Appendix 14.A. Topographic Data for Hydraulic Models

Table A.14 - Spatial Data Used in the Floodplain Model Construction

Data	Description	Use
PCC 1m contours	1m contours for Porirua urban areas showing elevation Contours supplied to PCC from Terralink International Ltd, 26thJuly 2005 Contours were captured using Photogrammetry with ground control and generally have an accuracy of +/- 1m Data won’t account for recent earthworks in major subdivisions	Primary source of elevation data for the floodplain DEM for the Mike21 component of the hydraulic model Delineation of sub-catchment boundaries
PCC 5m contours	5m contours for Porirua rural areas showing elevation. Contours supplied to PCC from Terralink International Ltd, 26thJuly 2005 Contours were captured using Photogrammetry with ground control and generally have an accuracy of +/- 3.5m Contours are recorded as being 98% complete and data won’t account for recent earthworks in major subdivisions.	Secondary source of elevation data for the floodplain DEM for the Mike21 component of the hydraulic model Delineation of sub-catchment boundaries
PCC Rural Aerial Photographs	Colour aerial photos of Porirua rural district Photos were flown in February 2005 at 1:2500 using a colour camera Accuracy of photos is generally +/-7.5m but worse in hilly areas	Delineation of modelled stream channel Model background
PCC Urban Aerial Photographs	Colour aerial photos of Porirua urban district using r27 series and r26 series tiles Photos were flown by NZAM Ltd. in January 2009 at 1:500 using a vexel colour digital camera Accuracy of photos is generally +/-1.3m but worse in hilly areas	Delineation of modelled stream channel Model background

Appendix 14.B. Rainfall Isohyet Report

B.1 Introduction

Meteorological and hydrological analyses were undertaken to provide up-to-date information for input to road drainage and waterway crossing design.

In 2008 SKM updated the 24-hour storm isohyet maps for the Kapiti Coast District Council. This report presents the data and analyses carried out to extend these isohyet maps south to Wellington.

The study comprised:

- Collection of daily and sub-daily rainfall data recorded at all the rainfall stations in the study area
- Analysis to determine period and completeness of the rainfall records
- Extraction of daily, and where data is available 24-hour, annual maximum rainfall depth time series for each rainfall record
- Determine suitable factor to adjust daily rainfall maxima to 24-hour maxima
- Regional statistical analysis of annual maximum 24-hour rainfall to determine rainfall depths for return periods of 2, 5, 10, 20, 50 and 100-years for all rainfall stations
- Impact of projected climate change on return period rainfall for 2090 time horizon
- Preparation of isohyet maps for each return period and current and 2090 climate change scenarios.

Analyses have been carried out to determine the temporal distribution of storm rainfall in the Region that will be used to disaggregate the 24-hour rainfall depths. Accordingly it was not required to analyse shorter duration rainfall as part of this study.

B.2 Rainfall Data

Daily and sub-daily rainfall data was obtained from the Greater Wellington Regional Council and from the National Institute of Water and Atmospheric Research, New Zealand (NIWA) CliFlo database. The stations are listed in Table B together with their location and length of record.

B.2.1 Selection of Rainfall Records

Analyses were carried out to determine the years and extent of missing data in each record. Annual maxima for these years were accepted if:

- The maximum occurs at approximately the same time as at least one of the other stations in the area
- Periods of missing data did not coincide with the maxima recorded at other nearby stations.

On this basis the number of annual maxima that could be used in the rainfall analysis was determined for each record.

Usually records with less than 15 years of data are considered too short for meaningful statistical analysis. This study is to extend the storm isohyets determined for the Kapiti Coast Region (SKM 2008) south to Wellington. Rainfall records with as few as 13 years of data were used in that study because of the poor distribution of longer records. These records now have 14 years of data and were retained in the dataset.

The rainfall stations listed in Table B are divided into northern and southern geographical regions. The boundary between the regions was set at the southern extent of the isohyets generated for the Kapiti Coast study coinciding with the rainfall station at Paekakariki Hill. This data was included in the regional analysis for both the northern and southern regions.

- **Table B1 - List of Rainfall Stations**

Station Name	Station Type1	Agent Number	Network Number	Location		Record Length (Years)	Number Annual Maxima
				Latitude	Longitude		
Northern Region							
Arawhata	D	3461	E15012	-41.006	175.13	34	24
Kapakapanui	P	3329	E05914	-40.926	175.163	14	14
Kapiti Island	D	3144	E04891	-40.855	174.932	45	36
MacIntosh		59201		-40.917	175.309		
Manakau	D	3302	E05722	-40.72	175.216	35	34
Mangaone Transmission Lines	P	-	E05813	-40.836	175.170	14	14
Mt Holdsworth Lodge	D	2460	D05944	-40.908	175.476	24	15
Oriwa	P	3305	57302	-40.750	175.349	18	15
Otaki 1	D	3296	E05711	-40.764	175.145	77	72
Otaki East	D	3299	E05714	-40.76	175.169	13	(12)0
Otaki River at Depot	D/P	7362	E05716	-40.770	175.144	26	20
Otaki Temuera St	D	3298	E05713	-40.76	175.134	16	14
Paekakariki Hill	D	3341	E14091	-41.018	174.98	54	52
Paraparaumu Aero	D/P	3145	E04991	-40.907	174.984	59	57
Paraparaumu Aero Aws	D	8567	E04994	-40.907	174.984	52	52
Reikorangi	D	3327	E05912	-40.903	175.11	35	31

Station Name	Station Type1	Agent Number	Network Number	Location		Record Length (Years)	Number Annual Maxima
				Latitude	Longitude		
Northern Region							
Taungata	P	58201		-40.812	175.255	16	14
Te Horo Longcroft	D	3308	E05811	-40.817	175.148	40	39
Te Horo, Jonelle	D	7387	E05717	-40.79	175.158	17	15
Titahi Bay T. Plant	D	3353	E1418F	-41.114	174.817	17	(9)0
Waikanae Waterworks	D/P	3307	E05802	-40.889	175.072	38	37
Warwicks	P	3322	E05907	-40.957	175.077	28	24

Station Name	Station Type1	Agent Number	Network Number	Location		Record Length (Years)	Number Annual Maxima
				Latitude	Longitude		
Southern Region							
Blue Gum Spur	P	150010		-41.048	175.019	29	16
Makara		3386	E14273	-41.253	174.694	21	21
Mill Creek Reservoir	P		141812	-41.148	174.796	24	19
Paekakariki Hill	D	3341	E14091	-41.018	174.98	54	52
Putaputaweta	P		150006	-41.012	175.005	7	(6)0
Seton Nossiter Park			142811	-41.210	174.816	18	14
Taupo Stream at Whenua Tapu			140806	-41.056	174.875	19	18
Wellington Aero	D	3445	E14387	-41.322	174.804	11	(11)0
Wellington Buckle St	D	3431	E14370	-41.3	174.783	7	(7)0
Wellington Glenside	D	3401	E14287	-41.208	174.811	7	(7)0
Wellington Kelburn Aws	D/P	25354	E1427P	-41.285	174.768	4	(4)0
Wellington Newlands	D	3400	E14286	-41.233	174.817	4	(4)0
Wellington Newlands	D	3402	E14288	-41.229	174.827	2	(2)0
Wellington Rongotai	D	3444	E14386	-41.321	174.801	13	(13)0
Wellington, Bowen St	D	3389	E14276	-41.283	174.783	2	(2)0
Wellington, Karori	D	3392	E14279	-41.284	174.737	2	(2)0
Wellington, Kelburn	P	3385	E14272	-41.286	174.767	50	48
Wellington, Knowles Obs	D	3383	E14270	-41.283	174.783	7	(6)0
Wellington, Thorndon	D	3391	E14278	-41.283	174.783	16	16
Linden	D	3355	E14181	-41.181	174.831	33	30
Belmont	D	3365	E14191	-41.167	174.900	25	0
Tawa	D	3352	E1418E	-41.157	174.829	19	17
Judgeford	D	3373	E14199	-41.123	174.941	31	22
Moonshine	D	3473	E1510D	-41.102	175.003	11	(8)0

Annual maximum 24-hour rainfall was extracted from the continuous pluviograph records using the Hilltop data management software used by Greater Wellington Regional Council. The output from this software provides the annual maxima and also identifies years where the data is incomplete and the periods of missing data.

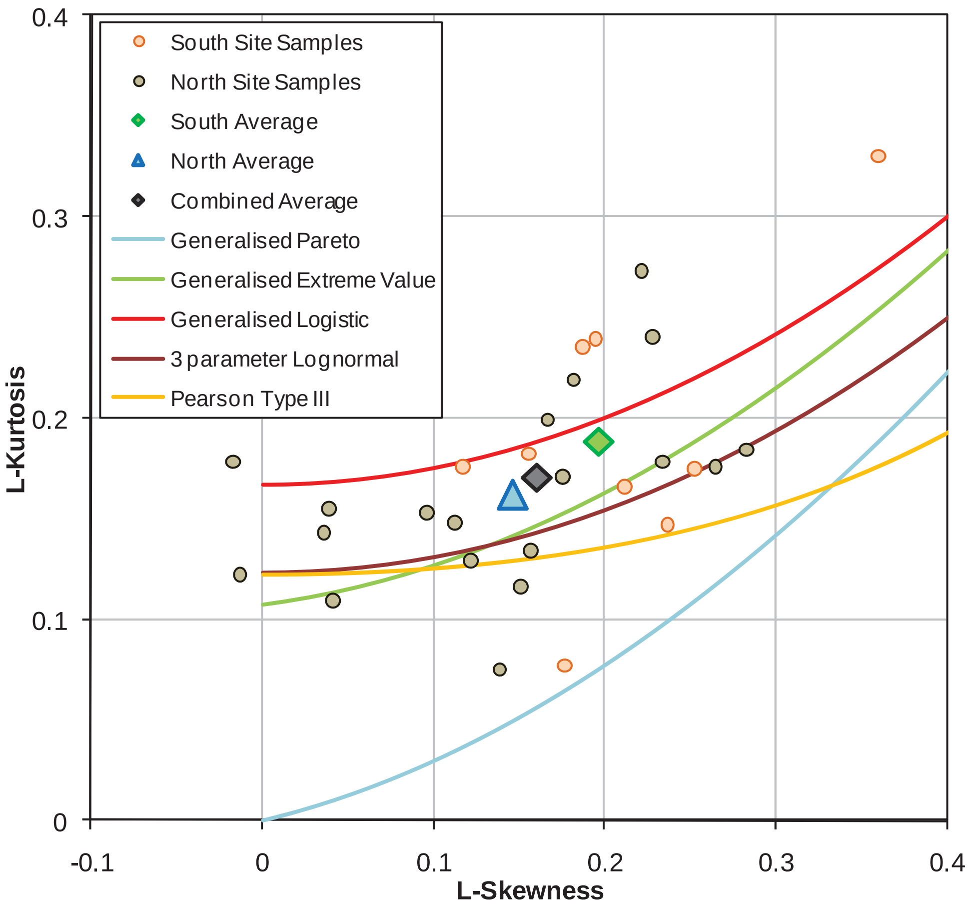
The records for stations where data is read daily were analysed using custom software that extracted the maximum daily rainfall for each year of record and listed the periods of missing data together with the number of days with missing data in each year of record. Daily rainfall measurements are made at the same time each day whereas the 24-hour maximum rainfall can start at any time of the day. Accordingly, the daily maxima need to be adjusted to compensate for the fixed time span. For the Kapiti study (SKM 2008), daily rainfall was factored by 1.16 (obtained from work published by Dwyer and Reed in 1995). The suitability of this factor was reviewed by comparing annual 24-hour maxima and daily maxima for the continuous records. The results showed that the ratio between 24-hour and daily maxima varied between 1.00 and 1.77 with an average of 1.15. Accordingly a factor of 1.16 is reasonable for the region and was retained for this study.

B.3 Frequency Analysis

B.3.1 Frequency Distribution

Previous analyses (SKM 2003, SKM 2008) used the L-moment technique to identify an appropriate distribution for regional rainfall analysis for the Kapiti Coast Region. The analyses showed the Generalised Logistic distribution to be appropriate.

The analysis carried out in 2008 was based on 20 rainfall stations distributed between Manakau in the north and Paekakariki Hill in the south. Additional data has been obtained for some of these stations and another 11 stations have been included to provide data for the area south to Wellington. The L-moment ratio diagram showing the rainfall station data and weighted averages for the northern, southern and combined dataset is shown in Figure 45.



▪ **Figure 45 - L-moment Ratio Diagram**

The plot indicates that either the Generalised Logistic (GL) or the Generalised Extreme Value (GEV) would be appropriate distributions for regional frequency analysis of the data sets. The GL distribution was selected in the previous analysis of the northern data set and was retained for both data sets to preserve consistency between the previous analysis and across the whole region.

The project area was divided into two regions because rainfall drivers differ between the Kapiti (northern) and Wellington (southern) regions of the project area.

Regional parameters for the Generalised Logistic distribution were determined using the RegFreq software. The regional parameters were calculated as the average of the individual station parameters weighted according to the number of annual maxima in the respective record. These parameters are listed in Table 15.

- **Table 15 - Regional Parameters for the Generalised Logistic Distribution**

Parameter	Parameter Value	
	North	South
Location parameter (ξ)	0.9625	0.9445
Scale parameter (α)	0.1548	0.1641
Shape parameter (k)	-0.1438	-0.1967

B.3.2 Estimation of Storm Rainfall

The Generalised Logistic distribution was used to estimate 24-hour storm rainfall for a range of recurrence intervals at each of the rainfall stations used in the analysis. These rainfall depths are summarised in Table 16. The values for Paekakariki Hill are the average of the values determined in the northern and southern region analysis.

- **Table 16 - 24-Hour Storm Rainfall Estimated Using the Generalised Logistic Distribution**

Site Name	24-hour storm rainfall (mm) for Average Recurrence Interval (years)					
	2	5	10	20	50	100
Northern Region						
Arawhata	130.1	162.1	184.1	206.7	239.1	266.2
Kapakapanui	118.5	147.7	167.7	188.3	217.8	242.5
Kapiti Island	74.5	92.9	105.5	118.4	137.0	152.5
Manakau	71.4	89.1	101.1	113.6	131.4	146.2
Mangaone	96.1	119.8	136.0	152.7	176.7	196.7
McIntosh	225.1	280.6	318.6	357.8	413.9	460.8
Mt Holdsworth	106.6	132.9	150.9	169.4	196.0	218.2
Oriwa	248.9	310.3	352.3	395.6	457.7	509.5
Otaki 1	57.6	71.8	81.5	91.6	105.9	117.9
Otaki Depot	62.3	77.6	88.1	99.0	114.5	127.4
Otaki Temuera	70.1	87.4	99.2	111.4	128.9	143.5
Paekakariki Hill	84.6	106.7	122.3	138.7	162.9	183.6
Paraparaumu Aero	66.0	82.3	93.4	104.9	121.3	135.1
Reikorangi	95.9	119.6	135.8	152.5	176.4	196.4
Te Horo Longcroft	78.4	97.8	111.0	124.7	144.2	160.5
Te Horo Jonelle	77.3	96.3	109.4	122.8	142.1	158.1
Taungata	150.2	187.3	212.6	238.8	276.2	307.5
Waikanae	77.8	97.0	110.2	123.7	143.1	159.3
Warwicks	134.0	167.1	189.7	213.0	246.4	274.3
Southern Region						
Blue Gum Spur	118.8	151.7	175.5	201.1	239.5	272.9
Judgeford	67.1	85.7	99.2	113.6	135.3	154.2
Linden	80.1	102.2	118.3	135.5	161.4	183.9

Site Name	24-hour storm rainfall (mm) for Average Recurrence Interval (years)					
	2	5	10	20	50	100
Makara	81.1	103.5	119.8	137.3	163.4	186.3
Mill Creek Reservoir	68.8	87.8	101.6	116.4	138.6	158.0
Paekakariki Hill	84.6	106.7	122.3	138.7	162.9	183.6
Whenua Tapu	63.8	81.5	94.3	108.0	128.7	146.6
Wellington, Thorndon	73.0	93.2	107.8	123.6	147.1	167.7
Seton Nossiter Park	65.4	83.5	96.6	110.7	131.8	150.2
Salamanca	74.2	94.8	109.7	125.7	149.7	170.6
Tawa	68.5	87.5	101.3	116.1	138.2	157.5

Comparisons were made between the storm rainfall determined for the 2008 update and the current study to assess the impact of additional years of data in some records and omission of three records that were previously used because of their record length. Storm rainfall depths increased by 3.5%, 2.3% and 1.6% for the stations at Warwicks, Manakau and Te Horo Longcroft respectively. For the other stations the difference is less than 0.2%.

B.3.3 Climate Change

The Ministry for the Environment published a guidance manual for Local Government in New Zealand for assessing the expected impact of climate change in May 2008 (MfE 2008). These guidelines were used to estimate the impact that climate change is likely to have on storm rainfall in the Wellington Region at 2040 and 2090 time horizons.

Percentage adjustments to storm rainfall per degree C change in temperature were obtained from Table 5.2 of the guideline and applied to the 2040 and 2090 projected increase in temperature for the Wellington Region of 0.9ºC and 2.1ºC obtained from Table 2.2 and Table 2.3 respectively. Factors for adjusting current storm rainfall to the 2040 and 2090 time horizons are listed in Table 17.

- **Table 17 - Climate Change Factors for 2040 and 2090 Time Horizons**

	Return Interval (Years)					
	2	5	10	20	50	100
Table 5.2 (adjustment to rainfall per 1ºC of warming)	4.3%	5.4%	6.3%	7.2%	8.0%	8.0%
Climate change Factor 2040	1.039	1.049	1.057	1.065	1.072	1.072
Climate change Factor 2090	1.090	1.113	1.132	1.151	1.168	1.168

Projected storm rainfall for the 2040 and 2090 time horizons were calculated using the factors in Table 17 and are summarised in Table 18 and Table 19 respectively.

- **Table 18 - 24-hour Storm Rainfall 2040 Time Horizon**

Site Name	24-Hour Storm Rainfall (mm) for Average Recurrence Interval (years)					
	2	5	10	20	50	100
Northern Region						
Arawhata	135.1	170.0	194.5	220.1	256.4	285.4
Kapakapanui	123.0	154.9	177.2	200.5	233.5	259.9
Kapiti Island	77.4	97.4	111.5	126.1	146.9	163.5

Site Name	24-Hour Storm Rainfall (mm) for Average Recurrence Interval (years)					
	2	5	10	20	50	100
Manakau	74.2	93.4	106.9	120.9	140.8	156.8
Mangaone	99.8	125.6	143.7	162.6	189.4	210.8
McIntosh	233.8	294.3	336.7	381.0	443.7	493.9
Mt Holdsworth	110.7	139.3	159.4	180.4	210.1	233.9
Oriwa	258.5	325.4	372.3	421.3	490.6	546.2
Otaki 1	59.8	75.3	86.2	97.5	113.5	126.4
Otaki Depot	64.7	81.4	93.1	105.4	122.7	136.6
Otaki Temuera	72.8	91.6	104.8	118.6	138.1	153.8
Paekakariki Hill	87.7	111.9	129.5	148.3	175.8	198.7
Paraparaumu Aero	68.5	86.2	98.7	111.7	130.0	144.8
Reikorangi	99.7	125.4	143.5	162.4	189.1	210.5
Te Horo Longcroft	81.5	102.5	117.3	132.7	154.6	172.1
Te Horo Jonelle	80.2	101.0	115.6	130.7	152.3	169.5
Taungata	156.0	196.4	224.7	254.2	296.1	329.6
Waikanae	80.9	101.8	116.4	131.7	153.4	170.8
Warwicks	139.2	175.2	200.5	226.8	264.2	294.1
Southern Region						
Blue Gum Spur	123.4	159.1	185.5	214.2	256.7	292.6
Judgeford	69.7	89.9	104.8	121.0	145.0	165.3
Linden	83.2	107.2	125.0	144.3	173.0	197.2
Makara	84.2	108.6	126.6	146.2	175.2	199.7
Mill Creek Reservoir	71.4	92.1	107.4	124.0	148.6	169.4
Paekakariki Hill	87.8	111.9	129.2	147.7	174.6	196.8
Whenua Tapu	66.3	85.5	99.6	115.0	137.9	157.2
Wellington, Thorndon	75.8	97.7	114.0	131.6	157.7	179.8
Seton Nossiter Park	67.9	87.5	102.1	117.9	141.3	161.0
Salamanca	77.1	99.4	115.9	133.8	160.4	182.8
Tawa	71.2	91.8	107.0	123.6	148.1	168.8

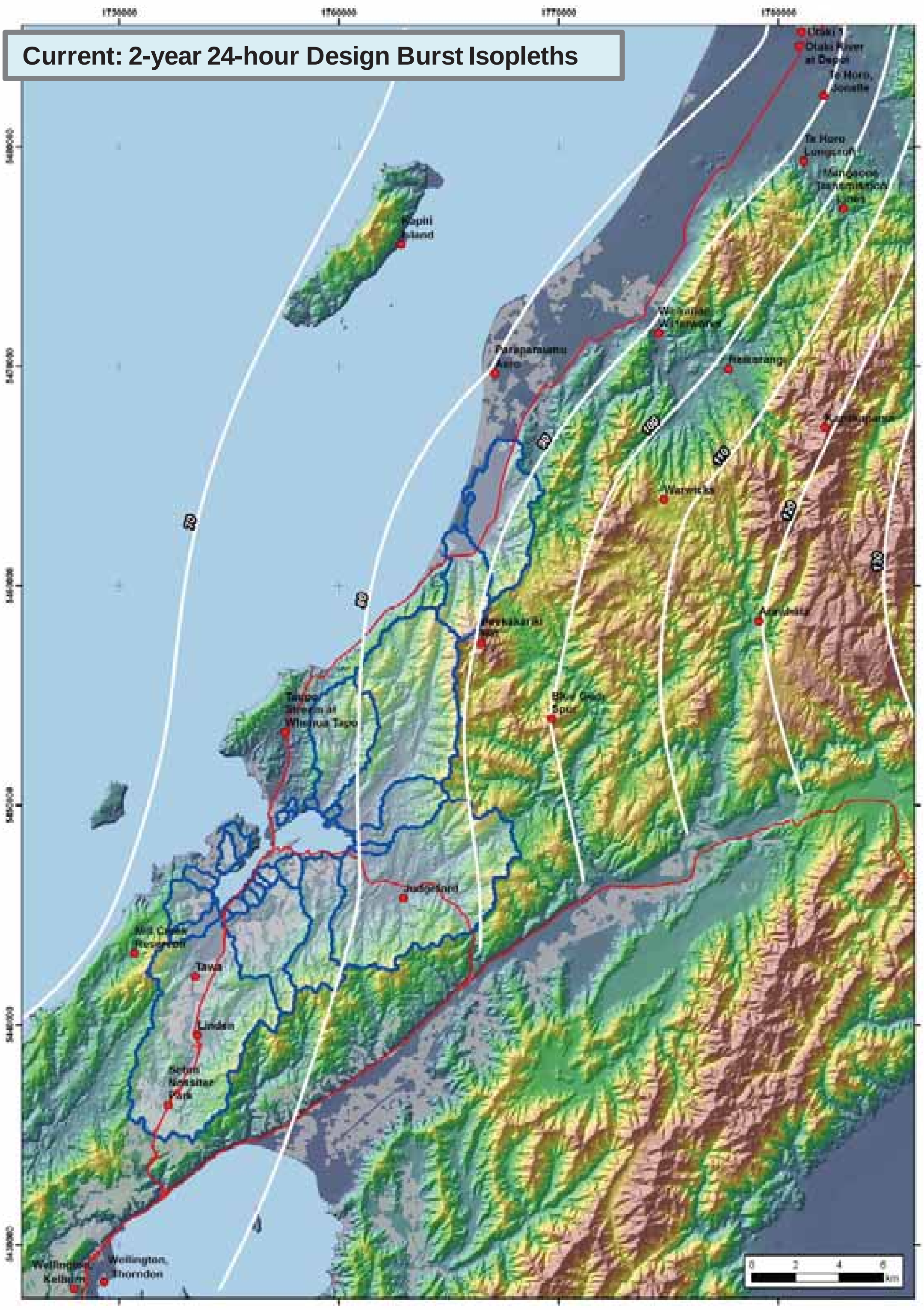
- **Table 19 - 24-Hour Storm Rainfall 2090 Time Horizon**

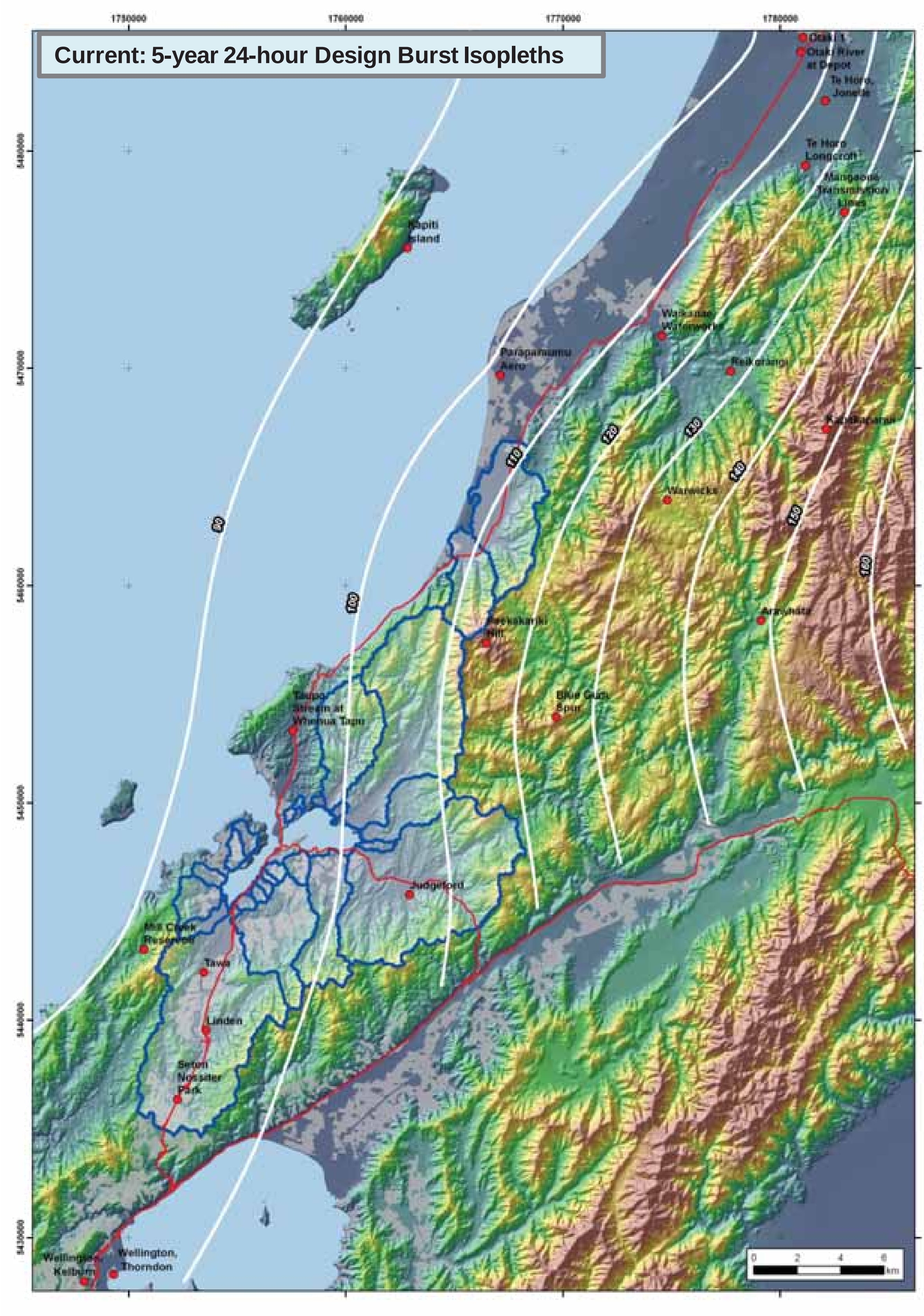
Site Name	24-hour Storm Rainfall (mm) for Average Recurrence Interval (years)					
	2	5	10	20	50	100
Northern Region						
Arawhata	141.8	180.5	208.4	238.0	279.3	310.9
Kapakapanui	129.2	164.4	189.9	216.8	254.4	283.2
Kapiti Island	81.2	103.4	119.4	136.3	160.0	178.1
Manakau	77.9	99.2	114.5	130.7	153.4	170.8
Mangaone	104.8	133.4	154.0	175.8	206.3	229.7
McIntosh	245.4	312.4	360.8	411.9	483.4	538.2
Mt Holdsworth	116.2	147.9	170.8	195.0	228.9	254.8
Oriwa	271.4	345.5	398.9	455.4	534.6	595.1
Otaki 1	62.8	80.0	92.3	105.4	123.7	137.7
Otaki Depot	67.9	86.4	99.8	113.9	133.7	148.8
Otaki Temuera	76.4	97.3	112.3	128.2	150.5	167.5
Paekakariki Hill	92.0	118.8	138.8	160.4	191.6	216.4

Site Name	24-hour Storm Rainfall (mm) for Average Recurrence Interval (years)					
	2	5	10	20	50	100
Paraparaumu Aero	71.9	91.6	105.7	120.7	141.7	157.7
Reikorangi	104.6	133.2	153.8	175.6	206.0	229.4
Te Horo Longcroft	85.5	108.9	125.7	143.5	168.4	187.5
Te Horo Jonelle	84.2	107.2	123.8	141.4	165.9	184.7
Taungata	163.8	208.5	240.8	274.9	322.6	359.2
Waikanae	84.9	108.0	124.8	142.4	167.2	186.1
Warwicks	146.1	186.0	214.8	245.2	287.8	320.4
Southern Region						
Blue Gum Spur	129.5	168.9	198.7	231.5	279.7	318.8
Judgeford	73.2	95.4	112.3	130.8	158.0	180.1
Linden	87.3	113.8	133.9	156.0	188.5	214.8
Makara	88.4	115.3	135.6	158.0	190.9	217.6
Mill Creek Reservoir	75.0	97.8	115.0	134.0	161.9	184.5
Paekakariki Hill	92.2	118.8	138.5	159.7	190.2	214.4
Whenua Tapu	69.6	90.7	106.8	124.4	150.3	171.3
Wellington, Thorndon	79.6	103.8	122.1	142.3	171.8	195.9
Seton Nossiter Park	71.3	93.0	109.4	127.4	153.9	175.5
Salamanca	80.9	105.5	124.2	144.7	174.8	199.2
Tawa	74.7	97.5	114.7	133.6	161.4	183.9

B.4 24-hour Design Burst Isopleths

B.4.1 Current (No Climate Change)

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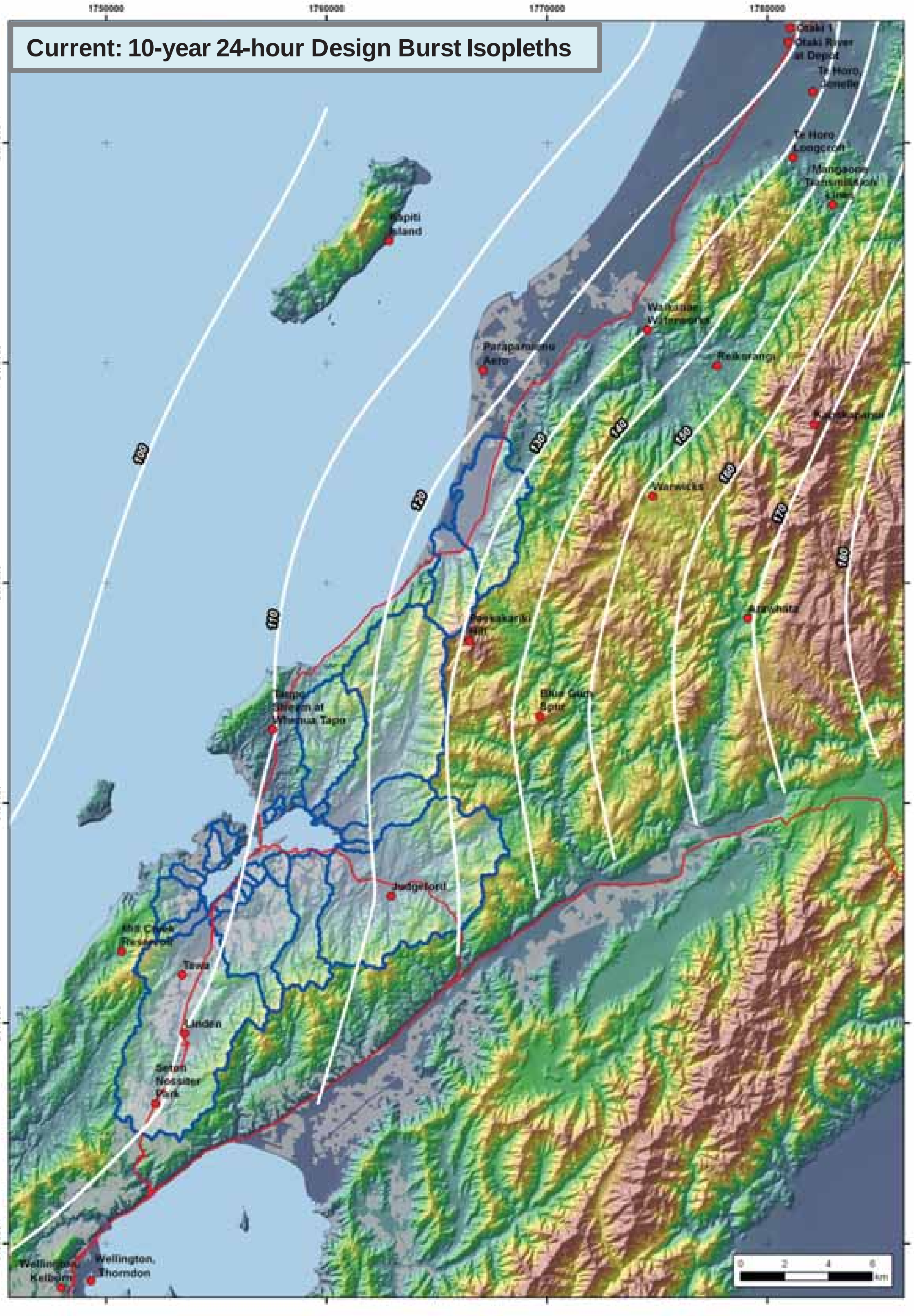
1750000
1760000
1770000
1780000
5480000
5470000
5460000
5450000
5440000
5430000
Otaki 1
Otaki River at Depot
Te Horo, Jonelle
Te Horo Longcroft
Mangaone Transmission Lines
Kapiti Island
Waikanae Waterworks
Paraparaumu Aero
Reikorangi
Kapakapanui
Warwicks
Arayhata
Pauatahanui Hill
Blue Gum Spur
Taupo Stream at Whenua Tapu
Judgeford
Mill Creek Reservoir
Tawa
Linden
Seton Nossiter Park
Wellington, Kelburn
Wellington, Thorndon
80
100
110
120
130
140
150
160
0
2
4
6
km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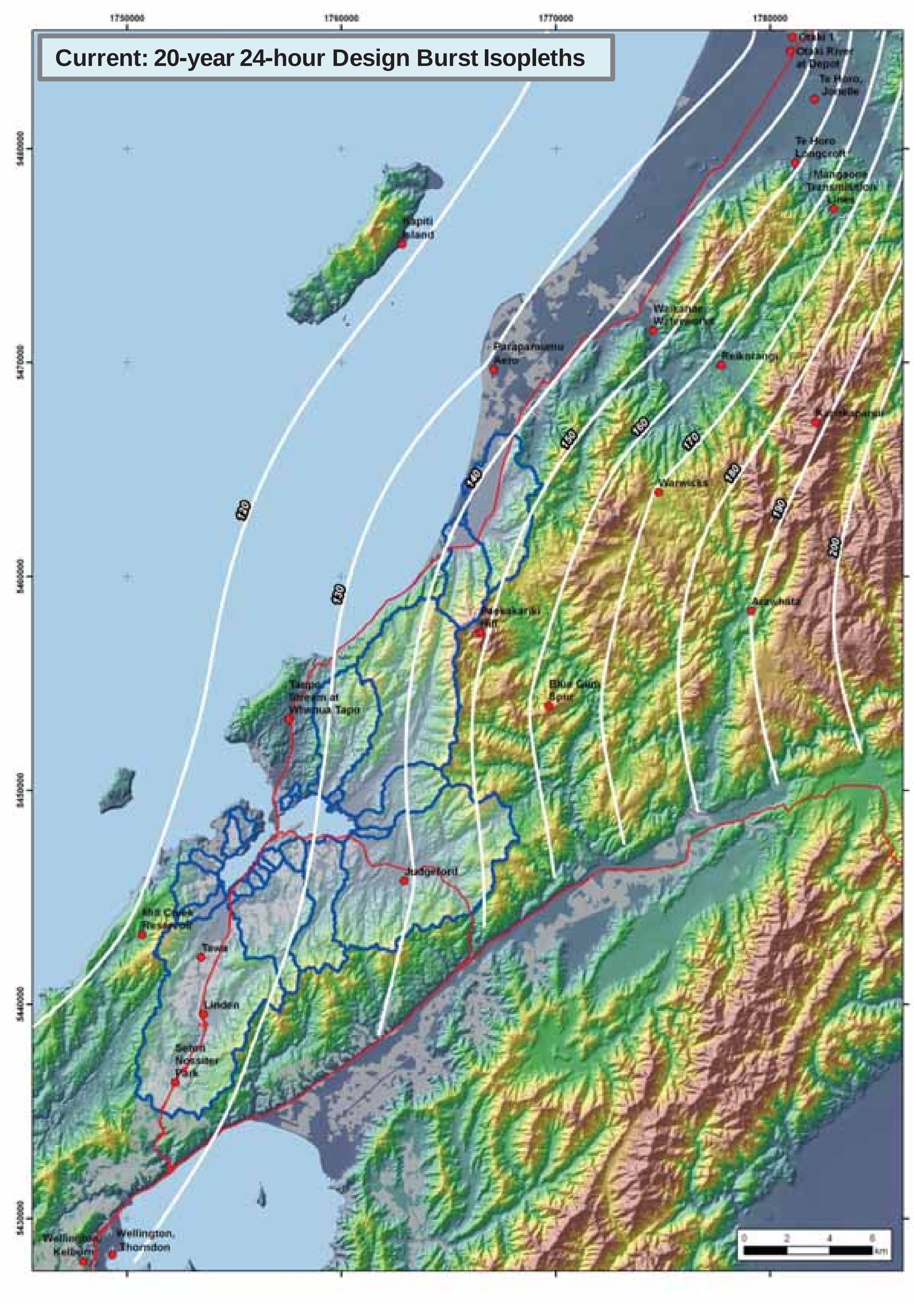
1750000
1760000
1770000
1780000
5480000
5470000
5460000
5450000
5440000
5430000
Otaki 1
Otaki River at Depot
Te Horo, Jonelle
Te Horo Longcroft
Mangaone Transmission Lines
Kapiti Island
Waikanae Water
Paraparaumu Aero
Reikorangi
Warwicks
Paekakariki Hill
Blue Gum Spur
Judgeford
Mill Creek Reservoir
Tawa
Linden
Seton Nossiter Park
Wellington, Kelburn
Wellington, Thorndon
0 2 4 6 km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Te Horo, Janelle
Te Horo Longcroft
Mangaone Transmission Lines
Kapiti Island
Waikanae Waterworks
Paraparaumu Aero
Reikorangi
Warwicks
Paekakariki Hill
Blue Gum Spur
Taupo Stream at Whenua Tapu
Judgeford
Mill Creek Reservoir
Tawa
Linden
Seton Nossiter Park
Wellington, Kelburn
Wellington, Thomdon
120
130
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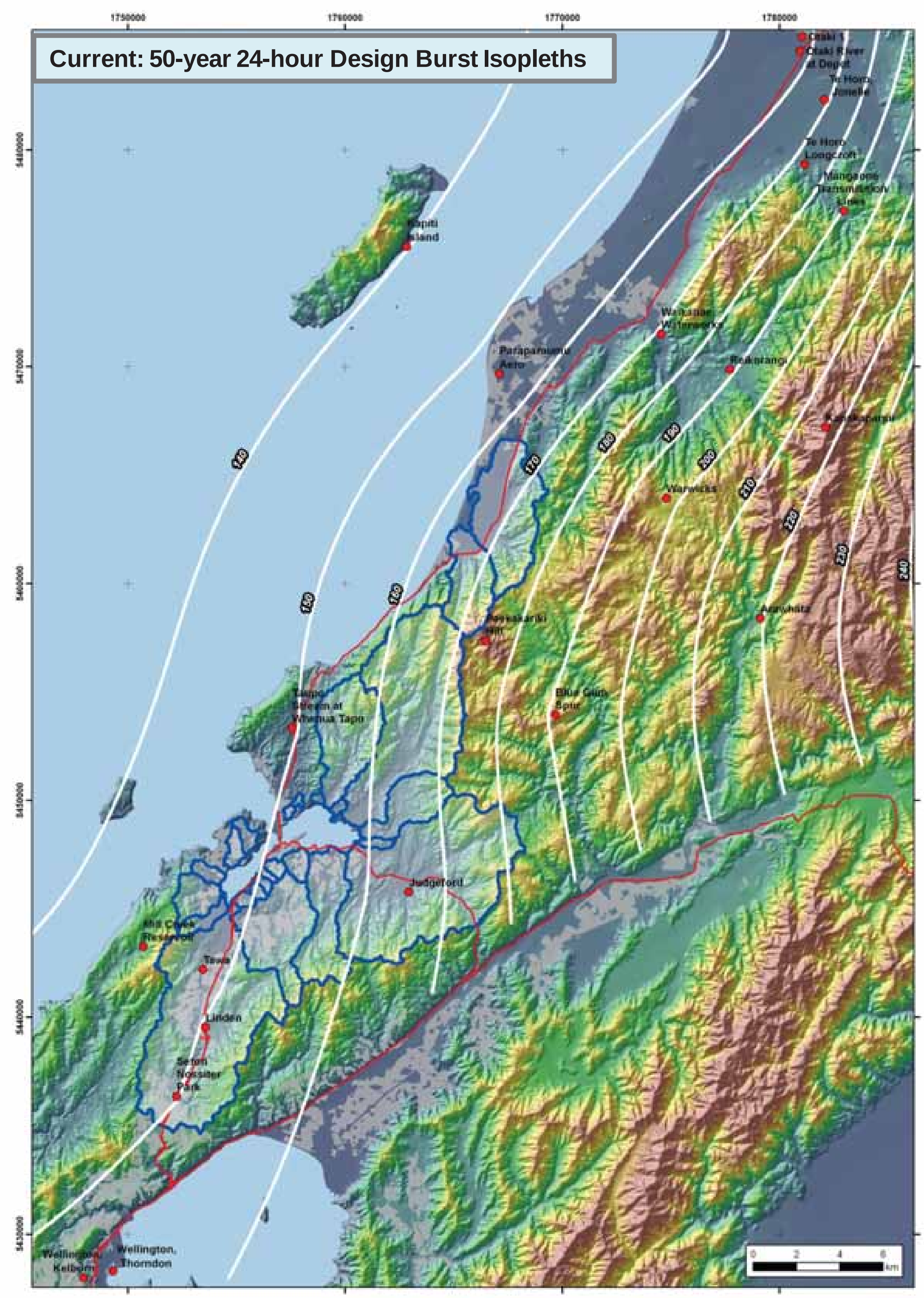
170
180
190
200
km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1770000
1780000
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Te Horo, Jonelle
Te Horo Longcroft
Mangaone Transmission Lines
Kapiti Island
Waikanae Waterworks
Paraparaumu Aero
Reikorangi
Kaitoke
Warwicks
Blue Gum Spur
Judgeford
Mill Creek Reservoir
Tawa
Linden
Seton Nossiter Park
Wellington, Kelburn
Wellington, Thorndon
140
150
160
170
180
190
200
210
220
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0
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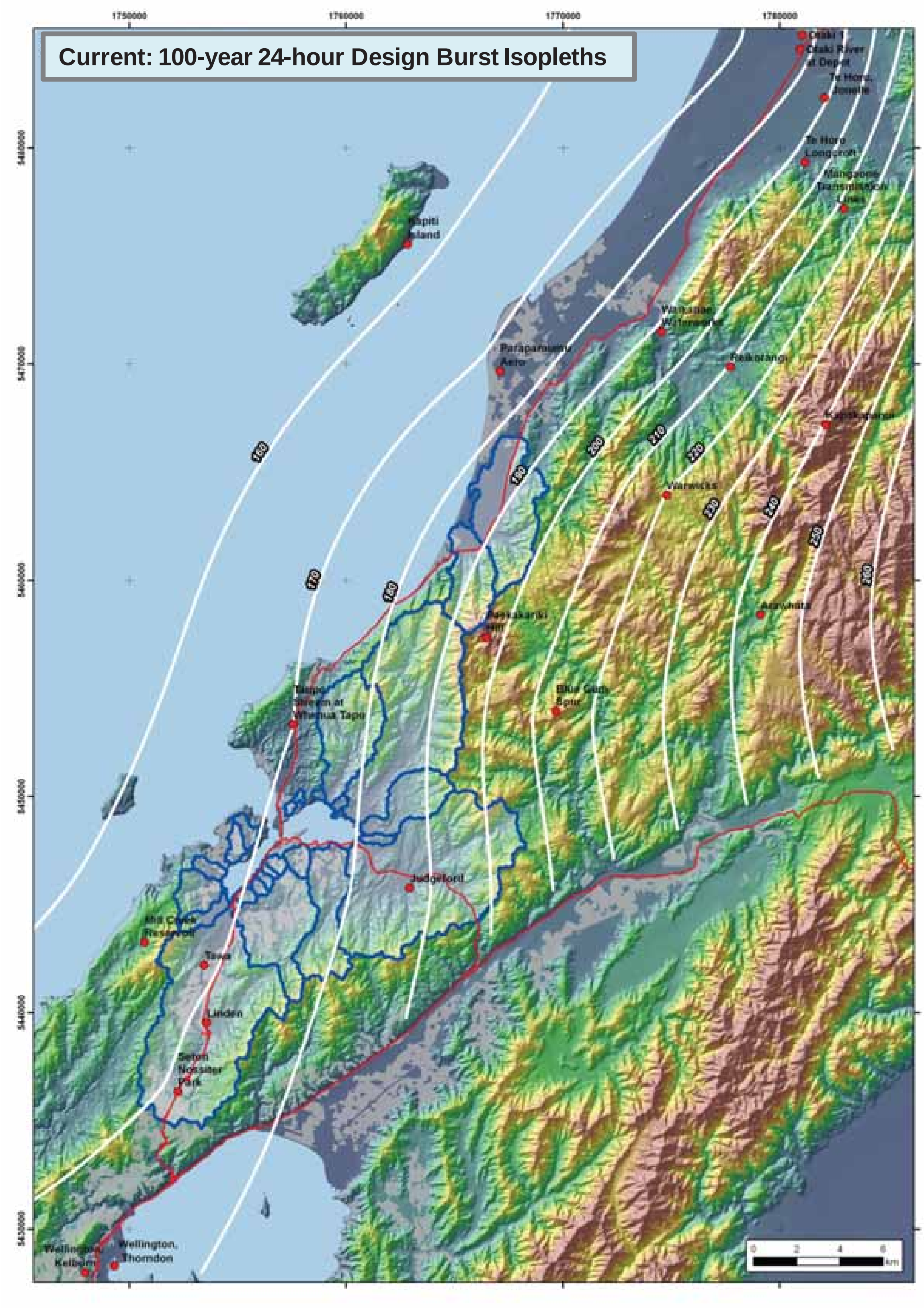
km


Current: 100-year 24-hour Design Burst Isopleths
1750000
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Kapiti Island
Paraparaumu Aero
Waikanae Waterworks
Reikorangi
Warwicks
Blue Gum Spur
Judgeford
Mill Creek Reservoir
Tawa
Linden
Wellington, Thorndon
160
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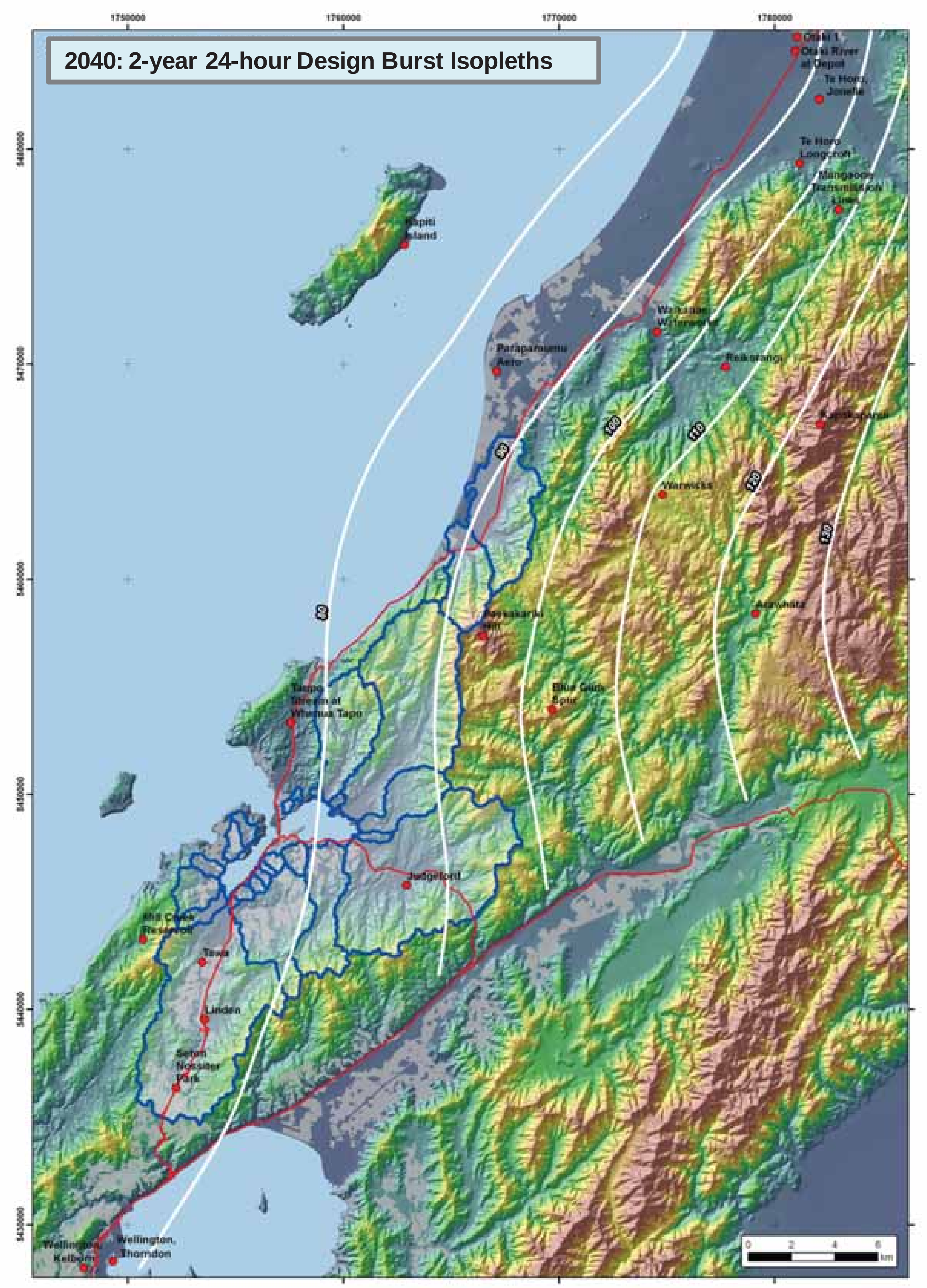
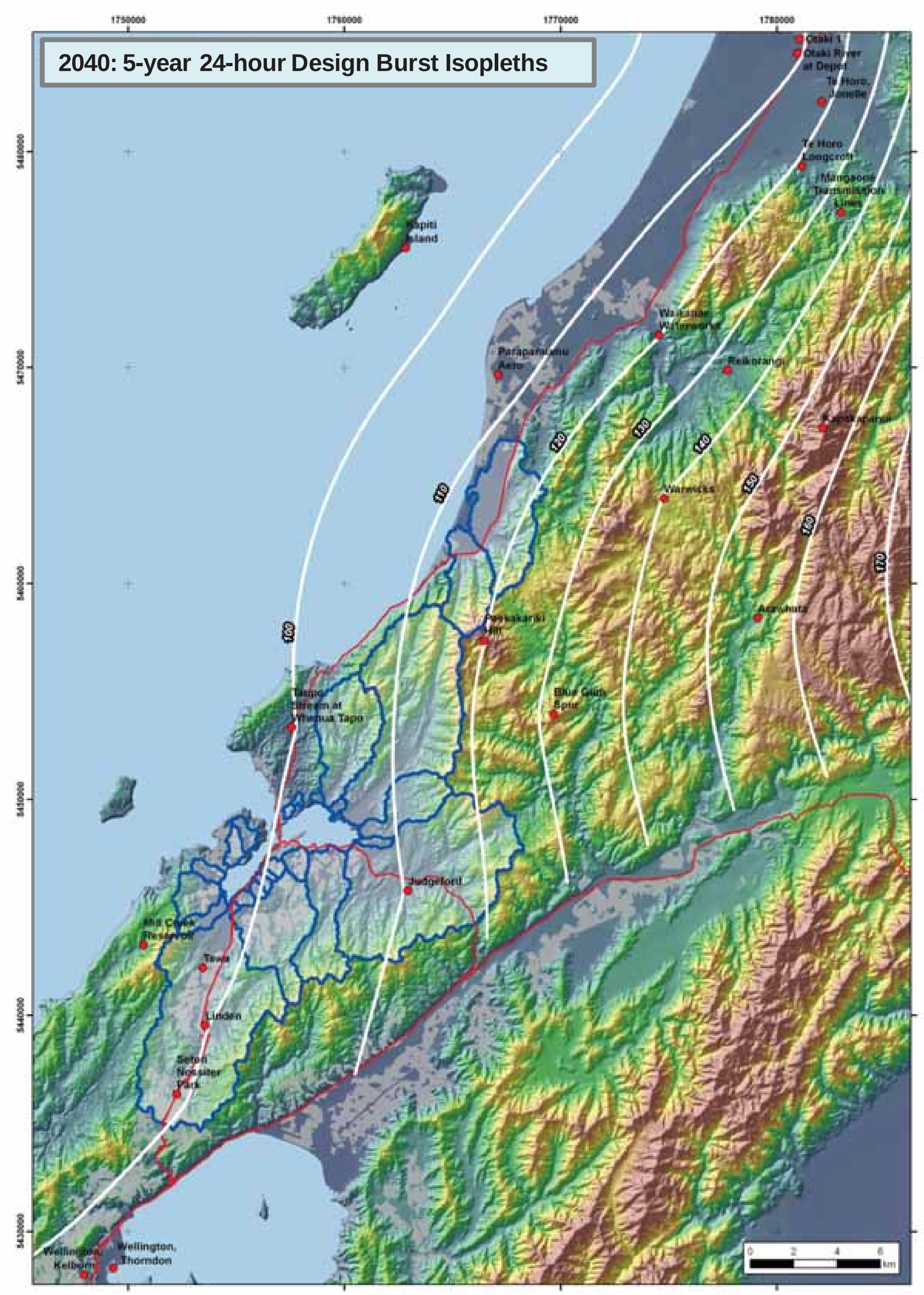
km

B.4.2 Projected 2040 Climate Change

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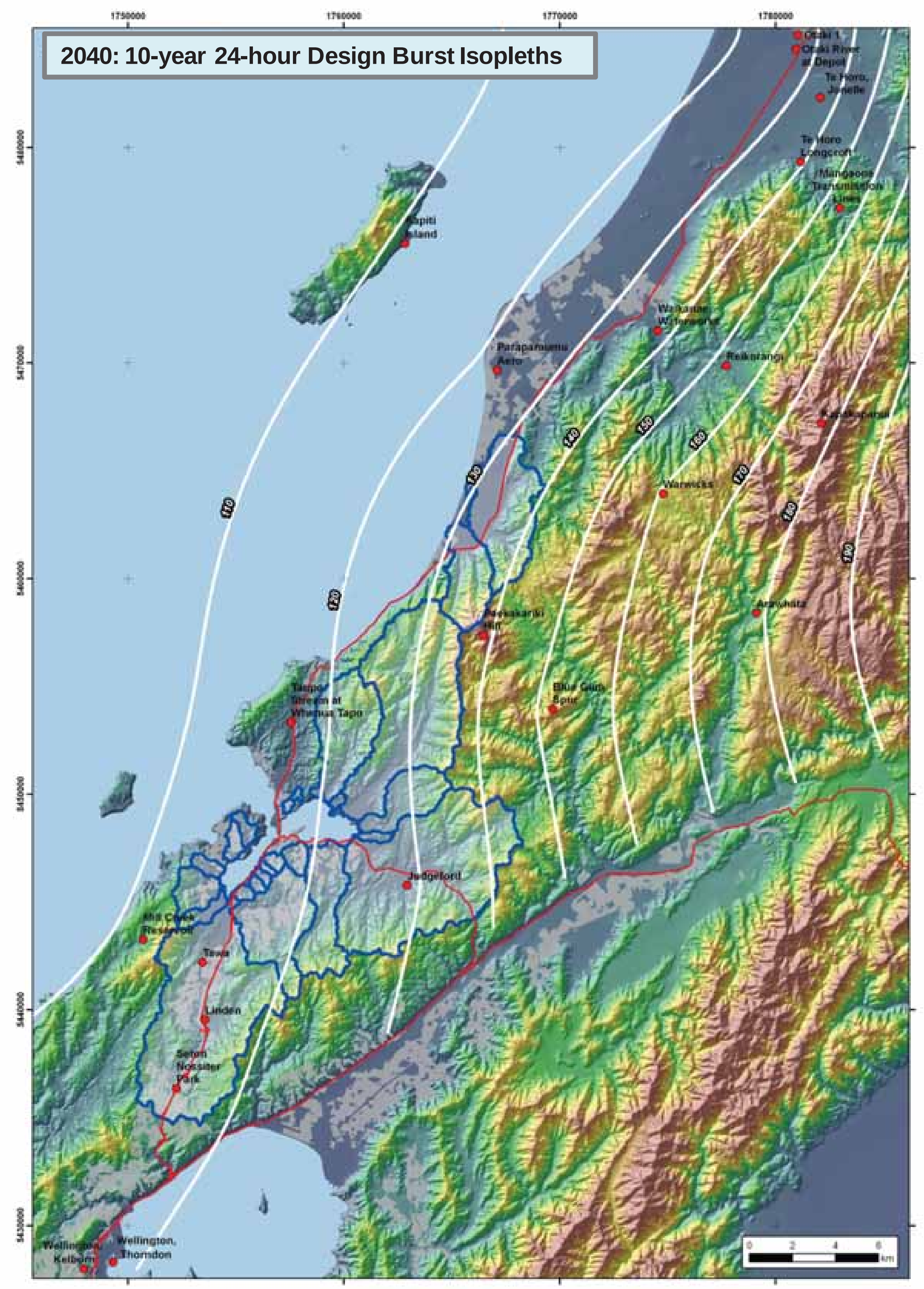
Reikorangi
Warwicks
Paekakariki Hill
Judgeford
Tawa
Linden
Wellington, Thorndon


2040: 10-year 24-hour Design Burst Isopleths
1750000
1760000
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Otaki 1
Otaki River at Depot
Te Horo, Janelle
Te Horo Longcroft
Mangaone Transmission Lines
Kapiti Island
Paraparaumu Aero
Waikanae Waterworks
Reikorangi
Kaitkaparua
Warwicks
Pauatahanui
Paekakariki Hill
Blue Gum Spur
Taupo Stream at Whenua Tapu
Judgeford
Mill Creek Reservoir
Tawa
Linden
Seton Nossiter Park
Wellington, Kelburn
Wellington, Thorndon
110
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170
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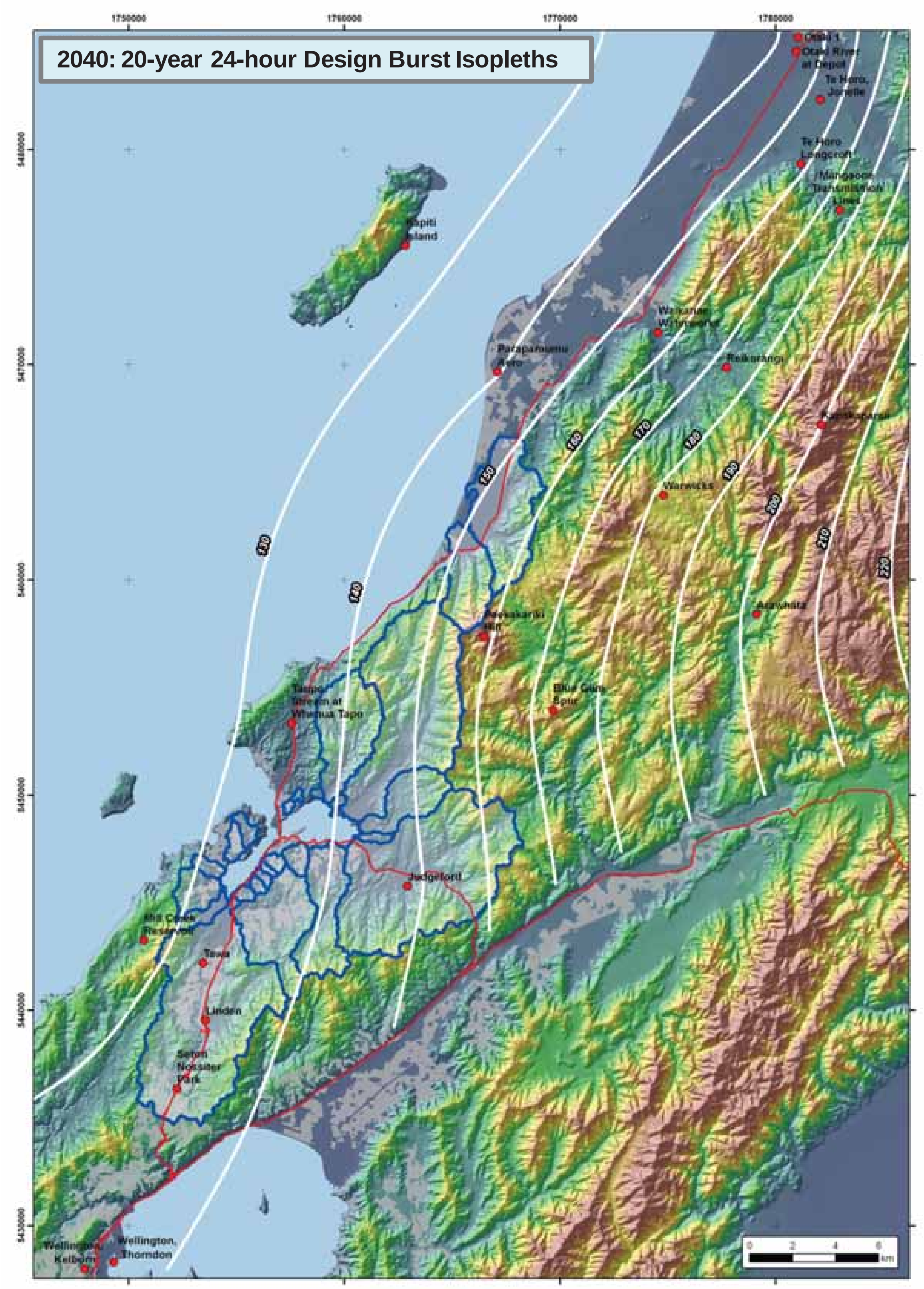
km


2040: 20-year 24-hour Design Burst Isopleths
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Kapiti Island
Paraparaumu Aero
Waikanae Waterworks
Reikorangi
Warwicks
Judgeford
Tawa
Linden
Seton Nossiter Park
Wellington, Thorndon
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Akatarawa
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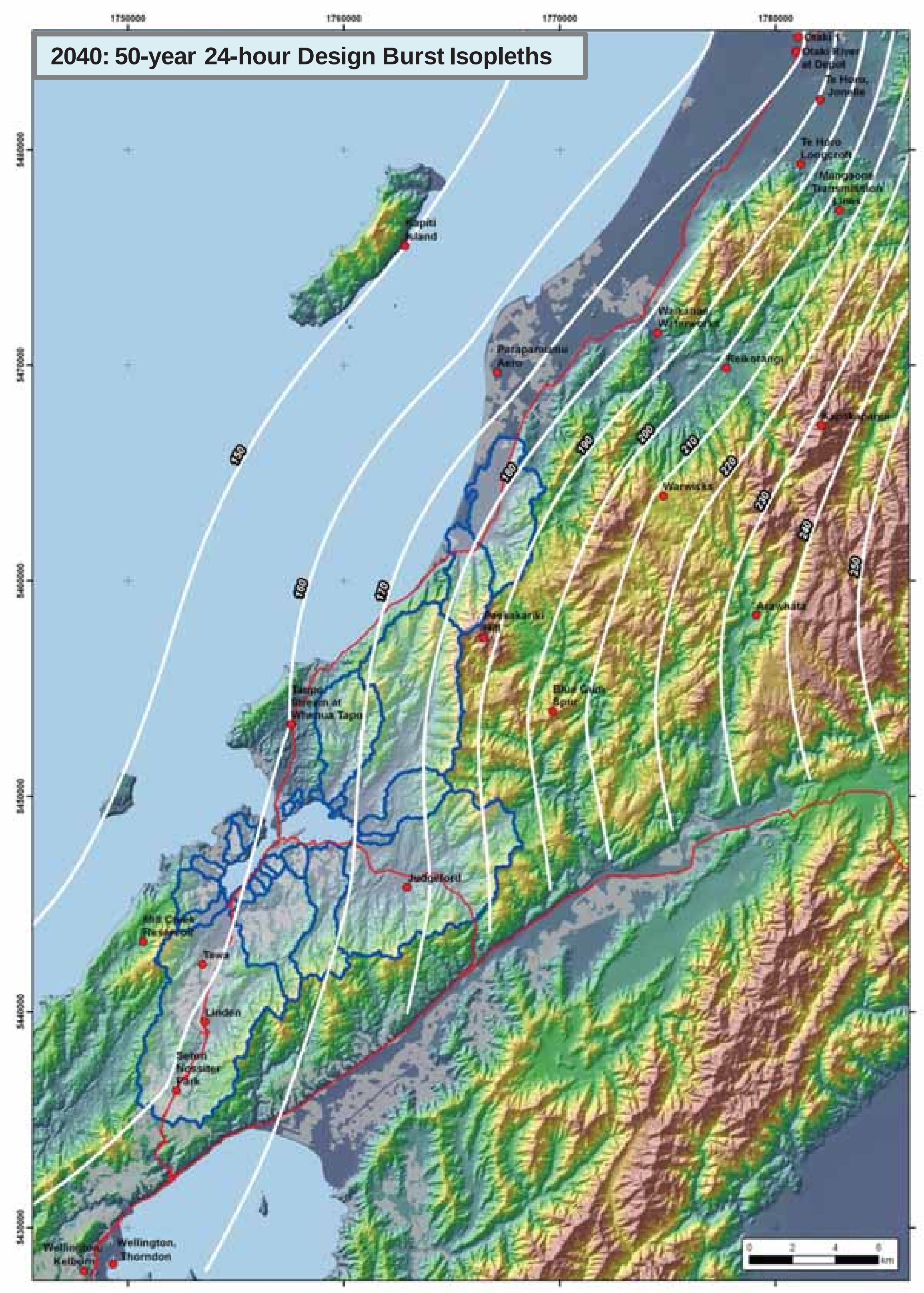
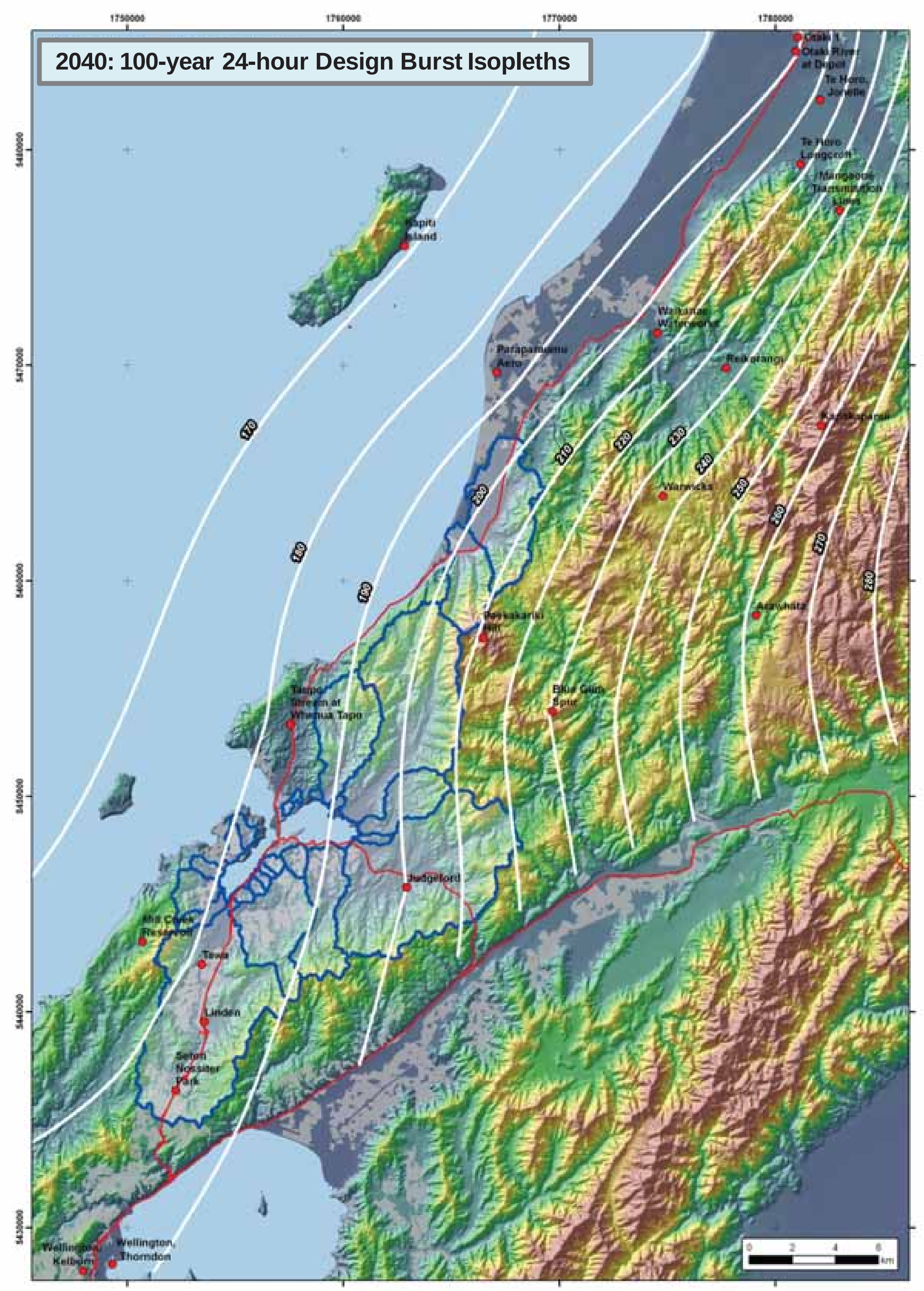
km


2040: 50-year 24-hour Design Burst Isopleths


2040: 100-year 24-hour Design Burst Isopleths
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Otaki River at Depot
Te Horo, Jonette
Te Horo Longcroft
Mangaone Transmission Lines
Kapiti Island
Waikanae Waterworks
Paraparaumu Aero
Reikorangi
Kapakapanui
Warwicks
Akatarawa
Paekakariki Hill
Blue Gum Spur
Taupo Stream at Whenua Tapu
Judgeford
Mill Creek Reservoir
Tawa
Linden
Seton Nossiter Park
Wellington, Kelburn
Wellington, Thorndon
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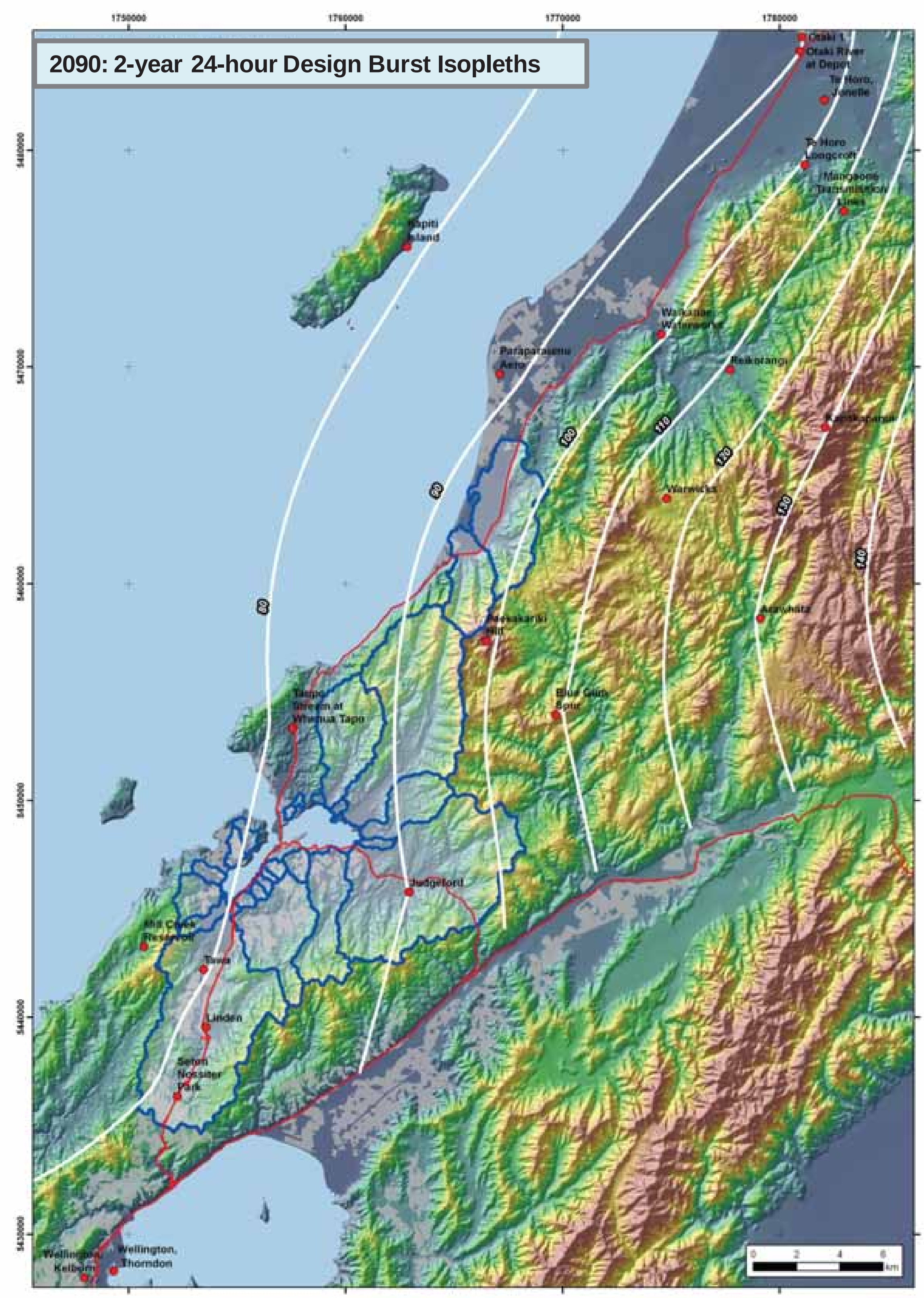
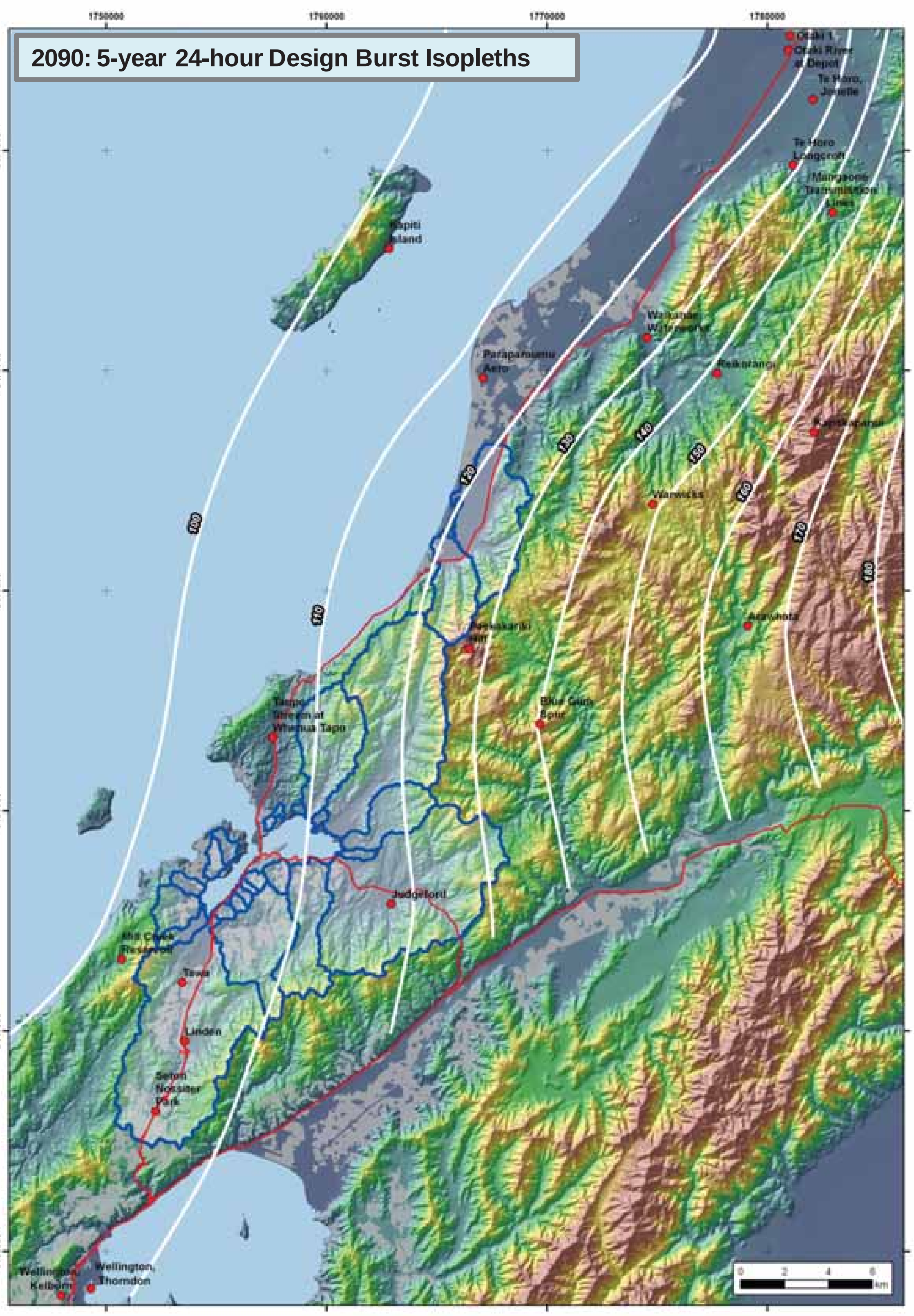
B.4.3 Projected 2090 Climate Change




2090: 5-year 24-hour Design Burst Isopleths
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Otaki River at Depot
Te Horo, Jonelle
Te Horo Longcroft
Mangaone Transmission Lines
Kapiti Island
Waikanae Waterworks
Paraparaumu Aero
Reikorangi
Kapakapanui
Warwicks
Akatarawa Hill
Blue Gum Spur
Taupo Stream at Whenua Tapu
Judgeford
Mill Creek Reservoir
Tawa
Linden
Seton Nossiter Park
Wellington, Kelburn
Wellington, Thorndon
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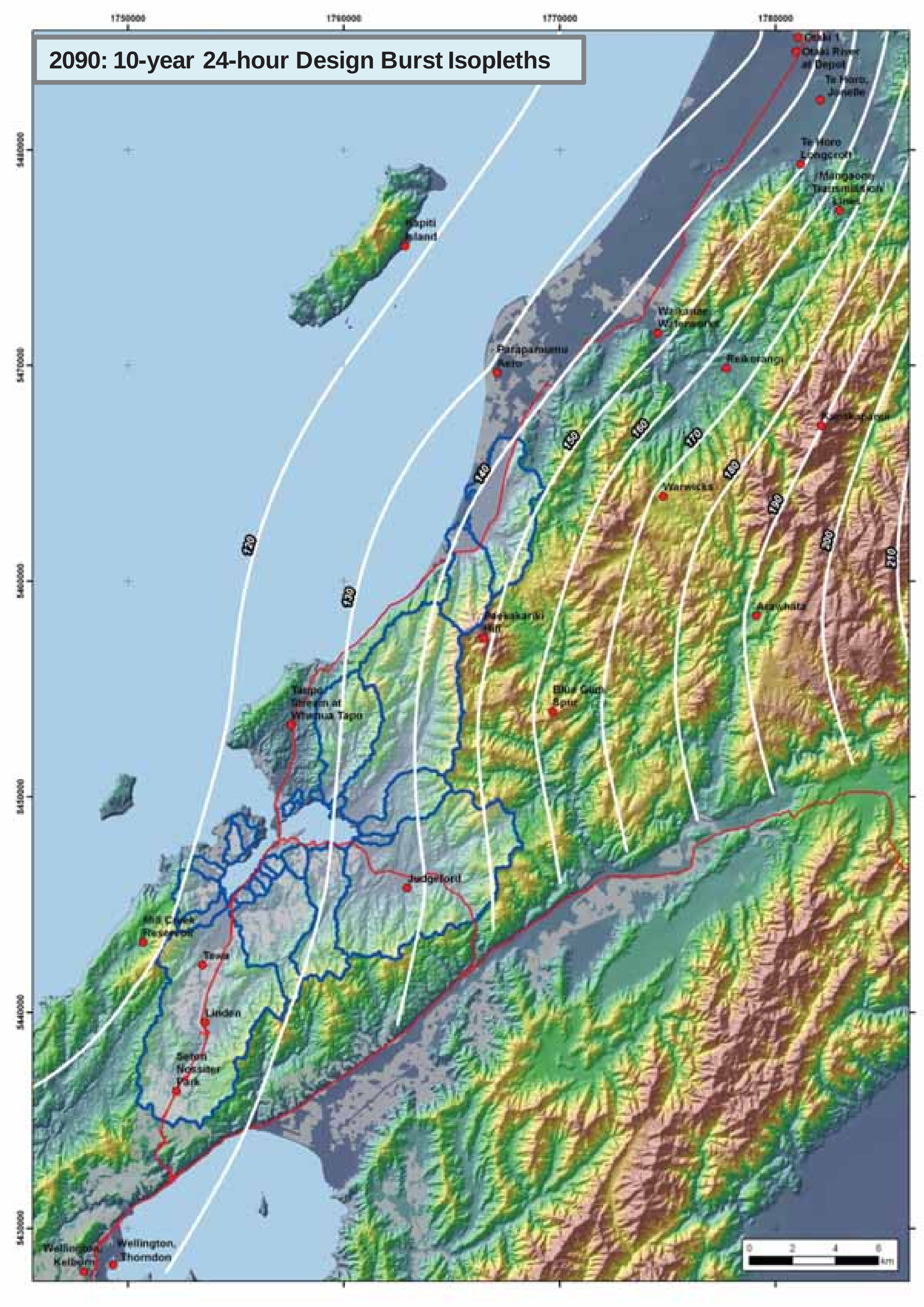
km


2090: 10-year 24-hour Design Burst Isopleths
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Otaki 1
Otaki River at Depot
Te Horo, Janelle
Te Horo Longcroft
Mangaone Transmission Lines
Kapiti Island
Waikanae Waterworks
Paraparaumu Aero
Reikorangi
Warwicks
Paekakariki Hill
Akatarawa
Blue Gum Spur
Taupo Stream at Whenua Tapu
Judgeford
Tawa
Linden
Seton Nossiter Park
Wellington, Kelburn
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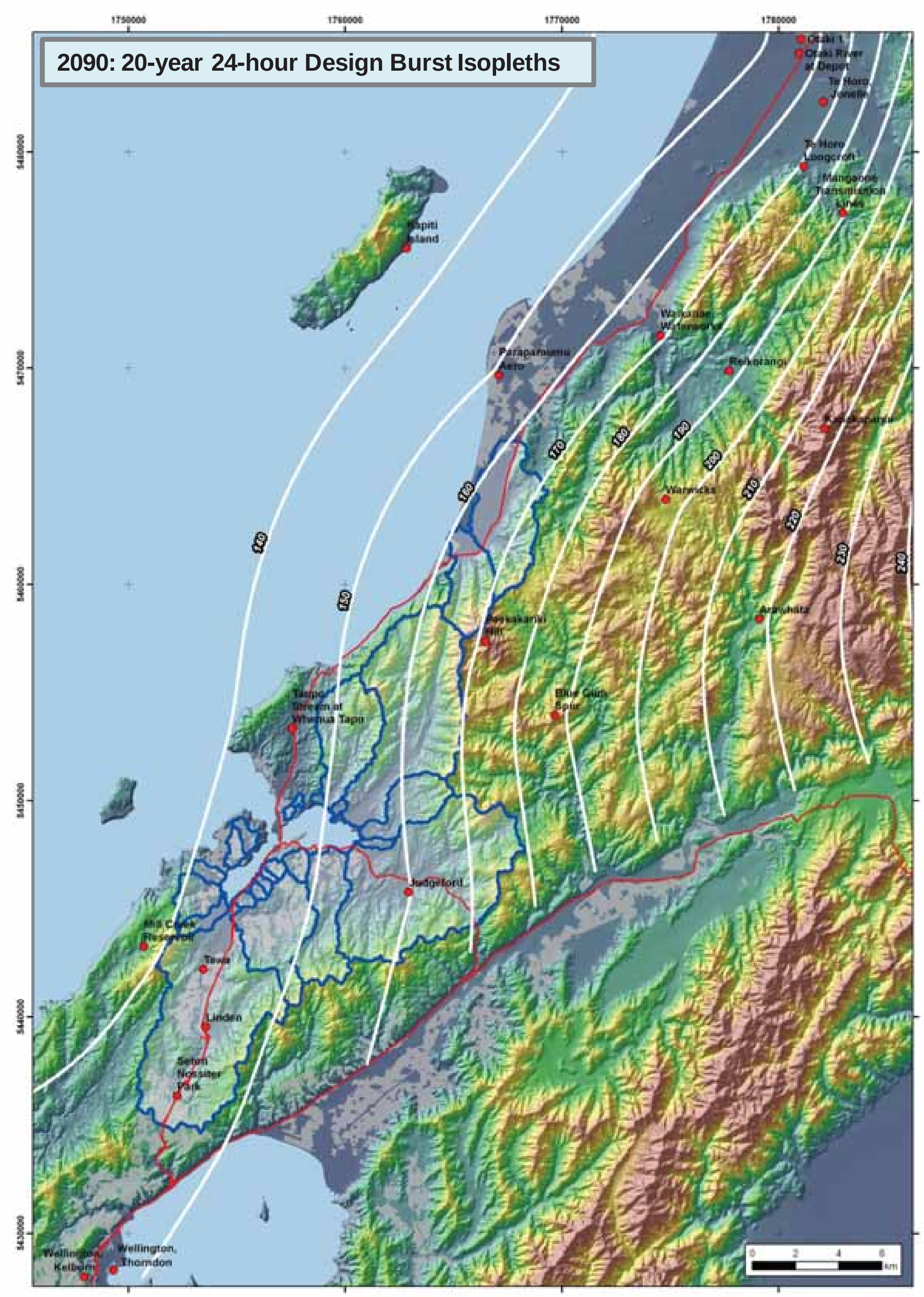
2090: 20-year 24-hour Design Burst Isopleths
1750000
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Otaki River at Depot
Te Horo Jonelle
Te Horo Longcroft
Mangaone Transmission Lines
Kapiti Island
Waikanae Waterworks
Paraparaumu Aero
Reikorangi
Kaitakaparaki
Warwicks
Pauatahanui Hill
Blue Gum Spur
Taupo Stream at Whenua Tapu
Judgeford
Mill Creek Reservoir
Tawa
Linden
Seton Nossiter Park
Wellington Kelburn
Wellington Thorndon
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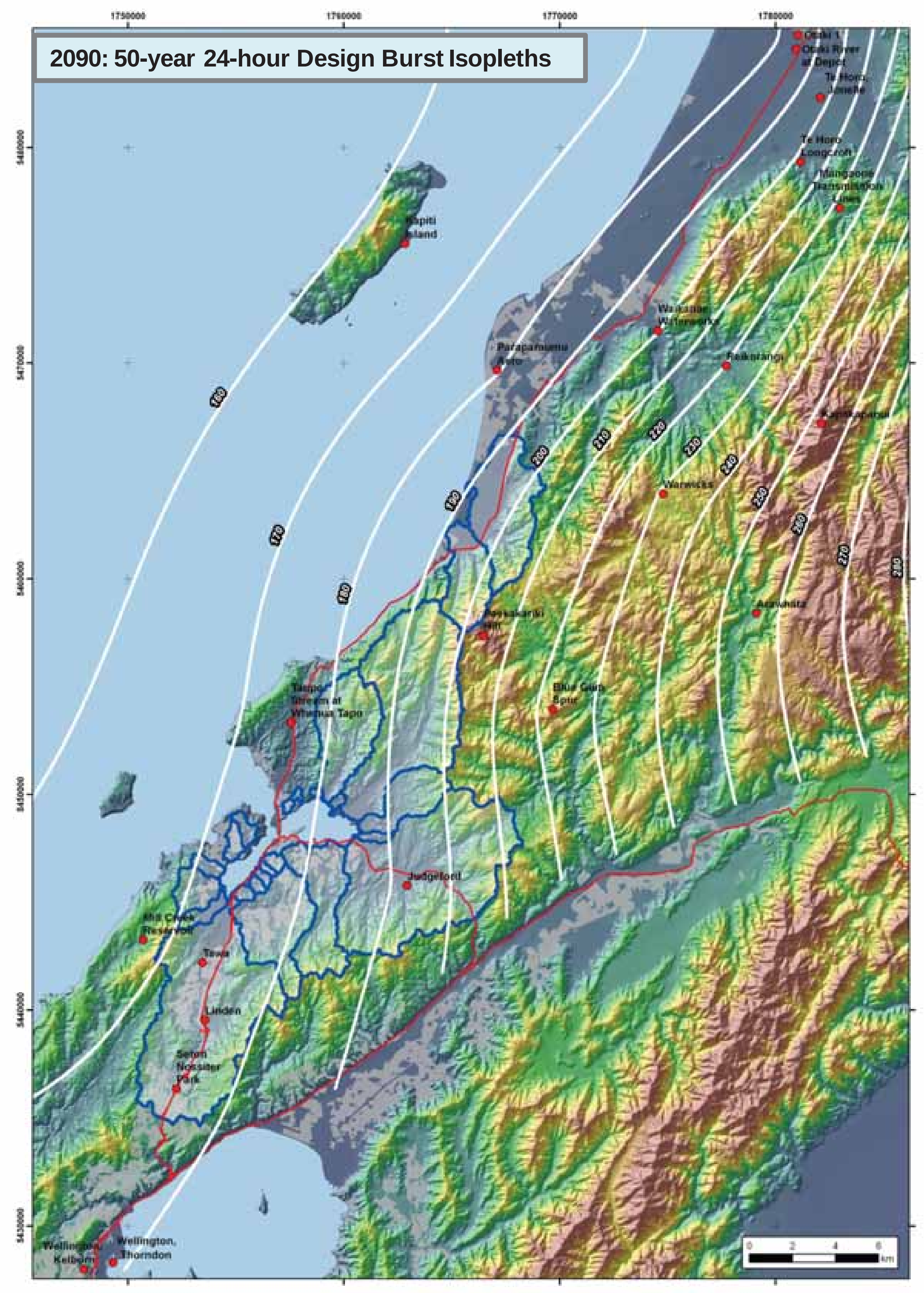
2090: 50-year 24-hour Design Burst Isopleths
1750000
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Kapiti Island
Paraparaumu Aero
Waikanae Waterworks
Paekakariki Hill
Blue Gum Spur
Judgeford
Taupo Stream at Whenua Tapu
Mill Creek Reservoir
Tawa
Linden
Seton Nossiter Park
Warwicks
Wellington, Thorndon
Te Horo, Longcroft
Mangaone Transmission Lines
Otaki River at Depot
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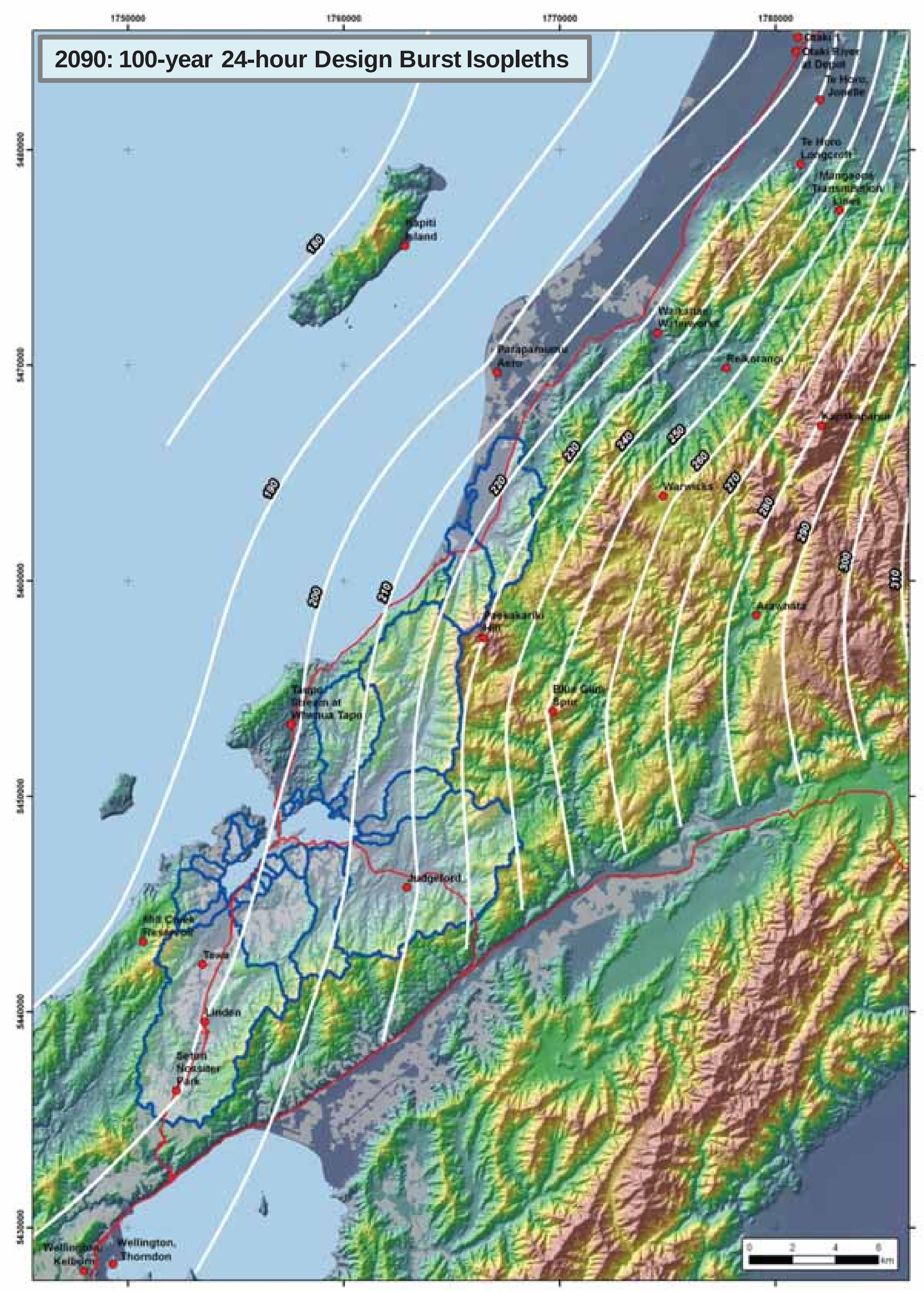
2090: 100-year 24-hour Design Burst Isopleths
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Otaki River at Depot
Te Horo, Jonette
Te Horo Longcroft
Mangaone Transmission Lines
Kapiti Island
Waikanae Waterworks
Paraparaumu Aero
Reikorangi
Warwicks
Paekakariki Hill
Blue Gum Spur
Judgeford
Mill Creek Reservoir
Tawa
Linden
Seton Nossiter Park
Wellington, Kelburn
Wellington, Thorndon
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300
310
0 2 4 6 km

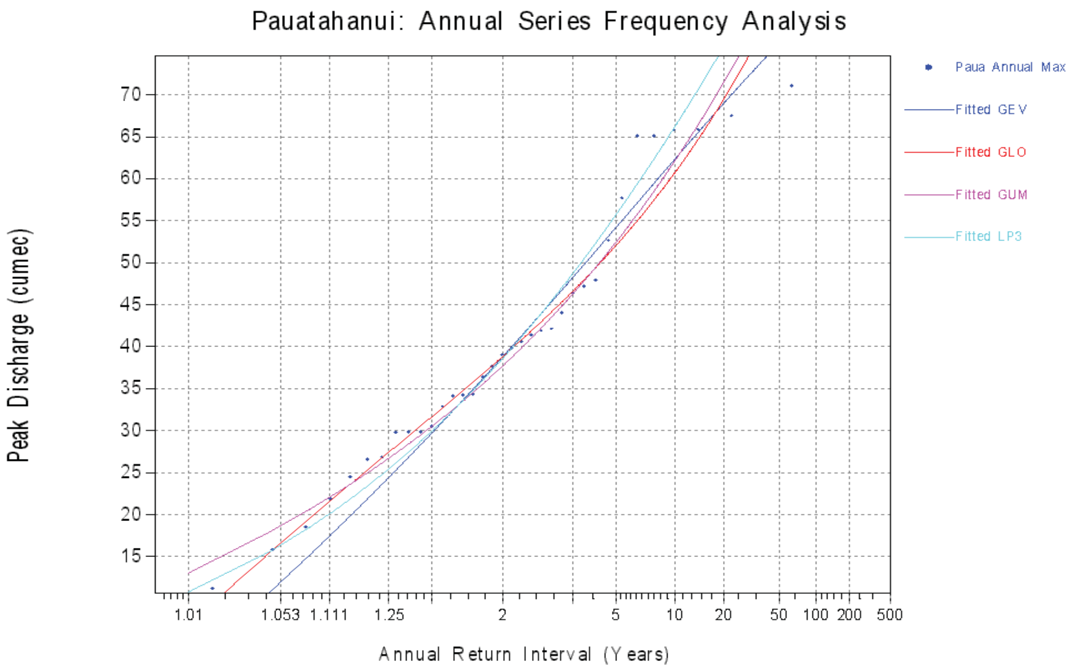
Appendix 14.C. Flood Frequency Analysis

This Appendix describes the methodology for flood frequency analysis.

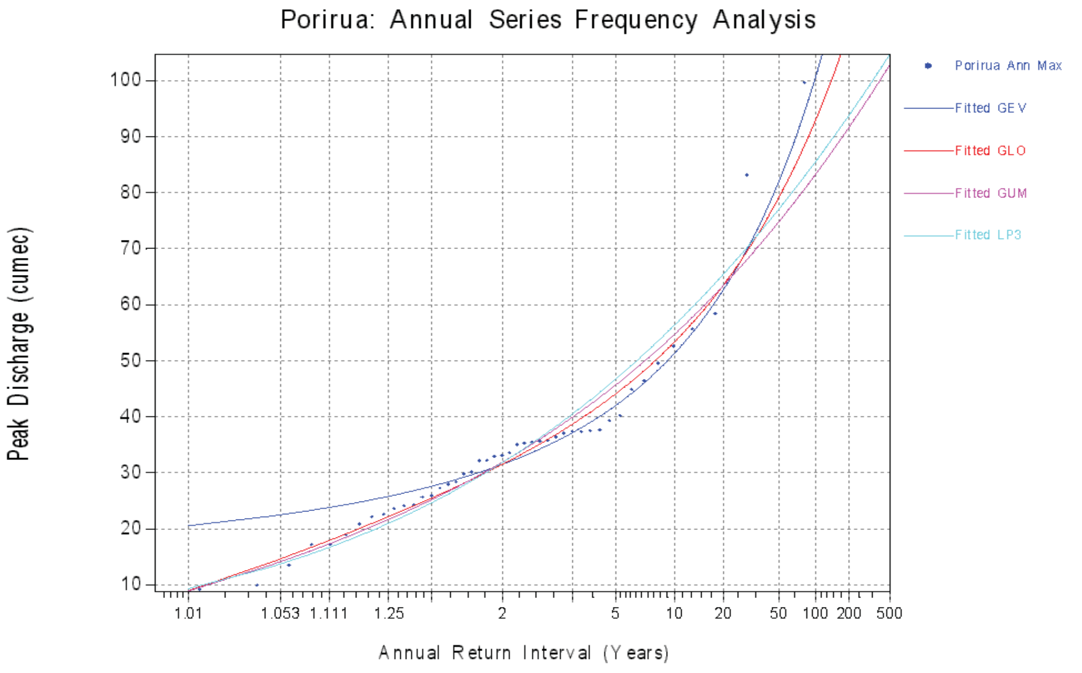
The GetDat software was used to carry out flood frequency analysis on the annual peak flow data for the three streamflow gauges.

Plots showing the General Extreme Value (GEV), General Logistic (GLO), Gumbel (GUM) and Log-Pearson 3 (LP3) distributions together with the input data are presented in **Figure 46** to **Figure 48** for the Pauatahanui, Porirua and Horokiri respectively.

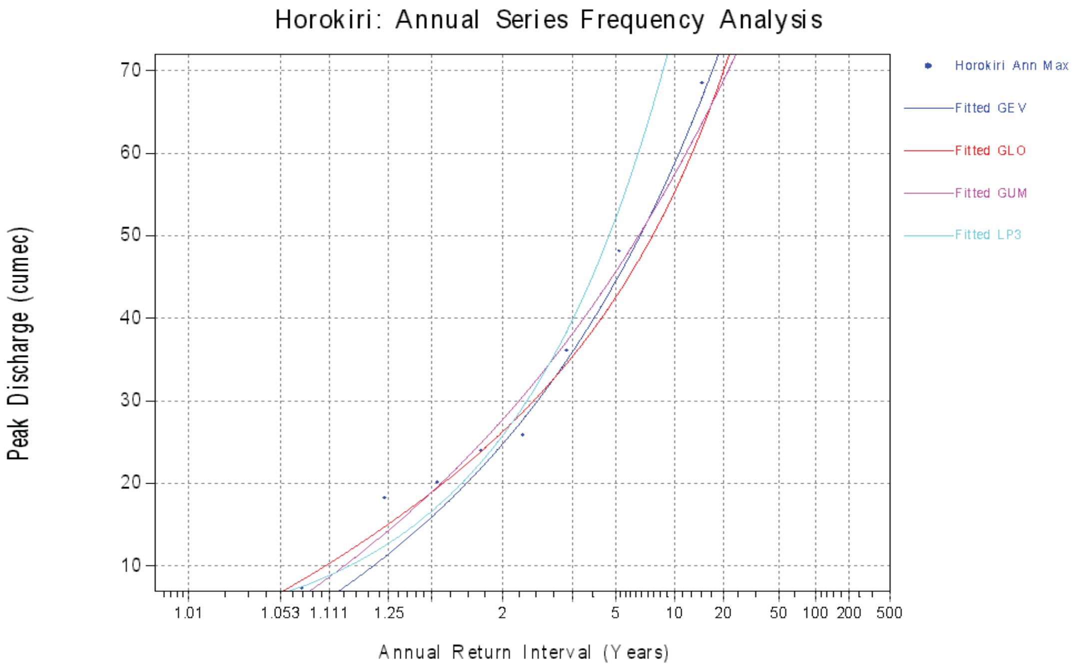
Based on inspection of the plots the GLO distribution was selected for each of the data sets as most representative of the flood distribution. The flood peaks for the three catchments, based on the GLO distribution are listed in **Table 1.**



- **Figure 46 - Pauatahanui Flood Distributions**



- **Figure 47 - Porirua Flood Distributions**



- **Figure 48 - Horokiri Flood Distributions**

- **Table 1 - Summary of ARI floods (Generalised Logistic Distribution)**

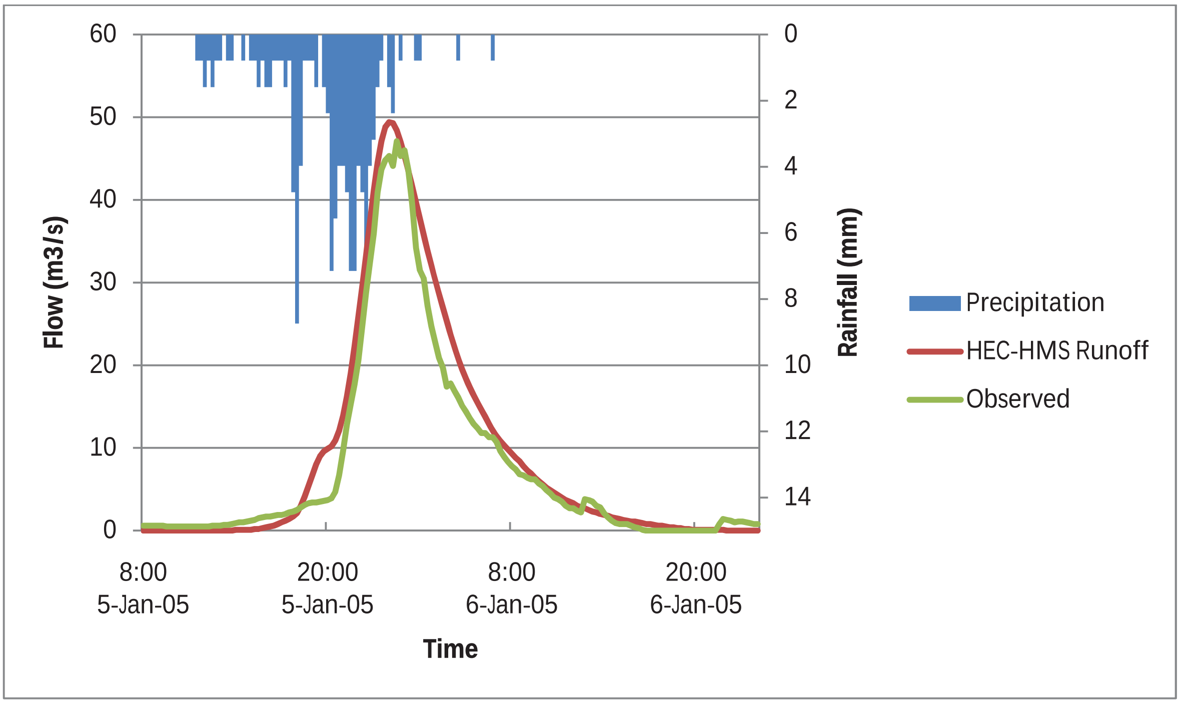
ARI (Years)	Peak Discharge (m^3/s)		
	Horokiri	Pauatahanui	Porirua
2	26	39	32
5	43	52	44
10	55	61	53
15	64	66	59
20	70	70	64
25	75	72	67
30	80	75	70
50	94	82	79
75	106	88	87
100	116	92	93
200	142	102	109

Appendix 14.D. Calibration Results

D.1 Horokiri Catchment

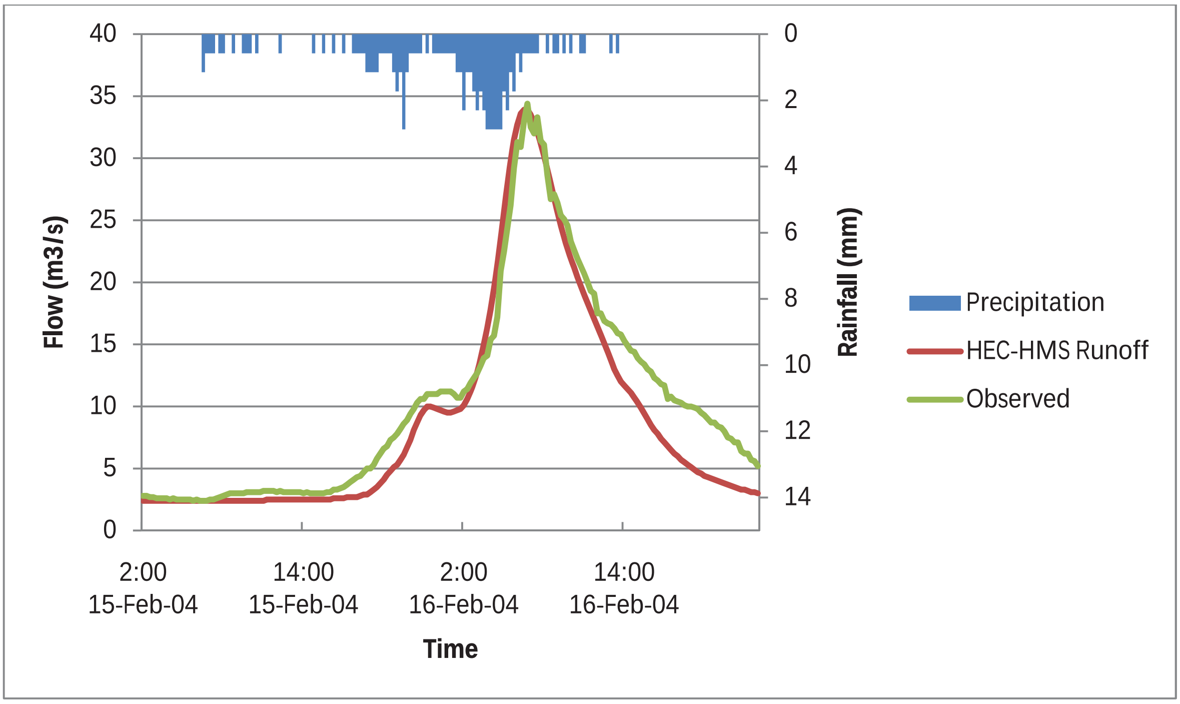
When calibrating the HEC-HMS runoff flows with the observed flows it was found that two parameters required adjustment; SCS Curve Number (CN) and Ratio. The following parameters were determined from the three calibration events:

Event	Ia (mm)	CN	CIA (%)	Tc (hrs)	R	ST (Hrs)
Calibration A	5	60	0	2	0.65	3.7
Calibration B	5	78	0	2	0.65	3.7
Calibration C	20	80	0	2	0.60	3.0



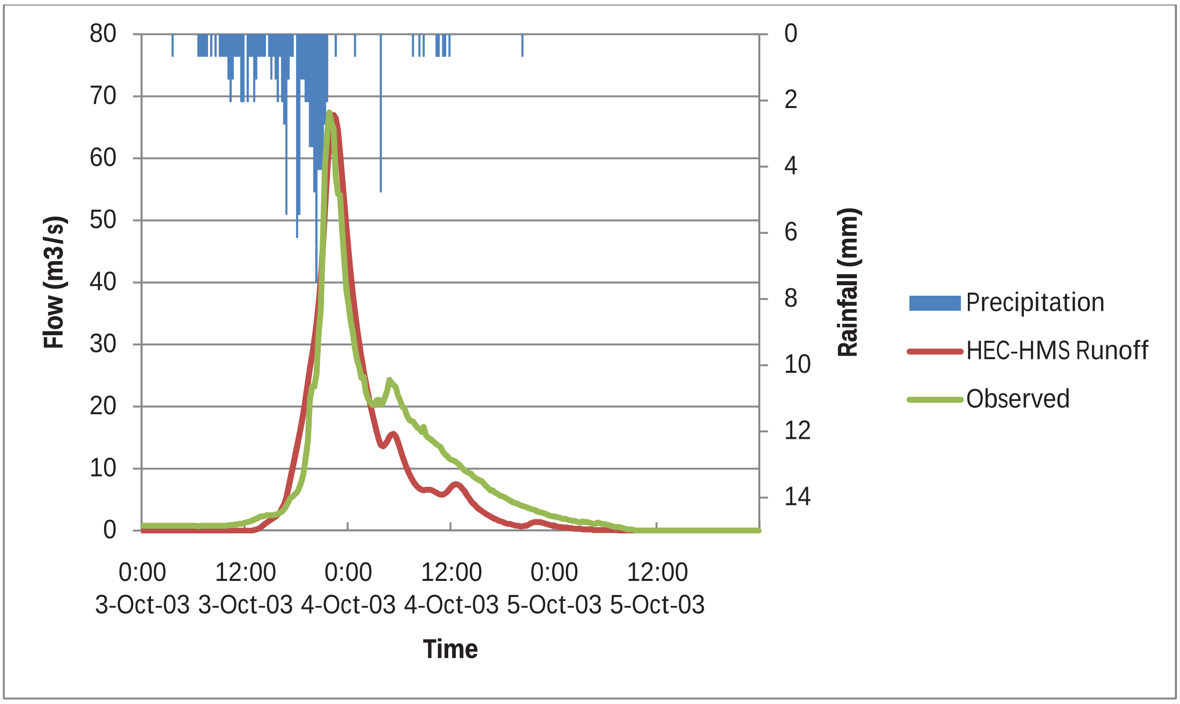
- **Figure 49 - Calibration A**

Calibration A provides a good fit for peak, total volume and hydrograph shape.



- **Figure 50 - Calibration B**

Calibration B provides a good fit for peak and a reasonably good fit for total volume and shape. It can be seen that the simulation slightly underestimates both the rising and receding limb of the hydrograph. This is possibly due to the significant baseflow component which is not being directly modelled.



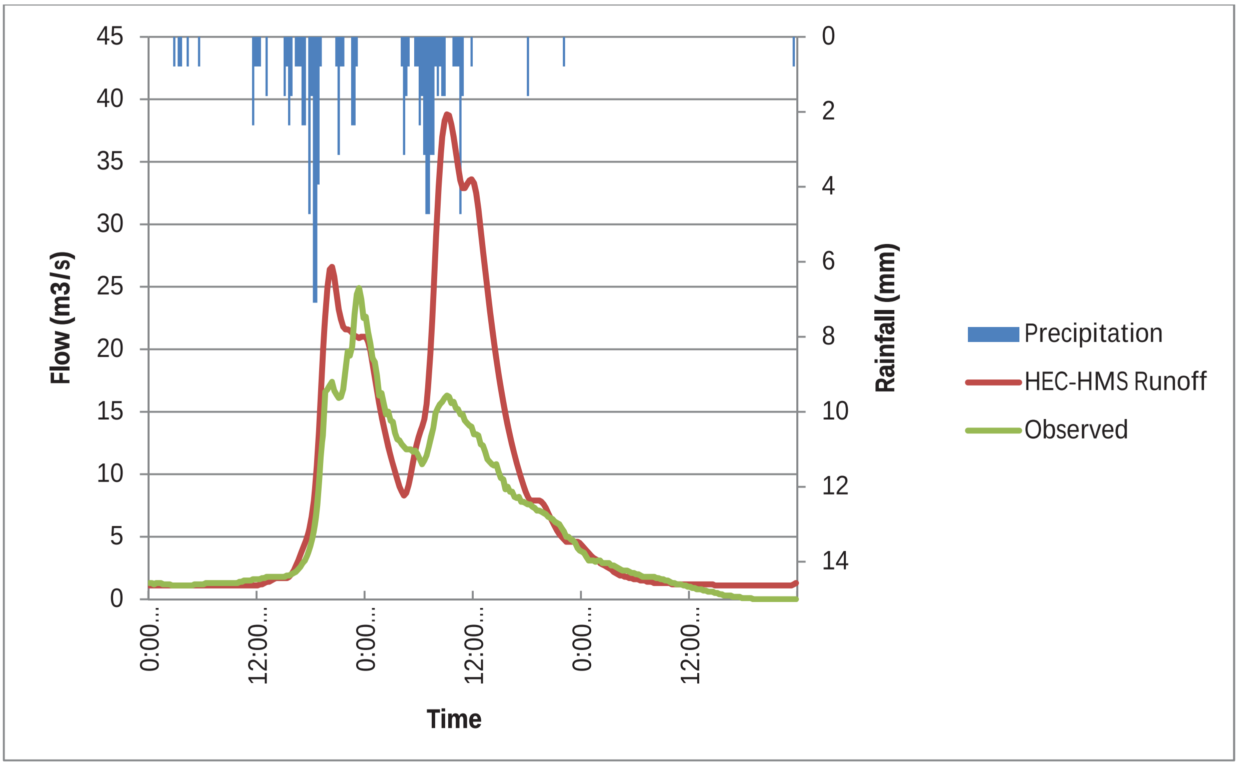
- **Figure 51 - Calibration C**

Calibration C uses a higher initial abstraction in order to accurately model the rising limb of the hydrograph. The peak and general shape of the hydrograph is fits well, the underestimation of the receding limb is possibly due to underrepresentation of rainfall in the catchment.

Using these three calibration events the following conservative catchment characteristics were set:

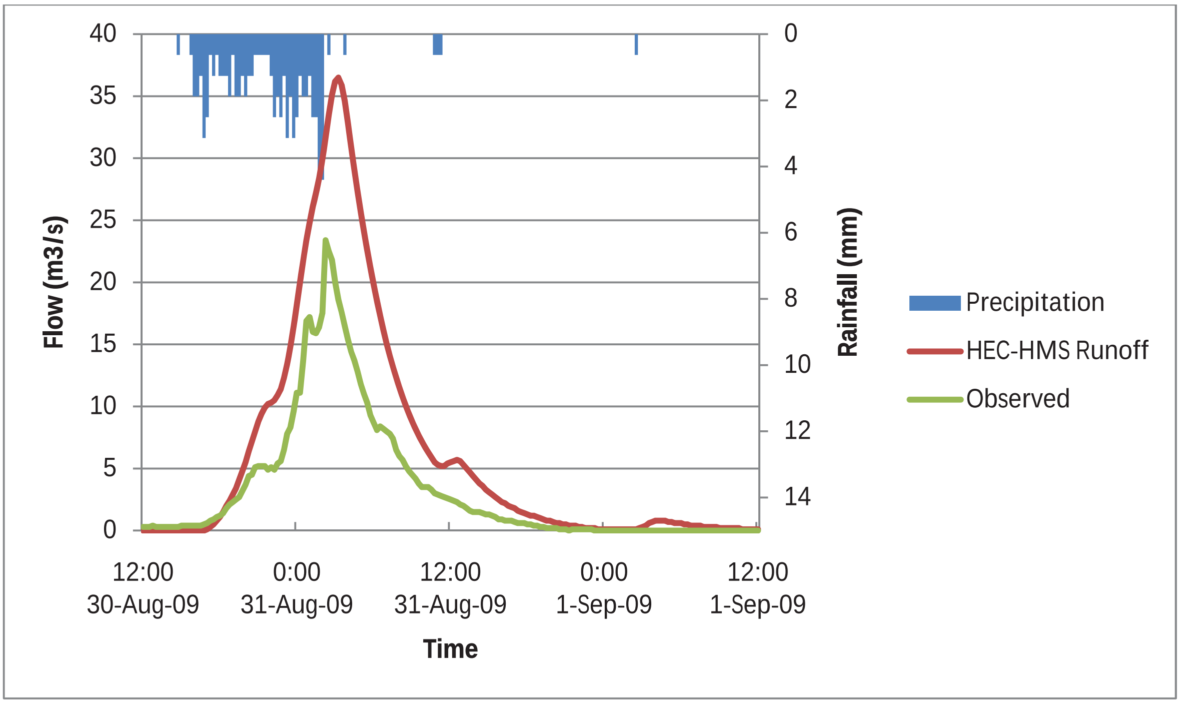
Catchment	Ia (mm)	CN	CIA (%)	Tc (hrs)	R	ST (Hrs)
Horokiri	5	80	0	2	0.65	3.7

Two validation events were simulated using the set catchment characteristics. We expected the validation events to be more variable, largely due to the fact that the rainfall for these events was more localised and therefore less likely to be well reflected, in both depth and/or distribution, by the surrounding rain gauges.



- **Figure 52 - Validation D**

Validation D depicts an event that is essentially two events over a short period of time. It is shown that the first event is simulated reasonably accurately whereas the second event is overestimated. This overestimation is due to HEC-HMS simulating initial losses only for the first event and not the second as well as a possibility of an overrepresentation of rainfall in the catchment for the second event.



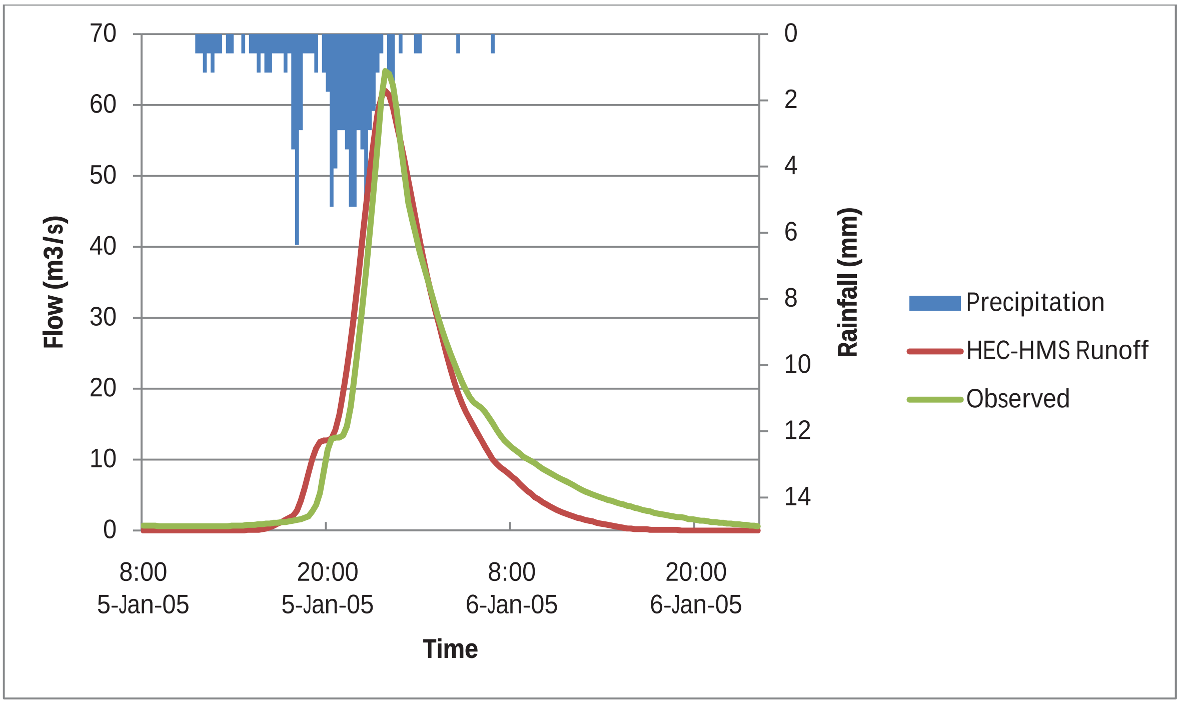
- **Figure 53 - Validation E**

Validation E shows a simulation of a small event. It can be seen that the shape of the simulated flow is reasonable however it is difficult to determine if the volume of rainfall is accurately represented. This validation is poor but at least simulated flows are conservative. With the quality of the calibration events it is felt the calibrated numbers should stand.

D.2 Pauatahanui Catchment

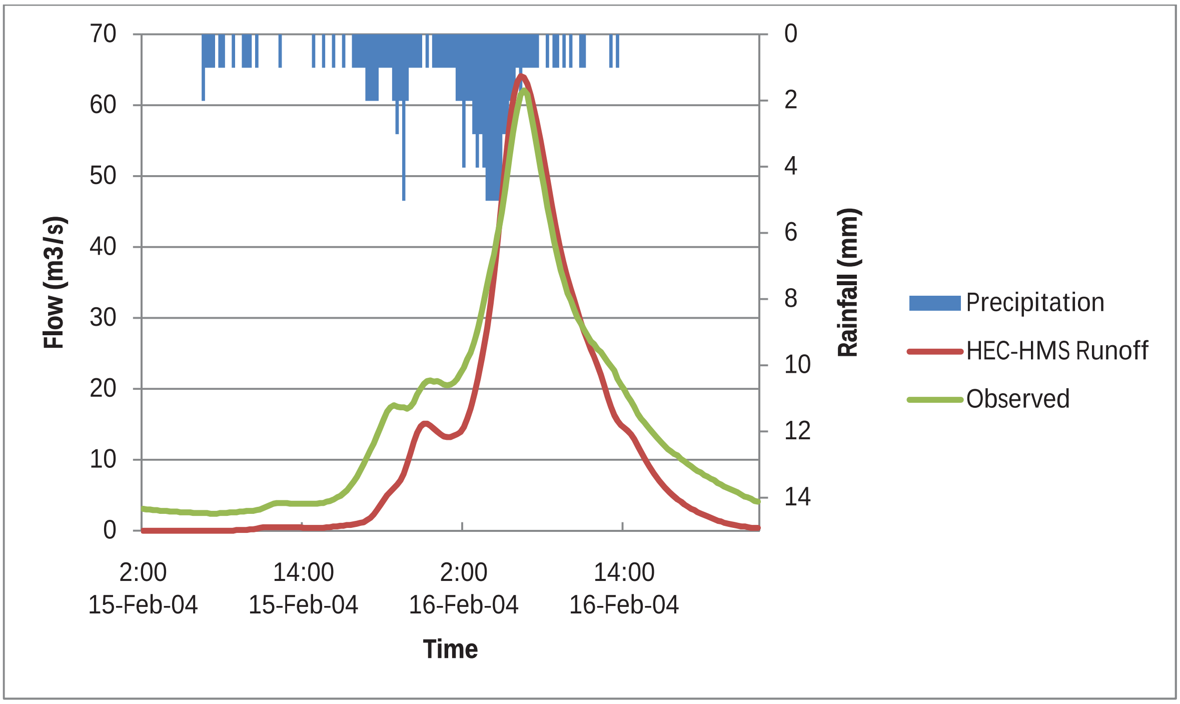
When calibrating the HEC-HMS runoff flows with the observed flows it was found that two parameters required adjustment; SCS Curve Number (CN) and Ratio. The following parameters were determined from the three calibration events:

Event	Ia (mm)	CN	CIA (%)	Tc (hrs)	R	ST (Hrs)
Calibration V	5	73	0	1.7	0.65	3.0
Calibration W	5	55	0	1.7	0.65	3.0
Calibration X	5	73	0	1.7	0.65	3.0



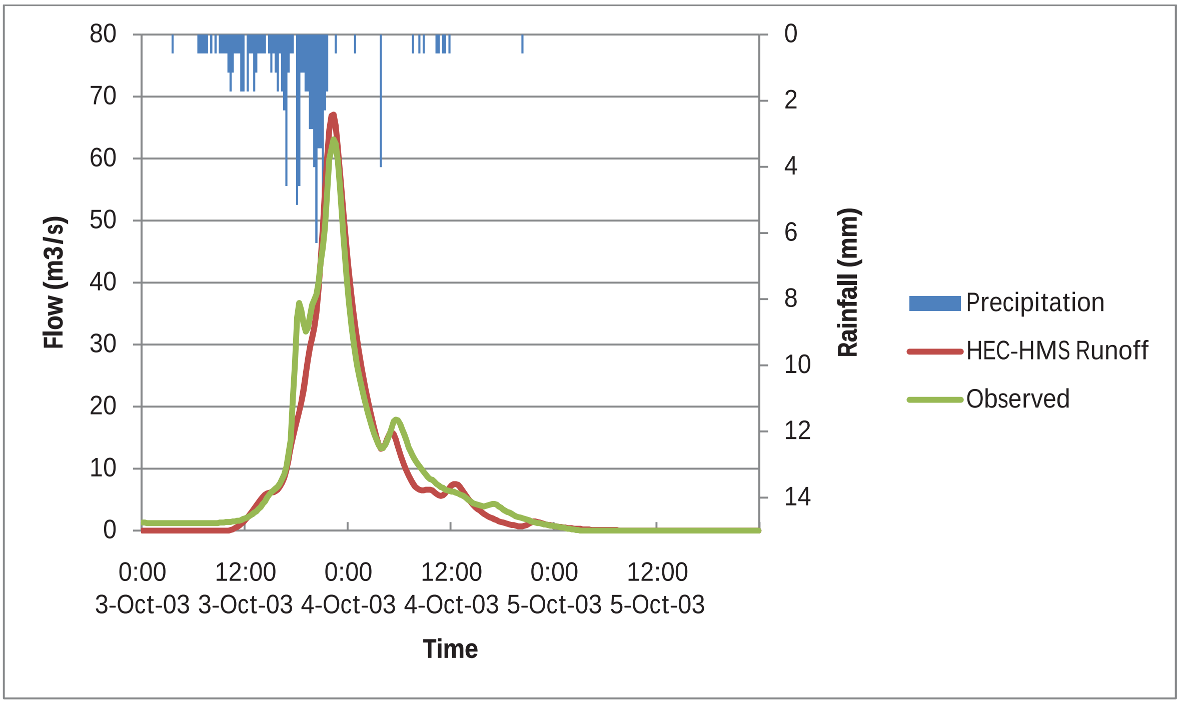
- **Figure 54 - Calibration V**

Calibration V shows a good fit for peak, total volume and shape. There is a slight under representation in the receding limb of the hydrograph possibly due to baseflow inaccuracies.



- **Figure 55 - Calibration W**

Calibration W shows a good fit for peak however the shape of the observed flow is somewhat 'fatter' than the simulation. An increase in both CN and R could produce a better fit in this situation however a fit to peak only was viewed as acceptable.



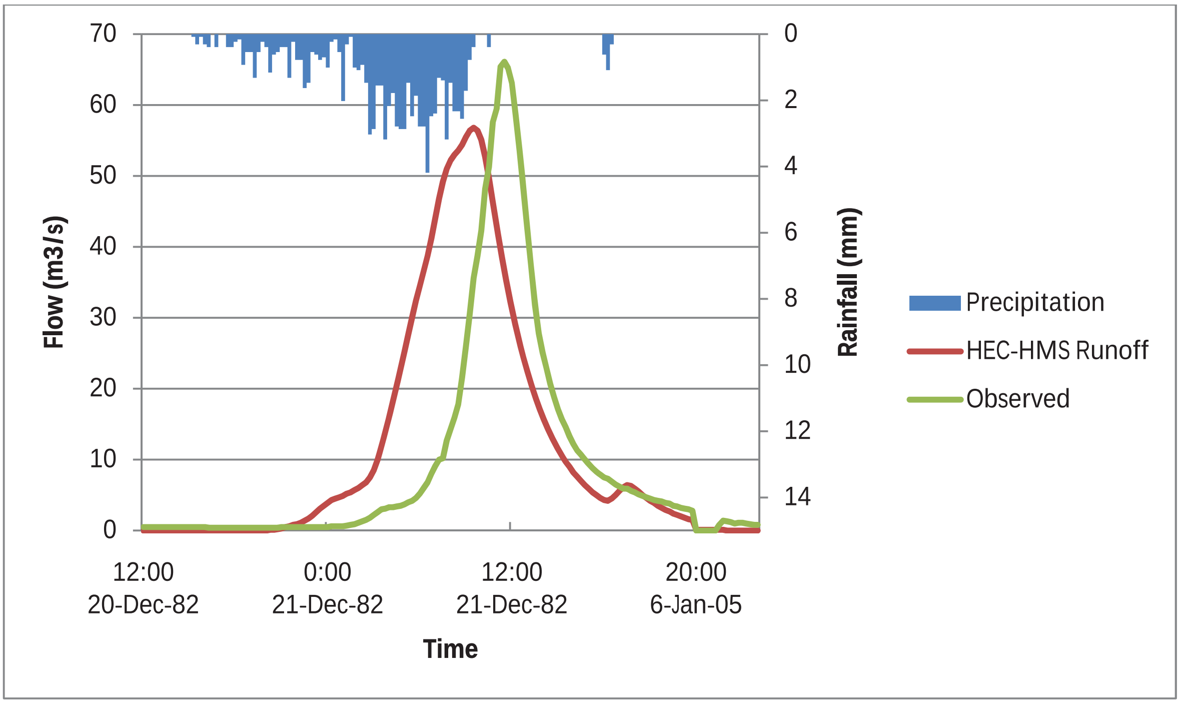
- **Figure 56 - Calibration X**

Calibration X shows a good fit in all aspects, peak, volume and shape, with only a slight preceding flow peak not becoming pronounced in the rainfall distribution.

Using these three calibration events the following catchment characteristics were set:

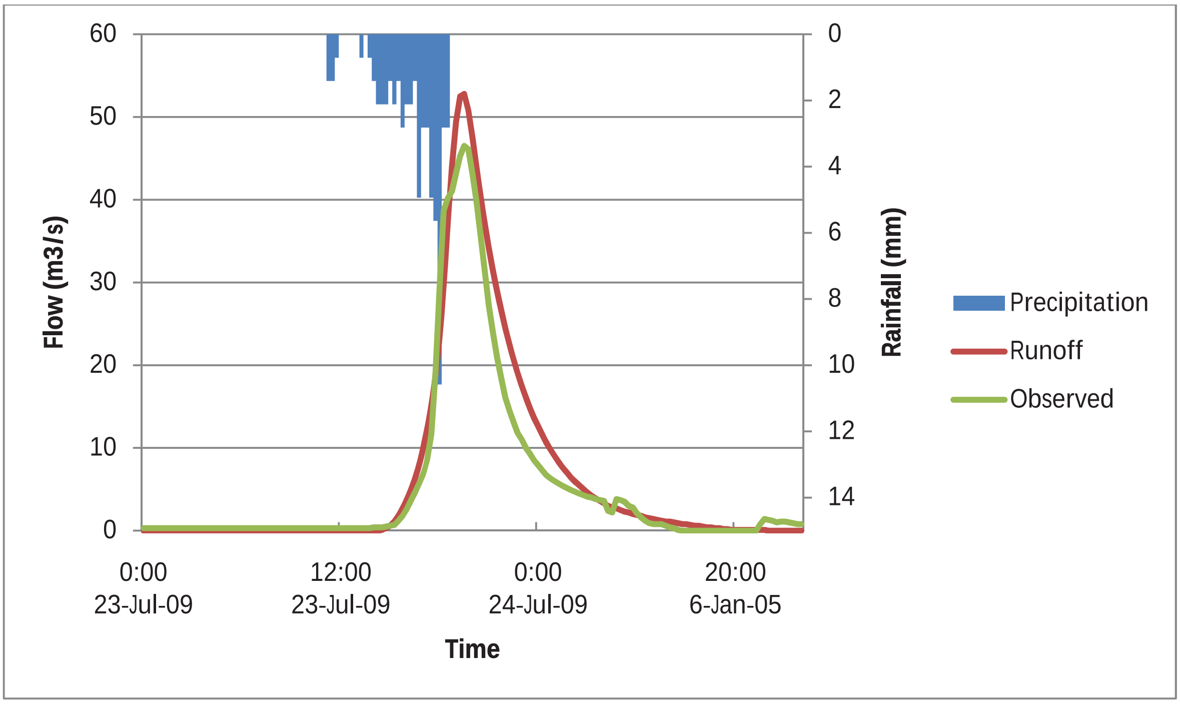
Catchment	Ia (mm)	CN	CIA (%)	Tc (hrs)	R	ST (Hrs)
Pauatahanui	5	75	0	1.7	0.65	3.0

Two validation events were simulated using the set catchment characteristics. Again we expected the validation events to be more variable due to the fact that the rainfall for these events was more localised and therefore less likely to be well reflected, in both depth and/or distribution, by the surrounding rain gauges.



- **Figure 57 - Validation Y**

Validation Y depicts a slight underestimation of peak and a slightly fatter shape in the runoff response. The observed response is also delayed. These differences can be explained by the rainfall not quite representing what occurred in the catchment both in terms of timing and rainfall peak.



- **Figure 58 - Validation Z**

Validation Z shows an excellent fit with observed data only tending to be slightly conservative with the estimation of flow peak.

Based on the calibration and validation results we have decided to retain the calibrated catchment characteristics.

D.3 Summary

The calibration of design storm parameters is considered to be acceptable although it highlights the wide variability of runoff response that can occur from any given rainfall event. The rainfall depths estimate is likely to be the single greatest variable and in the future the analysis would benefit from more rainfall gauges in the upper catchments.

Initially assessed runoff volumes were in the right order of magnitude hence CN numbers only needed to be adjusted slightly however more storage exists in the catchment than had been previously assessed and hence storage R values were increased. Times of concentration were found to be calculated accurately as well as initial abstraction.

Final calibrated catchment characteristics used for the three catchments are summarised in **Table 8.**

- **Table 8 - Calibrated Model Parameters in HEC-HMS**

Catchment Name	Area (km^2)	Initial Abstraction (mm)	SCS Curve No	Impervious Area	Tc (hr)	Ratio
Horokiri	28.7	5	80	0	2.0	0.65
Pauatahanui	38.3	5	75	0	1.7	0.65
Porirua	40.0	4	78	16	2.6	0.65

Appendix 14.E. Hydraulic Assessment Methodology

E.1 Introduction

This report describes in further detail the methodology, assumptions, sensitivity analysis, calibration and verification of the 1D-2D combined hydraulic modelling of the Pauatahanui, Horokiri and Te Puka/Wainui Streams.

E.2 Model Construction

E.2.1 Mike11 Base Model Construction & Assumptions

Using aerial photography the open channels within each of the study areas were schematised for the one dimensional modelling of the channel network. The dimensions and characteristics of structures and channel shape were specified based on cross-section survey data collected and supplied by Opus International Consultants (Opus) for this investigation.

Key structures such as culverts and bridges were represented in the 1D model using the software standard culvert/weir method. Where the length of the structure exceeded the maximum distance between cross-sections (dx max) the structure entrance was represented with a Mike11 culvert structure to take into account entry head losses and the remainder of the structure was represented by closed cross-sections. Inlet head loss coefficients for all modelled culverts have been based on the typical values as found in Austroads (1994), which provides standard entry conditions based on inlet design. For bridges the selection of the factor for the coefficient of contraction was based on the ratio of the bridge opening to the floodplain width. Typically on the constrained floodplains under investigation the contraction coefficient is between 0.1 and 0.3.

To model the effects of channel roughness, resistance values were selected based on the guidelines in Hicks &Mason (1998). The majority of the stream reaches have been modelled using Manning's roughness coefficient of 0.035.

E.2.2 Mike21 Base Model Construction & Assumptions

The 2D model bathymetry was prepared from the best available topographic information at the time. The quality of the topographic data varied for each of the study areas but was generally either derived from LiDAR or high resolution contour information supplied by the local authorities including Kapiti Coast District Council (KCDC) and Porirua City Council (PCC). A summary of the topographic data provided is included in Table 20.

- **Table 20 - Spatial Data Used in the Floodplain Model Construction**

Data	Description	Use

Data	Description	Use
PCC 1m contours	1m contours for Porirua urban areas showing elevation Contours supplied to PCC from Terralink International Ltd, 26thJuly 2005 Contours were captured using Photogrammetry with ground control and generally have an accuracy of +/- 1m Data won't account for recent earthworks in major subdivisions	Primary source of elevation data for the floodplain DEM for the Mike21 component of the hydraulic model Delineation of sub-catchment boundaries
PCC 5m contours	5m contours for Porirua rural areas showing elevation. Contours supplied to PCC from Terralink International Ltd, 26thJuly 2005 Contours were captured using Photogrammetry with ground control and generally have an accuracy of +/- 3.5m Contours are recorded as being 98% complete and data won't account for recent earthworks in major subdivisions.	Secondary source of elevation data for the floodplain DEM for the Mike21 component of the hydraulic model Delineation of sub-catchment boundaries
PCC Rural Aerial Photographs	Colour aerial photos of Porirua rural district Photos were flown in February 2005 at 1:2500 using a colour camera Accuracy of photos is generally +/-7.5m but worse in hilly areas	Delineation of modelled stream channel Model background
PCC Urban Aerial Photographs	Colour aerial photos of Porirua urban district using r27 series and r26 series tiles Photos were flown by NZAM Ltd. in January 2009 at 1:500 using a vexel colour digital camera Accuracy of photos is generally +/-1.3m but worse in hilly areas	Delineation of modelled stream channel Model background

Each of the three floodplains were modelled using a 5m grid. As the stream channels were simulated in the 1D model they were excluded from the 2D model to avoid the duplication of channel flows.

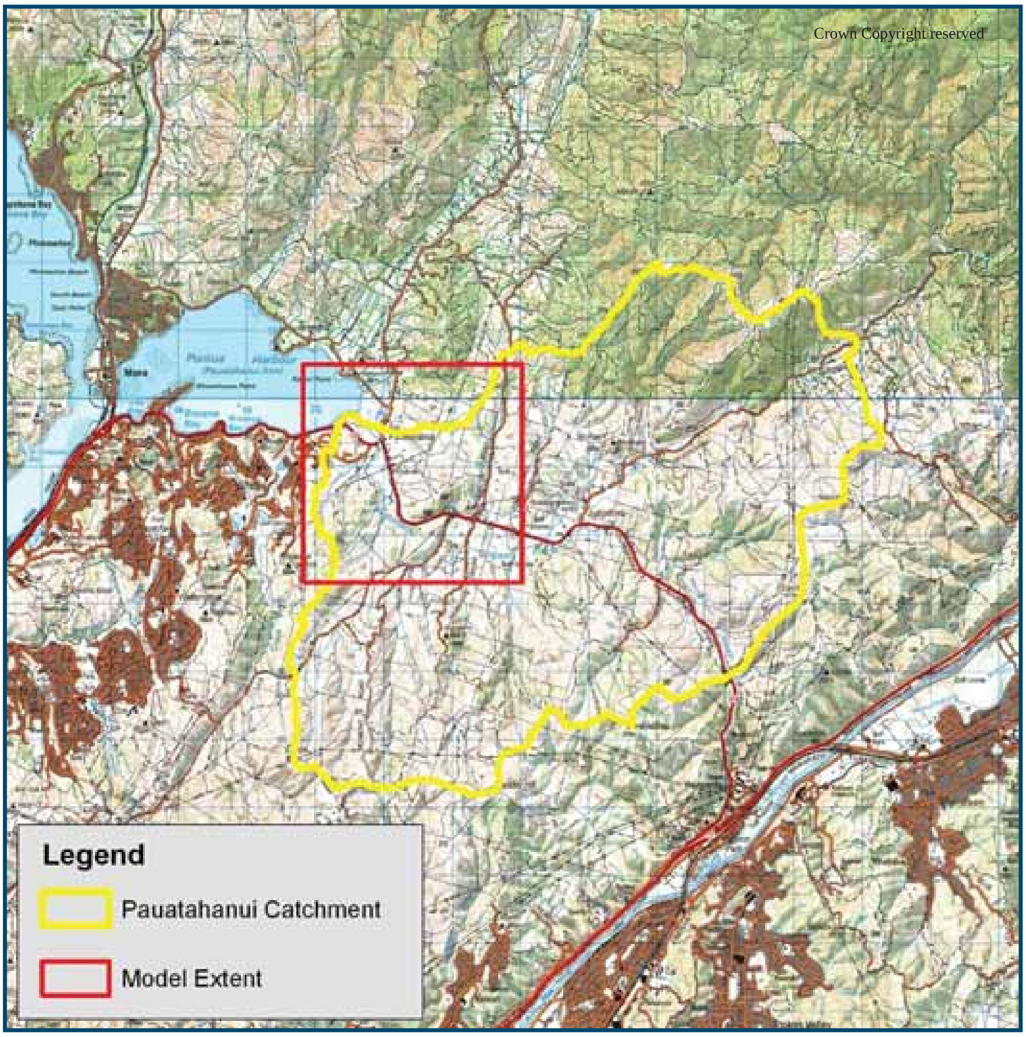
Aerial photography was used to classify floodplain resistance into four categories. Manning's n values for each category were estimated using industry best practice and sound engineering judgement. Floodplain roughness values used in the 2D model are listed below in Table 21.

- **Table 21 Floodplain Roughness Values**

Landuse	Manning's n
Road	0.02
Trees/Scrub	0.15
Open Space/Pasture	0.035
Residential Areas	0.1

E.3 Pauatahanui Stream

The Pauatahanui Stream drains a catchment of approximately 42km^2 on the eastern side of the Pauatahanui inlet. The catchment, shown in **Figure 59,** is bordered by the Collins and Ration Stream catchments to the north and the Duck Creek catchment to the west. The modelling investigation focussed on the catchment area surrounding the Transmission Gully Highway proposed alignment. This area is highlighted by the red square in **Figure 59.**



- **Figure 59 - Pauatahanui Catchment & Area of Modelling Investigation**

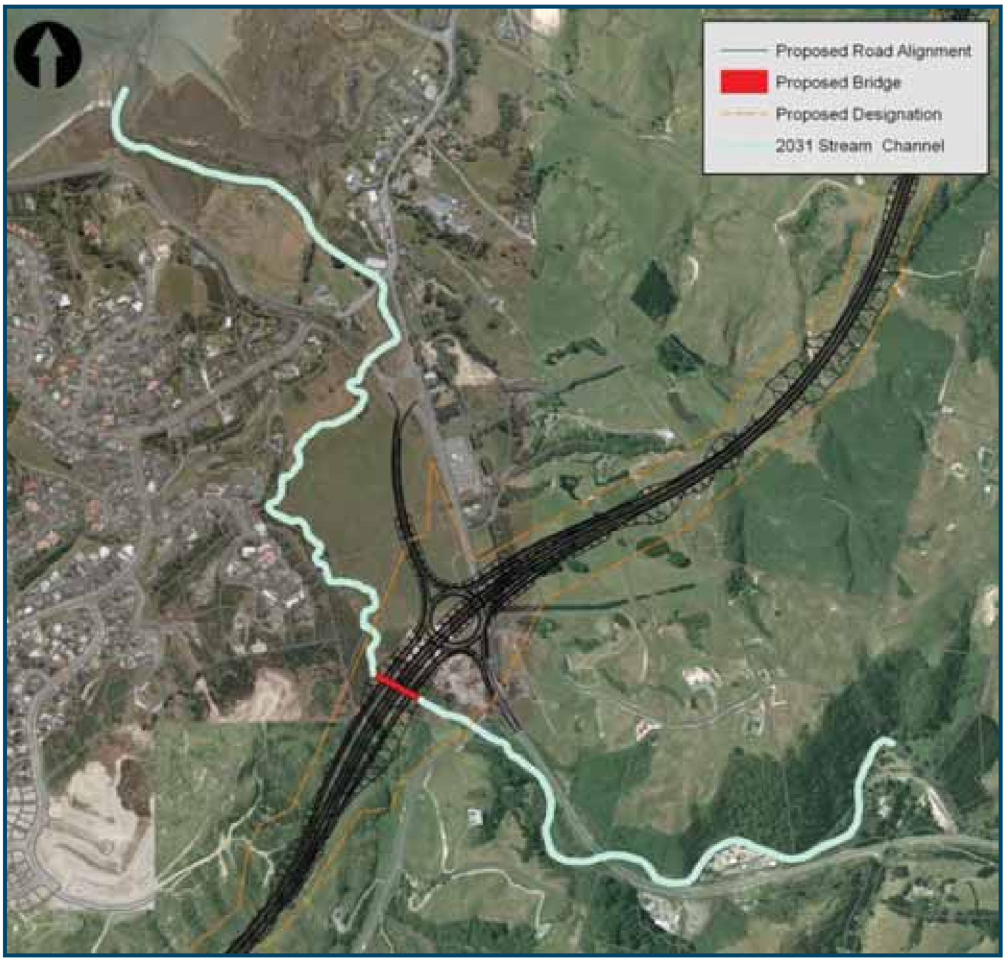
The upper Pauatahanui catchment has numerous steep sided valleys which converge and drain northwest out onto the Pauatahanui floodplain. The total fall over the catchment is greater than 400m, with the peak elevation in the upper catchment in the vicinity of 450m above Mean Sea Level (MSL) and the lower catchment at MSL.

This hydraulic modelling investigation focussed on the lower catchment where the topography opens out from a gorge environment to the Pauatahanui Stream floodplain.

The upper catchment is predominately a mixture of rural pasture land and forestry. As the lower catchment opens up the land use becomes a mixture of rural pasture land, residential and commercial. The residential suburb of Whitby lies on the western boundary and at the northern boundary is Pauatahanui Village.

E.3.1 Transmission Gully Project Main Alignment

The Project route through the Pauatahanui Catchment is shown in Figure 60. In relation to the chainages of the scheme design the section of highway located between Chainage 16,200 and Chainage 19,900 are within the Pauatahanui Catchment.

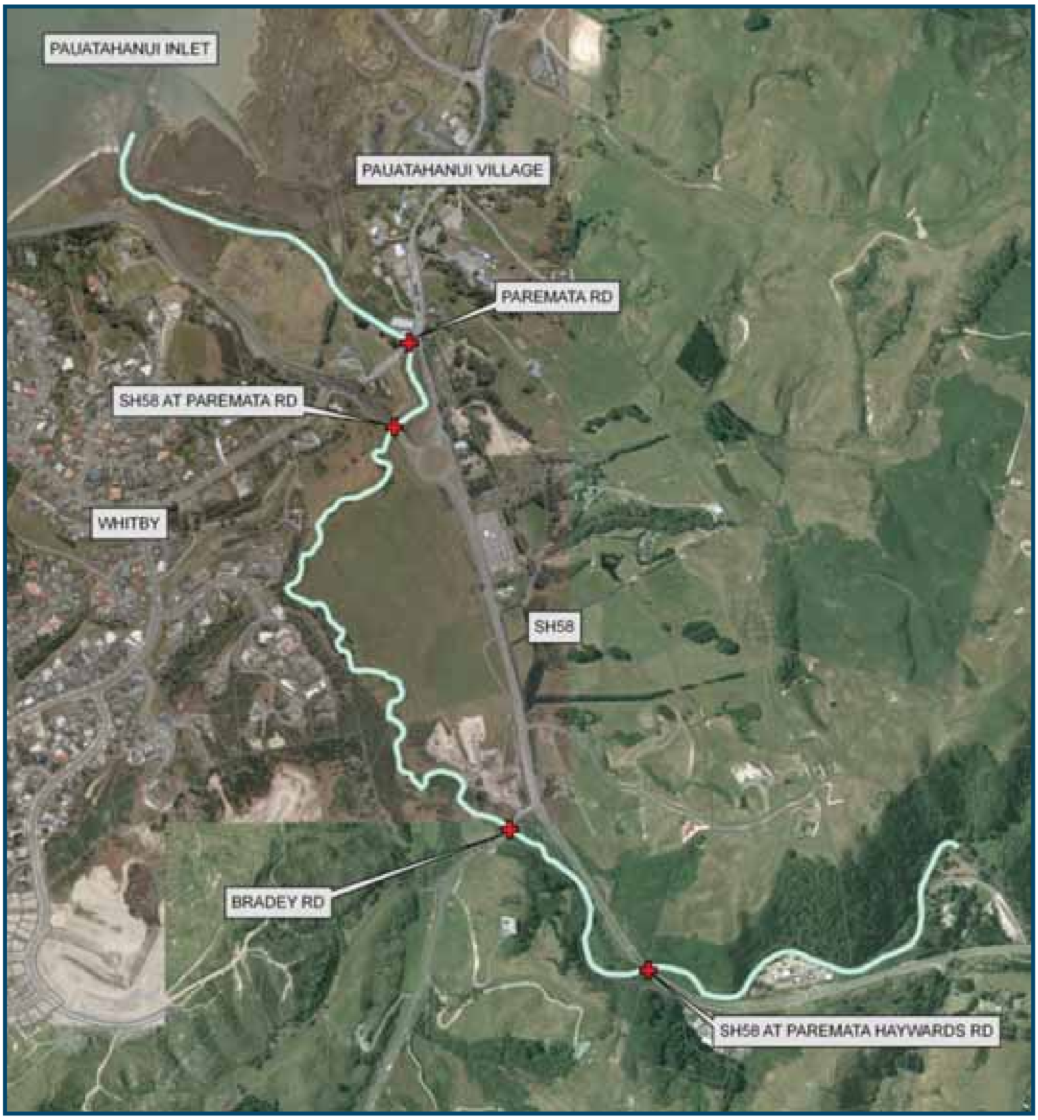


▪ **Figure 60 - Proposed Transmission Gully Alignment and Designation**

A significant interchange is proposed between the Transmission Gully Highway and State Highway 58 (SH58). This interchange is intended to be located on the floodplain of the stream. Furthermore a "lay down area" to facilitate the highway construction and a weigh station are being investigated at this location. The interchange has been identified as a potential consenting "hotspot" on the proposed alignment, due to the significant footprint of the proposed road and its potential impacts on the Pauatahanui stream.

E.3.2 Pauatahanui Stream Model

The reach of stream channel that was modelled is shown in Figure 14.5. The hydraulic model starts adjacent to the sawmill on SH58 (Paremata-Haywards Road) and extends c3.4km downstream to the Pauatahanui Inlet.



- **Figure 61 - Modelled Reach of the Pauatahanui Stream**

In the upper extent of the model the channel is located in a narrow steep sided gorge. The stream is constrained as it runs adjacent to SH58 until the topography levels out downstream of the Bradey Road Bridge. Downstream of Bradey Road the grade of the stream flattens out as it skirts the western perimeter of the floodplain before passing beneath SH58 at Paremata Rd and the Paremata Rd bridge adjacent to Pauatahanui Villages, and finally into the Pauatahanui arm of Porirua Harbour.

E.3.2.1 Topographic Survey

The lower reach of the Pauatahanui Stream is already crossed by four major structures. As shown in **Figure 14.5,** SH58 has two bridges while the other two bridges are located on Paremata Road (near Pauatahanui Village) and Bradey Road. The deck and soffit levels of all four structures were surveyed as well as the abutment locations.

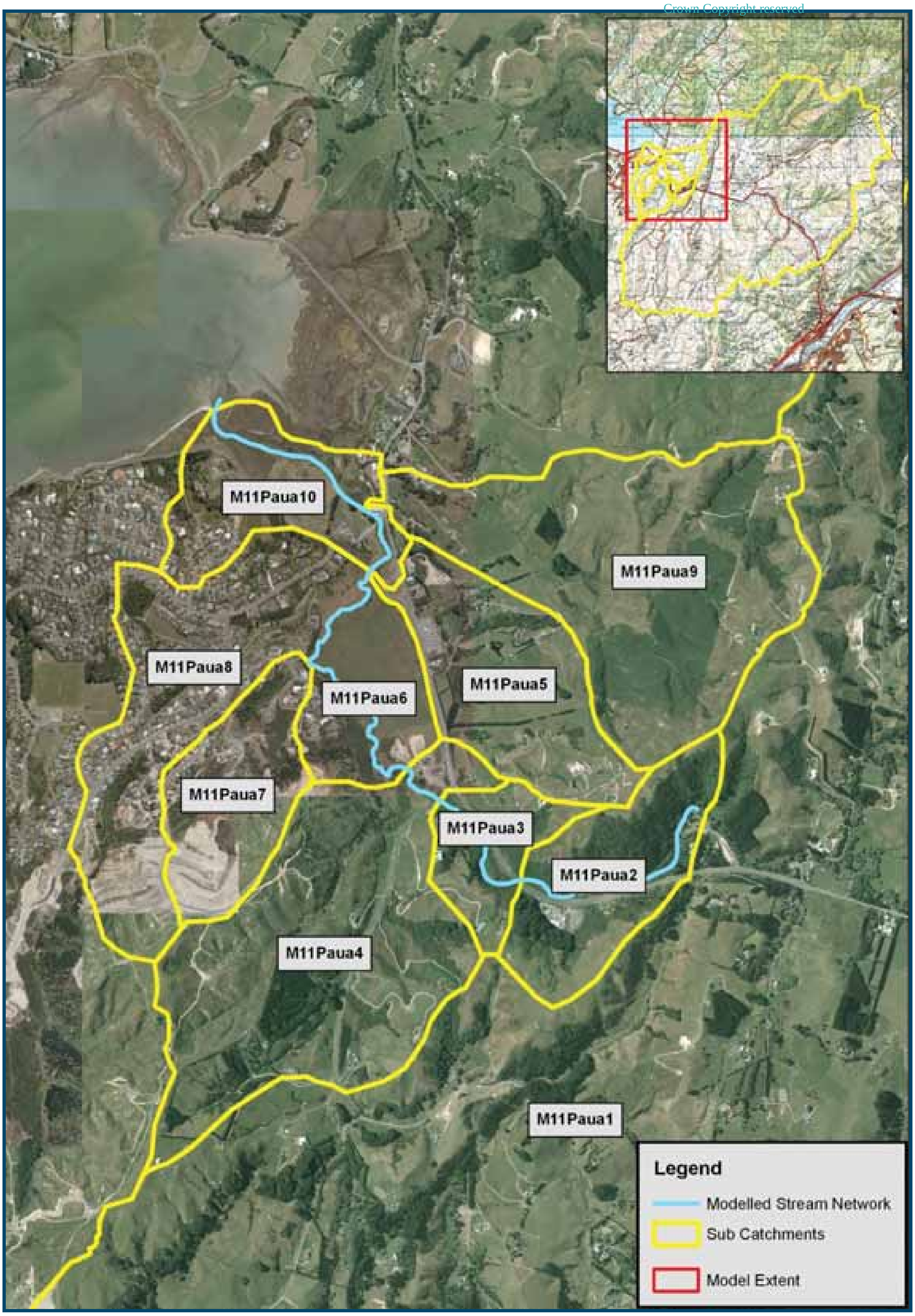
Twenty-one cross-sections of the stream were picked up in the survey. The cross sections picked up the channel invert and spot heights between the true left bank and true right bank. Where possible a cross section was surveyed immediately upstream of the bridges to allow accurate representation of the channel at these hydraulic constraints in the stream model.

E.3.3 Pauatahanui Catchment Hydrology

For hydrological inputs into the hydraulic model the Pauatahanui catchment was divided into 10 sub-catchments (refer to Figure 62). The inflow from each sub catchment was extracted from the HEC HMS hydrological model as a discharge time series. Peak flows from the sub-catchments in both the pre construction and the post construction scenario are detailed in **Table 22**.

▪ **Table 22 - Peak Flows – Pauatahanui Hydraulic Model Hydrology**

	Pre Construction Situation		Post Construction Situation	
Catchment	10-Year Storm (Q10)	100-Year Storm Including the Impacts of Climate Change ($Q100^{cc}$)	10-Year Storm (Q10)	100-Year Storm Including the Impacts of Climate Change ($Q100^{cc}$)
M11Paua1	86.1	197.7	86.1	197.7
M11Paua2	1.1	2.7	1.1	2.7
M11Paua3	0.7	1.7	0.7	1.7
M11Paua4	3.3	7.4	3.3	7.4
M11Paua5	1.5	3.6	1.5	3.6
M11Paua6	0.9	2.2	0.9	2.2
M11Paua7	1.0	2.4	1.2	2.6
M11Paua8	1.8	4.0	2.0	4.2
M11Paua9	3.2	7.3	3.2	7.3
M11Paua10	1.0	2.2	1.0	2.2
Total inflows	*100.6*	*231.2*	*101*	*231.6*



▪ **Figure 62 - Pauatahanui Stream Sub Catchments Calibration**

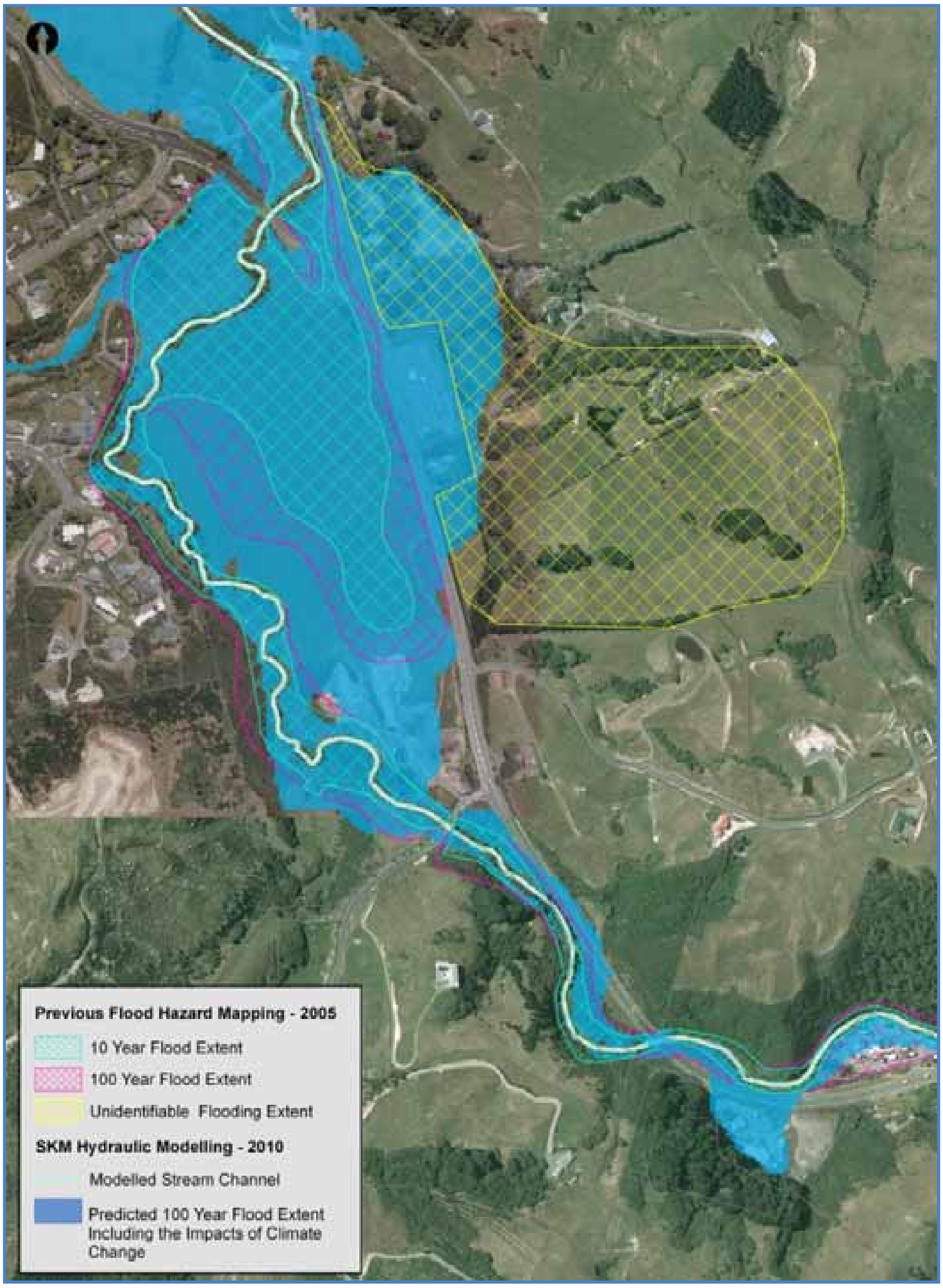
The return period of the rainfall was determined by analysis of the rainfall gauges in the region. Calibration and verification of the catchment characteristics and storm shape in the hydrological model was undertaken based on analysis of specific rainfall events combined with the corresponding data from the Greater Wellington

Regional Council (GWRC) flow gauge at Pauatahanui gorge. The hydrological calibration is provided in **Appendix 14.E**. This analysis was used to develop the inflow hydrographs for the hydraulic model.

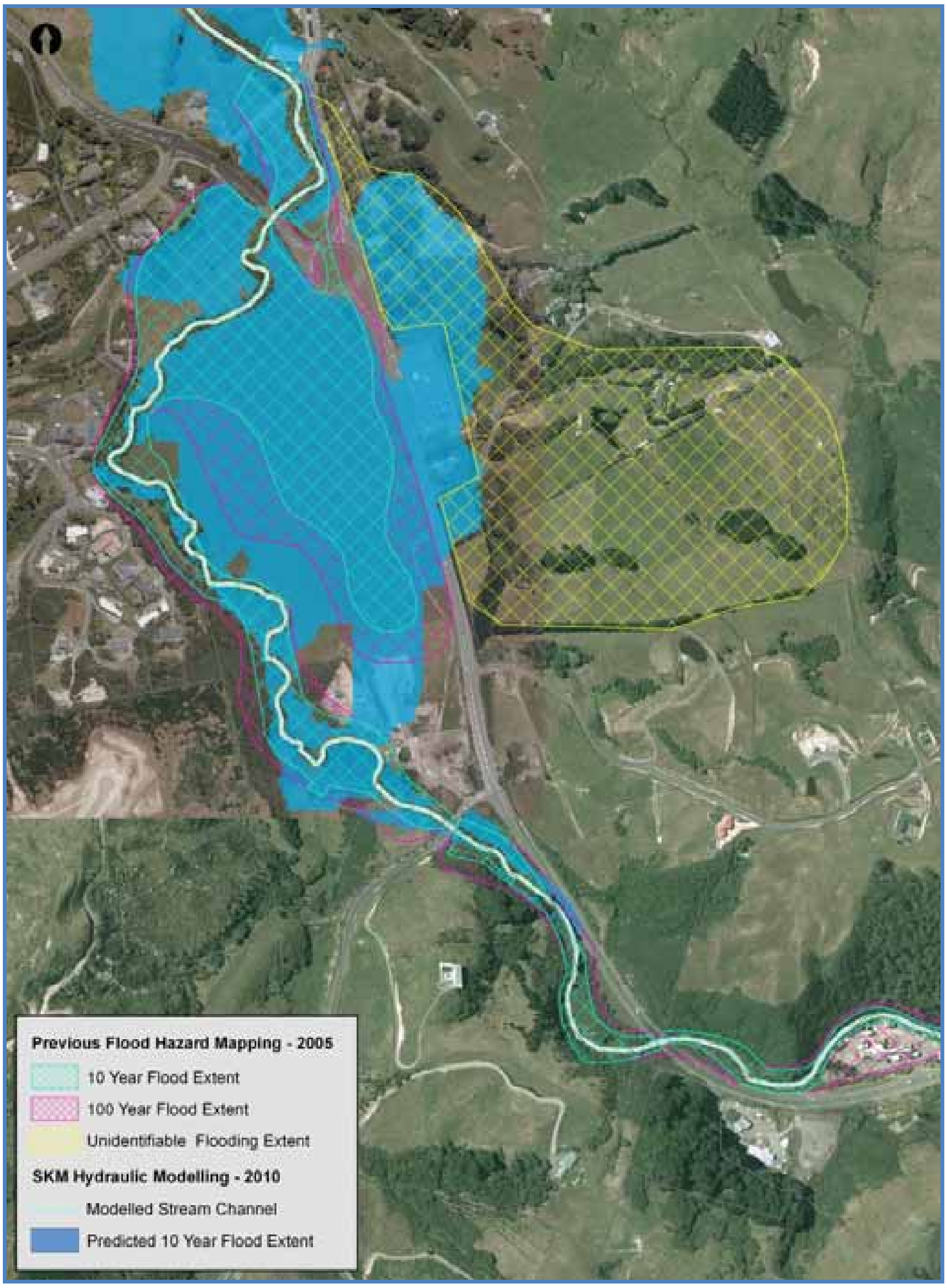
The analysis of the gauge data at Pauatahanui gorge indicates that the hydraulic model is likely to be overestimating the flooding for the lower order rainfall events. This is due to the storage in the upper catchment, especially in the area surrounding the golf course, which has not been included in the hydraulic model. However, due to the limited record period of the flow gauge it is difficult to determine if the hydraulic model is also overestimating the flooding in extreme rainfall events such as the 100 year storm event. In larger events the storage in the upper catchment is less likely to influence flows lower down. For this reason a conservative approach was taken and the inflows from the hydrological analysis were not scaled back to account for the storage in the upper catchment.

To provide further confidence in the hydraulic model the results were compared to the model results of previous flood studies in this area. In 2005 Connell Wagner completed flood hazard mapping for PCC on the Pauatahanui stream between the golf course on SH58 and the Pauatahanui Inlet. This work was prompted by flooding of a number of residential properties in January 2005. In this study a 1D hydraulic model of the stream was used to produce flood hazard extents for the 10 year and 100 year storm events without freeboard. As this model was only constructed in 1D the extent of the modelled floodplain was limited to that of the topographic survey undertaken. Because of this the mapping highlighted areas of “unidentifiable flooding”, or areas outside the model extent with the potential to be inundated by stream overflows.

As a coarse verification measure the predicted flood extents for the Transmission Gully investigation were compared with that of the 2005 study. This comparison was coarse as different modelling packages and methodologies were used in the two studies. However, the predicted flooding extents match well between the two studies. Where there are differences they can be explained by either the different approaches to modelling or the differing areas of investigation, as illustrated in **Figure 63** and **Figure 64.**



- **Figure 63 - Comparison of Flooding Extents Between the 2005 Study and the Current Project: 100-Year Event**



- **Figure 64 - Comparison of Flooding Extents between the 2005 Study and the Current Project: 10-Year Event**

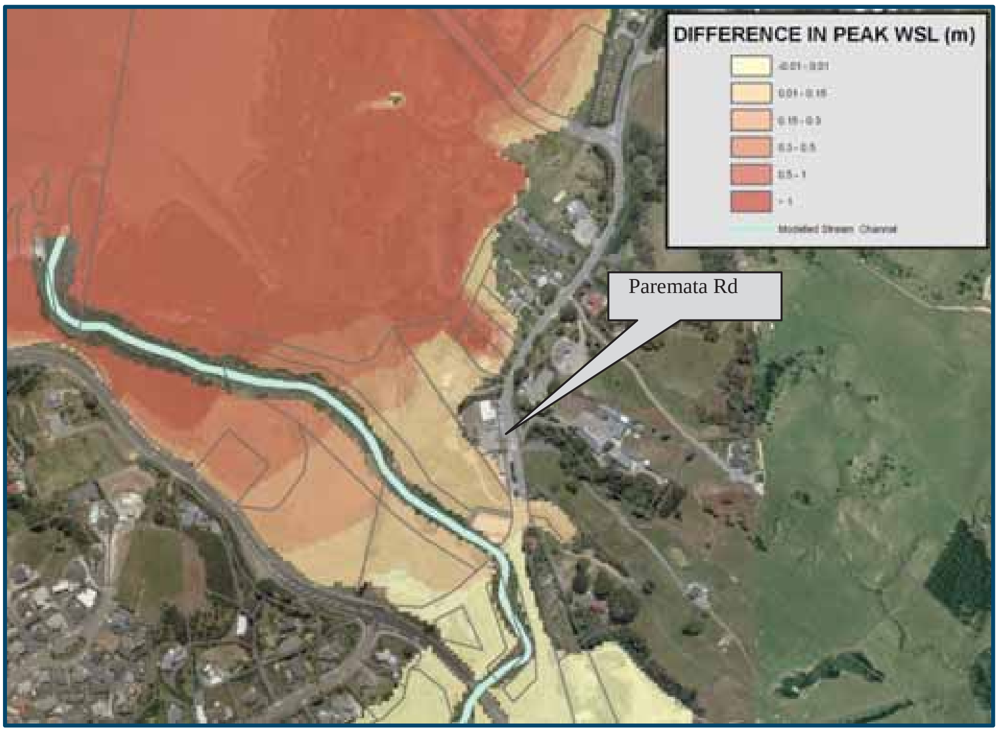
E.3.4 Sensitivity Analysis

To assess the impacts of changes in the model variables, a sensitivity analysis was undertaken on two key modelling parameters that could impact the results and alter the outcomes of the analysis. These variables were the downstream tidal boundary and the inflow hydrographs.

E.3.4.1 Tidal Boundary

The lower reaches of the Pauatahanui catchment are tidally influenced. A sensitivity analysis was undertaken to quantify the impact of assumptions in sea level conditions during the modelled storm events. The model of the 100 year rainfall event, with the predicted impacts of climate change ($Q100^{cc}$), was run with a range of different tidal levels: 0m relative to Mean Sea Level (MSL) to simulate a lower level tide, 1m above MSL to represent an astronomical high tide (based on sea level gauging at Mana Marina, and a 2m tide above Mean Sea Level to simulate an extreme tide under storm surge influence.

The sensitivity analysis of the tidal boundary indicated that tidal levels in the Pauatahanui inlet were significant only on the peak water surface levels downstream of the bridge at Paremata Road. Figure 65 shows a comparison of peak water surface levels for a $Q100^{CC}$ year event coinciding with a 2m tide and the same event with a 0m tide. Upstream of the SH58 Paremata Rd bridge the tidal impacts on water surface levels are predicted to be very small. Downstream of the bridge peak water surface levels in Pauatahanui village were found to differ by as much as 600mm between the two scenarios.



▪ **Figure 65 - Comparison of Peak Water Surface Levels in the $Q100^{CC}$ Event with a 2m & 0m Tide**

During the assessment of effects it was found that the potential impacts on flooding of the road construction were up stream of Paramata Road and therefore less influenced by the selection of tidal condition. With this consideration an astronomical high tide off 1m above MSL was selected for the remainder of the analysis.

E.3.4.2 Oversized Events

The hydraulic model's sensitivity to hydrological inputs was tested by running an oversized hydrological event. The oversized event inflow hydrographs were created by increasing the 100 year flood event including the predicted impacts of climate change (100^{cc}), by half again. The results from the oversized event and the 100^{cc} year ARI event were compared using the model of the pre construction situation. This analysis revealed that the predicted inundation extents in the oversized event did not increase greatly from the 100 year storm event but there were significant increase in the peak water surface levels. Water surface levels upstream of Bradey Road were predicted to increase by between 0.5m and 1m as were water surface levels in the pasture land upstream of the SH58 bridge at Paremata Rd. The lower catchment in the vicinity of Pauatahanui Village was predicted to experience increase in peak water surface levels of between 150mm and 300mm. This comparison influenced the selection of freeboard levels for the proposed bridge design.

E.4 Horokiri Stream

The Horokiri Stream drains a catchment of approximately 33km^2 on the eastern side of the Pauatahanui Inlet. The catchment, shown in Figure 66 , is bordered by the Ration Stream catchment to the south, Kakaho Stream catchment to the west and the Te Puka Stream catchment to the north.

Figure 66 Location of Horokiri Catchment

The main stream channel begins at the Wainui Saddle and drains south out into the Pauatahanui arm of the Porirua Harbour. There is significant fall over the catchment with the peak elevation in the upper catchment in the vicinity of 500m above Mean Sea Level (MSL) and the lower catchment (at the southern end) at MSL.

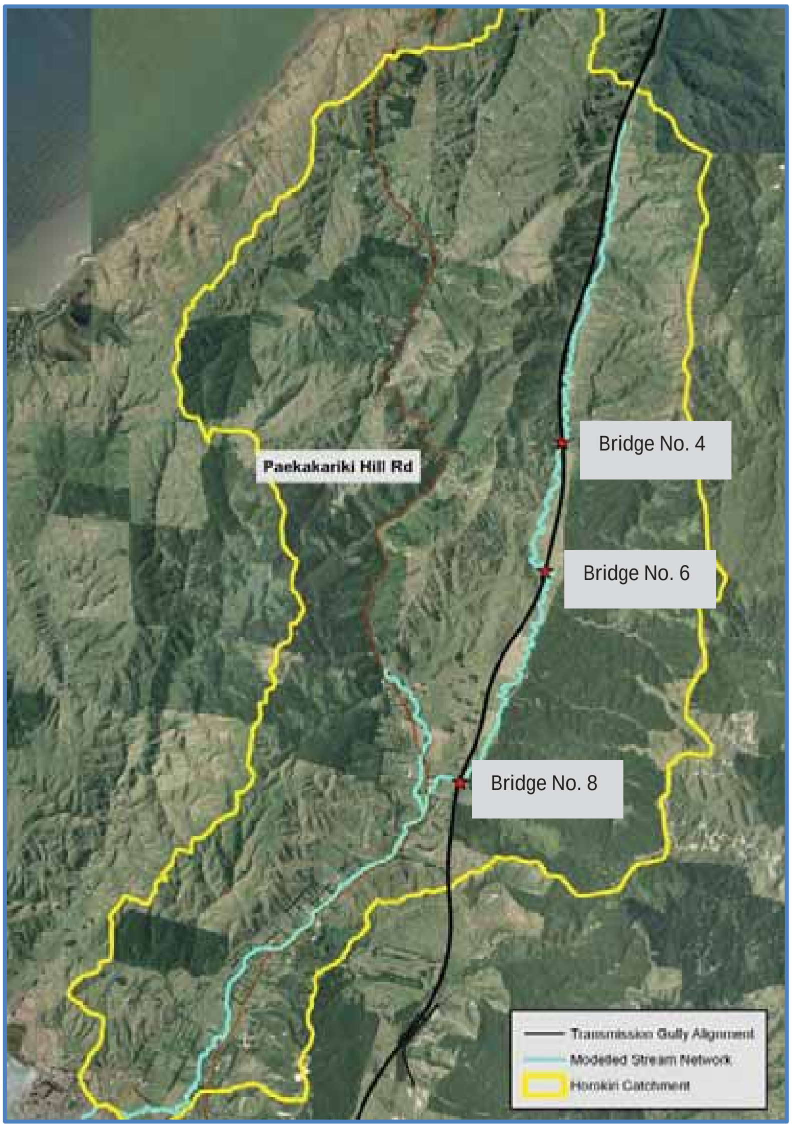
In the upper catchment the steep sided valleys on the western catchment boundary are predominantly forested, whereas, on the eastern boundary the land use is predominantly pasture. As the lower catchment opens up onto the Horokiri Stream floodplain the major land use is rural pasture with pockets of residential dwellings. The majority of dwellings are located on the true right bank of the Horokiri Stream and have private access bridges crossing to Paekakariki Hill Road that runs on the true left bank of the stream.

E.4.1 Transmission Gully Project Main Alignment

The Transmission Gully Project route will traverse the upper Horokiri catchment as shown in Figure 14.16. The road alignment runs adjacent to the stream for approximately seven kilometres (scheme design chainages 5,300m to 12,600m) and will cross the main stream channel three times:

- Bridge No. 4, scheme design chainage 8,450m
- Bridge No. 6, scheme design chainage 9,720m
- Bridge No. 8, scheme design chainage 11,750m.

In the upper catchment, the construction of earth fill embankments to support the new highway will require some permanent diversions of the main stream channel.



- **Figure 67 - Main Alignment in the Horokiri Catchment**

E.4.2 Horokiri Stream Model

The reach of the stream channel that has been modelled is shown above in **Figure 66** and **Figure 14.16**. The hydraulic model incorporates c14km of the main stream channel beginning near the Wainui Saddle and extending down to the Pauatahanui Inlet. The hydraulic model also included a reach of the main tributary branch of the stream. This tributary drains the eastern catchment before draining to the main stream channel south of Paekakariki Hill Road. The majority of the modelled channel network is constrained by the steep sided valley topography of the catchment. Only in the reach c1.5km upstream of the Pauatahanui Inlet does the topography open out onto a wide floodplain.

E.4.2.1 Topographic Survey

The majority of the structures crossing the Horokiri stream are located south of Paekakariki Hill Road. Two major culverts pass beneath Paekakariki Hill Road and a triple box culvert passes beneath Grays Road near the stream mouth. The stream is also crossed by numerous private access bridges connecting residential properties on the true right bank with Paekakariki Hill Road on the true left bank of the stream. It was not considered practical to survey all the structures in the stream so only the three major crossings and 14 of the private access bridges identified as being significant hydraulic constraints were surveyed.

Thirty-four cross sections of the stream were picked up in the survey. The cross sections picked up the channel invert and spot heights between the true left bank and true right bank. Where possible a cross section was surveyed immediately upstream of a bridge to allow accurate representation of the channel at these hydraulic constraints in the stream model.

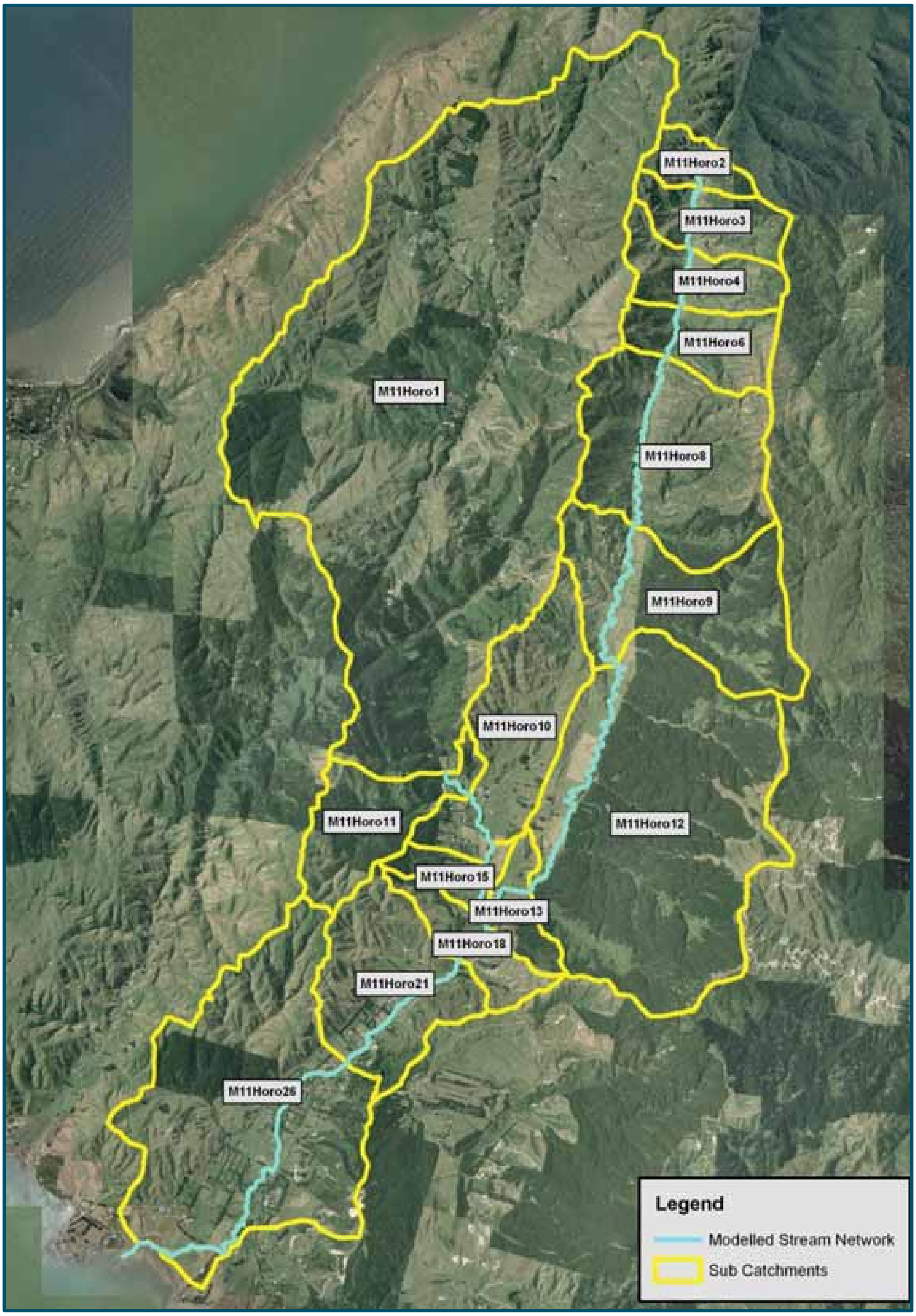
E.4.3 Horokiri Catchment Hydrology

To create hydrological inputs for the hydraulic model, the Horokiri catchment has been subdivided into 15 sub catchments (refer to **Figure 68)**.The inflow from each sub catchment was extracted from the HEC HMS hydrological model as a discharge time series. Peak flows from the sub catchments in both the current pre and the post construction scenario are detailed in Table 23.

- **Table 23 - Peak Flows – Horokiri Hydraulic Model Hydrology**

Catchment	Pre-Construction Situation		Post-Construction Situation	
	10-Year Storm (Q10)	100-Year Storm Including the Impacts of Climate Change ($Q100^{cc}$)	10-Year Storm (Q10)	100-Year Storm Including the Impacts of Climate Change ($Q100^{cc}$)
M11Horo1	18.7	31.5	18.7	31.5
M11Horo2	1.1	1.9	1.1	2.0
M11Horo3	1.8	3.4	1.9	3.4
M11Horo4	2.0	3.8	2.1	3.8
M11Horo6	2.2	4.1	2.2	4.1
M11Horo8	5.2	9.9	5.3	10.0

Catchment	Pre-Construction Situation		Post-Construction Situation	
	10-Year Storm (Q10)	100-Year Storm Including the Impacts of Climate Change ($Q100^{cc}$)	10-Year Storm (Q10)	100-Year Storm Including the Impacts of Climate Change ($Q100^{cc}$)
M11Horo9	5.1	9.4	5.2	9.5
M11Horo10	4.3	7.4	4.3	7.4
M11Horo11	2.6	4.4	2.6	4.4
M11Horo12	12.3	22.2	12.4	22.3
M11Horo13	1.2	2.0	1.2	2.1
M11Horo15	1.0	1.7	1.0	1.7
M11Horo18	2.0	3.3	2.0	3.4
M11Horo21	3.7	6.2	3.7	6.2
M11Horo26	7.9	13.1	7.9	13.1
Total Inflows	*71.1*	*124.2*	*71.5*	*124.7*



- **Figure 68 - Horokiri Stream Hydraulic Model Catchments**

E.4.3.1 Calibration

The hydrological calibration of catchment characteristics is recorded provided in **Appendix 14.C.** This analysis records the calibration and verification of flows at the Greater Wellington Regional Council (GWRC) flow gauge at the Snodgrass property on Paekakariki Hill Road.

During construction of the hydraulic model the compounding effect of the target rainfall events being applied to the 15 sub catchments was found to be over predicting the flows when compared to the calibrated hydrological model predictions at the gauging station. The return period of the rainfall used to generate the inflow hydrographs in the hydraulic model was scaled back until a close match was achieved between the flows in the hydraulic model and the flows predicted by the calibrated hydrological model of the catchment for the design rainfall event.

The hydraulic model indicated that a 2 year rainfall over the 15 Horokiri sub catchments results in flows that are a close match with the 10 year flows predicted by the hydrological model at the gauging station. Similarly a 10 year rainfall over the 15 Horokiri sub catchments results in a close match of flows with those predicted by the calibrated hydrological model for the 100 year flood including the predicted mid range impacts of climate change. A comparison of the flows in the hydraulic model and hydrological model and those from the frequency analysis of the observed data at the gauging station is shown in **Table 24.** It should be noted that the gauging station has only a short (5-6 years) record and is therefore of only limited value for calibration of the hydraulic model. The close match with the calibrated hydrological model predictions provides sufficient confidence in the model results for an assessment of effects.

- **Table 24 - Comparison of the Peak Flows in the Hydraulic and Hydrological Model and the Flows Predicted in the Frequency Analysis of the Snodgrass Gauging Station**

ARI (Years)	Hydraulic Model Peak Flow (m^3/s)	Hydrological Model Peak Flow (m^3/s)	Flood Frequency Analysis of Snodgrass gauge Data 2002 - 2010 (m^3/s)
10	62	60	55
100	133*	132*	116

*Includes the mid range prediction of the impacts of climate change on rainfall intensities. Climate change is predicted to result in c20% increase in peak flood flows

E.4.4 Sensitivity Analysis

To assess the impacts on the results of changes in the model variables, a sensitivity analysis was undertaken on two key modelling parameters. These variables were the downstream tidal boundary and the inflow hydrographs.

E.4.4.1 Tidal Boundary

The mouth of the Horokiri stream is tidally influenced due the flat gradient of the stream channel and the low lying floodplain at this location. The sensitivity analysis was undertaken to quantify the impact of assumptions in sea level conditions during the modelled storm events. The model was run with two different tidal levels: 0m above Mean Sea Level (MSL) to simulate a commonly occurring sea level scenario and 2m above MSL to simulate an extreme sea level including storm surge and wave setup. These levels were selected following a review of tidal water surface levels from Porirua Harbour.

The sensitivity analysis of the sea level boundary indicated that tidal levels only influenced peak water surface levels within about 500m of the stream mouth. Over the majority of the modelled stream network, tidal boundary conditions in the Pauatahanui Inlet were predicted to have no significant impact on peak water surface levels in the stream channel and on the floodplain and therefore little influence on the assessment of hydraulic effects. With this consideration, a mid range boundary condition of 1m above MSL was selected for hydraulic modelling of the pre and post road construction scenarios.

E.4.4.2 Oversized Events

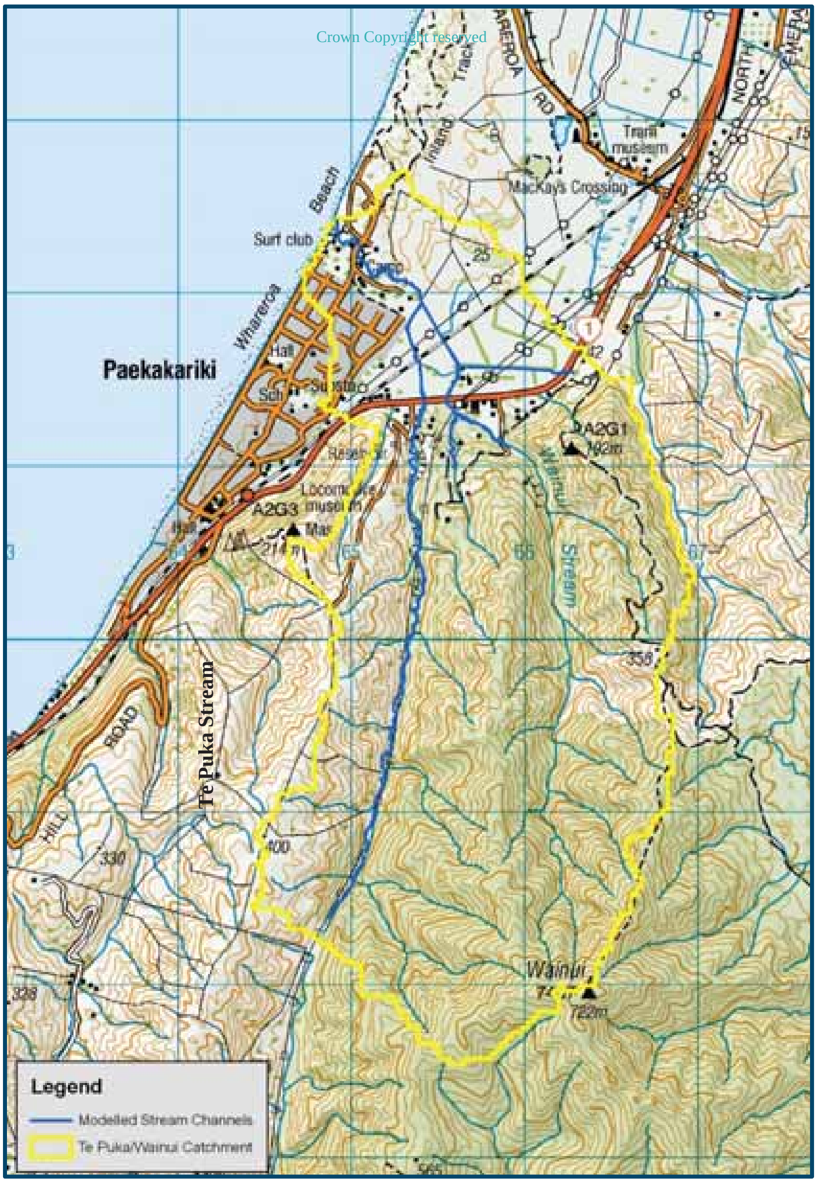
The hydraulic model's sensitivity to hydrological inputs was tested by running it with an oversized hydrological event and comparing it to the bridge design event. To create the oversized event inflow hydrographs for the hydraulic model, the 100 year storm rainfall including the mid range prediction of climate change was applied across all sub catchments. This resulted in over double the predicted flows for a 100 year flood at the gauging station.

The results of the oversized event revealed significant increases in flooding extents and peak water surface levels over the majority of the modelled stream network. Upstream of Paekakariki Hill Road peak water surface levels were predicted to increase by up to 500mm, while in the lower catchment, downstream of Paekakariki Hill Road, water surface levels were, in places, found to have increased by greater than 1m.

As the Transmission Gully Highway only crosses the Horokiri Stream upstream of Paekakariki Hill Road, this oversized event provided some confidence in the selection of a minimum of 600mm freeboard, from the Transit *Bridge Manual*, when sizing the three proposed bridge crossings.

E.5 Te Puka and Wainui Stream

The topography traversed by the Te Puka and Wainui Streams is typical of the Kapiti Region. The steep upper catchment drops down onto an undulating dune environment. This change in grade between the hills and the coastal zone, combined with the restrictions as the stream runs through the dunes, has resulted in historical flooding problems for the developed land surrounding the stream. For this reason, and the difficulty of constructing a highway through the steep sided valley, these streams have been classified as critical streams and have been investigated in detail to identify the effects of the Transmission Gully Project.



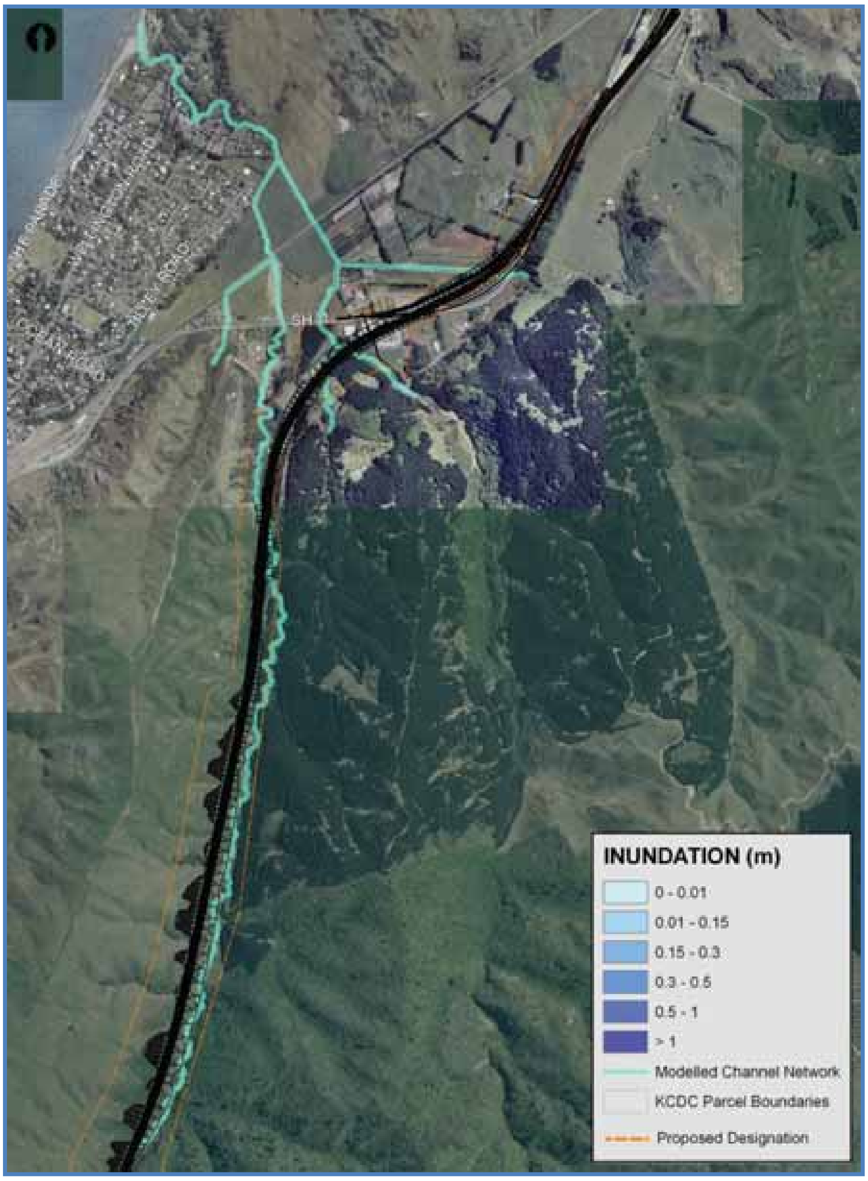
■ **Figure 69 - Te Puka and Wainui Catchment**

As shown in **Figure 69**, the two main streams drain an area of approximately 8 square kilometres, starting in the eastern hills before passing under State Highway 1 (SH1) and the NMIT Railway Line on the low lying coastal area. The streams converge into the Lower Wainui Stream north of the Paekakariki residential area and follow a gentle gradient to the sea.

Landuse in the local drainage area is a mixture of residential, commercial and agriculture on the coastal dunes and a mixture on pasture, plantation pine and native bush on the hills.

E.5.1 Transmission Gully Project Main Alignment

The Main Alignment route runs parallel to the Te Puka stream for 3km, from the top of the catchment until it crosses both the Te Puka and the Wainui streams before reconnecting with SH1. The alignment of the proposed highway is shown in **Figure 70.**



- **Figure 70 - Proposed Transmission Gully Alignment and Designation**

In this catchment the construction of the highway is complicated by the steep sides of the Te Puka valley. To construct the highway it is likely that in places the earthworks will encroach on to the existing stream, resulting in a number of stream diversions. The hydraulic model has been used to assist in the design of the diversions and identify changes in the stream hydraulics. The model has also been used to appropriately locate and size the stream crossings to help avoid or reduce impacts on the waterway.

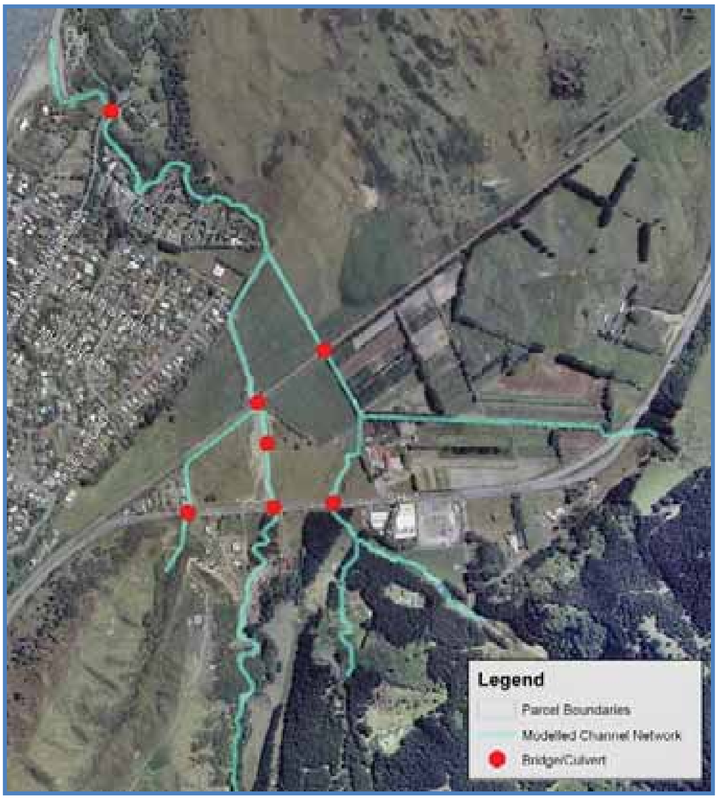
E.5.2 Te Puka and Wainui Stream Model

The reaches of the stream channels that were hydraulically modelled are shown above in **Figure 70.** Almost the full length of the Te Puka has been modelled from the saddle between the Horokiri and Te Puka valleys down to the coast. Only the lower reaches of the Wainui Stream have been modelled as the new highway encroaches on the stream much lower in its catchment.

While a coupled 1D/2D model was used, the steep sides of the Te Puka valley mean that much of the upper catchment was modelled only in the 1D model of the stream. It was only when the floodplain opens out near the coast that flooding spilled out onto the 2D model.

E.5.2.1 Topographic Survey

There are seven major structures on the Te Puka / Wainui Stream including various tributaries that pass through culverts under the State highway and railway line, a weir on the main channel west of the highway and the bridge at the southern entrance to QE2 Park. The dimensions of each structure were surveyed as part of this project (see **Figure 71**).



- **Figure 71 - Major Structures on the Te Puka / Wainui Stream**

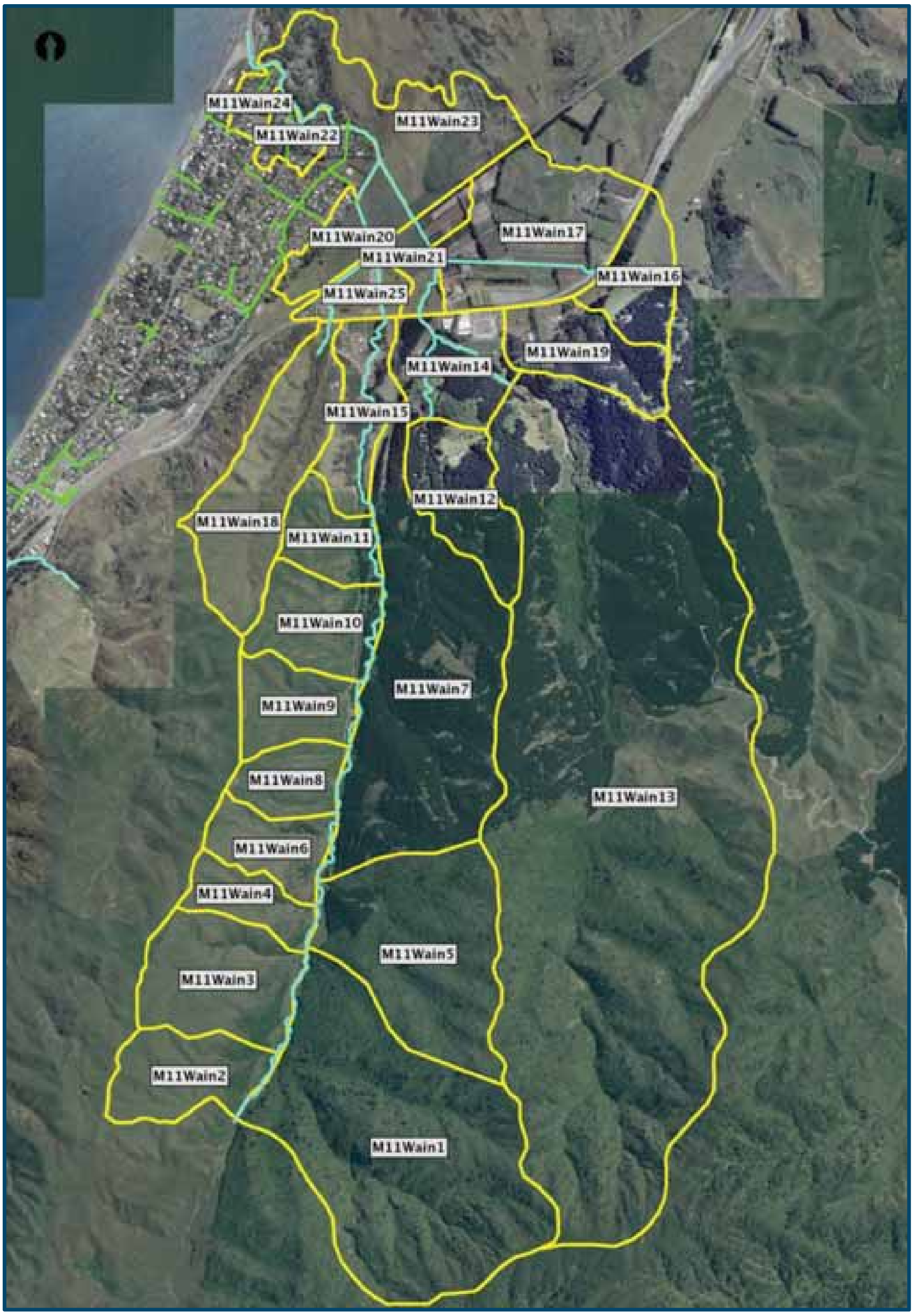
28 cross sections of the stream were picked up in the survey. The cross sections picked up the channel invert and spot heights between the true left bank and true right bank. Where possible a cross section was surveyed immediately upstream of the bridges to allow accurate representation of the channel at these hydraulic constraints in the stream model.

E.5.3 Te Puka and Wainui Catchment Hydrology

For the hydrological inputs into the hydraulic model the Te Puka catchment has been subdivided into 25 sub catchments (**see Figure 72**). The inflow from each sub catchment was extracted from the hydrological model as a discharge time series for entry into the hydraulic model. Peak flows from the sub catchments in both the pre and post construction scenario are detailed in Table 25.

Table 25 - Peak Flows – Te Puka MikeFlood Hydrology

Catchment	Pre- Construction Situation		Post- Construction Situation	
	10- Year Storm (Q10)	100- Year Storm Including the Impacts of Climate Change ($Q100_{cc}$)	10- Year Storm (Q10)	100- Year Storm Including the Impacts of Climate Change ($Q100_{cc}$)
M11Wain1	5.2	11.2	5.2	11.2
M11Wain2	1.5	3.1	1.6	3.2
M11Wain3	1.7	3.3	1.7	3.3
M11Wain4	0.7	1.3	0.7	1.3
M11Wain5	2.2	4.9	2.2	4.9
M11Wain6	0.8	1.6	0.8	1.6
M11Wain7	4.0	8.4	4.0	8.4
M11Wain8	0.7	1.5	0.8	1.5
M11Wain9	0.9	1.9	1.0	1.9
M11Wain10	1.1	2.2	1.1	2.2
M11Wain11	0.7	1.4	0.7	1.4
M11Wain12	1.1	2.2	1.1	2.2
M11Wain13	13.4	28.4	13.4	28.4
M11Wain14	1.0	2.2	1.1	2.2
M11Wain15	0.8	1.8	0.9	1.8
M11Wain16	0.7	1.6	0.7	1.6
M11Wain17	1.3	2.8	1.4	2.9
M11Wain18	1.6	3.3	1.6	3.3
M11Wain19	0.9	1.9	0.9	1.9
M11Wain20	0.8	1.9	0.8	1.9
M11Wain21	0.4	0.9	0.4	0.9
M11Wain22	0.2	0.4	0.2	0.4
M11Wain23	0.8	2.0	0.8	2.1
M11Wain24	0.1	0.3	0.1	0.3
M11Wain25	0.2	0.5	0.2	0.5
Total	**42.8**	**91**	**43.4**	**91.3**



- **Figure 72 - Te Puka and Wainui Streams Sub Catchments**

Note: The catchment, in the northern residential area of Paekakariki, is drained by a long section of stormwater pipe that has not been included in the model. Given the topography and size of the stormwater system it is not considered that this catchment will contribute significantly to the stream flows.

E.5.3.1 Calibration

Very little calibration information was available for either the Te Puka or the Wainui Streams. As neither stream was gauged the calibration has relied on historical flood records to confirm the sensibility of the results. The flood extents were compared with Kapiti Coast District Councils flood records database which records flood damage to buildings. The model extents have also been confirmed as being in line with the experience of Kapiti Coast District Council Stormwater Asset Managers who have a detailed understanding of the flooding issues in this catchment.

A conservative approach to the modelling of runoff from the stream catchment has been taken. The 100 and 10 year rainfall events were used on each of the sub-catchments. With this assumption it is possible that at the lower end of the model the peak water levels are likely to be overestimating the flooding for the return period event being modelled.

E.5.4 Sensitivity Analysis

To assess the impacts of changes in the model variables, a sensitivity analysis was undertaken on two key modelling parameters that could impact the results and alter the outcomes of the analysis. These variables were the downstream tidal boundary and the inflow hydrographs.

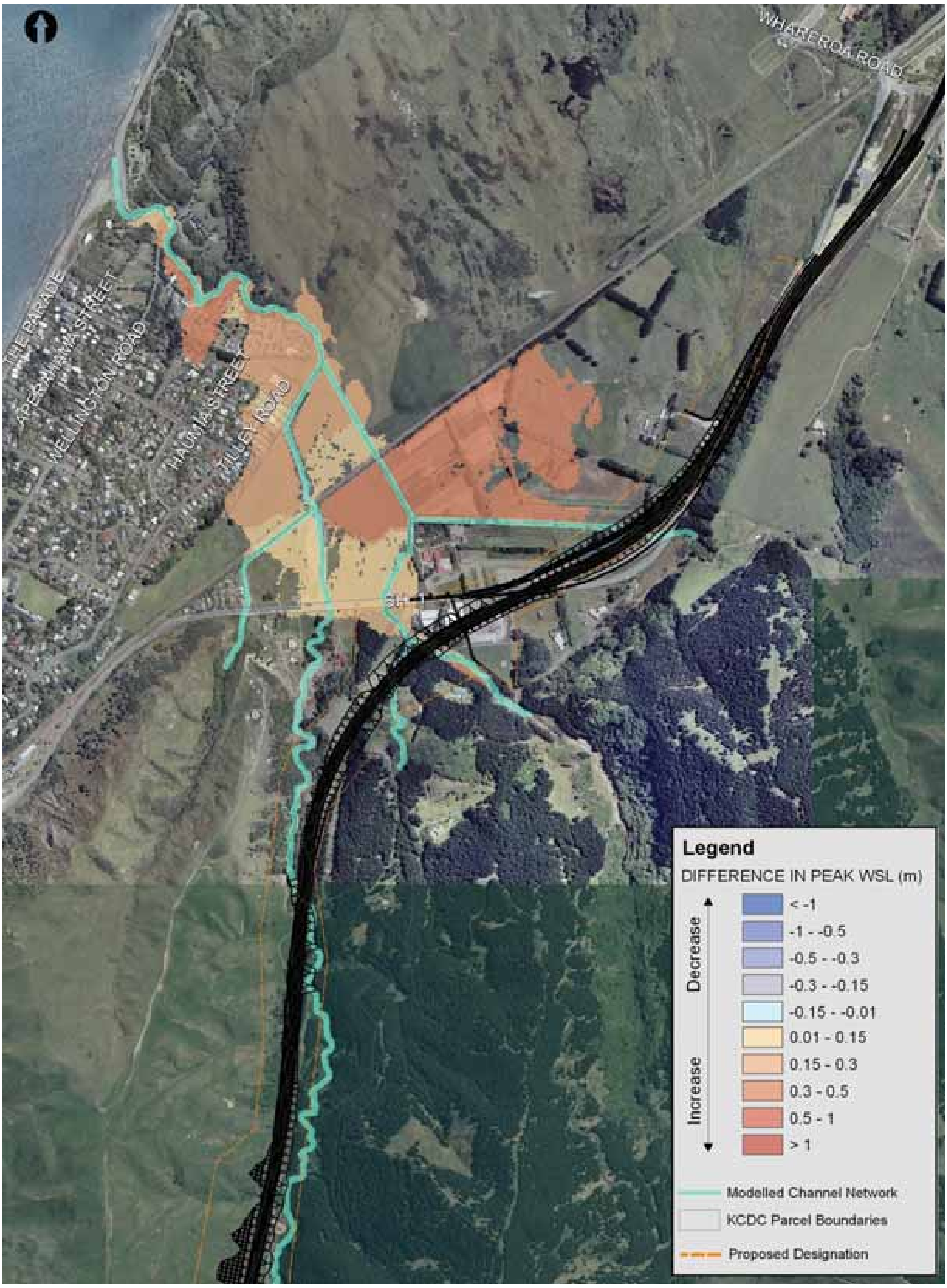
E.5.4.1 Tidal Boundary

The lower reaches of the catchment are tidally influenced. The sensitivity analysis was undertaken to quantify the impact of assumptions in sea level conditions during the modelled storm events. The model of the 100 year storm event was run with two different tidal levels: an oscillating sea level to simulate an astronomical tide and the same boundary raised by 1.5m to account for storm surge, wave setup and the predicted impacts of climate change.

The modelling results showed that the sea level conditions had very little impact on the catchment flooding in high rainfall events. The reason for this largely relates to the bridge at the southern entrance to QE2 Park. This bridge is a constraint to high flows that masks the influence of the sea level.

E.5.4.2 Oversized Events

The oversized event inflow hydrographs were created by increasing the 100 year flood event, including the mid range predictions of climate change, by half again. This was used to assess the hydraulic model's sensitivity to variations in hydrological inputs. A comparison of the 100^{cc} year flood flows and the oversized event is shown in **Figure 73**. These results show that as the floodplain opens up between the hills and the dunes there is up to 500mm difference in flood levels. Flooding on residential property, the highway and the railway is increased by 100-200mm. This provides a measure of confidence in the appropriateness of the freeboard allowance required in the NZTA *Bridge Manual* that culverts and bridges must convey the 100 year flows with a maximum water depth of 500mm below the carriageway level.



- **Figure 73 - Comparison of Peak Water Surface Levels Between a 100-Year Event and an Oversized Event**

Appendix 14.F. Culvert Catchment Assessment

- **Table 26 - Culvert Catchment Characteristics**

Main Catchment	Sub-catchment	Loss Rate Method - SCS Curve Number			Runoff Method - Clark's Unit Hydrograph				$Q10^{CC}$	$Q100^{CC}$
		Area (km^2)	Initial Abstraction	CN	CIA (%)	Tc (Hrs)	Ratio	Storage Coefficient (R)		
Wainui	Wainui 1	0.1	5	78	0	0.26	0.65	0.48	0.841	1.531
Wainui	Wainui 2	0.18	5	74	0	0.2	0.65	0.37	1.579	2.963
Wainui	Wainui 3	2.64	5	78	0	0.26	0.65	0.48	22.596	41.211
Wainui	Wainui 4	0.21	5	79	0	0.28	0.65	0.52	1.719	3.091
Wainui	TePuka 1	3.14	5	79	0	0.21	0.65	0.39	29.405	53.441
Wainui	TePuka 2	0.09	5	84	0	0.2	0.65	0.38	0.958	1.661
Wainui	TePuka 3	0.09	5	84	0	0.26	0.65	0.47	0.86	1.489
Wainui	TePuka 4	0.03	5	84	0	0.24	0.65	0.44	0.295	0.51
Wainui	TePuka 5	0.1	5	85	0	0.25	0.65	0.47	0.976	1.675
Wainui	TePuka 6	0.02	5	84	0	0.17	0.65	0.31	0.237	0.411
Wainui	TePuka 7	0.05	5	84	0	0.23	0.65	0.42	0.501	0.865
Wainui	TePuka 8	0.08	5	85	0	0.24	0.65	0.44	0.803	1.377
Wainui	TePuka 9	0.08	5	84	0	0.24	0.65	0.45	0.779	1.347
Wainui	TePuka 10	0.15	5	84	0	0.23	0.65	0.43	1.488	2.57
Wainui	TePuka 11	0.04	5	85	0	0.25	0.65	0.46	0.394	0.678
Wainui	TePuka 12	0.07	5	84	0	0.28	0.65	0.51	0.64	1.109
Wainui	TePuka 13	0.07	5	85	0	0.16	0.65	0.3	0.856	1.472
Wainui	TePuka 14	0.03	5	84	0	0.17	0.65	0.31	0.356	0.617
Wainui	TePuka 15	0.02	5	85	0	0.21	0.65	0.39	0.213	0.367
Horokiri	Horokiri 1	4.48	5	76	0	0.28	0.65	0.51	34.291	63.793
Horokiri	Horokiri 2	0.09	5	85	0	0.17	0.65	0.32	1.073	1.844
Horokiri	Horokiri 3	0.1	5	85	0	0.24	0.65	0.45	0.989	1.704
Horokiri	Horokiri 4	0.12	5	84	0	0.24	0.65	0.44	1.176	2.041
Horokiri	Horokiri 5	0.04	5	85	0	0.2	0.65	0.37	0.44	0.759
Horokiri	Horokiri 6A	0.02	5	85	0	0.17	0.65	0.31	0.242	0.416
Horokiri	Horokiri 6B	0.01	5	84	0	0.17	0.65	0.31	0.119	0.206
Horokiri	Horokiri 7	0.17	5	85	0	0.21	0.65	0.4	1.781	3.08
Horokiri	Horokiri 8	0.01	5	85	0	0.17	0.65	0.31	0.121	0.208
Horokiri	Horokiri 9	0.05	5	85	0	0.18	0.65	0.33	0.586	1.009
Horokiri	Horokiri 10	0.03	5	84	0	0.19	0.65	0.35	0.334	0.58
Horokiri	Horokiri 11	0.04	5	85	0	0.24	0.65	0.45	0.397	0.683
Horokiri	Horokiri 12	0.06	5	85	0	0.22	0.65	0.42	0.611	1.055

Main Catchment	Sub-catchment	Loss Rate Method - SCS Curve Number			Runoff Method - Clark's Unit Hydrograph				$Q10^{CC}$	$Q100^{CC}$
		Area (km²)	Initial Abstraction	CN	CIA (%)	Tc (Hrs)	Ratio	Storage Coefficient (R)		
Horokiri	Horokiri 13	0.05	5	84	0	0.18	0.65	0.33	0.575	0.998
Horokiri	Horokiri 14	0.03	5	84	0	0.22	0.65	0.41	0.303	0.528
Horokiri	Horokiri 15	0.15	5	72	0	0.21	0.65	0.4	1.185	2.264
Horokiri	Horokiri 16	0.15	5	70	0	0.22	0.65	0.41	1.114	2.146
Horokiri	Horokiri 17	0.07	5	70	0	0.16	0.65	0.3	0.619	1.193
Horokiri	Horokiri 18	0.1	5	69	0	0.2	0.65	0.37	0.771	1.503
Horokiri	Horokiri 19	0.09	5	69	0	0.18	0.65	0.33	0.743	1.444
Horokiri	Horokiri 20	0.04	5	69	0	0.16	0.65	0.3	0.347	0.676
Horokiri	Horokiri 21	0.55	5	77	0	0.35	0.65	0.64	3.809	7.017
Horokiri	Horokiri 21A	0.11	5	79	0	0.23	0.65	0.42	0.998	1.811
Horokiri	Horokiri 22	0.06	5	82	0	0.26	0.65	0.47	0.554	0.982
Horokiri	Horokiri 23	0.03	5	82	0	0.19	0.65	0.36	0.318	0.565
Horokiri	Horokiri 24	1.06	5	80	0	0.56	0.65	1.04	6.125	11.099
Horokiri	Horokiri 25	11.28	5	79	0	0.67	0.65	1.25	54.94	100.861
Horokiri	Horokiri 26	0.03	5	81	0	0.17	0.65	0.31	0.335	0.599
Horokiri	Horokiri 27	0.03	5	84	0	0.17	0.65	0.32	0.35	0.613
Horokiri	Horokiri 28	0.05	5	81	0	0.17	0.65	0.31	0.556	0.991
Horokiri	Horokiri 29	0.03	5	80	0	0.17	0.65	0.31	0.327	0.587
Horokiri	Horokiri 30	0.01	5	83	0	0.17	0.65	0.31	0.116	0.203
Horokiri	Horokiri 31	0.01	5	83	0	0.17	0.65	0.31	0.114	0.203
Horokiri	Horokiri 32	0.01	5	83	0	0.17	0.65	0.31	0.114	0.203
Horokiri	Horokiri 33	0.04	5	82	0	0.17	0.65	0.31	0.449	0.802
Horokiri	Horokiri 34	0.02	5	71	0	0.19	0.65	0.36	0.163	0.316
Horokiri	Horokiri 35	0.05	5	77	0	0.19	0.65	0.35	0.473	0.882
Horokiri	Horokiri 36	0.06	5	79	0	0.22	0.65	0.41	0.536	0.988
Horokiri	Horokiri 37	0.04	5	84	0	0.2	0.65	0.37	0.424	0.749
Horokiri	Horokiri 38	0.03	5	85	0	0.17	0.65	0.31	0.357	0.623
Ration	Ration 1	0.47	5	83	0	0.29	0.65	0.54	4.05	7.198
Ration	Ration 2	0.02	5	85	0	0.18	0.65	0.34	0.228	0.398
Ration	Ration 3	0.12	5	84	0	0.33	0.65	0.61	0.973	1.725
Ration	Ration 4	0.01	5	84	0	0.21	0.65	0.39	0.103	0.181
Ration	Ration 5	0.03	5	84	0	0.18	0.65	0.33	0.339	0.598
Ration	Ration 6	0.01	5	82	0	0.2	0.65	0.37	0.102	0.183
Ration	Ration 7	1.49	5	82	0	0.22	0.65	0.41	14.459	25.762
Ration	Ration 8	0.29	5	83	0	0.17	0.65	0.31	3.316	5.889

Main Catchment	Sub-catchment	Loss Rate Method - SCS Curve Number			Runoff Method - Clark's Unit Hydrograph				$Q10^{CC}$	$Q100^{CC}$
		Area (km²)	Initial Abstraction	CN	CIA (%)	Tc (Hrs)	Ratio	Storage Coefficient (R)		
Ration	Ration 9	0.05	5	84	0	0.27	0.65	0.5	0.446	0.802
Ration	Ration 10	1.08	5	83	0	0.5	0.65	0.92	6.78	12.151
Ration	Ration 10a	0.02	5	85	0	0.32	0.65	0.59	0.168	0.269
Ration	Ration 11	0.08	5	85	0	0.17	0.65	0.31	0.924	1.614
Ration	Ration 12	0.02	5	84	0	0.28	0.65	0.52	0.173	0.306
Ration	Ration 13	0.13	5	83	0	0.29	0.65	0.53	1.085	1.938
Ration	Ration 14	0.05	5	85	0	0.31	0.65	0.57	0.41	0.73
Pauatahanui	Pauatahanui 1	0.28	5	79	0	0.31	0.65	0.57	2.013	3.767
Pauatahanui	Pauatahanui 2	0.15	5	79	0	0.25	0.65	0.47	1.205	2.255
Pauatahanui	Pauatahanui 3	0.01	5	80	0	0.24	0.65	0.45	0.084	0.155
Pauatahanui	Pauatahanui 4	0.01	5	81	0	0.26	0.65	0.49	0.082	0.151
Pauatahanui	Pauatahanui 5	0.03	5	81	0	0.22	0.65	0.41	0.266	0.486
Pauatahanui	Pauatahanui 6	0.11	5	80	0	0.31	0.65	0.57	0.801	1.494
Pauatahanui	Pauatahanui 7	39.09	5	75	0	1.48	0.65	2.75	104.792	200.123
Pauatahanui	Pauatahanui 8	0.14	5	78	0	0.27	0.65	0.50	0.9722	1.8409
Pauatahanui	Pauatahanui 9	0.03	2	77	55	0.24	0.65	0.45	0.286	0.487
Duck	Duck 1	0.01	5	78	0	0.17	0.65	0.31	0.093	0.178
Duck	Duck 2	0.02	5	74	4	0.17	0.65	0.31	0.174	0.339
Duck	Duck 3	0.02	5	78	5	0.17	0.65	0.31	0.19	0.357
Duck	Duck 4	0.01	5	82	0	0.17	0.65	0.31	0.102	0.187
Duck	Duck 5	0.02	5	82	0	0.17	0.65	0.31	0.204	0.374
Duck	Duck 6	0.03	5	82	0	0.17	0.65	0.31	0.305	0.561
Duck	Duck 7	0.39	5	82	0	0.35	0.65	0.66	2.656	4.951
Duck	Duck 8	0.13	5	84	0	0.27	0.65	0.49	1.087	1.969
Duck	Duck 9	0.18	5	84	0	0.28	0.65	0.52	1.458	2.642
Duck	Duck 10	0.09	5	85	0	0.25	0.65	0.47	0.787	1.411
Duck	Duck 11	1.83	5	84	0	0.29	0.65	0.54	14.475	26.474
Duck	Duck 12	0.84	5	84	0	0.19	0.65	0.36	8.258	14.929
Duck	Duck 13	0.02	5	85	0	0.22	0.65	0.4	0.185	0.336
Duck	Duck 14	0.21	5	85	0	0.27	0.65	0.5	1.76	3.185
Duck	Duck 15	0.39	5	85	0	0.24	0.65	0.44	3.473	6.267
Duck	Duck 16	0.01	5	85	0	0.19	0.65	0.36	0.098	0.18
Duck	Duck 17	0.01	4	84	21	0.17	0.65	0.31	0.113	0.199
Duck	Duck 18	5.72	5	84	1	0.63	0.65	1.17	29.096	53.008
Duck	Duck 19	0.02	5	70	0	0.18	0.65	0.34	0.145	0.296

Table 27 - Culvert Details

Culvert ID	Culvert sub-catchment	Chainage (m)	U/S Invert level (m)	D/S Invert Level (m)	Culvert Length (m)	Culvert Diameter (mm)	Type of fish passage required
W1	Wainui 1	1525	16	10	155	1050	Std Design
W2	Wainui 2	1630	16	10	109	1050	Std Design
W3	Wainui 3	2100	19	18	96	Two 3m (W) x 2.5m (H) box culverts	Std Design
W4	Wainui 4	2250	27	18	95	900	Std Design
BSN 3	Te Puka 1	2750	Refer to Schedule of Bridges				
T3	Te Puka 3	3075	84	65	91	1050	None
T4	Te Puka 4	3300	98	80	69	600	New Design
T5	Te Puka 5	3475	115	95	56	1050	None
T6	Te Puka 6	3725	134	124	58	600	None
T7	Te Puka 7	3900	148	117	72	900	None
T8	Te Puka 8	4025	152.5	121	85	1050	None
T9	Te Puka 9	4300	178	140	85	1050	None
T10	Te Puka 10	4475	178	150	93	1200	Std Design
T15	Te Puka 15	4575	205	164	84	600	None
T11	Te Puka 11	4775	220	184	80	600	None
T12	Te Puka 12	4875	220.5	185	65	1050	None
T13	Te Puka 13	5025	236.5	218	58	1050	None
T14	Te Puka 14	5200	276	222	245	900	None
H2	Horokiri 2	5375	276	254	266	1050	Std Design
H3	Horokiri 3	5650	257	251	51	1050	New Design
H4	Horokiri 4	5825	247.5	235	72	1050	New Design
H5	Horokiri 5	5930	244	229	69	750	None
H6A	Horokiri 6A	6075	236	225	61	600	None
H6B	Horokiri 6B	6150	232	218	54	600	None
H7	Horokiri 7	6275	226	218	84	1350	Std Design
H8	Horokiri 8	6400	223	200	73	600	None
H9	Horokiri 9	6575	217	196	57	900	None
H10	Horokiri 10	6625	215	195	58	600	None
H11	Horokiri 11	6675	206	182	80	750	None
H12	Horokiri 12	6850	203	190	64	900	None
H13	Horokiri 13	7050	182	168	72	900	None
H14	Horokiri 14	7250	174	157	93	600	None
H15	Horokiri 15	7400	168	154	96	1200	New Design
H16	Horokiri 16	7675	158	148	68	1200	New Design
H17	Horokiri 17	8000	144	130	64	900	None
H18	Horokiri 18	8150	134	125	44	1050	New Design

Culvert ID	Culvert sub-catchment	Chainage (m)	U/S Invert level (m)	D/S Invert Level (m)	Culvert Length (m)	Culvert Diameter (mm)	Type of fish passage required
H19	Horokiri 19	8375	120	119.5	51	900	New Design
BSN 4	Horokiri 1	8550	Refer to Schedule of Bridges				
H21A	Horokiri 21A	8850	109	108.5	50	1200	None
H22	Horokiri 22	9000	108	107.5	45	900	None
H23	Horokiri 23	9150	104	103.5	33	600	None
H24	Horokiri 24	9325	98	95	64	3m (W) x 2.5m (H) box culvert	Std Design
BSN 6	Horokiri 21	9750	Refer to Schedule of Bridges				
H26	Horokiri 26	9925	79.5	75	52	600	None
H27	Horokiri 27	10175	78	74	74	600	None
H29	Horokiri 29	10550	70.5	68	66	900	None
H30	Horokiri 30	10750	69	64	74	600	None
H31	Horokiri 31	10800	69	64	74	600	None
H32	Horokiri 32	11125	63	59	73	600	None
H33	Horokiri 33	11250	56	54	63	900	None
BSN 8	Horokiri 25	11775	Refer to Schedule of Bridges				
BSN 9	Horokiri 25	n/a	Refer to Schedule of Bridges				
H34	Horokiri 34	12025	59.5	59	41	600	None
H35	Horokiri 35	12125	62	59	49	900	None
H36	Horokiri 36	12200	63.5	55	96	900	None
H37	Horokiri 37	12400	69	62	81	750	None
BSN 11	Ration 1	12840	Refer to Schedule of Bridges				
R2	Ration 2	13000	92.5	89	33	750	None
R3	Ration 3	13100	92.5	86	89	1050	Std Design
R4	Ration 4	13250	95.5	95	50	600	None
R5	Ration 5	13400	91.5	81	113	600	None
R6	Ration 6	13450	88.5	83	86	600	None
R7	Ration 7	13550	84.5	78	136	3000	Std Design
R8	Ration 8	13900	81.5	78	74	1600	Std Design
R9	Ration 9	13950	83.5	80	72	750	None
R10	Ration 10	14775	48	44	125	2100	Std Design
R10A	Ration 10a	14650	58	54	110	600	None
R11	Ration 11	15075	49.5	39	133	1200	None
R12	Ration 12	15350	55.5	48	126	600	None
R13	Ration 13	15600	56.5	51	109	1200	Std Design
R14	Ration 14	15800	53.5	44	153	900	None
C1	Collins 1	16125	58.5	58	88	750	None
Pa1	Pauatahanui 1	16700	28	22	107	1200	None

Culvert ID	Culvert sub-catchment	Chainage (m)	U/S Invert level (m)	D/S Invert Level (m)	Culvert Length (m)	Culvert Diameter (mm)	Type of fish passage required
Pa2	Pauatahanui 2	16875	27.5	23	81	1200	Std Design
Pa3	Pauatahanui 3	17000	29	28.5	55	600	None
Pa4	Pauatahanui 4	17175	18	17	63	600	None
Pa5	Pauatahanui 5	17350	13.5	2	128	600	None
Pa6	Pauatahanui 6	17475	6	4	40	1050	Std Design
Pa6A	Pauatahanui 6a	17475	6	4	40	1050	None
BSN 15	Pauatahanui 7	17675	Refer to Schedule of Bridges				
Pa8	Pauatahanui 8	18225	51.5	51	52	1200	None
Pa9	Pauatahanui 9	18450	65.5	64	78	600	None
D17	Duck 17	19550	99	93	62	600	None
D19	Duck 19	n/a	66	65	45	600	None
D20	Duck 20	n/a	79	66	70	600	None
D21	Duck 21	n/a	89	83	46	600	None
D22	Duck 22	n/a	98.5	84	63	600	None
D23	Duck 23	n/a	86.5	79	91	900	None
D24	Duck 24	n/a	92.5	79	95	750	None
D25	Duck 25	n/a	109.5	100	48	600	None
D26	Duck 26	n/a	102	99	44	600	None
D1	Duck 1	19950	105.5	62	195	600	None
D2	Duck 2	20100	95.5	70	141	600	None
D3	Duck 3	20200	95.5	70	128	600	None
D4	Duck 4	20375	93	66	113	600	None
D5	Duck 5	20525	90.5	81	74	600	None
D6	Duck 6	20600	87.5	57	154	600	None
D7	Duck 7	20650	88	62	164	1600	Std Design
D8	Duck 8	21000	94.5	76	119	1050	New Design
D9	Duck 9	21225	95.5	82	167	1200	New Design
D10	Duck 10	21425	107.5	91	109	1050	None
BSN 29	Duck 18	n/a	Refer to Schedule of Bridges				
BSN 17	n/a	21600	Refer to Schedule of Bridges				
BSN 18	n/a	21950	Refer to Schedule of Bridges				
D13	Duck 13	22450	141	135	62	600	None
D14	Duck 14	22700	142.5	140	76	1350	Std Design
BSN 19	Duck 15	22850					
D16	Duck 16	23050	172	170	49	600	None
DM1*	n/a	n/a	79.3	76.6	10	Replace as existing	Std Design
DM2*	n/a	n/a	90.0	90.0	10	Replace as existing	Std Design
DM3*	n/a	n/a	84.6	84.3	10	Replace as existing	Std Design

Culvert ID	Culvert sub-catchment	Chainage (m)	U/S Invert level (m)	D/S Invert Level (m)	Culvert Length (m)	Culvert Diameter (mm)	Type of fish passage required
DM4*	n/a	n/a	90.1	90.0	10	Replace as existing	Std Design
DM5*	n/a	n/a	90.4	90.0	10	Replace as existing	Std Design
DM6*	n/a	n/a	115.0	114.5	15	Replace as existing	Std Design
DM7*	n/a	n/a	129.2	126.3	15	Replace as existing	Std Design
DM8*	n/a	n/a	136.1	135.3	12	Replace as existing	Std Design
BSN 20	Kenepuru 1	23650	Refer to Schedule of Bridges				
K2	Kenepuru 2	24475	151	146	39	600	None
K3	Kenepuru 3	24625	146.5	145.5	82	600	None
K4	Kenepuru 4	24700	141.5	122	53	600	None
K5	Kenepuru 5	24850	133.5	121	72	900	None
K6	Kenepuru 6	24875	135	112	67	600	None
K7	Kenepuru 7	25100	123.5	109	83	975	None
K8	Kenepuru 8	25200	116	115	49	600	None
K9	Kenepuru 9	25325	115	105	54	1200	New Design
BSN 21	Kenepuru 10	25825	Refer to Schedule of Bridges				
BSN 22	Porirua 1	26050	Refer to Schedule of Bridges				
Po2	Porirua 2	26200	45.5	36.5	73	600	None
Po3	Porirua 3	26325	54	44	84	825	None
Po4	Porirua 4	26425	58	44	115	900	None
Po5	Porirua 5	26775	45.5	39.5	149	1200	None
Po6	Porirua 6	27000	10.5	9.1	140	975	None

* Replacing existing culverts on grade to allow fish passage, as detailed in Technical Report 11

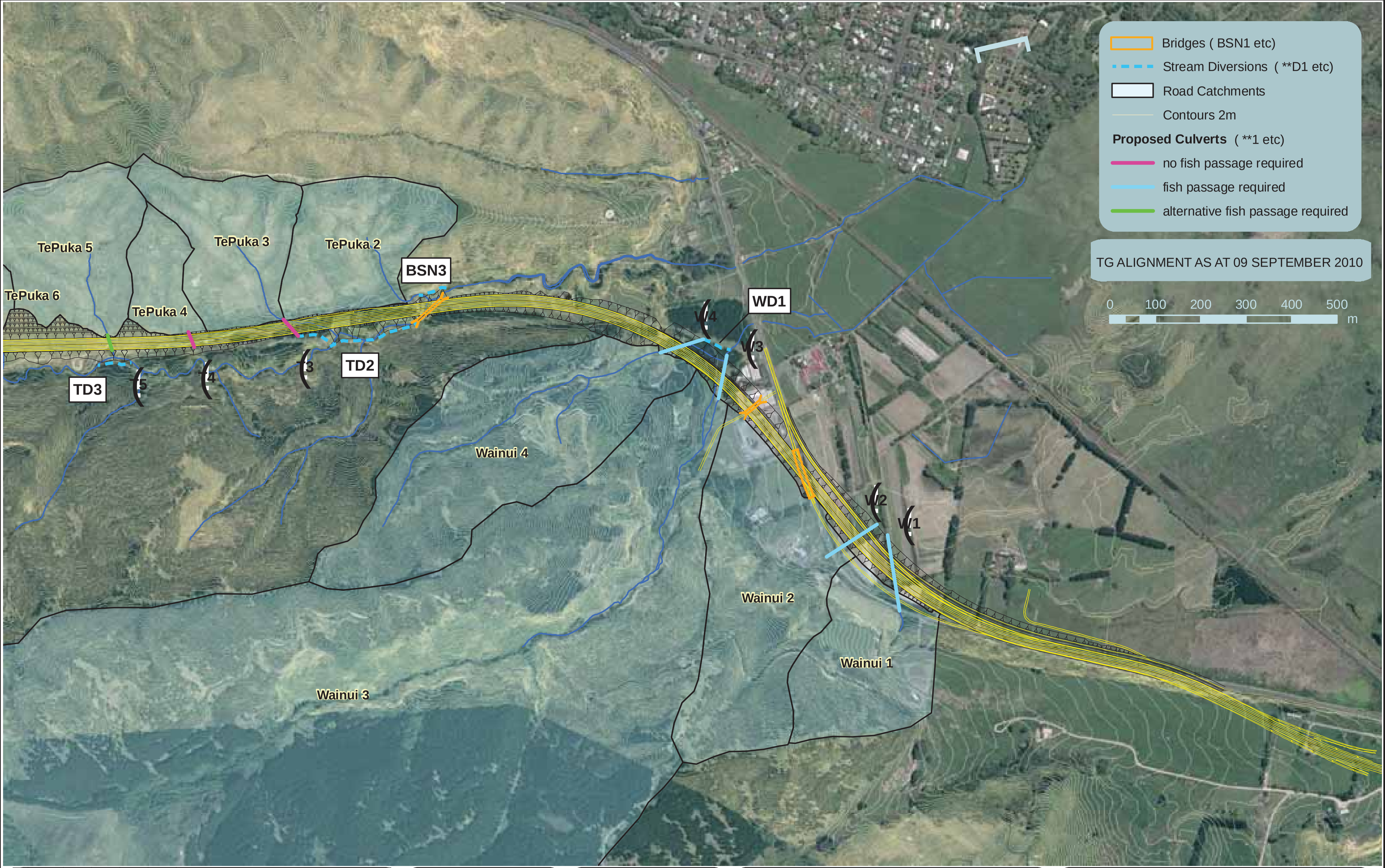
Table 28 – Temporary Access Culverts Requirements

Catchment	Area (ha)	Rainfall	C coefficient	Intensity (mm/hr)	Tc (hours)	Q2 Peak	Fish Passage Required?	Final Culvert Size (mm)	Or Box Culvert
TC1	317	88	0.35	31	0.58	9.4	Y	3060	3000*1900
TC2	6	86	0.35	41	0.33	0.2		600	
TC3	8	86	0.35	45	0.27	0.3		600	
TC4	10	86	0.35	44	0.28	0.4	Alternative	750	
TC5	3	86	0.35	49	0.23	0.1		600	
TC6	220	88	0.35	31	0.57	6.7	Y	2550	
TC7	219	88	0.35	31	0.57	6.6	Y	2550	
TC8	8	86	0.35	47	0.25	0.4		750	
TC9	195	88	0.35	32	0.55	6.0	Y	2300	
TC10	37	88	0.35	43	0.31	1.5	Y	1500	
TC11	85	88	0.35	42	0.32	3.5	Y	1950	
TC12	15	87	0.35	43	0.30	0.6		900	
TC13	7	86	0.35	46	0.26	0.3	Y	900	
TC14	44	87	0.35	41	0.34	1.7	Y	1500	
TC15	64	87	0.35	31	0.55	1.9	Y	1650	
TC16	17	86	0.35	44	0.28	0.7	Y	1200	
TC17	114	87	0.35	31	0.55	3.5	Y	1950	
TC18	30	88	0.35	42	0.32	1.3		1050	
TC19	155	87	0.35	30	0.60	4.5	Y	2300	
TC20	6	86	0.35	51	0.22	0.3		600	
TC21	214	87	0.35	30	0.60	6.2	Y	2300	
TC22	219	87	0.35	30	0.60	6.4	Y	2300	
TC23	225	87	0.35	30	0.60	6.5	Y	2300	
TC24	226	87	0.35	30	0.60	6.6	Y	2300	
TC25	241	87	0.35	25	0.82	5.9	Y	2300	
TC26	2	87	0.35	50	0.23	0.1		600	
TC27	3	87	0.35	50	0.23	0.2		600	
TC28	314	87	0.35	24	0.93	7.2	Y	2550	
TC29	453	87	0.35	23	0.97	10.2	Y	3060	3000*1900
TC30	5	87	0.35	47	0.26	0.2		600	
TC31	105	88	0.35	34	0.48	3.4	Y	1950	
TC32	640	87	0.35	20	1.25	12.5	Y	3060	3000*2200
TC33	4	86	0.35	44	0.28	0.2		600	

Catchment	Area (ha)	Rainfall	C coefficient	Intensity (mm/hr)	Tc (hours)	Q2 Peak	Fish Passage Required?	Final Culvert Size (mm)	Or Box Culvert
TC34	2	85	0.35	44	0.28	0.1		600	
TC35	1059	87	0.35	18	1.57	18.4	Y	3000*2800	
TC36	22	85	0.35	39	0.35	0.8	Y	1200	
TC37	3	84	0.35	40	0.32	0.1	Y	750	
TC38	1	84	0.35	47	0.24	0.0	Y	600	
TC39	50	85	0.35	33	0.46	1.6	Y	1500	
TC40	51	85	0.35	33	0.46	1.7	Y	1500	
TC41	113	84	0.35	28	0.63	3.1	Y	1800	
TC42	7	83	0.35	39	0.33	0.3		600	
TC43	3	83	0.35	39	0.33	0.1		600	
TC44	13	83	0.35	38	0.34	0.5	Y	1050	
TC45	3	82	0.35	41	0.29	0.1		600	
TC46	3	82	0.35	41	0.30	0.1		600	
TC47	1	82	0.35	44	0.26	0.1		600	
TC48	19	82	0.35	36	0.38	0.7		900	
TC49	10	81	0.35	39	0.32	0.4		750	
TC50	576	78	0.35	21	0.92	11.9	Y	3060	3000*2100
TC51	0	76	0.35	47	0.20	0.0		600	
TC52	2	76	0.35	40	0.27	0.1		600	
TC53	1	76	0.35	44	0.22	0.0		600	
TC54	1	76	0.35	45	0.22	0.0		600	
TC55	1	76	0.35	45	0.21	0.0		600	
TC56	1	76	0.35	44	0.22	0.0		600	
TC57	3	75	0.35	40	0.26	0.1	Y	750	
TC58	40	75	0.35	34	0.35	1.3	Y	1350	
TC59	1	75	0.35	43	0.23	0.1		600	
TC60	4	75	0.35	39	0.28	0.2		600	
TC61	11	75	0.35	35	0.34	0.4		750	

Main Catchment	Sub-catchment	Loss Rate Method - SCS Curve Number			Runoff Method - Clark's Unit Hydrograph				$Q10^{CC}$	$Q100^{CC}$
		Area (km²)	Initial Abstraction	CN	CIA (%)	Tc (Hrs)	Ratio	Storage Coefficient (R)		
Duck	Duck 20	0.03	5	72	0	0.22	0.65	0.4	0.206	0.415
Duck	Duck 21	0.01	5	72	0	0.23	0.65	0.43	0.067	0.134
Duck	Duck 22	0.02	4	74	29	0.2	0.65	0.36	0.181	0.333
Duck	Duck 23	0.09	5	83	1	0.24	0.65	0.44	0.771	1.41
Duck	Duck 24	0.05	5	84	0	0.23	0.65	0.44	0.428	0.79
Duck	Duck 25	0.03	5	85	0	0.23	0.65	0.43	0.265	0.48
Duck	Duck 26	0.03	5	84	0	0.21	0.65	0.4	0.27	0.494
Collins	Collins 1	0.04	5	84	0	0.26	0.65	0.48	0.356	0.638
Kenepuru	Kenepuru 1	1.49	5	94	0	0.38	0.65	0.71	12.038	20.391
Kenepuru	Kenepuru 10	0.04	5	88	0	0.2	0.65	0.36	0.41	0.711
Kenepuru	Kenepuru 2	0.02	5	83	0	0.22	0.65	0.4	0.173	0.321
Kenepuru	Kenepuru 3	0.03	5	82	0	0.19	0.65	0.36	0.273	0.502
Kenepuru	Kenepuru 4	0.03	5	82	0	0.23	0.65	0.44	0.244	0.449
Kenepuru	Kenepuru 5	0.06	5	94	0	0.28	0.65	0.52	0.571	0.95
Kenepuru	Kenepuru 6	0.01	5	92	0	0.19	0.65	0.35	0.113	0.19
Kenepuru	Kenepuru 7	0.09	5	92	0	0.3	0.65	0.56	0.792	1.34
Kenepuru	Kenepuru 8	0.02	5	94	0	0.17	0.65	0.31	0.249	0.41
Kenepuru	Kenepuru 9	0.16	5	94	0	0.34	0.65	0.63	1.373	2.284
Porirua	Porirua 1	0.39	5	89	2	0.17	0.65	0.31	4.44	7.584
Porirua	Porirua 2	0.02	2	91	54	0.17	0.65	0.32	0.248	0.402
Porirua	Porirua 3	0.05	4	91	25	0.18	0.65	0.34	0.56	0.963
Porirua	Porirua 4	0.1	5	92	9	0.29	0.65	0.54	0.906	1.509
Porirua	Porirua 5	0.24	5	84	0	0.39	0.65	0.73	1.536	2.784
Porirua	Porirua 6	0.13	5	78	0	0.29	0.65	0.54	0.824	1.626
Porirua	Porirua 7	0.83	4	76	10	0.4	0.65	0.74	4.633	8.703

Appendix 14.G. Culvert Catchments



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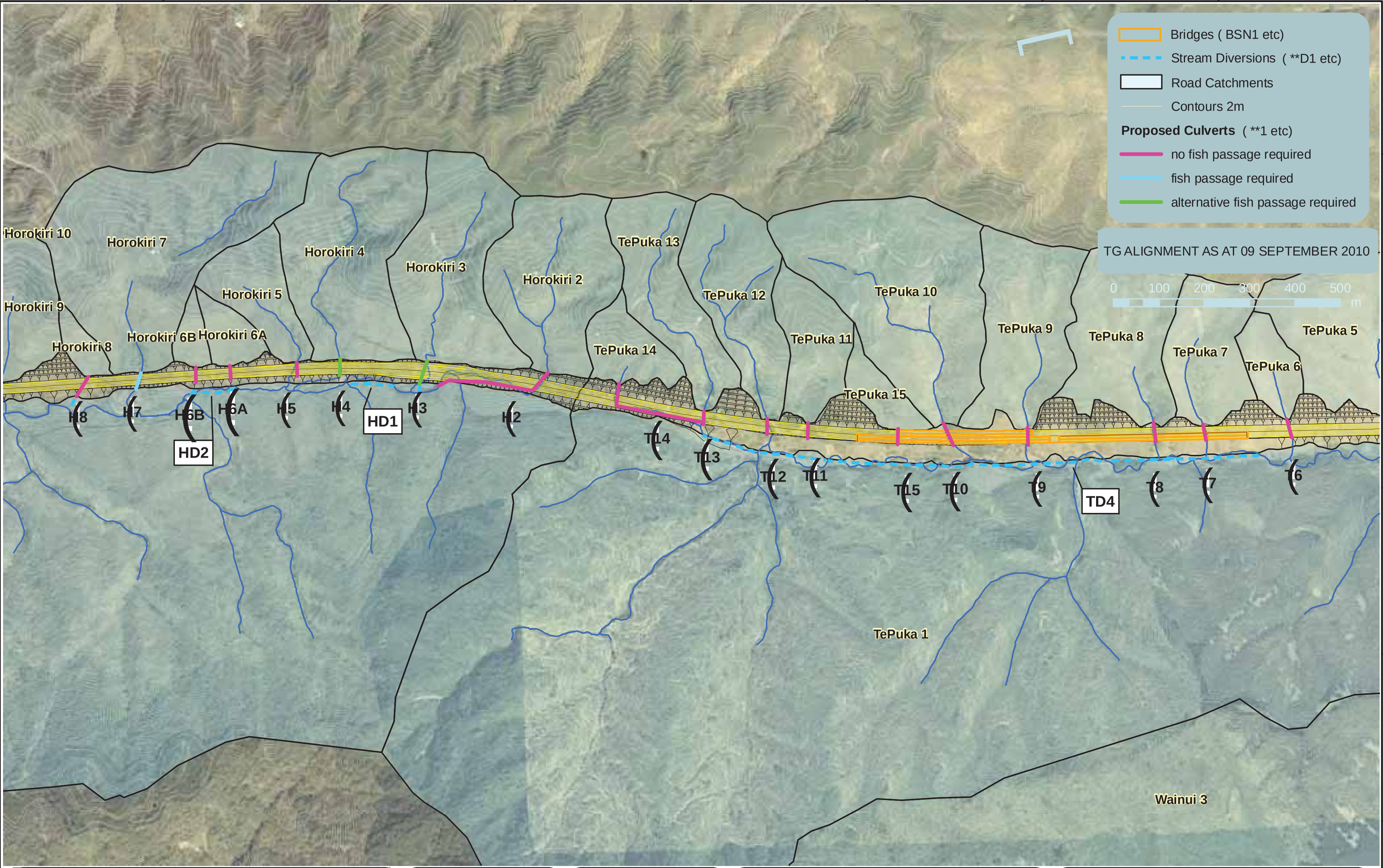

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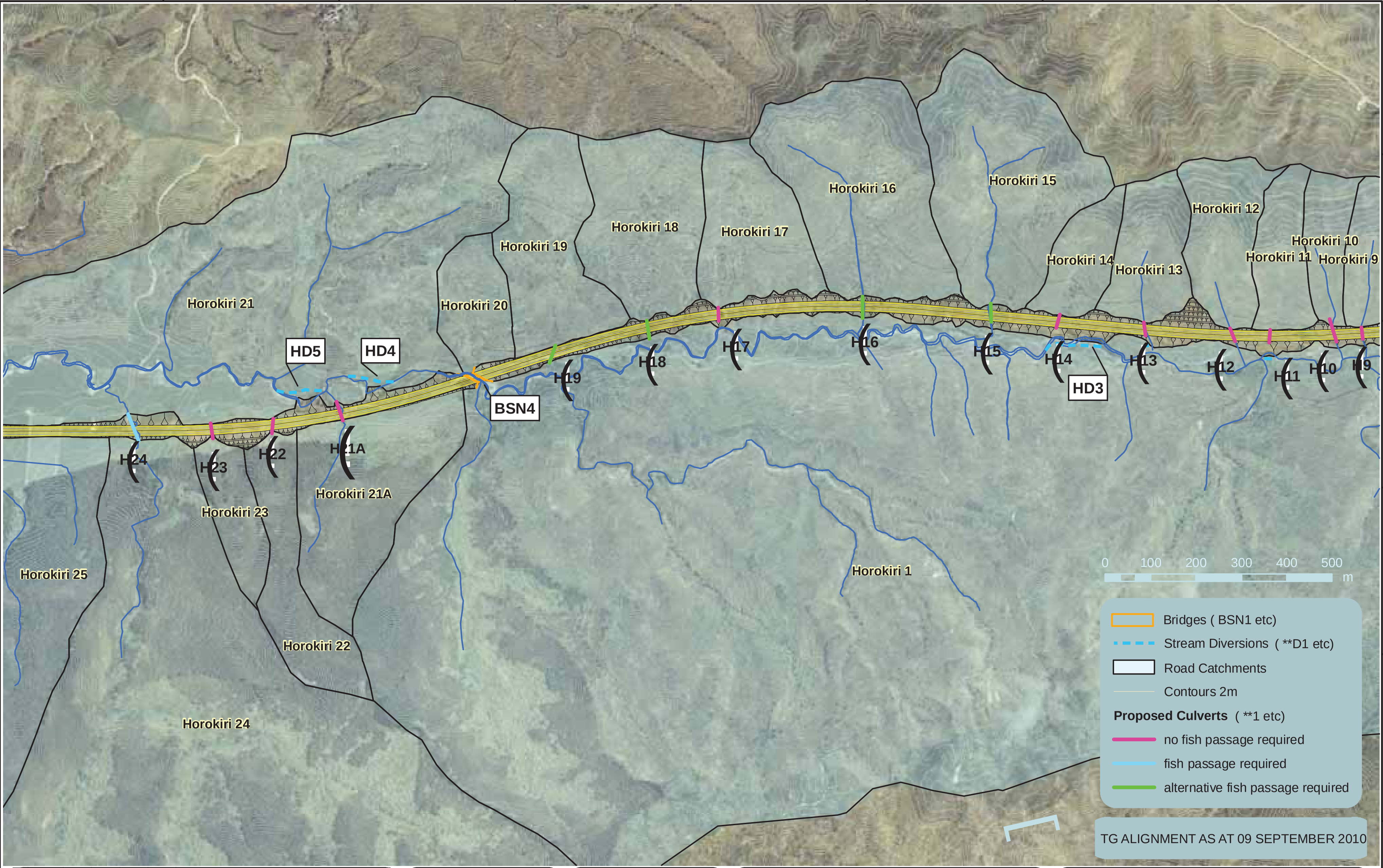

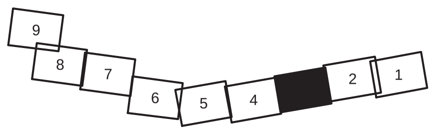

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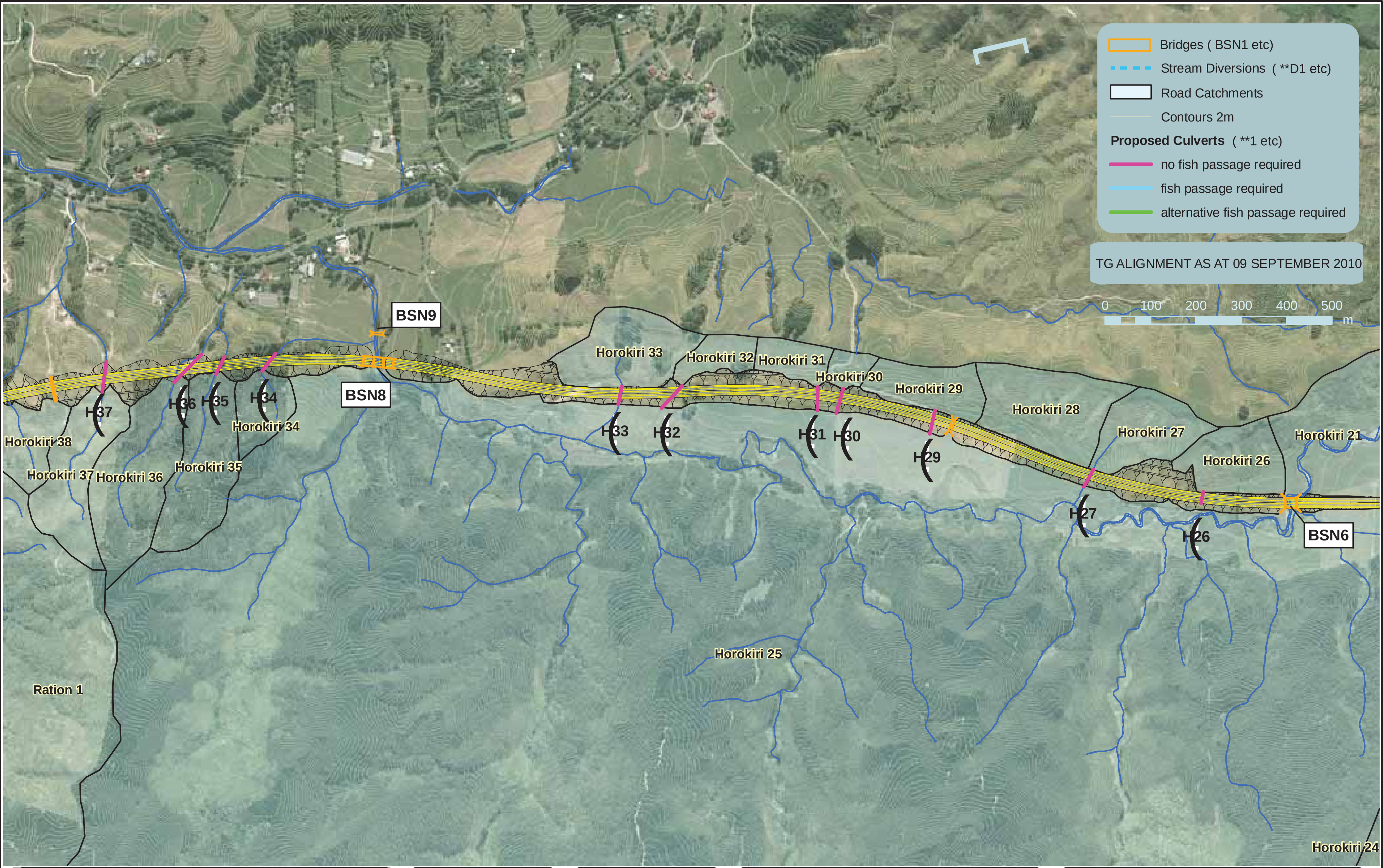

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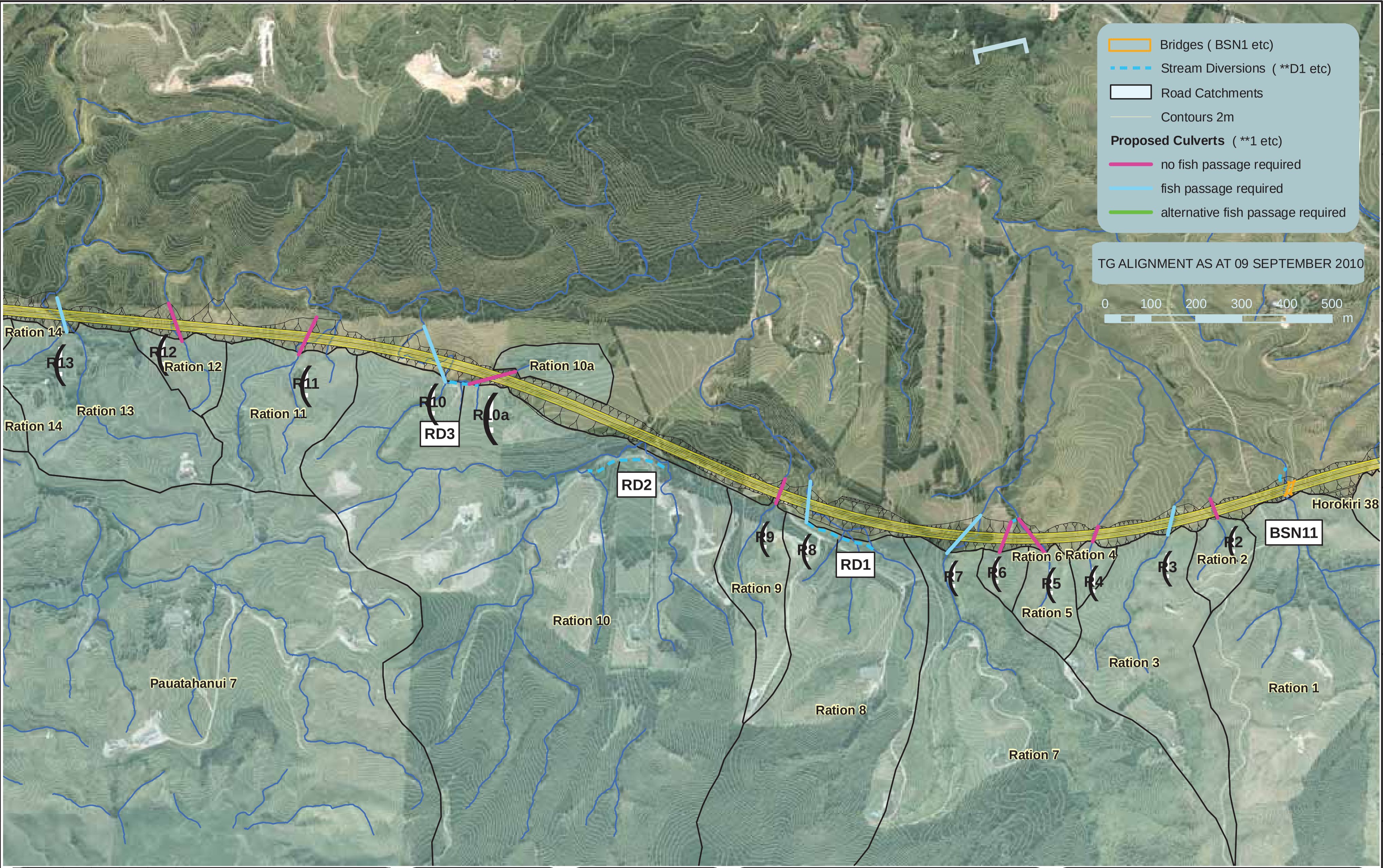

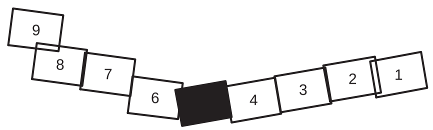

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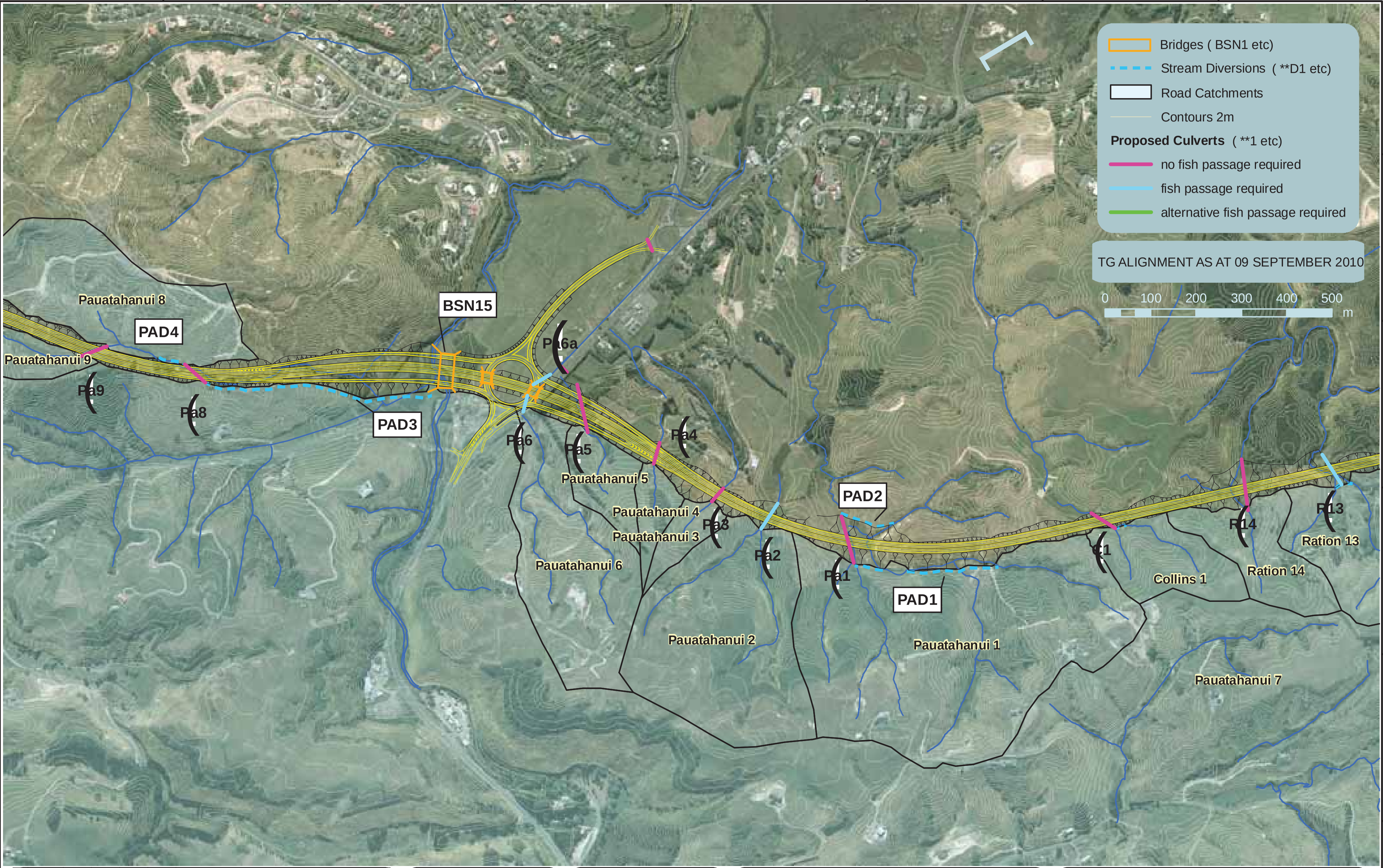

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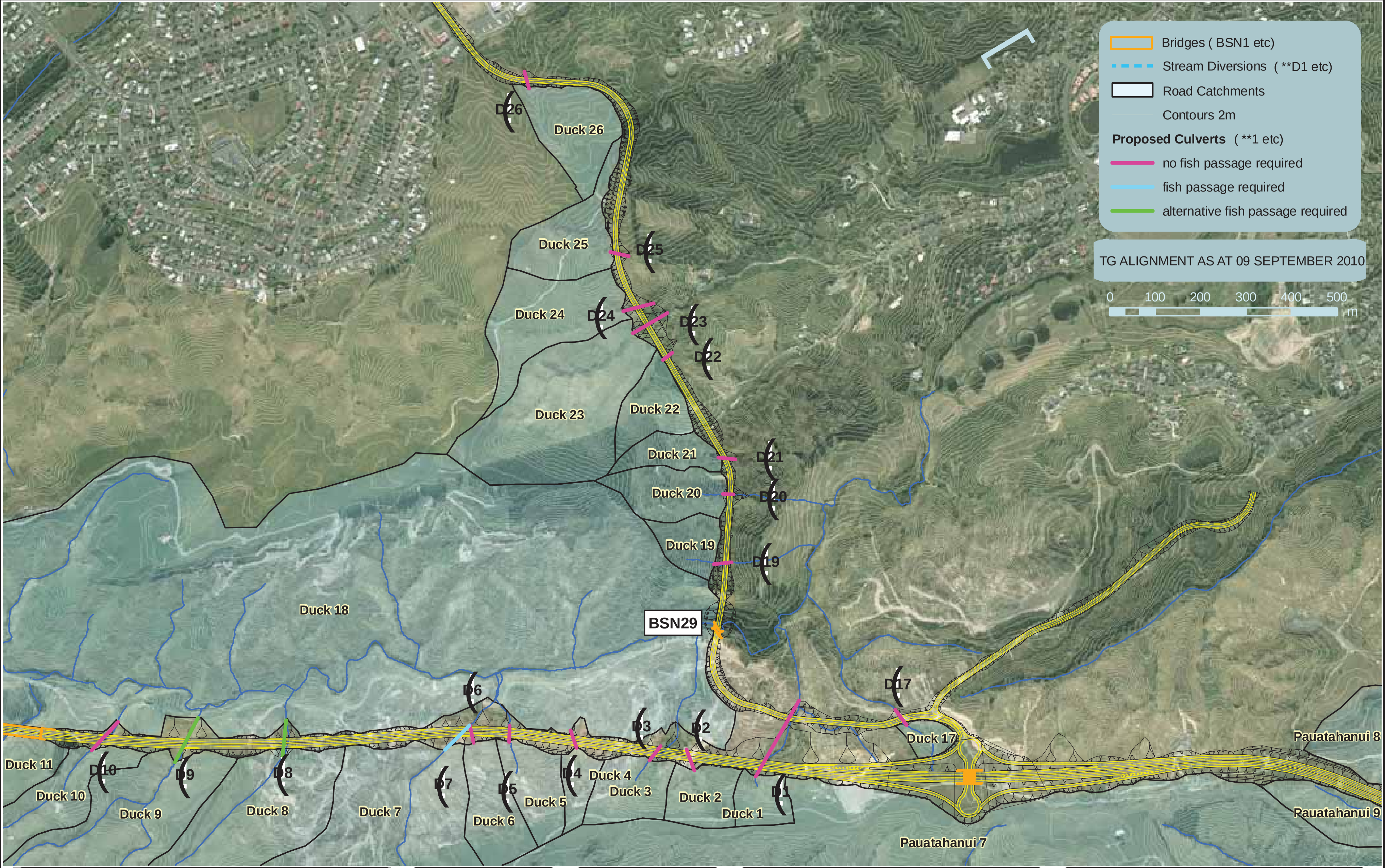

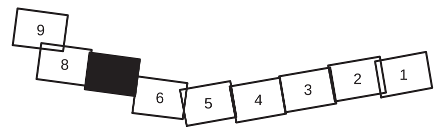

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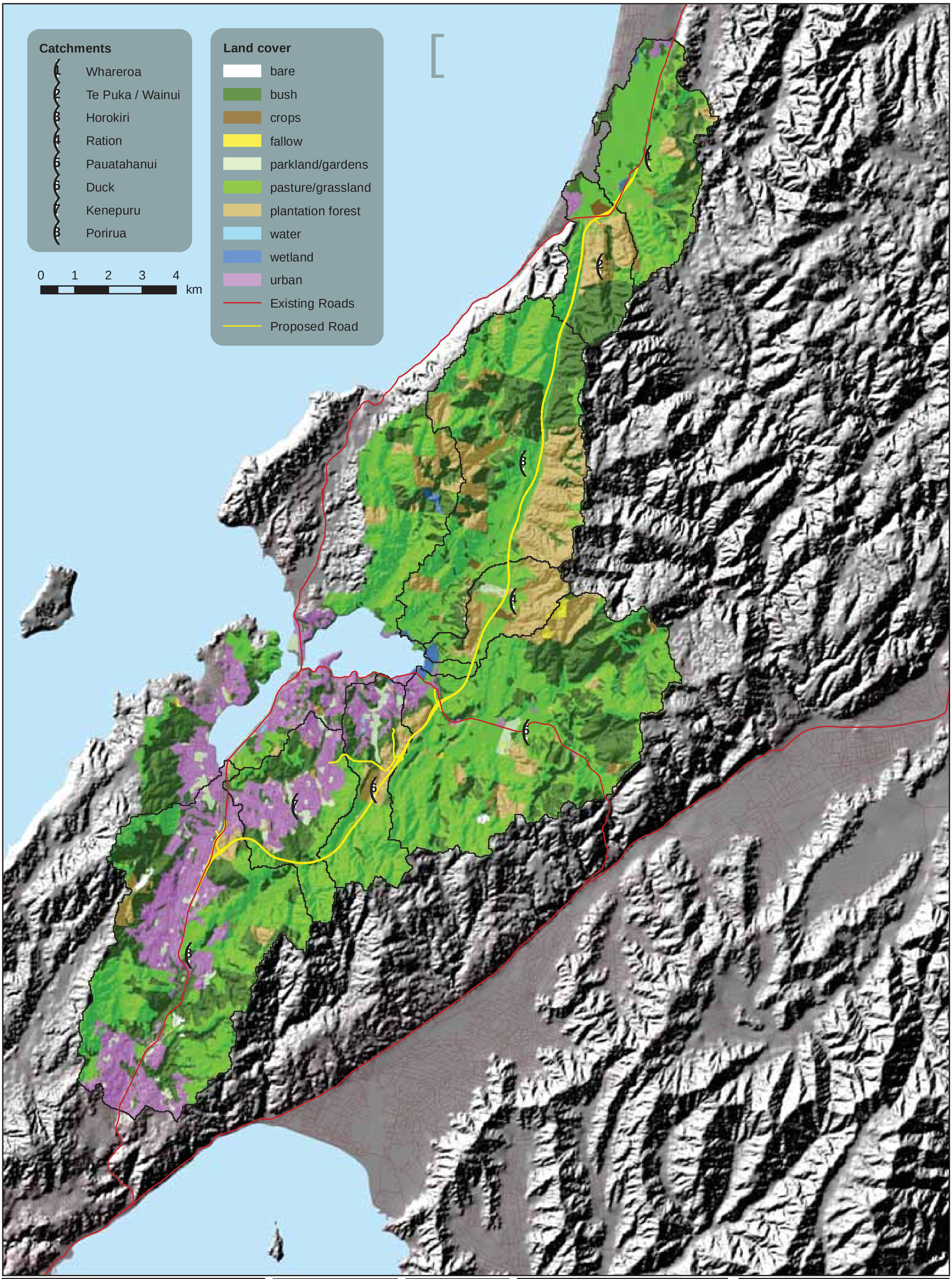
Appendix 14.H. Maps



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TITLE
MAP 1
CATCHMENT LAND COVER

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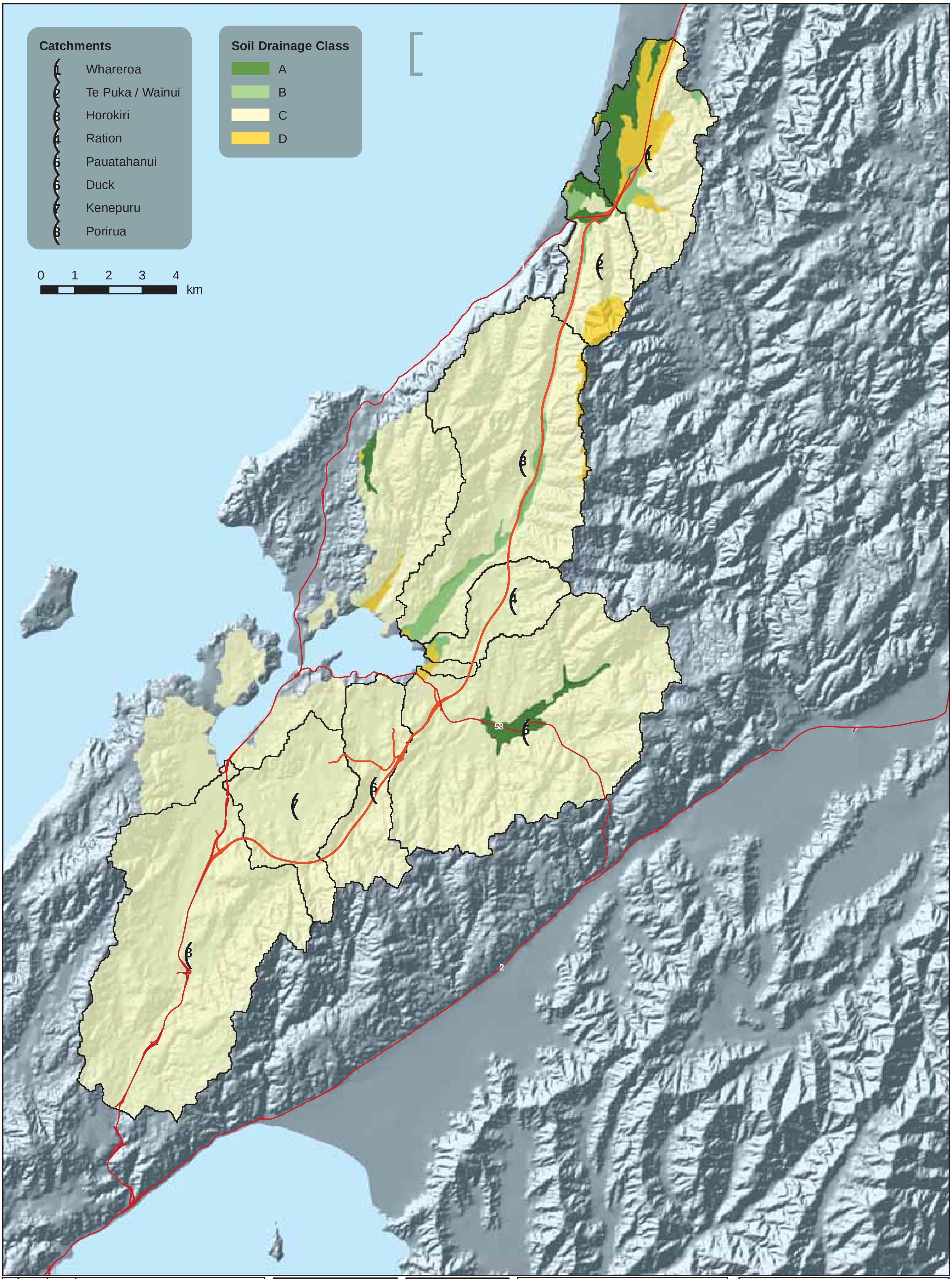

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MAP 2
SOIL DRAINAGE CLASSES

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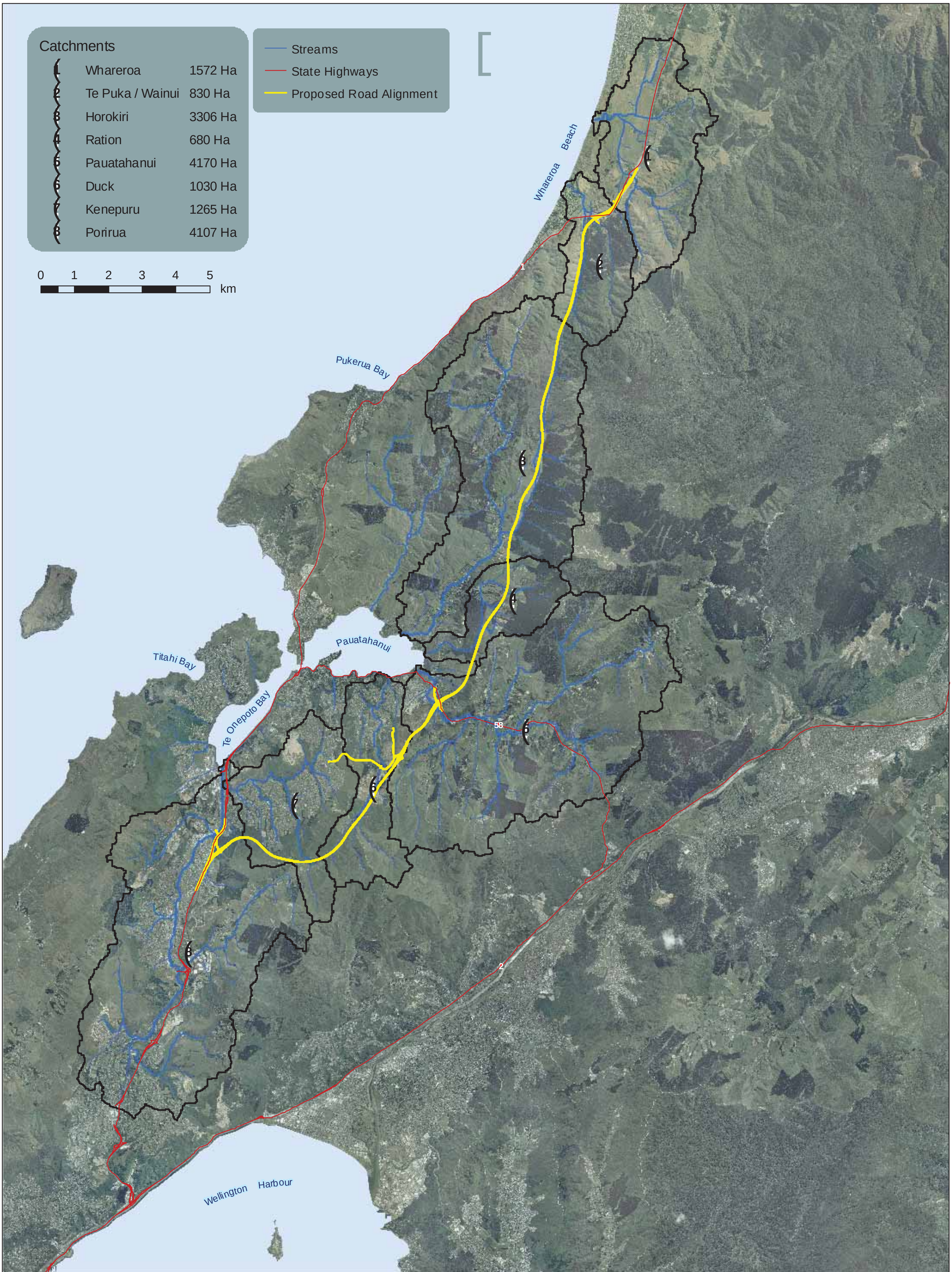

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TITLE
MAP 3
STREAM CATCHMENTS

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TITLE: MAP 4 RAINFALL AND FLOW GAUGING STATIONS

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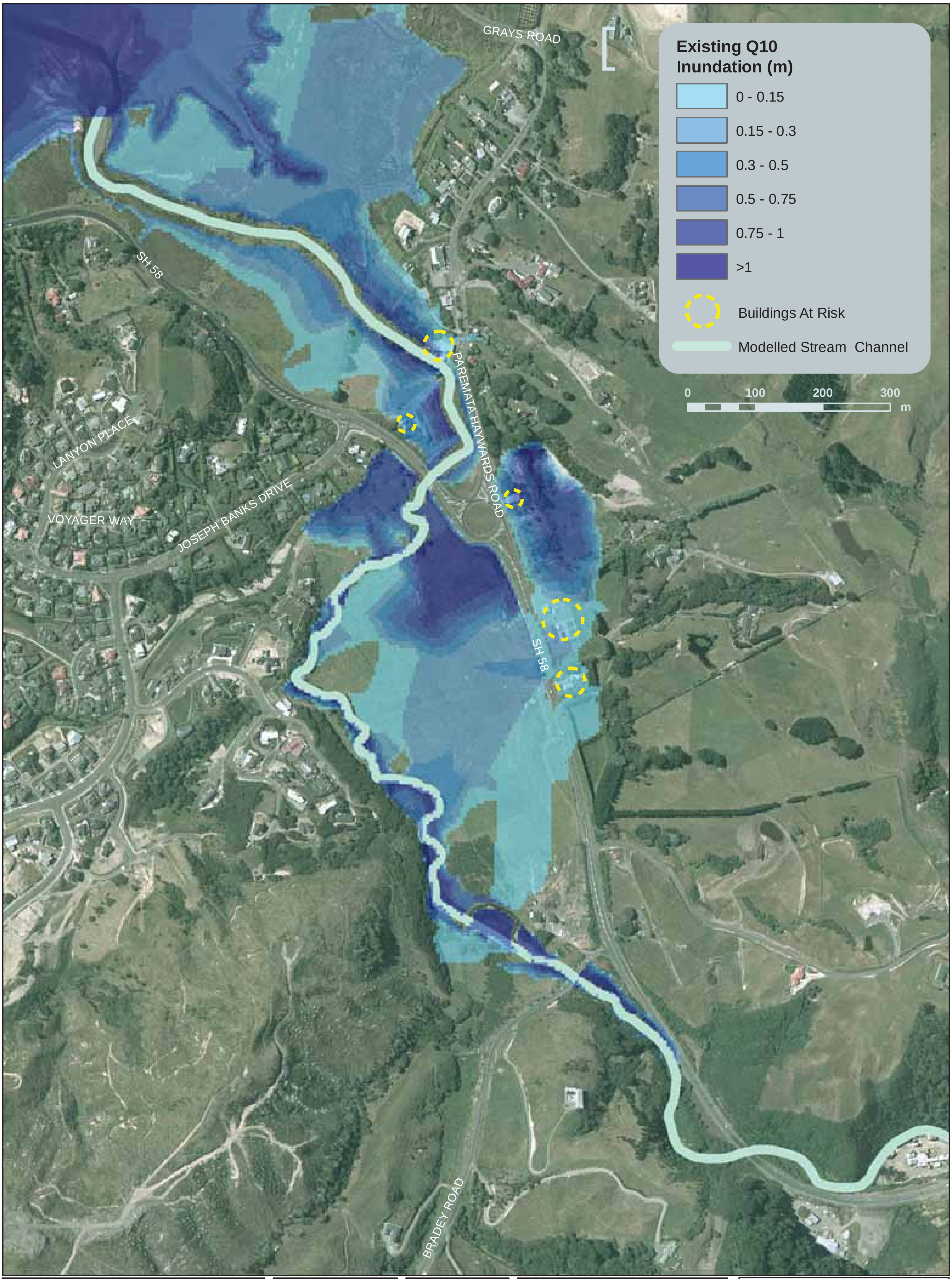

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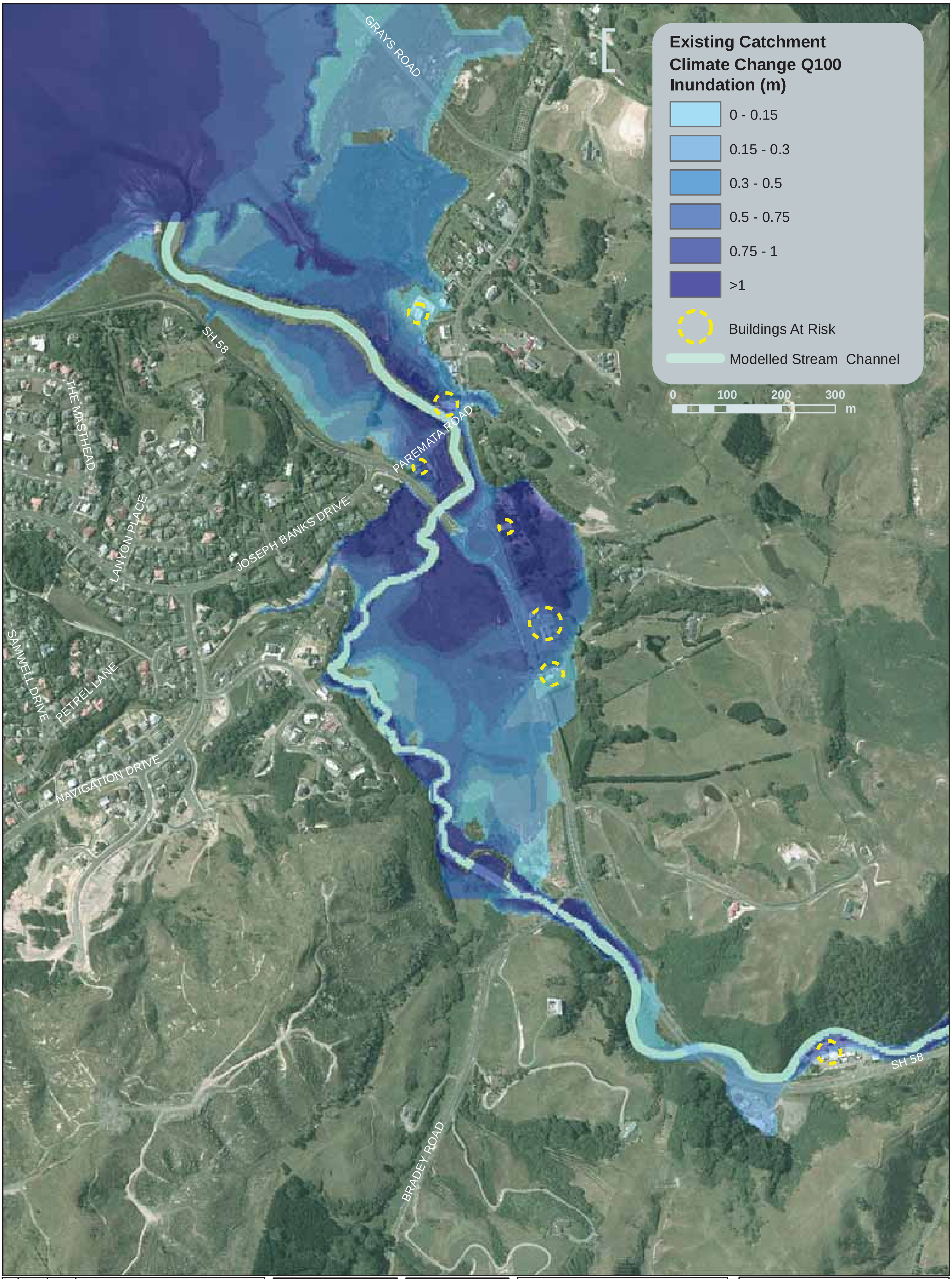
TITLE
MAP 5A
PAUATAHANUI PEAK
INUNDATION DEPTHS

SCALE @ A3 1:5,000 | SKM PROJECT No AE03778 | DRAWING No | AMDT



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TITLE
MAP 5B PAUATAHANUI EXISTING PEAK INUNDATION DEPTHS

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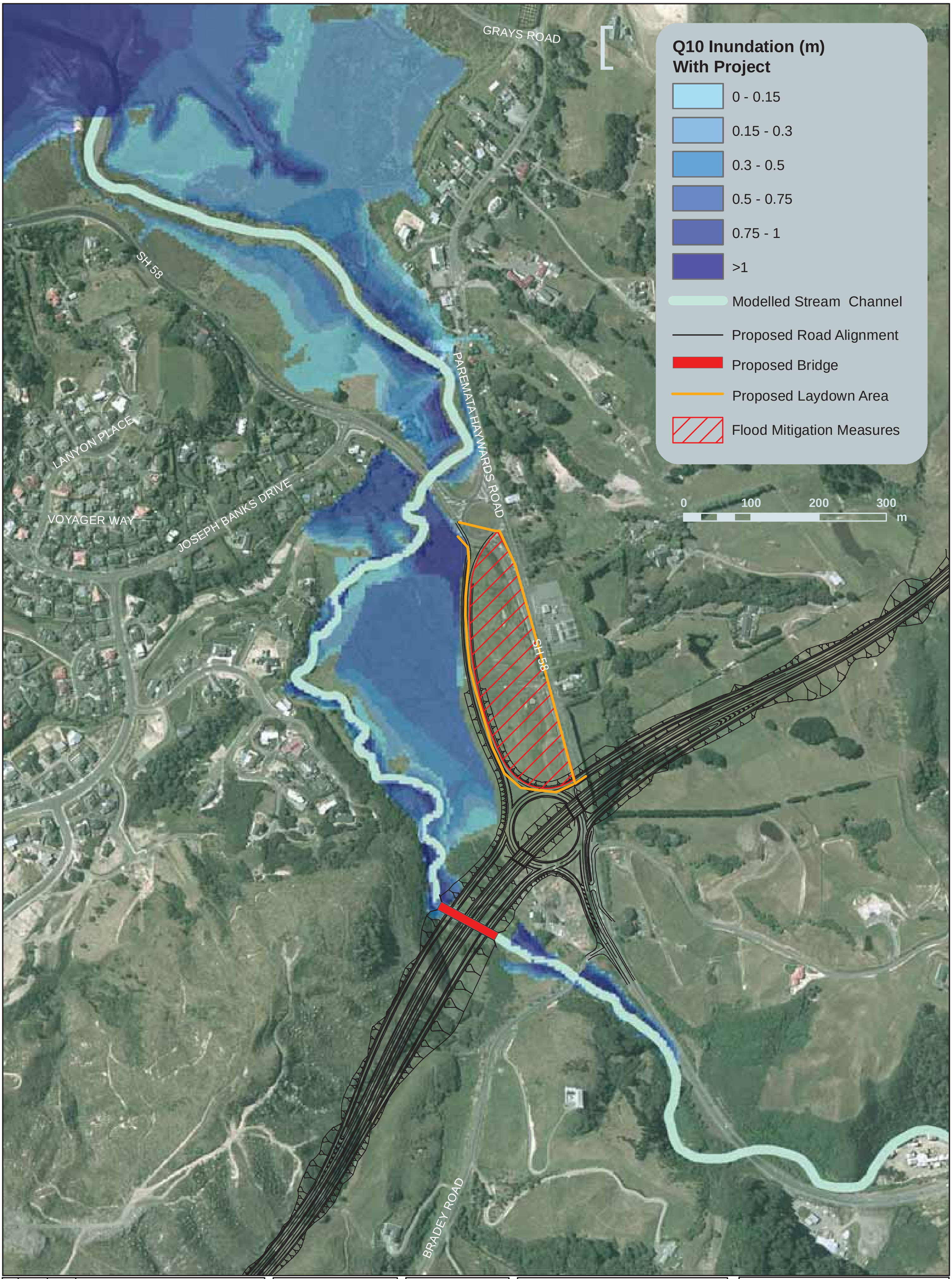

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MAP 6A
PAUATAHANUI FLOOD RISK

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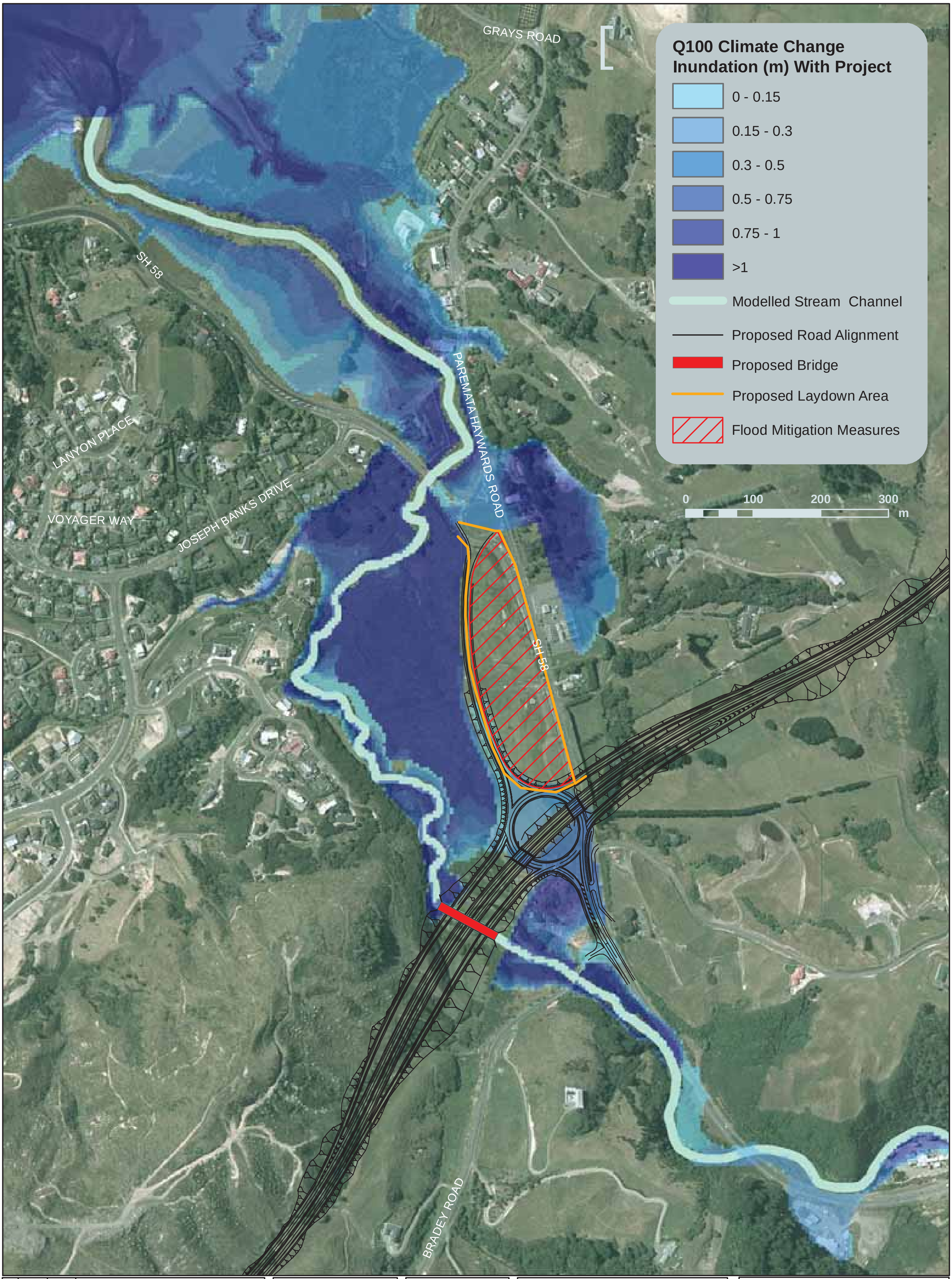

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MAP 6B PAUATAHANUI FLOOD RISK

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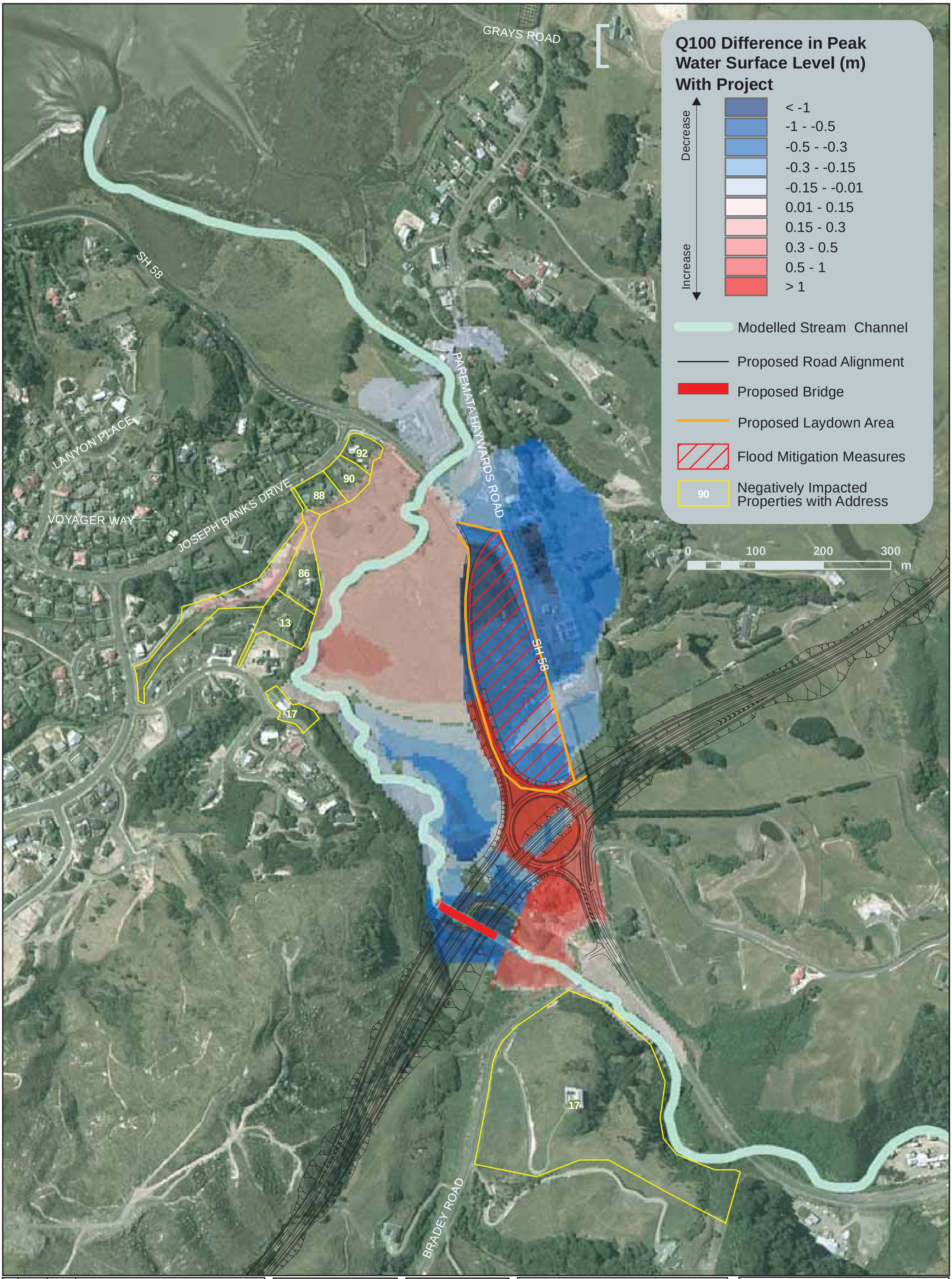

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MAP 7
COMPARISON OF PEAK WATER LEVELS IN PAUATAHANUI

SCALE @ A3	SKM PROJECT No	DRAWING No	AMDT
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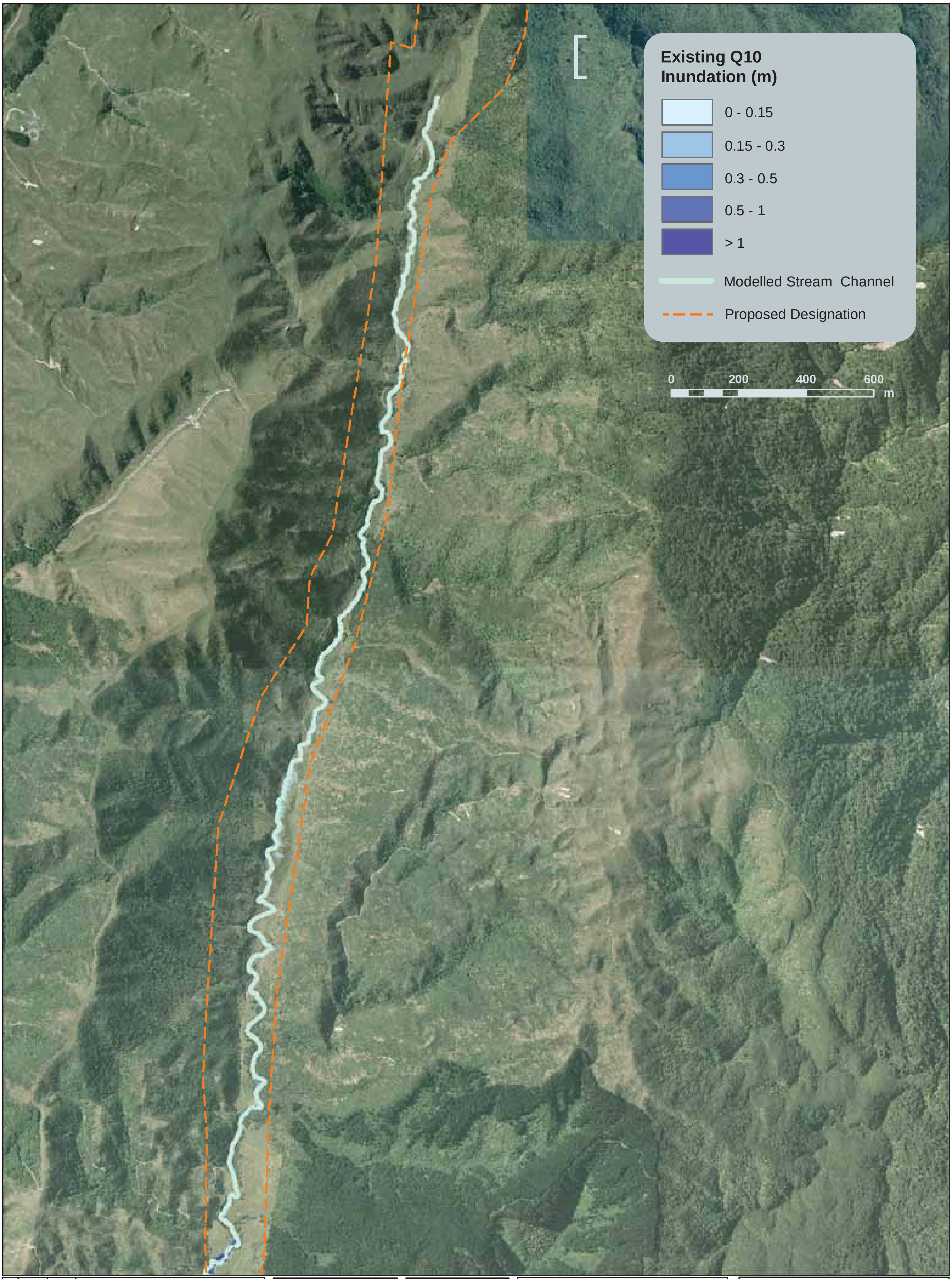

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TITLE: MAP 8A
HOROKIRI PEAK
INUNDATION DEPTHS
UPPER CATCHMENT

SCALE @ A3	SKM PROJECT No	DRAWING No	AMDT
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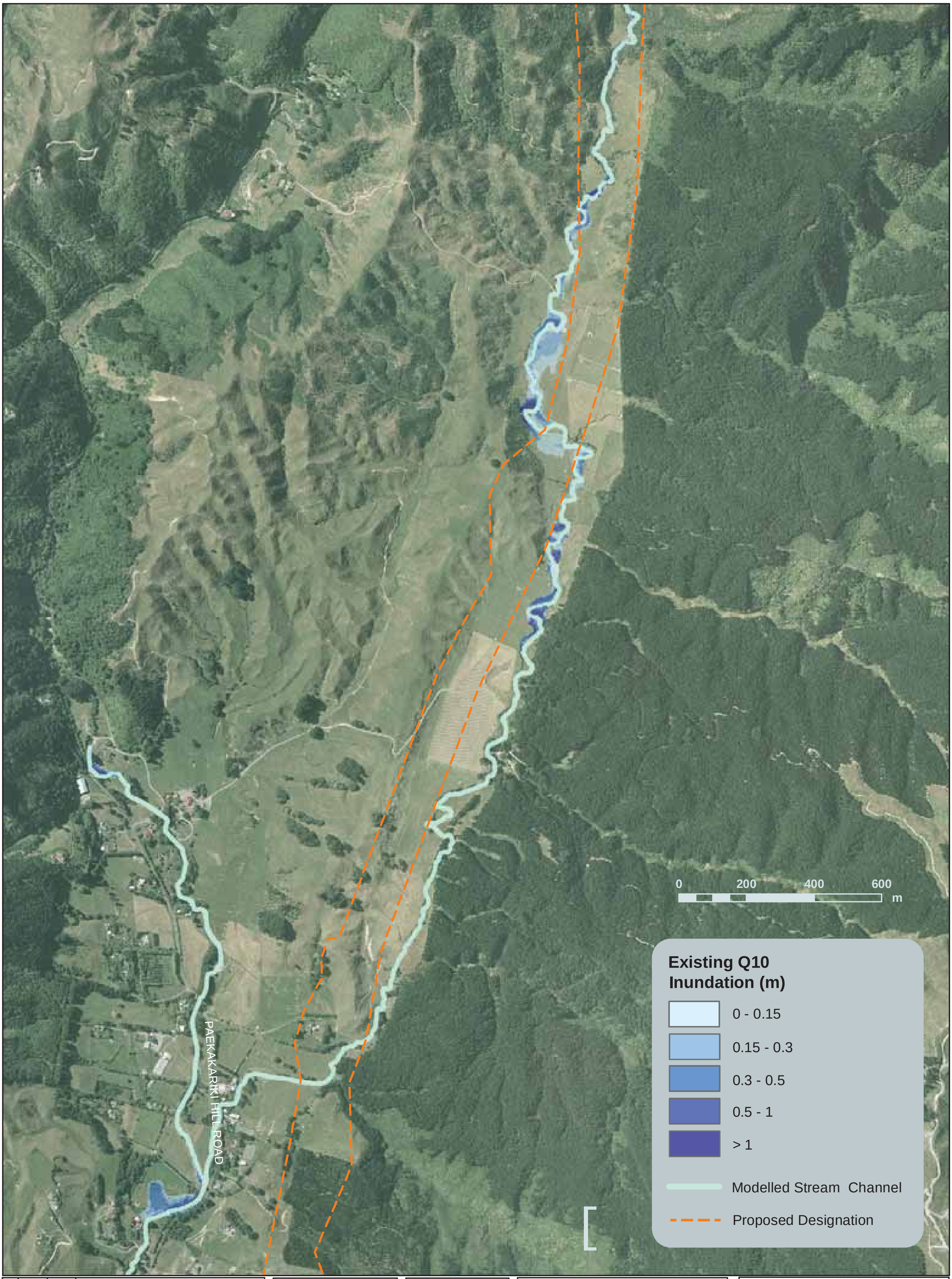

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TITLE
MAP 8B
HOROKIRI PEAK
INUNDATION DEPTHS
MID CATCHMENT

SCALE @ A3	SKM PROJECT No	DRAWING No	AMDT
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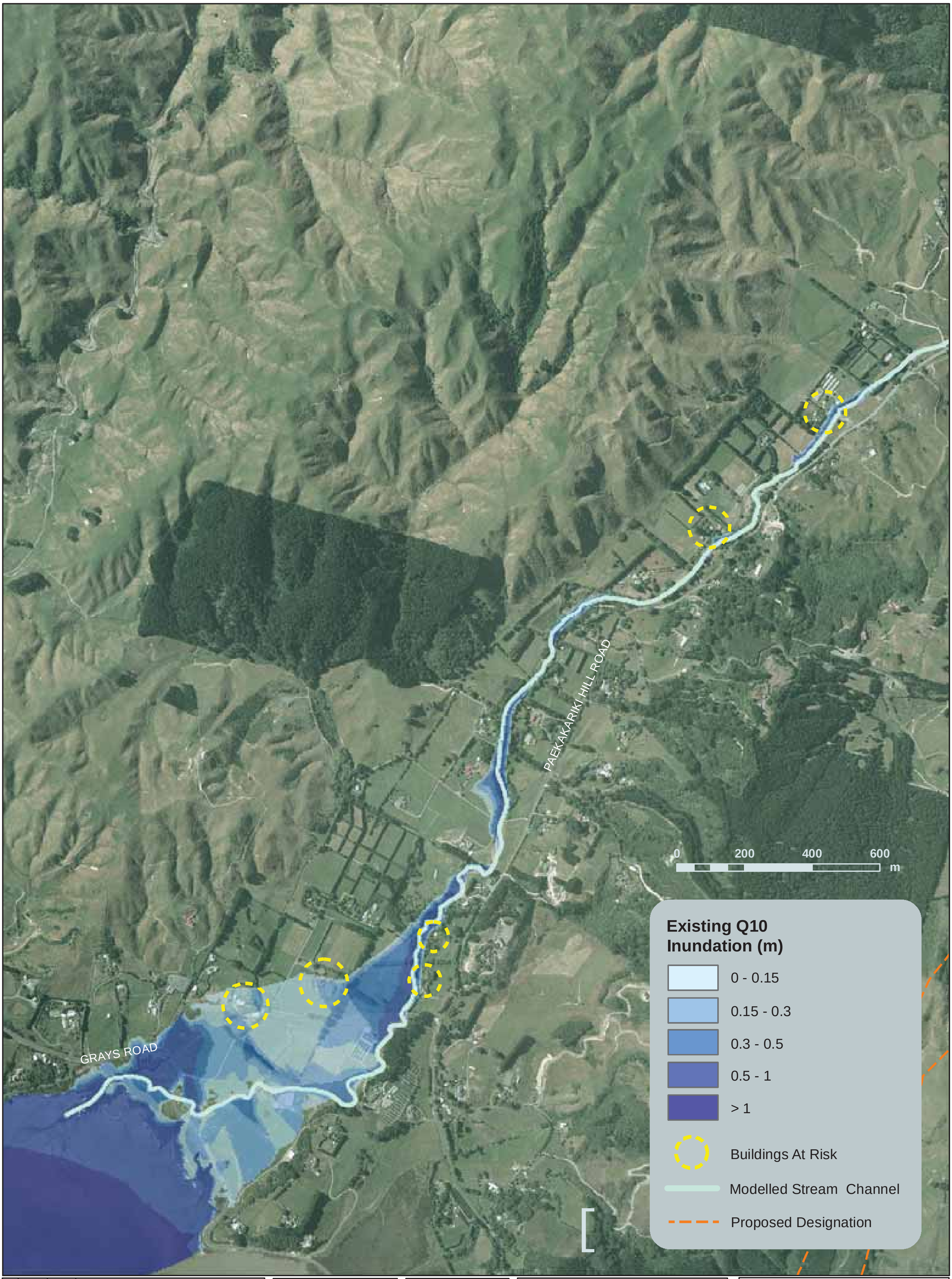

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TITLE
MAP 8C HOROKIRI PEAK INUNDATION DEPTHS LOWER CATCHMENT

SCALE @ A3	SKM PROJECT No	DRAWING No	AMDT
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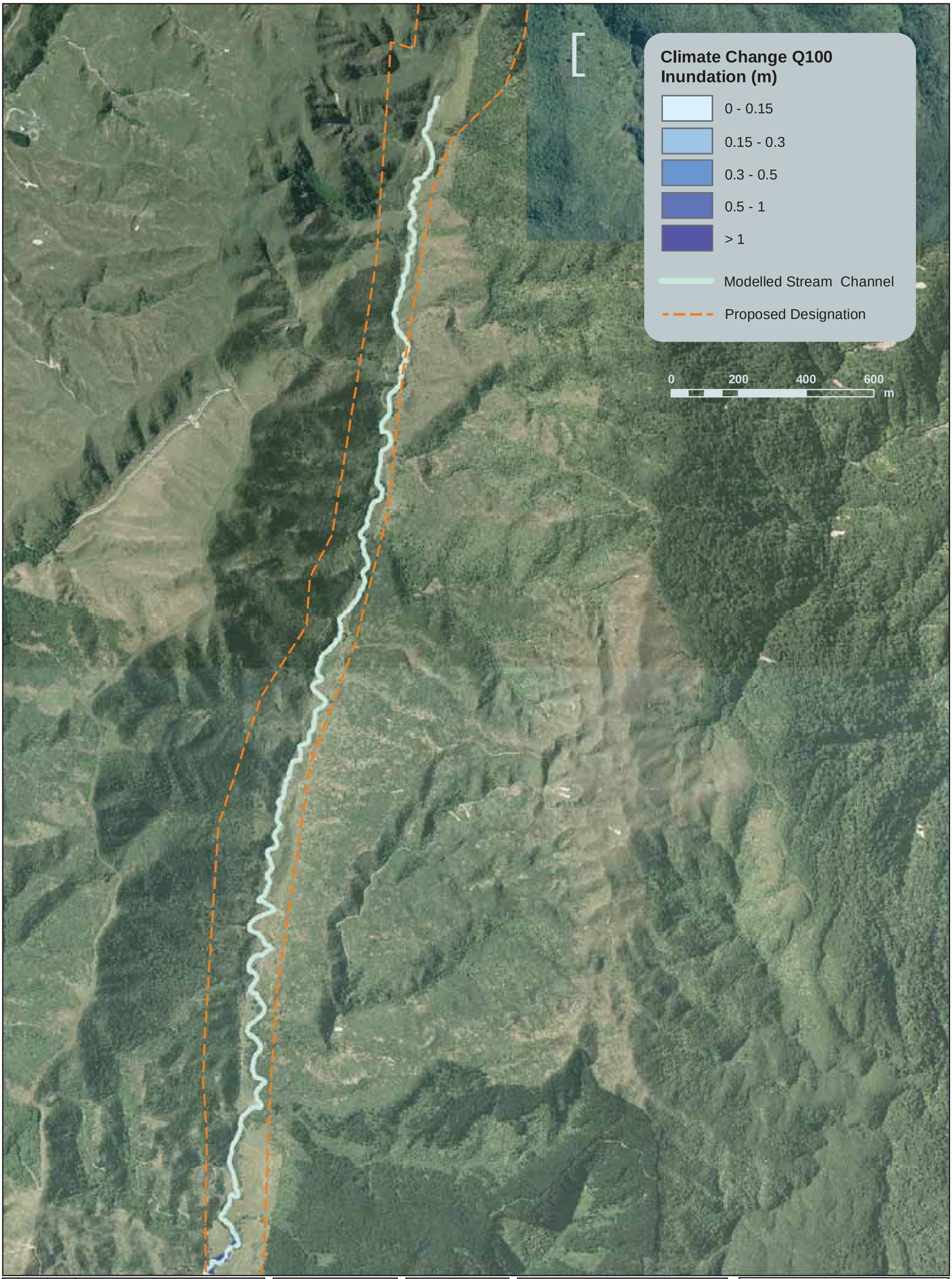

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DESIGNED: CMM	DESIGN REVIEW		

TITLE
MAP 8D
HOROKIRI PEAK
INUNDATION DEPTHS
UPPER CATCHMENT

SCALE @ A3	SKM PROJECT No	DRAWING No	AMDT
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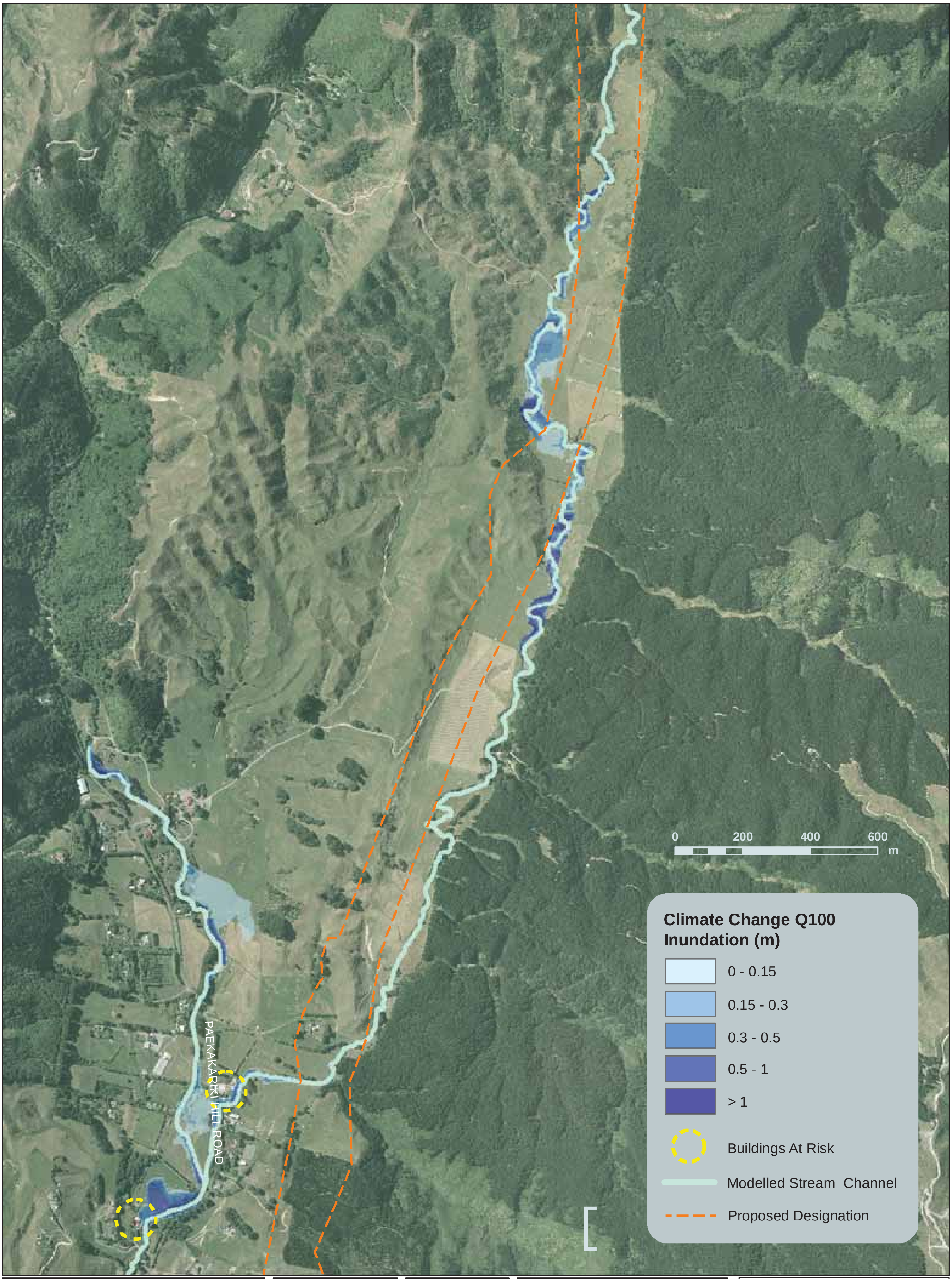

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TECHNICAL REPORT 14
DRAWN KWH
DATE MAY 2011
REVIEWED PROJECT MANAGER
APPROVED PROJECT DIRECTOR
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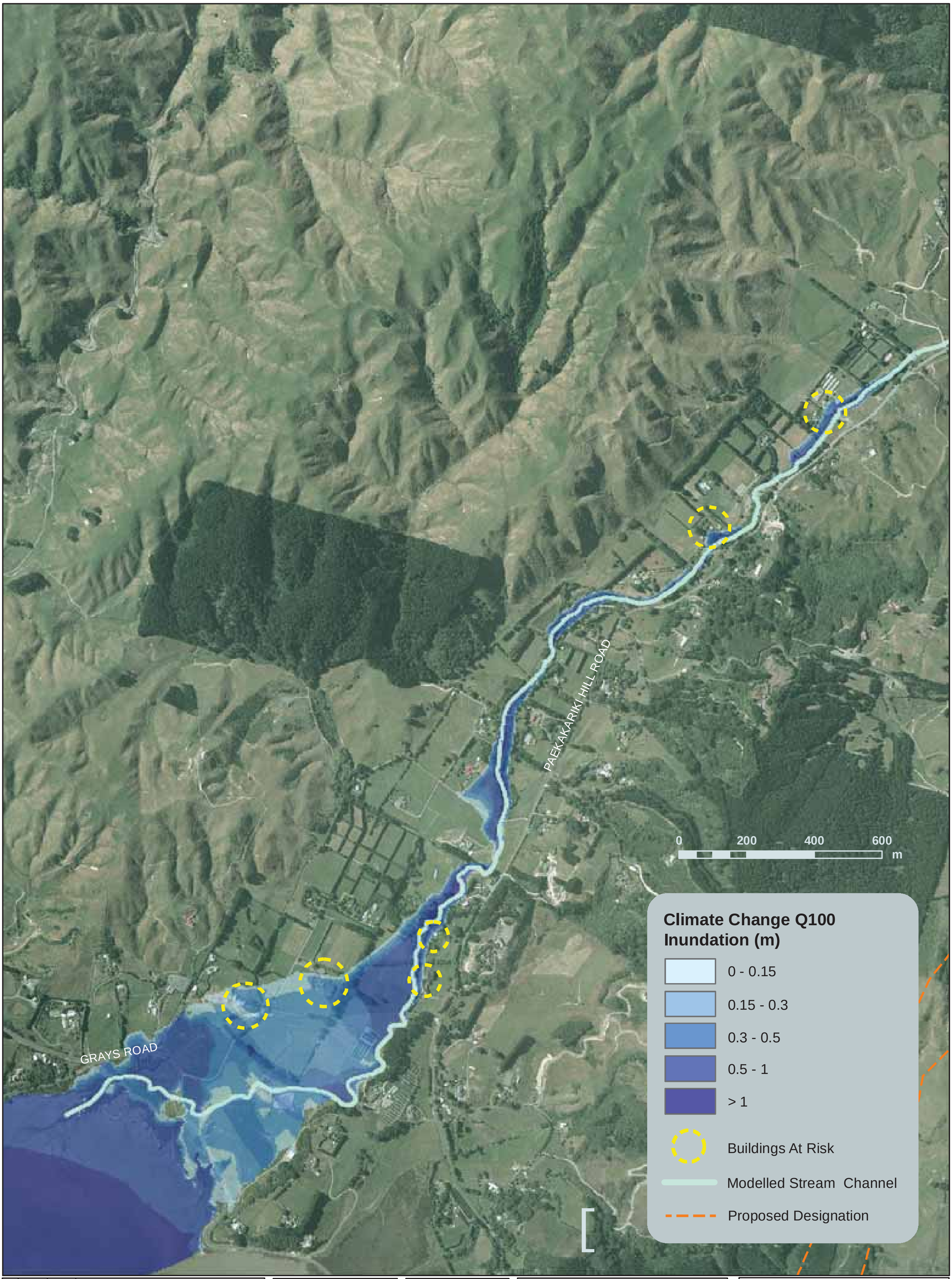
TITLE
MAP 8E
HOROKIRI PEAK
INUNDATION DEPTHS
MID CATCHMENT

SCALE @ A3 1:10,000
SKM PROJECT No AE03778
DRAWING No
AMDT



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APPROVED PROJECT DIRECTOR	
DESIGNED	CMM
DESIGN REVIEW	

TITLE	MAP 8F HOROKIRI PEAK INUNDATION DEPTHS LOWER CATCHMENT
SCALE @ A3	1:10,000
SKM PROJECT No	AE03778
DRAWING No	
AMDT	

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TITLE
MAP 9A TE PUKA / WAINUI PEAK INUNDATION DEPTHS

SCALE @ A3	SKM PROJECT No	DRAWING No	AMDT
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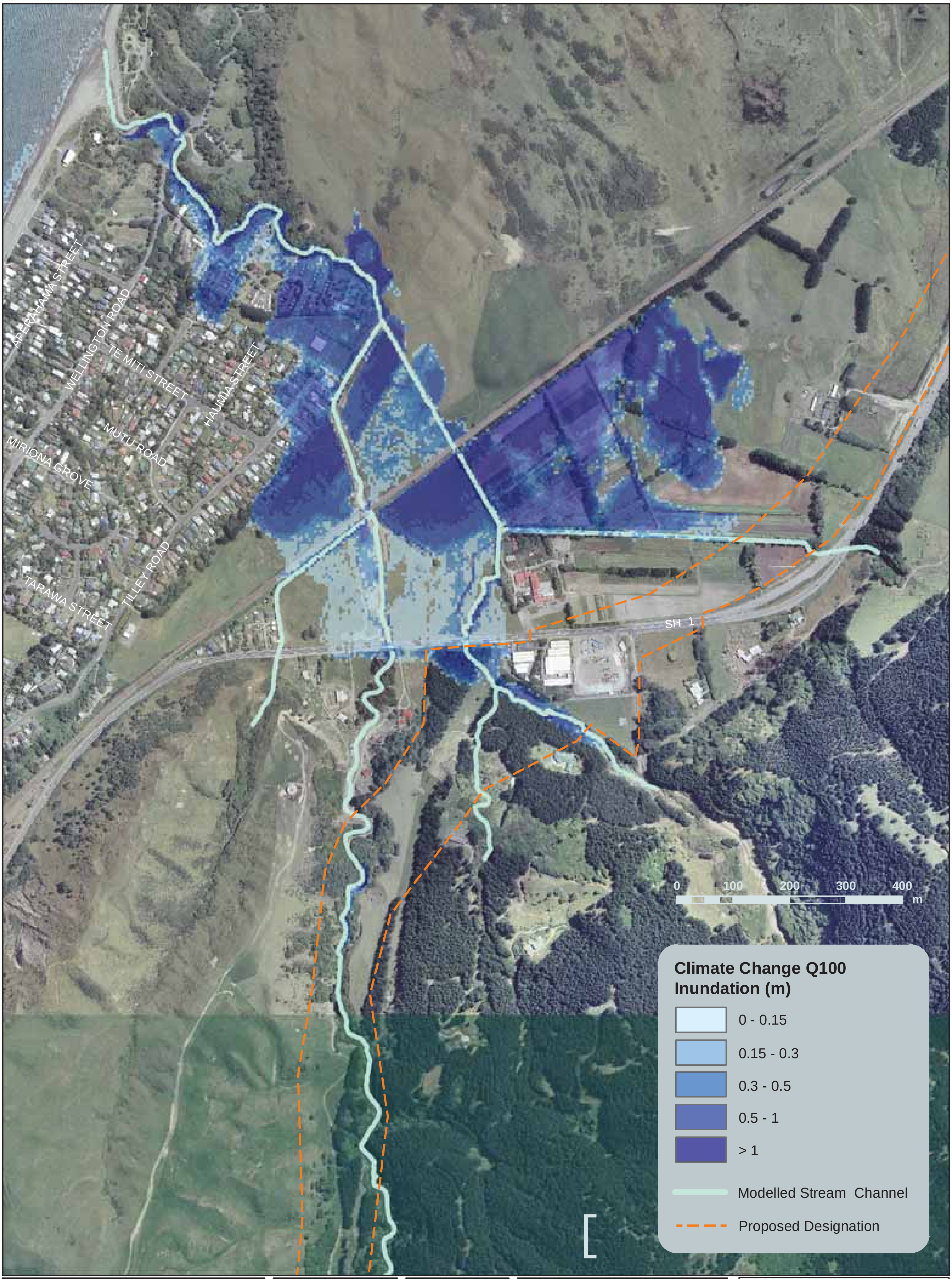

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TITLE

MAP 9B
TE PUKA / WAINUI PEAK
INUNDATION DEPTHS

SCALE @ A3	SKM PROJECT No	DRAWING No	AMDT
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