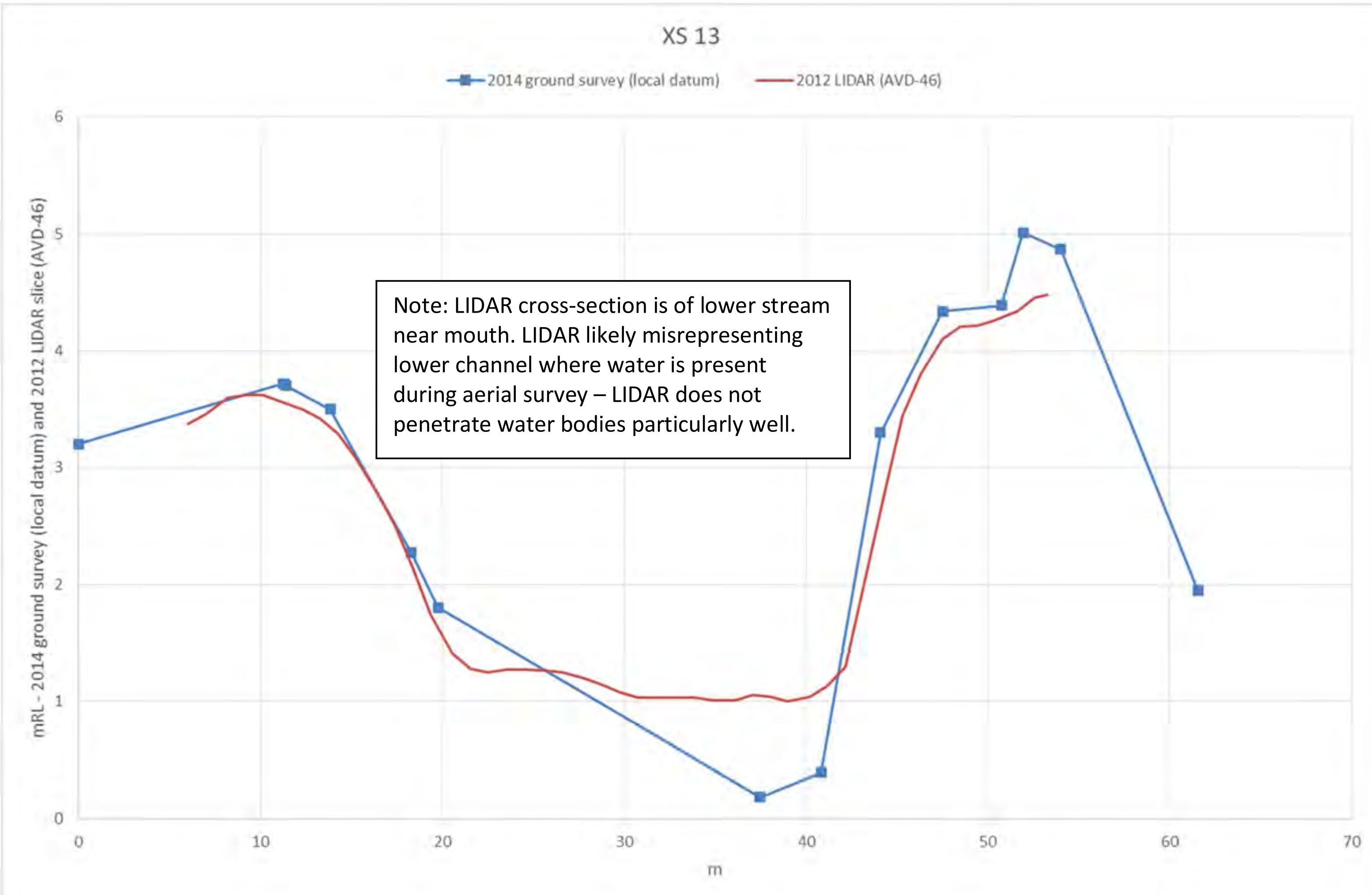

Figure A13 XS 13 (MIKE11 model chainage 600m – location shown in Figure A16)

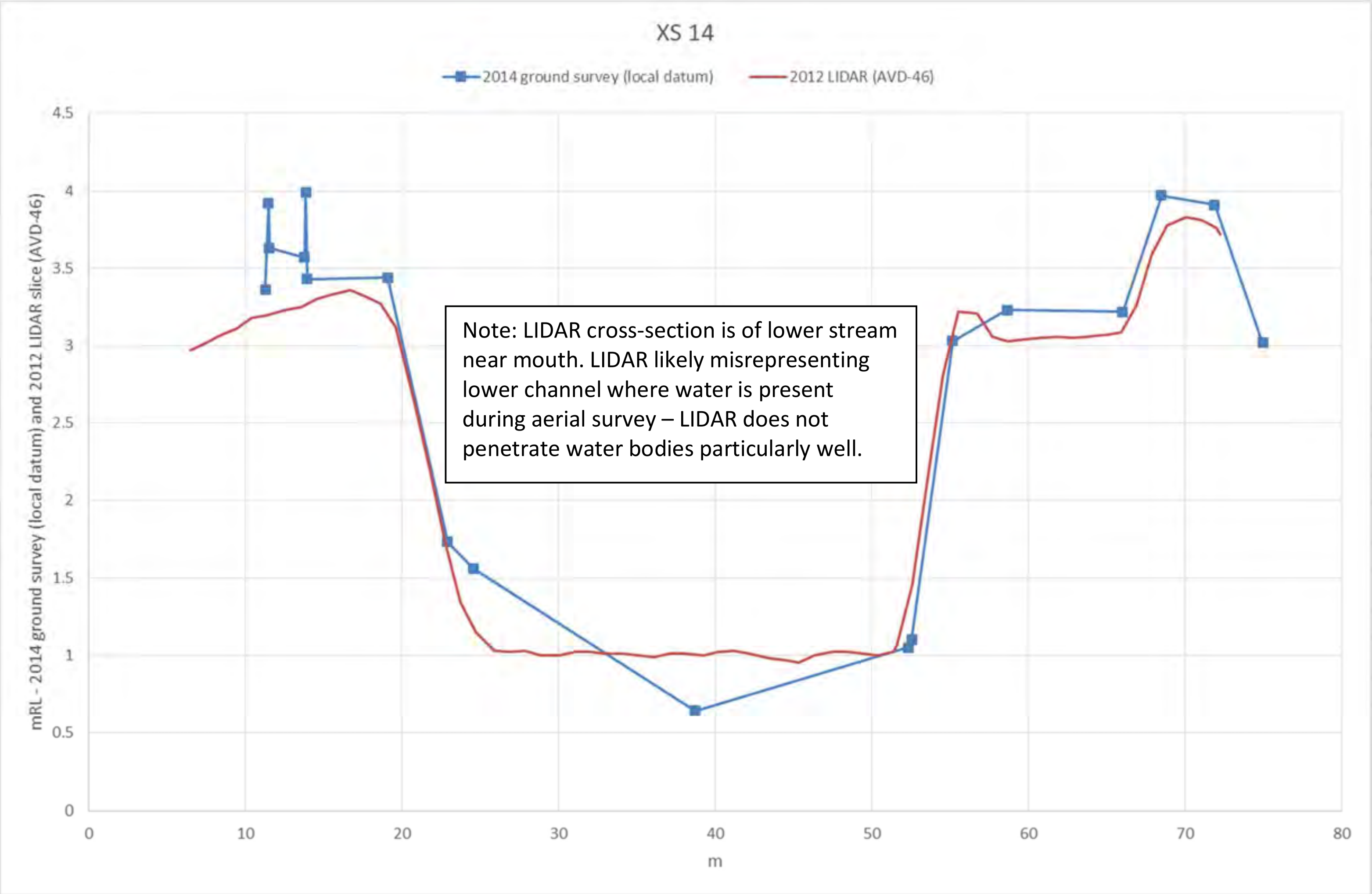

Figure A14 XS 14 (MIKE11 model chainage 650m – location shown in Figure A16)

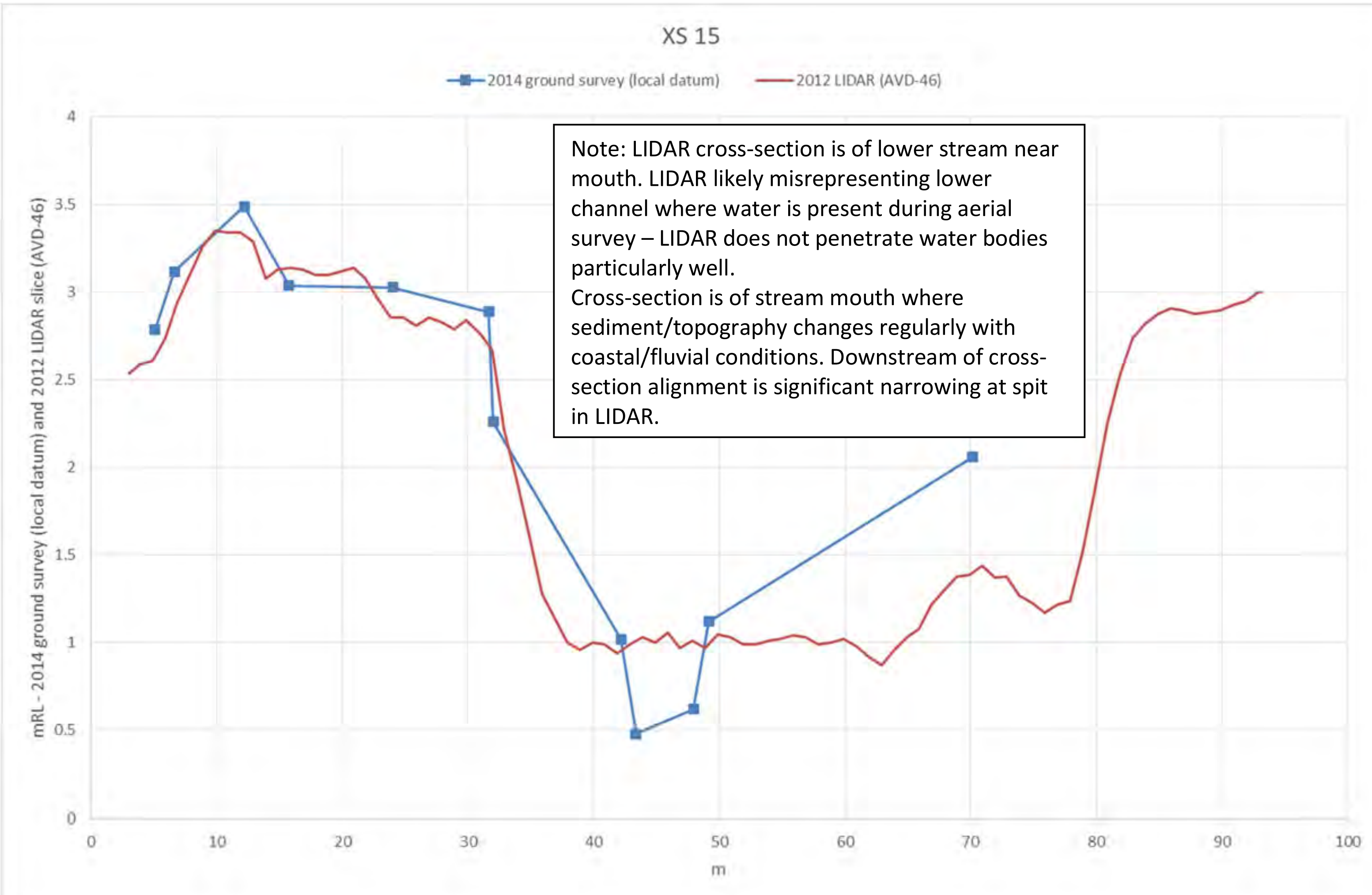

Figure A15 XS 15 (MIKE11 model chainage 710m – location shown in Figure A16)

Figure A16 Location of 2014 ground survey cross-sections as shown in the MIKE11 model. Note model chainages are shown in image but cross-sections are XS 1 (upstream) to XS 15 (downstream).

Appendix B – Comparison of 2004 and 2014 ground survey cross-sections

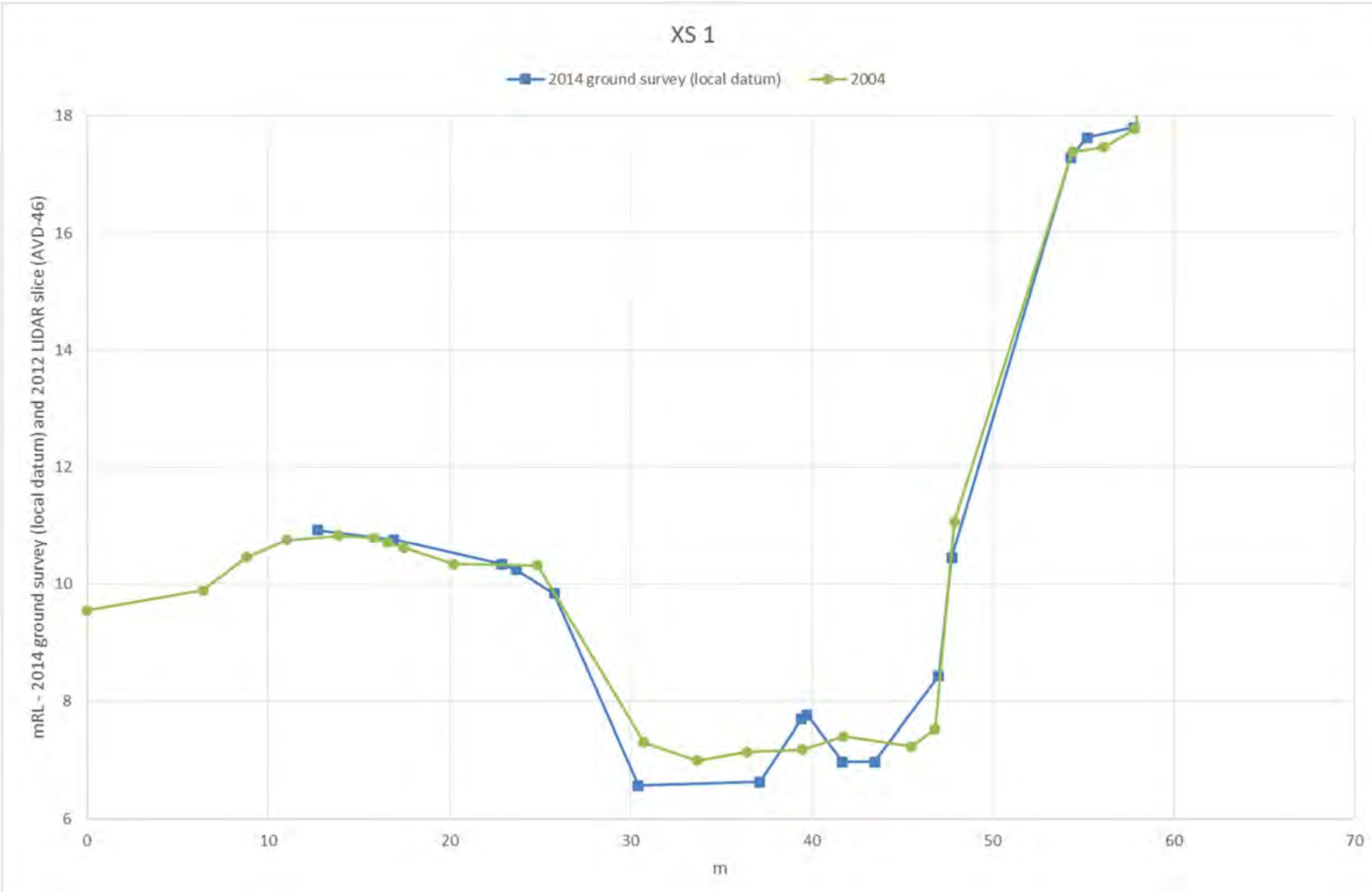

Figure B1 **Comparison of 2004 and 2014 survey at XS 1 (MIKE11 model chainage 0m – location shown in Figure A16)**

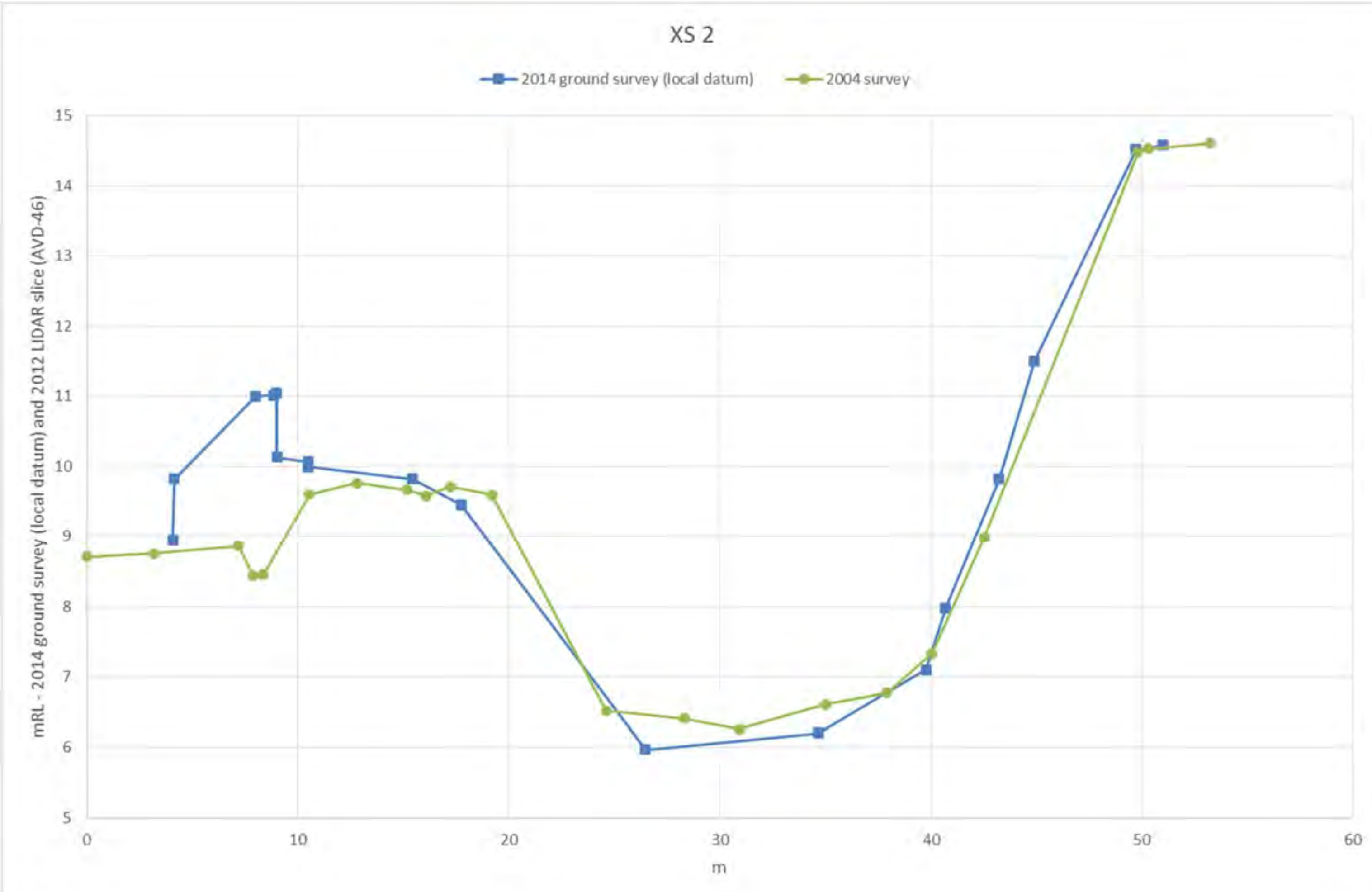

Figure B2 Comparison of 2004 and 2014 survey at XS 2 (MIKE11 model chainage 44m – location shown in Figure A16)

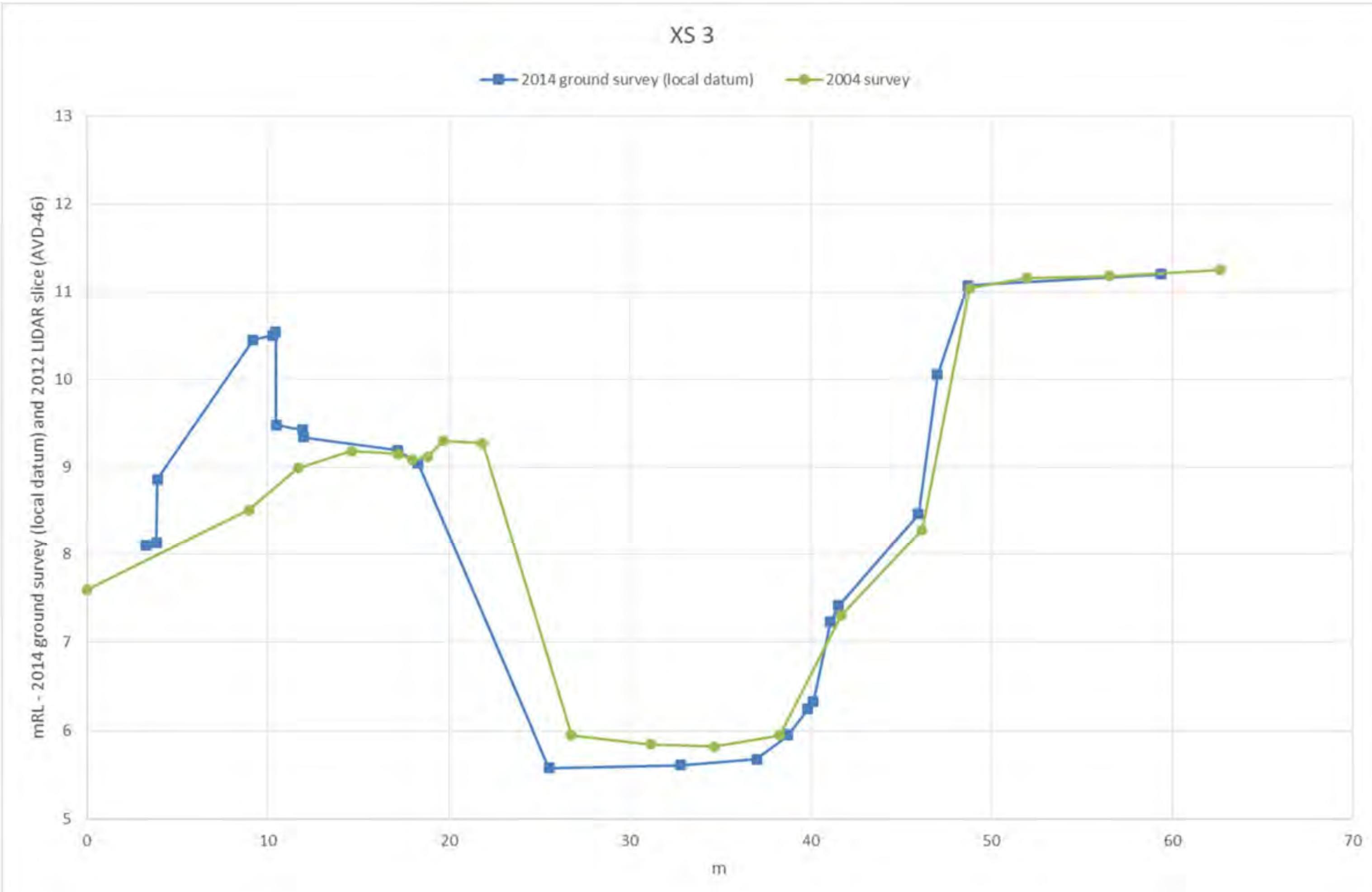

Figure B3 Comparison of 2004 and 2014 survey at XS 3 (MIKE11 model chainage 94m – location shown in Figure A16)

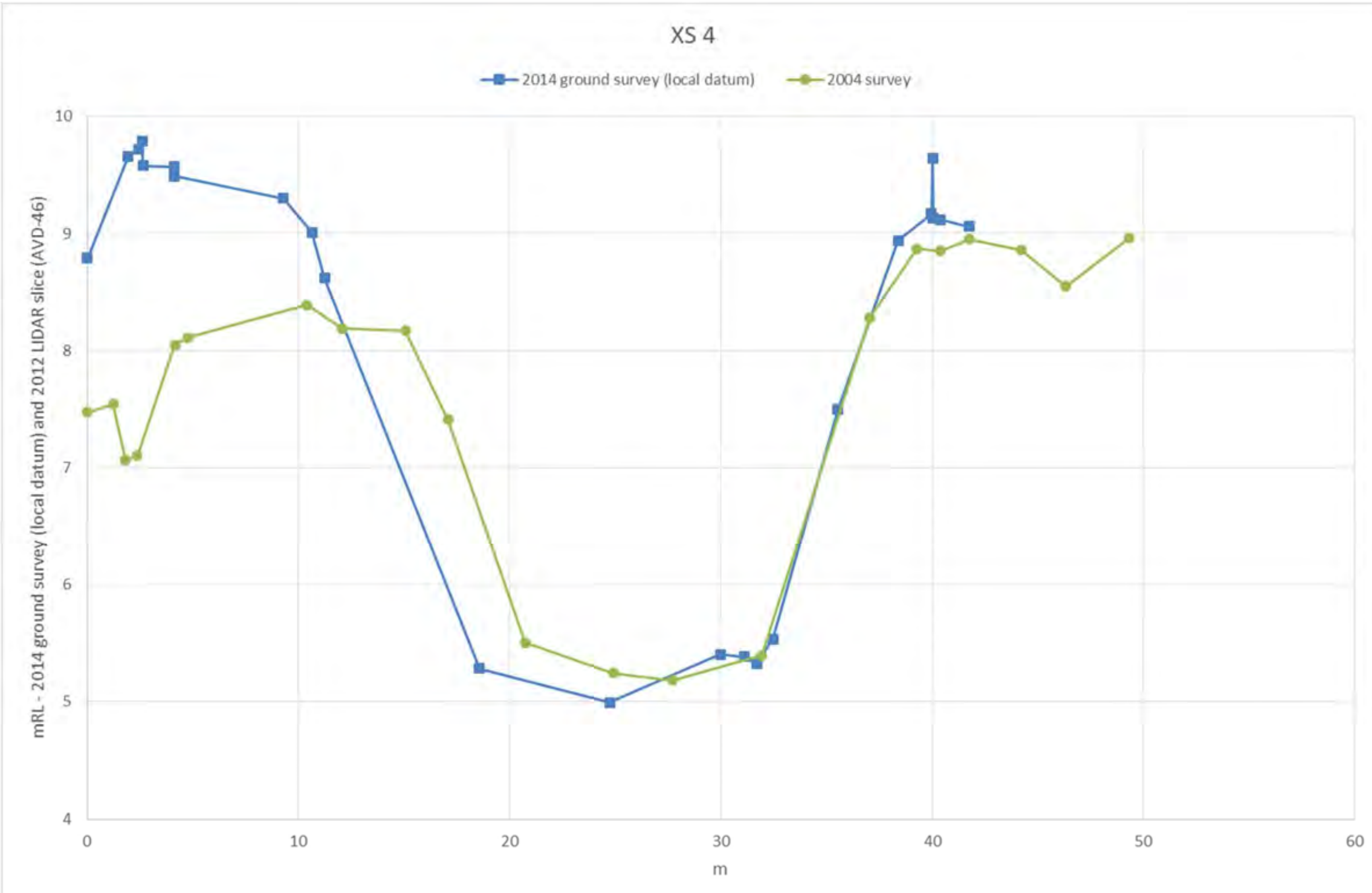

Figure B4 **Comparison of 2004 and 2014 survey at XS 4 (MIKE11 model chainage 144m – location shown in Figure A16)**

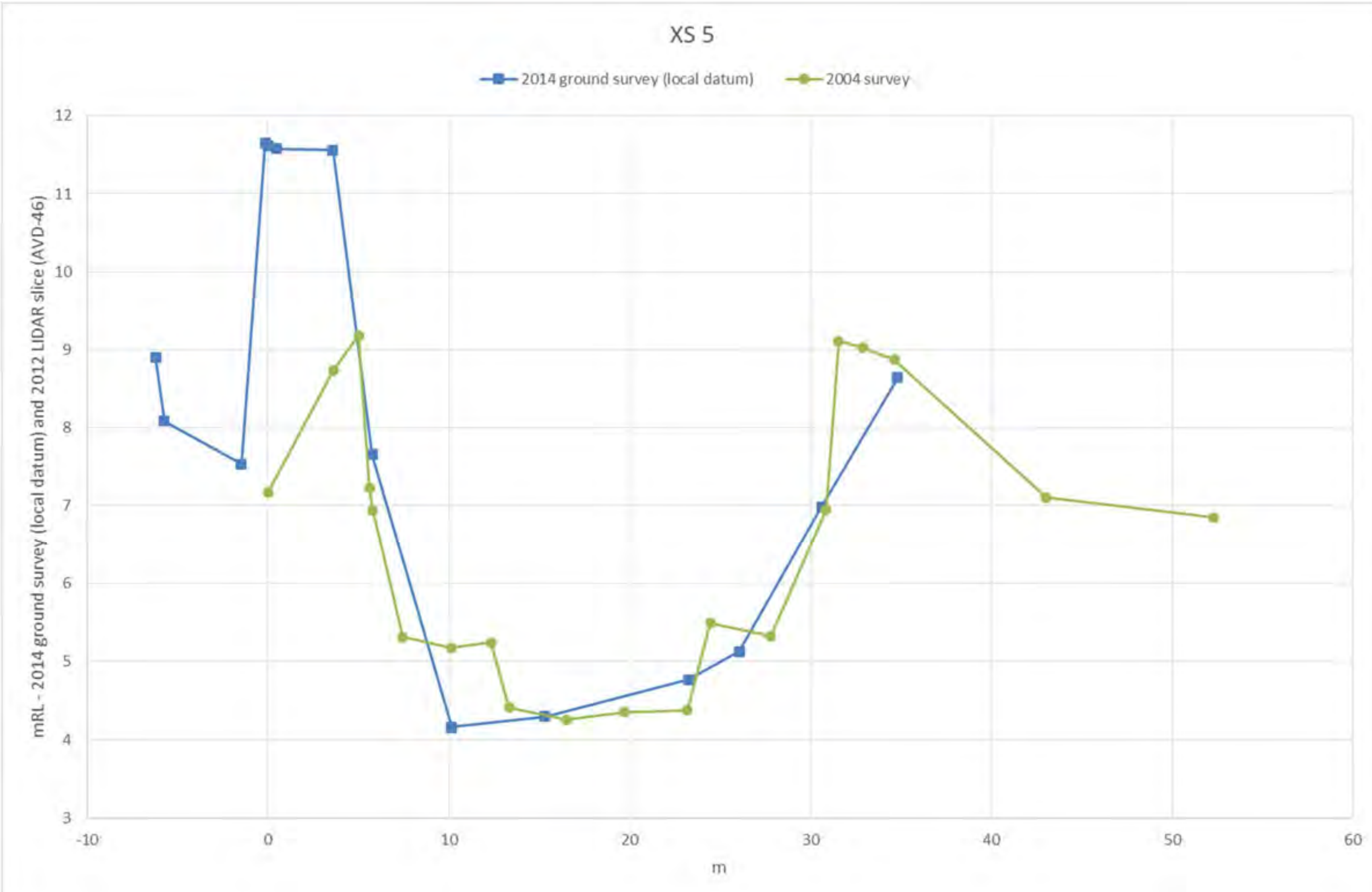

Figure B5 **Comparison of 2004 and 2014 survey at XS 5 (MIKE11 model chainage 202m – location shown in Figure A16)**

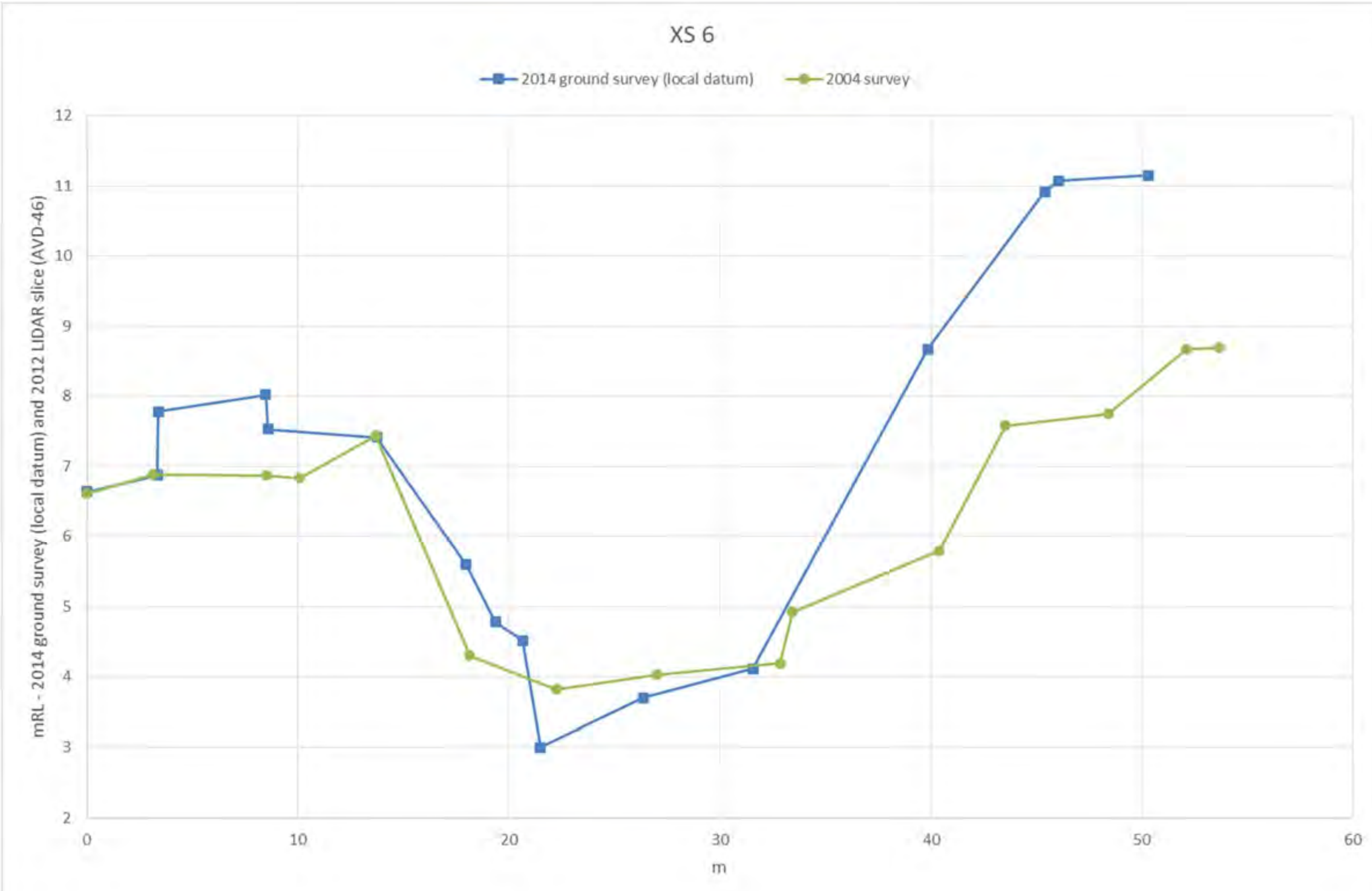

Figure B6 **Comparison of 2004 and 2014 survey at XS 6 (MIKE11 model chainage 249m – location shown in Figure A16)**

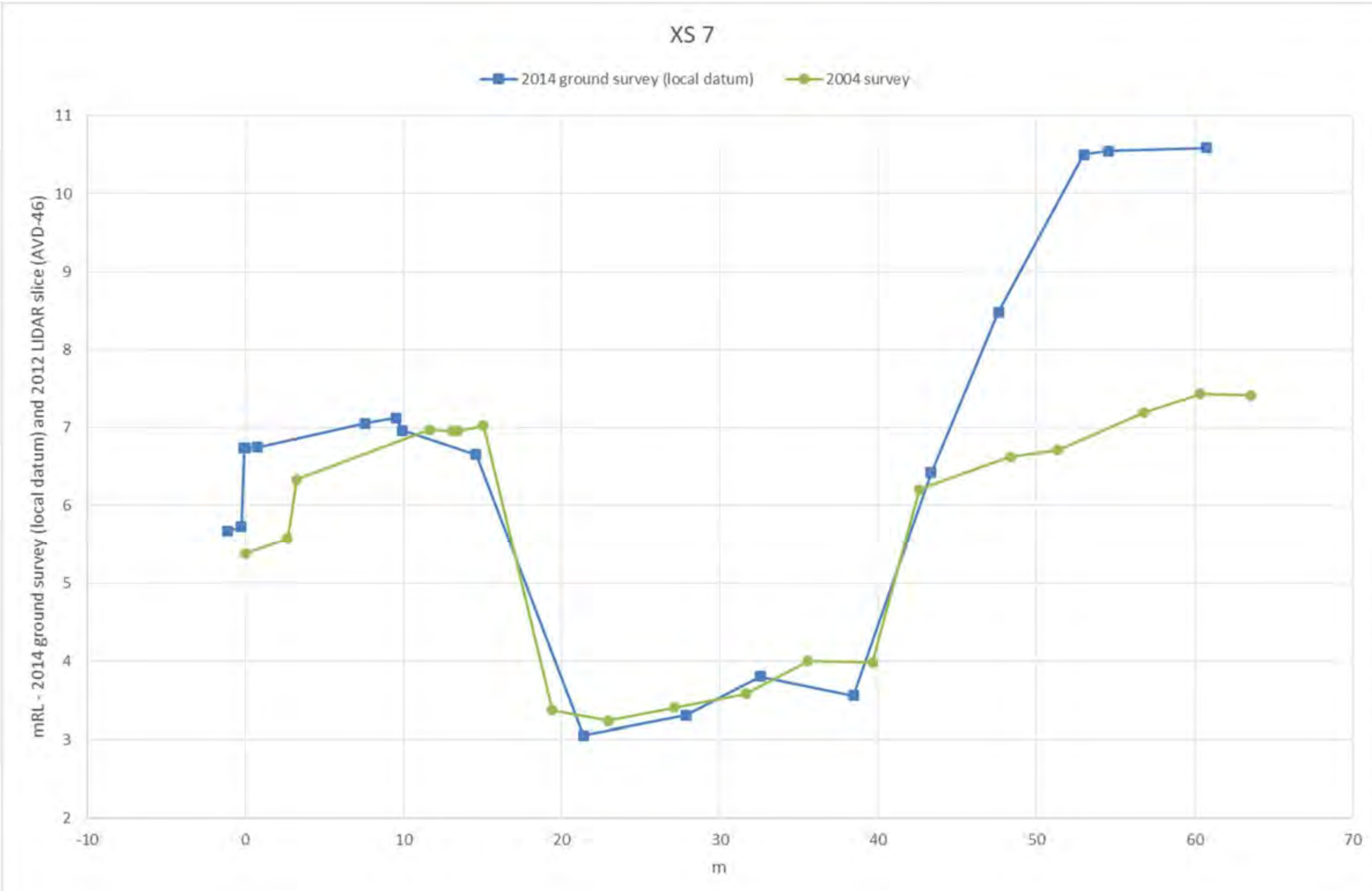

Figure B7 **Comparison of 2004 and 2014 survey at XS 7 (MIKE11 model chainage 295m – location shown in Figure A16)**

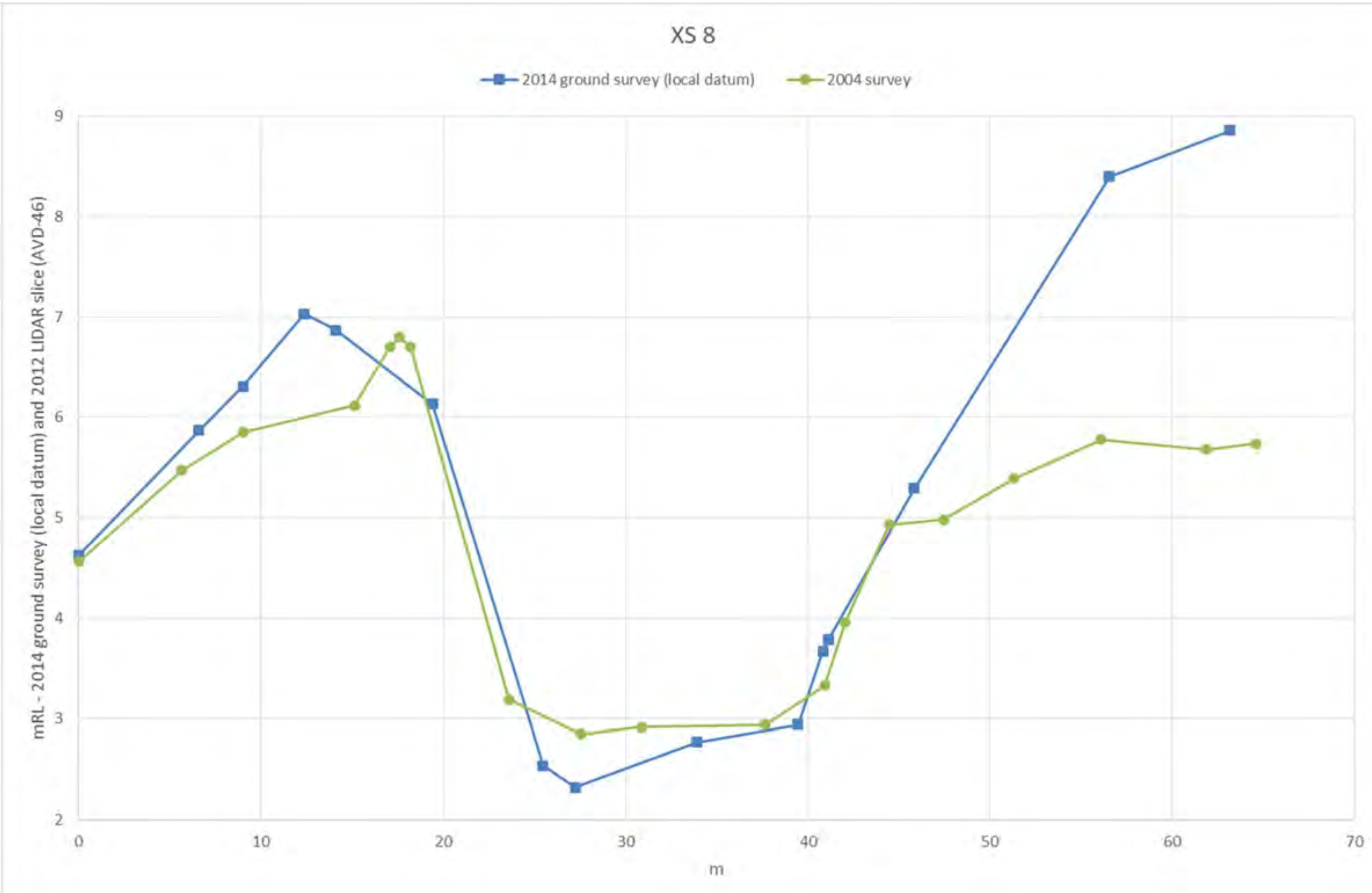

Figure B8 **Comparison of 2004 and 2014 survey at XS 8 (MIKE11 model chainage 350m – location shown in Figure A16)**

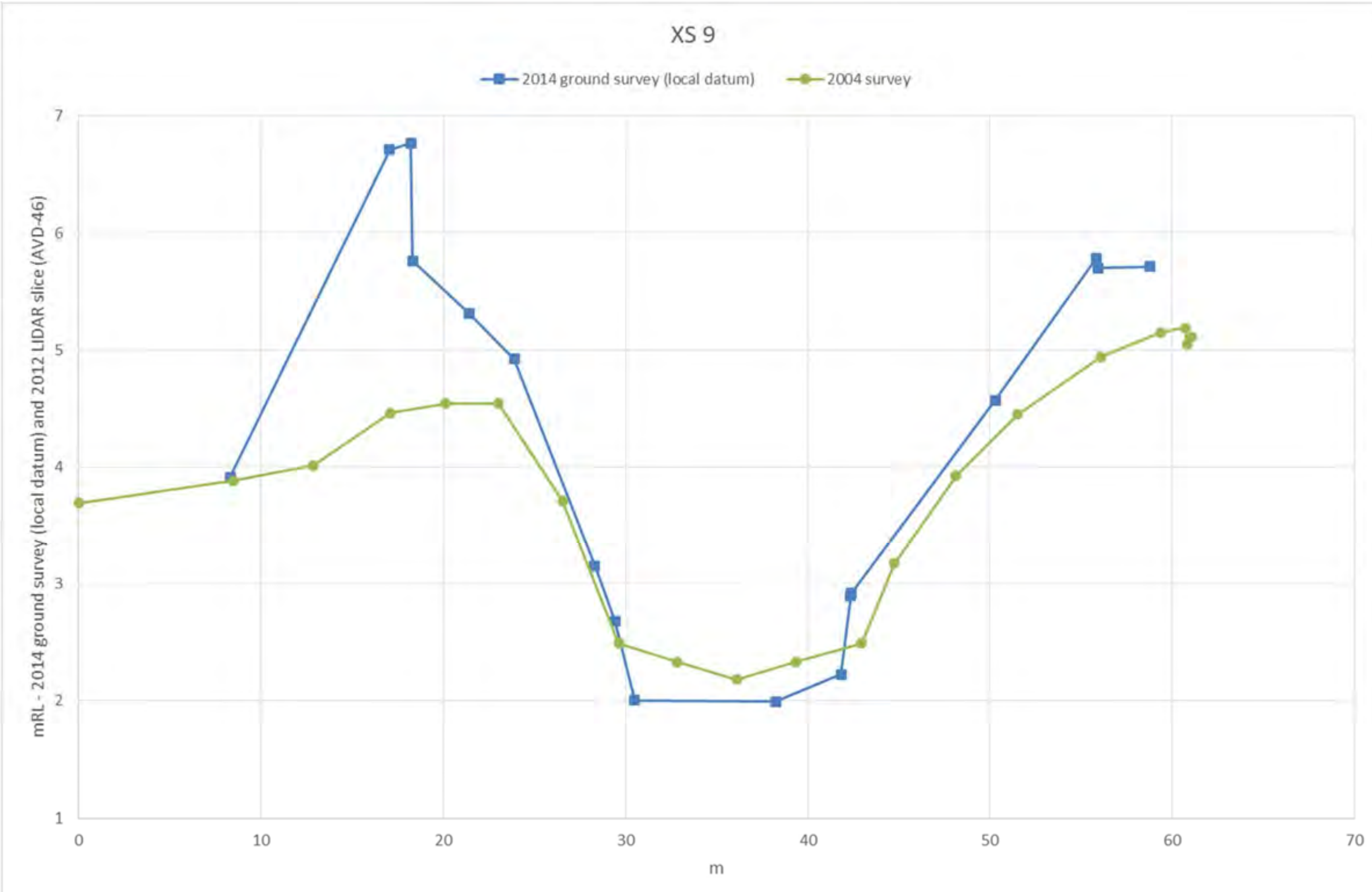

Figure B9 **Comparison of 2004 and 2014 survey at XS 9 (MIKE11 model chainage 402m – location shown in Figure A16)**

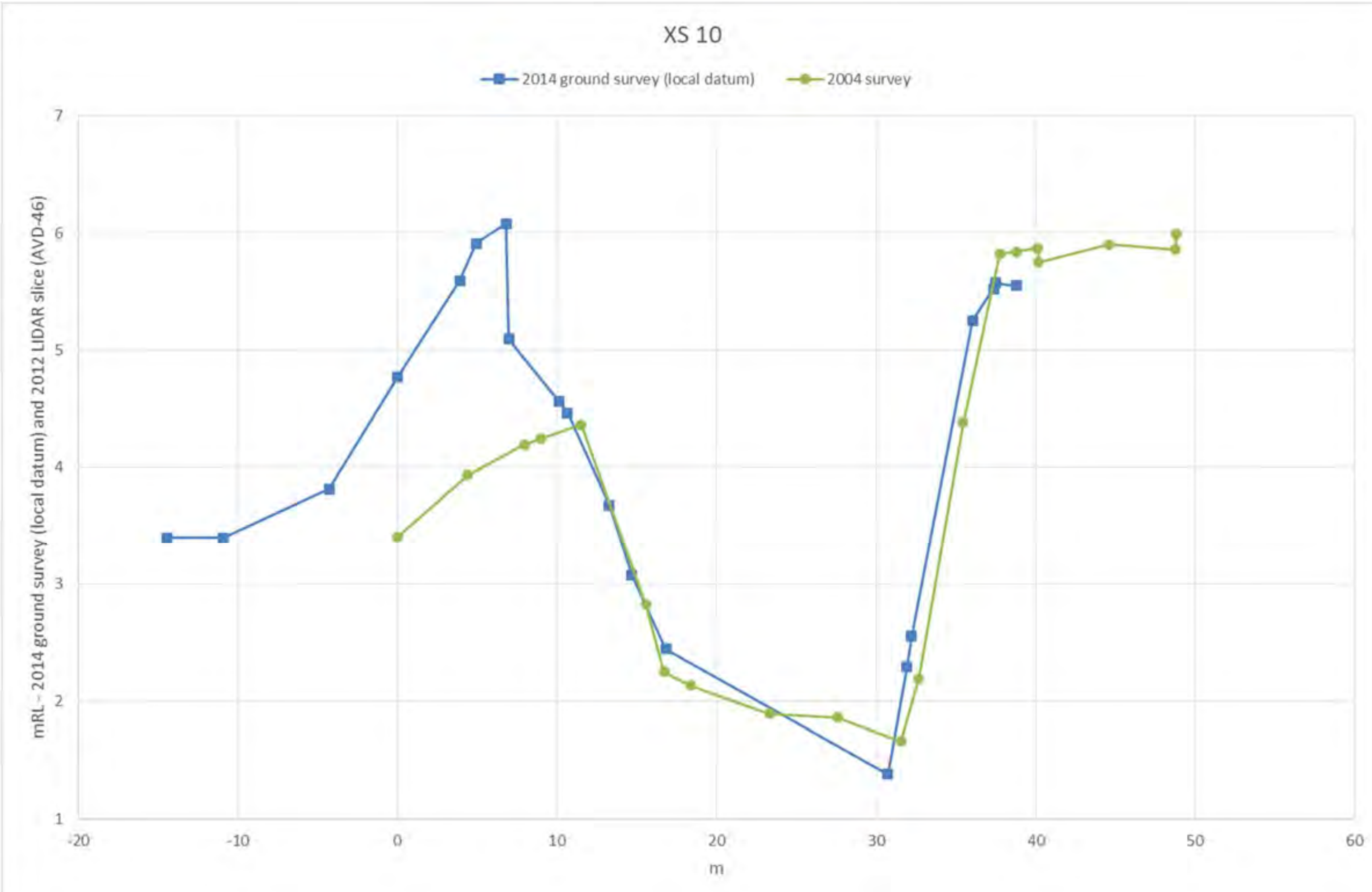

Figure B10 **Comparison of 2004 and 2014 survey at XS 10 (MIKE11 model chainage 450m – location shown in Figure A16)**

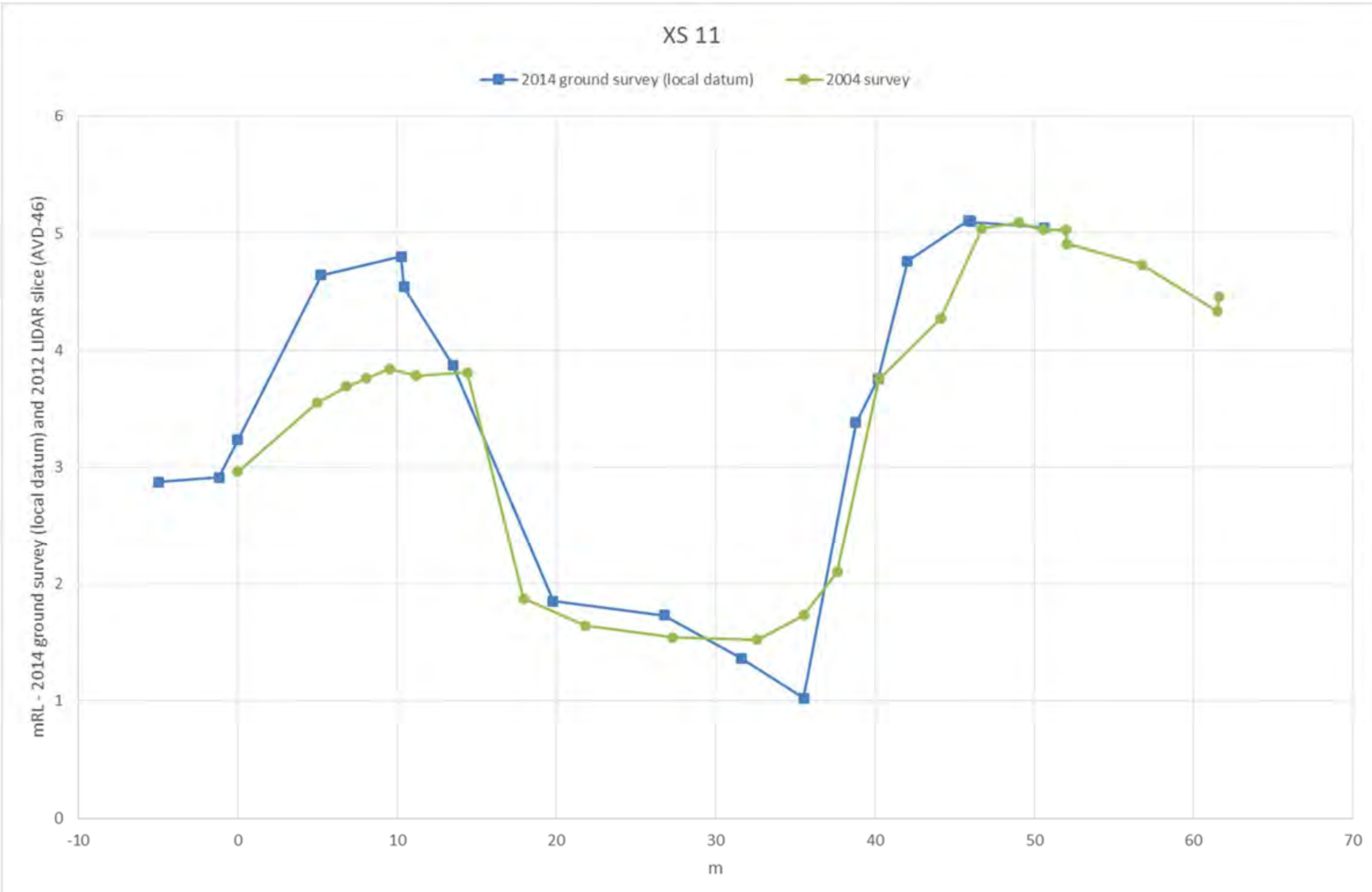

Figure B11 Comparison of 2004 and 2014 survey at XS 11 (MIKE11 model chainage 501m – location shown in Figure A16)

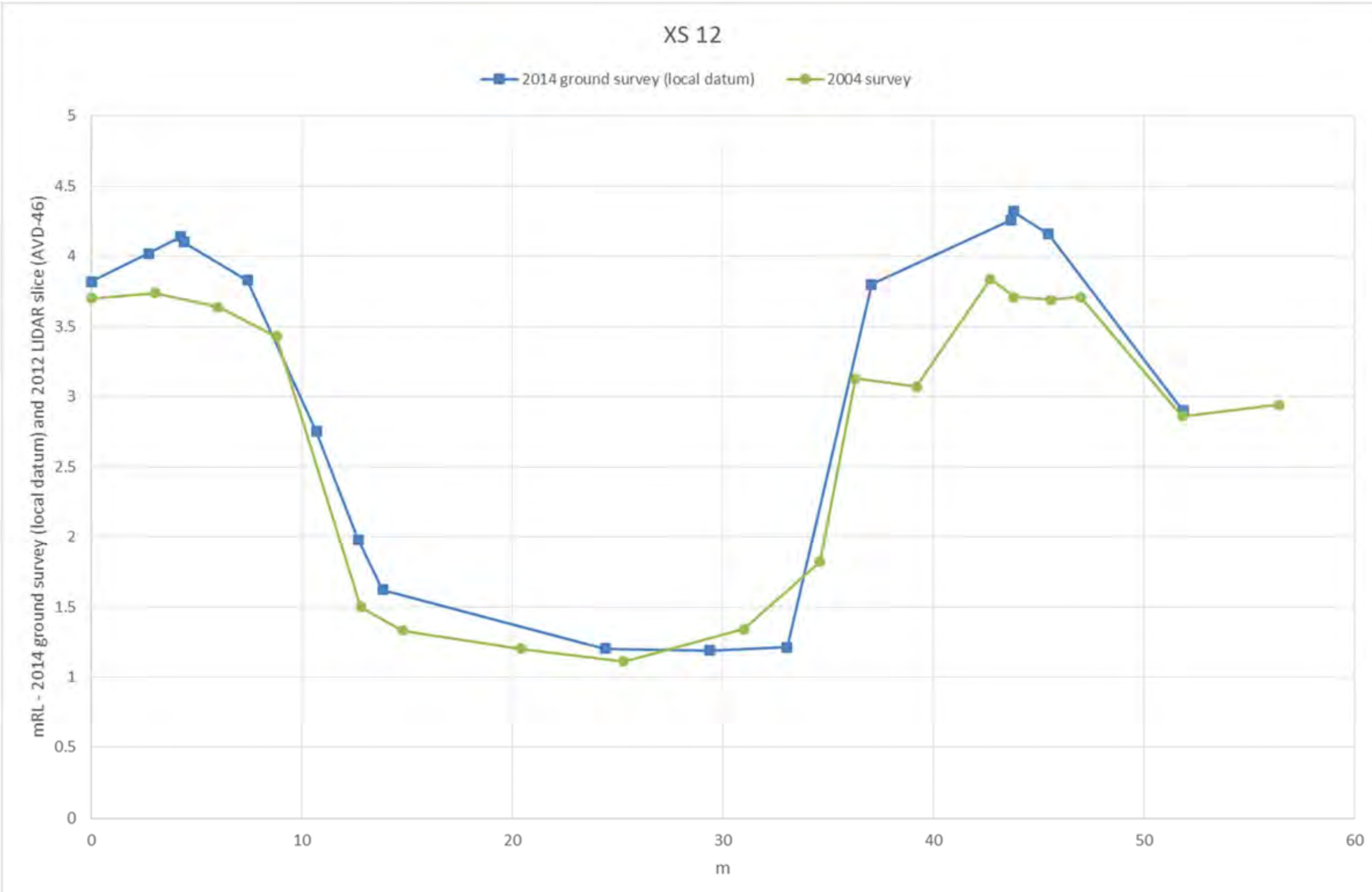

Figure B12 **Comparison of 2004 and 2014 survey at XS 12 (MIKE11 model chainage 551m – location shown in Figure A16)**

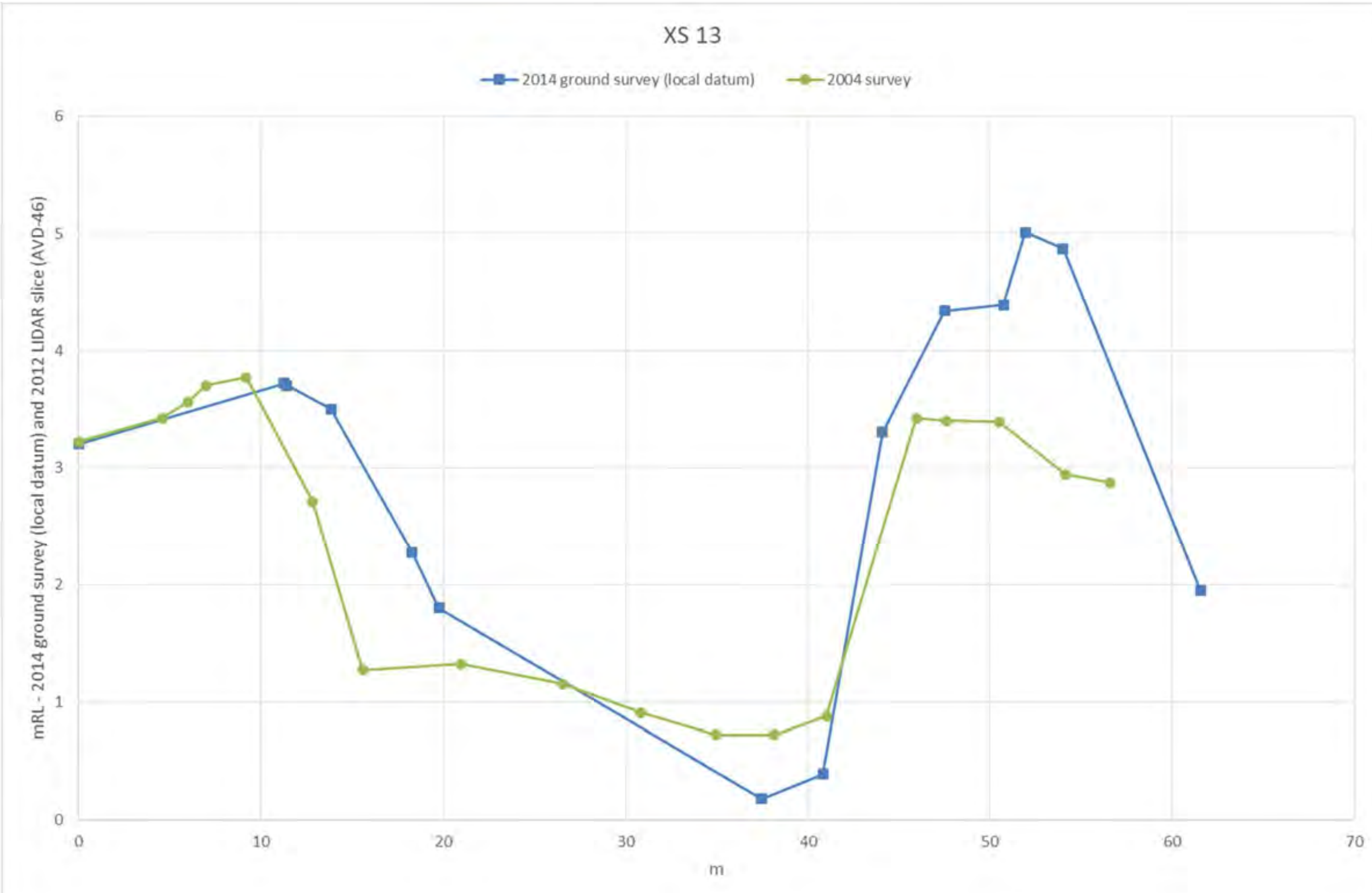

Figure B13 **Comparison of 2004 and 2014 survey at XS 13 (MIKE11 model chainage 600m – location shown in Figure A16)**

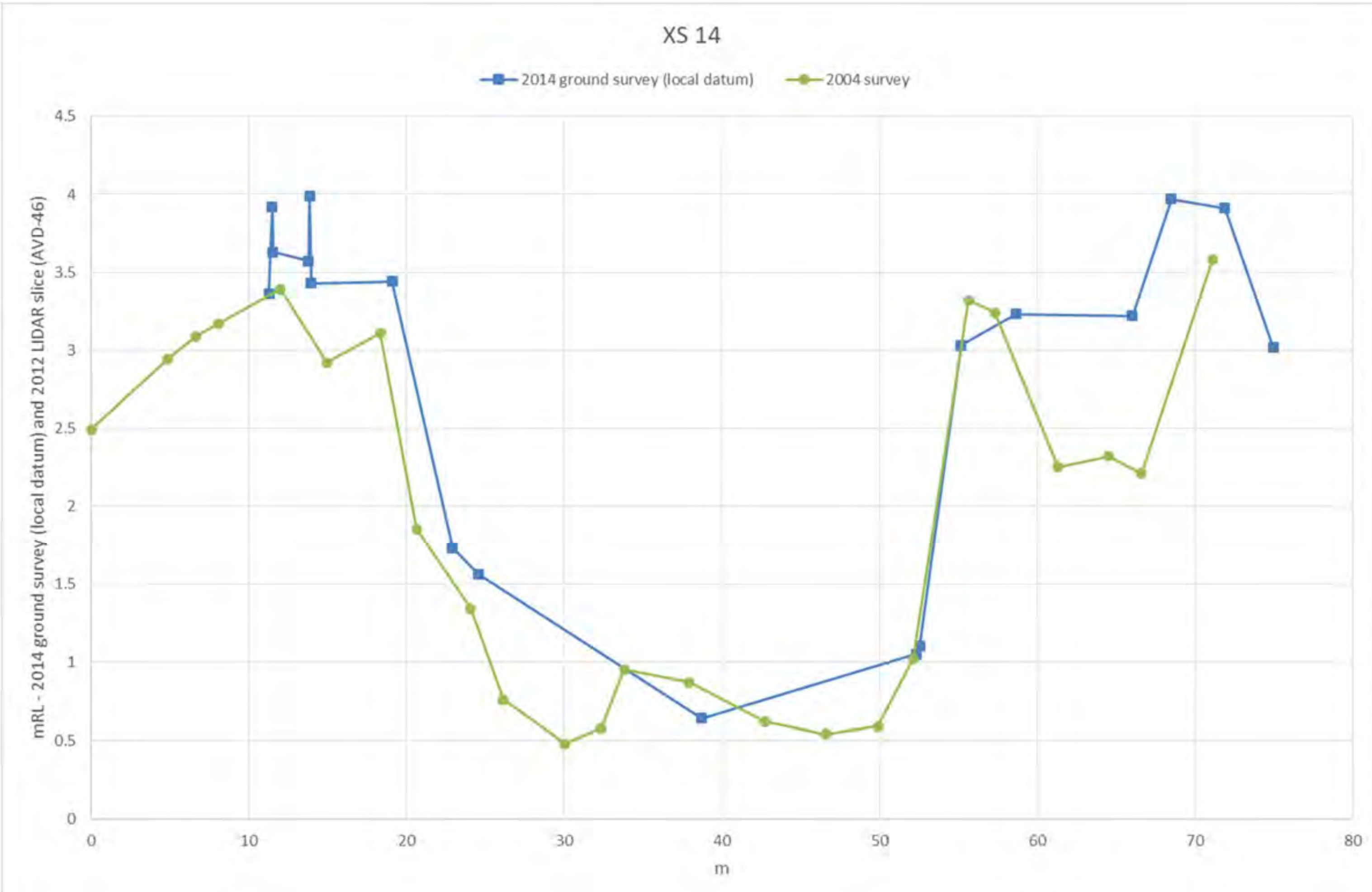

Figure B14 Comparison of 2004 and 2014 survey at XS 14 (MIKE11 model chainage 650m – location shown in Figure A16)

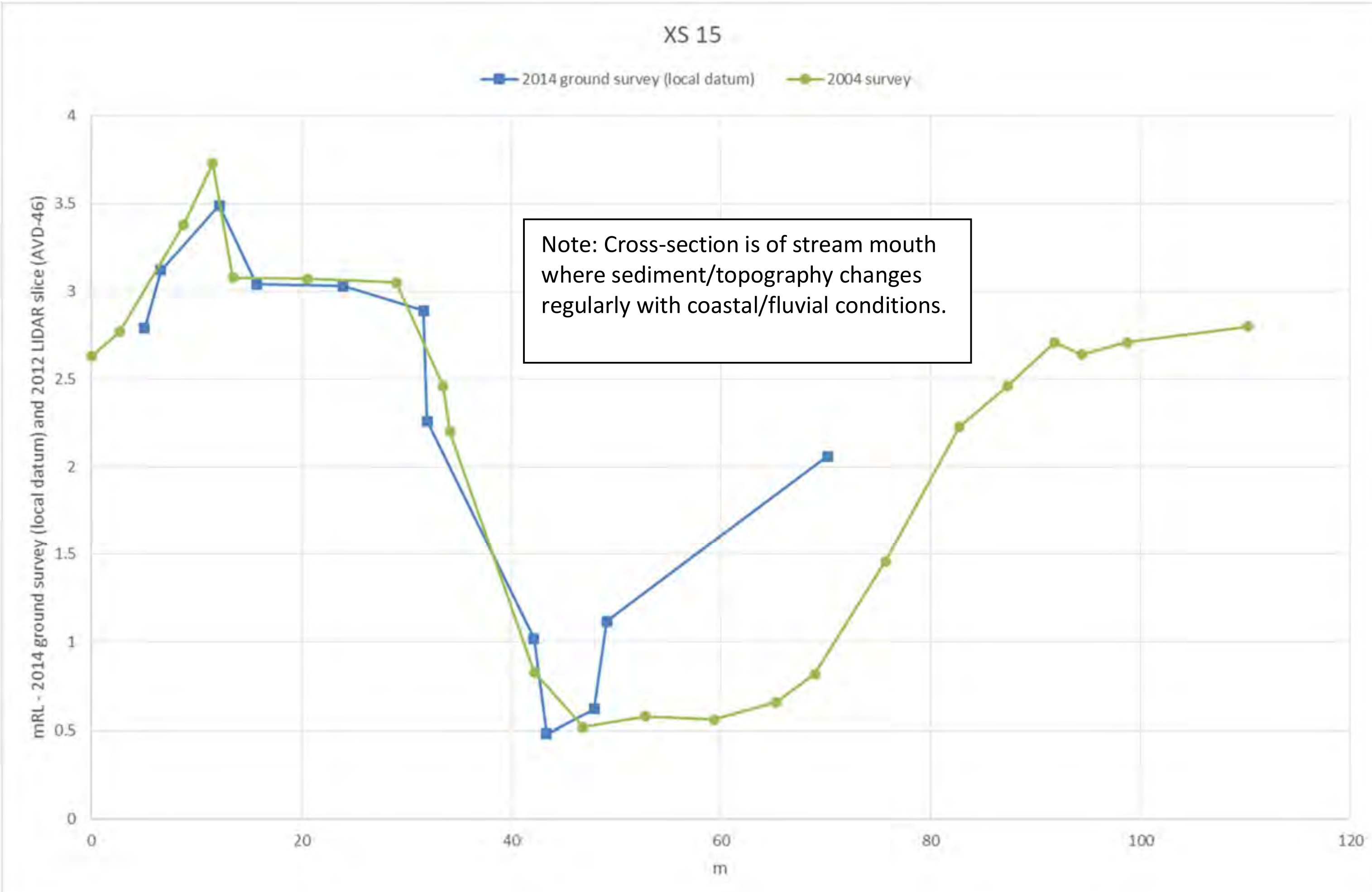

Figure B15 Comparison of 2004 and 2014 survey at XS 15 (MIKE11 model chainage 710m – location shown in Figure A16)

Appendix C – Conquest service level data

Table 13 Conquest service level review data table.

(Note: more detailed information is provided in Table 12)

Parent asset ID	Asset ID	Description	Asset chainage (m)	Cross-section	Easting (NZTM)	Northing (NZTM)	Revised design flood level (RL m)	Free-board (m)	Revised design crest level (RL m)
Te Puru Left Below State Highway Floodwall – 463m ***Service level: 1%AEP + 600mm freeboard***									
76074	76378	TP Left Below SH Floodwall 00	**0**		1824025.41	5897373.06	3.34	0.60	3.94
76074	76380	TP Left Below SH Floodwall 02	**100**		1824110.37	5897415.42	4.26	0.60	4.86
76074	76381	TP Left Below SH Floodwall 03	**200**		1824190.45	5897363.15	5.26	0.60	5.86
76074	76382	TP Left Below SH Floodwall 04	**300**		1824191.71	5897264.45	6.31	0.60	6.91
76074	76383	TP Left Below SH Floodwall 05	**400**		1824218.13	5897170.24	7.17	0.60	7.77
76074	76383	TP Left Below SH Floodwall 05	**463**	XS 5	1824264.60	5897127.85	7.94	0.60	8.54
Te Puru Left Above State Highway Floodwall – 168m ***Service level: 1%AEP + 600mm freeboard***									
76084	76387	TP Left Above SH Floodwall 01	**0**		1824307.07	5897116.77	8.34	0.60	8.94
76084	76389	TP Left Above SH Floodwall 03	**100**		1824406.87	5897122.61	9.49	0.60	10.09
76084	76389	TP Left Above SH Floodwall 03	**168**		1824470.15	5897115.16	10.19	0.60	10.79
Te Puru Right Below State Highway Stopbank – 134m ***Service level: 1%AEP + 600mm freeboard***									
76076	76392	TP Right Below SH Stopbank 00	**0**		1824012.45	5897460.34	3.64	0.60	4.24
76076	76398	TP Right Below SH Stopbank 02	**100**		1824103.67	5897451.31	4.15	0.60	4.75
76076	76398	TP Right Below SH Stopbank 02	**134**		1824137.78	5897452.84	4.43	0.60	5.03
Te Puru Right Below State Highway Floodwall – 199m. ***Service level varied: downstream XS11 - 1%AEP + 600mm freeboard (68m)*** ***upstream XS11 - %AEP (climate change) + no freeboard (131m)***									
76076	76384	TP Right Below SH Floodwall 00	**0**		1824137.78	5897452.84	4.43	0.60	5.03
76076	76385	TP Right Below SH Floodwall 01	68	XS 11	1824193.70	5897415.10	4.91	0.60	5.51
Change in service level as detailed in header									
76076	76385	TP Right Below SH Floodwall 01	69		1824194.81	5897414.28	5.36	0.00	5.36
76076	76386	TP Right Below SH Floodwall 02	**100**		1824208.86	5897387.44	5.62	0.00	5.62

Parent asset ID	Asset ID	Description	Asset chainage (m)	Cross-section	Easting (NZTM)	Northing (NZTM)	Revised design flood level (RL m)	Free-board (m)	Revised design crest level (RL m)
76076	76386	TP Right Below SH Floodwall 02	**199**		1824238.60	5897293.48	6.54	0.00	6.54
Te Puru Right Above State Highway Floodwall Spillway – 62m Service level: 1%AEP + 300mm freeboard									
76086	76390	TP Right Above SH Floodwall Spillway	**0**	XS 5	1824273.69	5897167.53	7.80	0.30	8.10
76086	76391	TP Right Above SH Floodwall Spillway	**62**		1824334.10	5897152.83	8.65	0.30	8.95