NZ TRANSPORT AGENCY
WAKA KOTAHI

Peka Peka to North Ōtaki Expressway Detailed Hydraulic Investigations for Expressway Crossing of Mangapouri Stream

Quality Assurance Statement

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NZ Transport Agency

Contents

List of Abbreviations

AEE	Assessment of Environmental Effects
AEP	Annual Exceedance Probability
CC	Climate change
DS	Downstream
EPA	Environmental Protection Agency
GEV	Generalised Extreme Value (a statistical distribution used to fit flood maxima series data)
GWRC	Greater Wellington Regional Council
KCDC	Kāpiti Coast District Council
MfE	Ministry for the Environment
MSL	Mean Sea Level
NIMT	North Island Main Trunk (railway)
NZTA	New Zealand Transport Agency
NZVD	New Zealand Vertical Datum
PE3	Log Pearson 3 (a statistical distribution used to fit flood maxima series data)
PP2O	Peka Peka to North Ōtaki
RMA	Resource Management Act
RoNS	Roads of National Significance
SAR	Scheme Assessment Report
SH1	State Highway 1
US	Upstream

1. Introduction

1.1 Rationale for Further Investigations

This report complements an overview report (Webby and Smith, 2013) describing an assessment of hydraulic effects for major watercourse crossings which was carried out to inform development of the scheme design for the proposed Peka Peka to North Ōtaki (PP2O) Expressway.

Feedback from Greater Wellington Regional Council (GWRC) and Kāpiti Coast District Council (KCDC) on a preliminary assessment carried out during the earlier scheme phase for the Expressway together with new discoveries during a site reconnaissance of technical specialists on 7 March 2012 identified a number of specific hydraulic issues that required further investigation. This report presents the results of those further investigations.

The site reconnaissance on 7 March 2012 resulted in two critical issues being identified:

- The potential for conflict within the County Rd / Rahui Rd / State Highway 1 triangle between the requirements for stormwater detention of urban runoff from the Te Manuao Catchment to the north of the Mangapouri Catchment and the flood storage requirements for the throttling of storm runoff from the more rural Mangapouri Catchment.
- The desirability of retaining the existing NIMT railway culvert / County Rd culvert system for throttling storm runoff from the Mangapouri Catchment instead of removing it and using the new Expressway / realigned railway culvert system to replicate the throttling function as assumed for the initial scheme design. The former approach is considered to be a superior solution from both technical and other perspectives.

With respect to the first issue, the function of an existing wetland to the west of State Highway 1 (SH1)[1] (hereafter referred to as the railway wetland) in providing detention storage for urban storm runoff from the Te Manuao Catchment was previously recognised but its connection with the Mangapouri Stream via a culvert under the NIMT railway line and a drain along the western side of the railway line was unknown until the site reconnaissance. This railway wetland will be significantly reduced in size with construction of the proposed PP2O Expressway so that other detention provisions need to be made to mitigate for this loss of wetland capacity. The impact of wetland outflows on flood detention within the Pare-o-Matangi Reserve along the Mangapouri Stream is also unknown.

Further observations from the 7 March 2012 site reconnaissance identified a stormwater sump on the eastern side of County Road capturing road runoff and possibly also some runoff from the Te Manuao Catchment. The stormwater system drains under County Road to a drain between County Road and the existing railway embankment which connects with the stream upstream of the existing NIMT railway culvert. This stormwater system was also previously unknown to KCDC. It was observed on the day of the reconnaissance under dry weather conditions to be passing what was suspected to be spring flows from the Te Manuao Catchment.

[1] This wetland area is sandwiched between the terrace on which the Te Manuao Catchment is located and a line of sand hills. The North Island Main Trunk (NIMT) railway line currently passes through this wetland area.

Observations from the site reconnaissance also resulted in slight changes being made to the estimated catchment areas for the Mangapouri and Te Manuao Catchments (slightly increased and slightly decreased respectively).

1.2 Feedback on Appendix E Report from GWRC and KCDC

In their review of the initial scheme assessment, GWRC suggested that consideration needed to be given to the consequences of partial blockage of culverts by flood transported woody debris. In the context of the Mangapouri Stream, this would probably only apply to the County Road culvert as County Road itself effectively shields the existing NIMT railway culvert and other downstream culverts (e.g. under the proposed Expressway and the realigned railway line) from being blocked.

GWRC also suggested that sensitivity testing should be undertaken given the uncertainty in the estimates of catchment runoff. They noted that the additional storm runoff from the Te Manuao Catchment diverted via the railway wetland into the Mangapouri Stream would be likely to increase flood levels in the flood storage area upstream of the Expressway embankment for the proposed situation for storm events of different magnitudes.

SKM reviewed the initial scheme assessment on behalf of KCDC. They noted that the level at which ponded floodwaters in the Mangapouri Stream upstream of the existing railway embankment would overtop Rahui Road and flow southwards into the Racecourse Catchment in the existing situation was actually lower than that assumed in the report. They suggested that the level at which this flood relief mechanism comes into play needed more detailed examination.

SKM also noted that the proposal to relocate the existing throttle in the form of the under-sized NIMT railway culvert to the proposed Expressway culvert has the effect of considerably increasing the contributing catchment area to the existing flood storage area upstream of the railway line. They commented that the analysis reported in the initial scheme assessment was insufficient to quantify the impact of the additional runoff from the increased catchment area on properties within the flood storage area. This observation by SKM is similar to one made by GWRC and is one reason why the initial concept of relocating the culvert throttle has now been abandoned in favour of retaining it in its present location.

SKM also suggested that the initial scheme assessment did not consider the effects of land use change associated with the proposed Expressway. Storm runoff from the Expressway will generally be mitigated through attenuation ponds and swales but SKM noted that the initial stormwater drainage plans show these attenuation ponds and swales to be located within the originally proposed flood storage area upstream of the Expressway embankment. More detailed conceptual development of the stormwater drainage system for the proposed Expressway along with reconfiguration of the Expressway and realigned railway culverts and retention of the existing railway culvert throttle has eliminated this issue.

All of the outstanding issues identified by GWRC and KCDC are addressed in this report.

1.3 Scope of Additional Investigations

The issues identified in Sections 1.1 and 1.2 have been explored by undertaking further detailed hydraulic modelling investigations. The earlier one-dimensional computational hydraulic model of the Mangapouri Stream in the vicinity of County Road, Rahui Road, the proposed Expressway and SH1was therefore modified accordingly for both the existing and proposed situations. In particular the model was utilised to assess the effects of urban stormwater inputs from the Te Manuao Catchment as well as revised Mangapouri Catchment inflows and to account for the effects of flood relief through overflow of Rahui Road.

Specifically for the hydraulic model of the existing situation, the following modifications were made:

- the existing railway wetland, the culvert outlet from the wetland under the NIMT railway line and the downstream drain to the Mangapouri Stream were incorporated in the model;
- the storm runoff from the Te Manuao Catchment into the railway wetland was defined as an additional upstream boundary condition for the model; and
- the effect of flood relief through the overtopping of Rahui Road into the neighbouring Racecourse Catchment was accounted for in the model.

Specifically for the hydraulic model of the proposed Expressway situation, the following modifications were made relative to the model of the existing situation:

- the throttle formed by the existing NIMT railway culvert was retained in the model;
- flood storage within the railway wetland area was down-sized significantly to reflect the remnant area remaining after construction of the proposed Expressway;
- a new outlet culvert from the remnant railway wetland was incorporated in the model;
- a new compensatory storage area downstream of the culvert outlet from the remnant railway wetland was incorporated in the model (in reality this storage area utilises space between the old abandoned railway embankment and the new Expressway embankment);
- a culvert outlet from the new compensatory storage area feeding into the existing drain to the Mangapouri Stream was incorporated in the model;
- the effect of blockage by the eastern approach embankment to the Rahui Road overbridge of the secondary overflow path over Rahui Road into the neighbouring Racecourse Catchment was accounted for in the model; and
- leakage paths through and around the eastern approach embankment to the Rahui Road overbridge were incorporated in the model to match as closely as possible the existing flood relief capacity of the secondary overflow path over Rahui Road.

1.4 Principle of Hydraulic Neutrality

Section 4 of the overview report (Webby and Smith, 2013) discusses the design philosophy for setting the level of service for the PP2O Expressway with respect to flood hazards and outlined the treatment philosophies for major watercourse crossings to achieve the required level of service. This reflects the fact that an elevated transport link constructed across a floodplain interferes with the natural drainage function of such a feature such that adequate provision must be made for relief measures within the elevated link to allow the passage of floodplain flows to pass safely through or over it.

This description clearly applies to the Mangapouri Stream in the vicinity of the State Highway 1 / Rahui Road / NIMT railway line triangle in both the current and proposed situations.

A fundamental principle which has been applied consistently with respect to the treatment of individual floodplain crossings on the PP2O Expressway Project is that of hydraulic neutrality. What this means is that the impact of flood hazards from the proposed Expressway should be no worse than in the current situation. This objective can sometimes be extremely difficult to achieve while still maintaining the required level of service for the Expressway. Where it has not been possible to achieve this desired objective, a fall-back position has been adopted whereby flood hazards that have been made worse have been kept away from residential properties and instead redirected towards uninhabited rural areas[2].

Application of this principle of hydraulic neutrality is demonstrated by the proposed retention of the existing NIMT railway embankment and culvert in the proposed Expressway situation and the direction of storm runoff out of the remnant railway wetland along the eastern side of the Expressway embankment into the Mangapouri Stream on the downstream side of the railway embankment. This arrangement ensures that existing drainage patterns will be preserved in the proposed Expressway situation and that the function of the existing flood storage area upstream of the current NIMT railway embankment and County Road will not be compromised.

1.5 Topographic Data

Topographic data for the general area of these investigations was obtained from LiDAR data provided by KCDC. The LiDAR data was collected in July and August 2010 over a 255km^2 area of the Kāpiti Coast. The height accuracy of the data in areas of open land cover only was checked against a set of surveyed ground points. The standard deviation between the LiDAR derived levels and the ground surveyed levels was ± 0.04m.

Existing streambed levels for the Mangapouri Stream were sourced from a 1998 Wellington Regional Council report (WRC, 1998).

1.6 Level Datums

Since flood levels in a river or stream near the outlet to the sea are affected by sea levels, Greater Wellington Regional Council (GWRC) consistently uses the Mean Sea Level Wellington (1953) level datum for their flood hazard investigations and flood protection works design. The investigations described in this report have made use of stream cross-section and culvert level information sourced from GWRC which is expressed in terms of this mean sea level datum. To ensure consistency with GWRC publications and information, these investigations have used the same level datum to evaluate flood levels along the Mangapouri Stream for both the existing situation and for the proposed Expressway situation.

Existing ground levels from LiDAR data and construction levels for the proposed Expressway on the other hand are expressed in terms of the NZ Vertical Datum (2009). It has therefore been necessary to translate between the two level data when specifying design flood levels and road design levels at key stream / river crossing locations.

Throughout this report then, flood levels are generally expressed in terms of Mean Sea Level (MSL) Wellington (1953) datum. To adjust these levels to be in terms of NZ Vertical Datum (2009), 0.44m needs to be

[2] In this context, the fall-back position has been partially adopted for the Rahui Road overflow relief path from the primary flood storage basin upstream of the existing NIMT railway culvert where an additional flood relief culvert under Rahui Road has been provided in the proposed situation. The flood relief culvert compensates for blockage of the primary flood relief path by the eastern approach embankment to the new Rahui Road overbridge and directs relief flows to an unnamed watercourse within uninhabited land. This mitigation measure is discussed in in detail in Section 4 of the report.

subtracted. Conversely to adjust levels in NZ Vertical Datum (2009) to be in terms of MSL Wellington Datum, 0.44m needs to be added.

2. Flood Estimates for Mangapouri Stream Catchment

2.1 Catchment Areas

The boundary of the Mangapouri Catchment was refined slightly after the 7 March 2012 site reconnaissance. This is shown on the Catchment Area Plan contained in Appendix A.

The original catchment boundary was expanded slightly to include the Ōtaki Racecourse[3] after it was observed that a drainage system along the northern side of the racecourse (Figures 2-1 and 2.2) captures surface runoff and directs it under Rahui Road into the Mangapouri Stream. This gives a total catchment area of 2.37km^2 at the NIMT railway culvert (inferred from ground level contour data and drainage patterns)

The drainage system from the racecourse has only limited capacity so that this catchment area may be overestimated for extreme storm events. Any storm runoff exceeding the capacity of the drainage system would instead flow overland towards the unnamed watercourse draining under the railway line, the railway precinct retail area and SH1 to the soakage area on the grounds of Ōtaki College. Furthermore, the ground level contours over the area of the racecourse suggest that the centre of the race track is utilised for surface ponding and groundwater soakage. The assumption of a 2.37km^2 area for the Mangapouri Catchment for all storm events will therefore be conservative.

The area of the Te Manuao Catchment on the terrace to the north of the Mangapouri Catchment was estimated to be 0.316km^2 (inferred from ground level contour data and the layout of the urban stormwater drainage network). The urban stormwater drainage network in this catchment is quite limited in extent (B Fountain (SKM), pers. comm.) with only a single 0.45m diameter outlet pipe under SH1. Any rainfall on the catchment not infiltrating into the ground or captured by the piped drainage system will therefore flow overland towards SH1. Surface runoff reaching SH1 will mostly flow over the road into the railway wetland along with the stormwater conveyed by the piped drainage system. However some of the surface runoff may flow down the eastern side of County Road to a sump that drains via a pipe under the road to a drain between the road and the existing NIMT railway embankment to the Mangapouri Stream upstream of the existing railway culvert.

The layout of the proposed drainage system modifications for the Expressway in the part of the Mangapouri Catchment covered by these investigations is shown on the drawing contained in Appendix E.

[3] The additional catchment area includes the area enclosed by the racecourse track and also bounded by Rahui Road to the north and Te Roto Road to the west.

Figure 2-1 Drain along north side of Ōtaki Racecourse directing storm runoff into Mangapouri Stream (viewed looking east from site of culvert under Rahui Road to Mangapouri Stream)

Figure 2-2 Culvert under Rahui Road directing storm runoff from Ōtaki Racecourse to Mangapouri Stream

2.2 Flood Estimates for Mangapouri and Te Manuao Catchments

2.2.1 Mangapouri Catchment

A regional flood frequency approach (McKerchar and Pearson, 1989) was previously used to obtain flood estimates for the Mangapouri Catchment at the NIMT railway culvert in the previous investigations for the initial scheme assessment. Flood frequency estimates obtained from the annual flood maxima series for the Mangaone at Ratanui hydrological gauging station were scaled according to catchment area $A^{0.8}$ as per McKerchar and Pearson (1989) to produce corresponding flood estimates for the Mangapouri Stream. The same approach was used for the revised catchment area.

Table 2-1 summarises the flood estimates for the Mangapouri Stream obtained in this manner based on three different flood frequency distributions (Gumbel, PE3 and GEV).

Table 2-1 Flood estimates for Mangapouri Stream at existing NIMT railway culvert scaled from Mangaone Stream at Ratanui gauging station flood estimates

AEP (%)	**Flood Estimate (m^3/s)**					
	Mangaone (Gumbel) [1]	***Mangaone (PE3)*** [1]	***Mangaone (GEV)*** [1]	**Mangapouri (Gumbel)**	**Mangapouri (PE3)**	**Mangapouri (GEV)**
42.9	*15.2*	*15.2*	*15.2*	5.1	5.1	5.1
20	*20.5*	*20.7*	*20.5*	6.9	7.0	6.9
10	*24.9*	*25.0*	*24.9*	8.4	8.4	8.4
5	*29.0*	*29.0*	*29.0*	9.8	9.8	9.8
2	*34.4*	*34.0*	*34.5*	11.6	11.5	11.6
1	*38.4*	*37.6*	*38.6*	13.0	12.7	13.0
0.5	*42.5*	*41.1*	*42.7*	14.3	13.9	14.4
0.2	*47.8*	*45.7*	*48.1*	16.1	15.4	16.2

[1] Note catchment area of Mangaone Stream at Ratanui Gauging Station is 9.2km^2.

In the previous investigations reported for the initial scheme assessment, the flood estimates for the Mangapouri Stream were adjusted for the effects of possible future climate change to 2090 based on a mid-range estimate for increased average rainfall of +17% for the Wellington and Manawatu Regions from the MfE (2010) Guidelines. The same climate change adjustment factor was applied to the revised flood estimates in Table 2-1. The resulting flood estimate adjusted for possible climate change effects to 2090 are given in Table 2-2.

Table 2-2 Flood estimates for Mangapouri Stream at existing railway culvert adjusted for effects of possible future climate change to 2090

AEP (%)	**Flood Estimate (m^3/s)**					
	Current climate (Gumbel)	**Current climate (PE3)**	**Current climate (GEV)**	**Adjusted (Gumbel)**	**Adjusted (PE3)**	**Adjusted (GEV)**
2	11.6	11.5	11.6	13.6	13.4	13.6
1	13.0	12.7	13.0	15.2	14.8	15.2
0.5	14.3	13.9	14.4	16.8	16.2	16.9
0.2	16.1	15.4	16.2	18.9	18.0	19.0

It was noted in the previous investigations for the initial scheme assessment that all three frequency distributions fitted the annual flood maxima data for the Mangaone at Ratanui hydrological gauging station (and hence the Mangapouri Stream) very well with the Gumbel and GEV distributions producing almost identical flood estimates. For the purposes of the more detailed hydraulic modelling investigations reported in this report, the flood estimates based on the GEV frequency distribution have been adopted.

2.2.2 Te Manuao Catchment

The area of the Te Manuao Catchment is much smaller than that of the Mangapouri Catchment so that there is increased uncertainty in using the same regional flood frequency approach to derive flood estimates for the Te Manuao Catchment by scaling flood frequency estimates from the annual flood maxima series for the Mangaone at Ratanui hydrological gauging station. However, because the flood estimates were to be used as inputs to the same hydraulic model, it was important that a consistent approach was used to obtain them. The same method was therefore used to derive flood estimates for the Te Manuao Catchment although they were subsequently validated using an alternative method (refer Section 2.2.3).

Table 2-3 summarises the flood estimates obtained for the Te Manuao Catchment for current climate conditions and for the effects of possible future climate change to 2090. The same three frequency distributions have been used based on the results of the frequency analysis of the annual flood maxima series for the Mangaone at Ratanui hydrological gauging station although, as noted for the Mangapouri Catchment, the flood estimates based on the GEV frequency distribution were adopted for the more detailed hydraulic modelling investigations reported in this report.

Table 2-3 Flood estimates for Te Manuao Catchment for existing climate conditions and adjusted for effects of possible future climate change to 2090

AEP (%)	**Flood Estimate (m^3/s)**					
	Current climate (Gumbel)	**Current climate (PE3)**	**Current climate (GEV)**	**Adjusted (Gumbel)**	**Adjusted (PE3)**	**Adjusted (GEV)**
42.9	1.0	1.0	1.0	1.2	1.2	1.2
20	1.4	1.4	1.4	1.6	1.6	1.6
10	1.7	1.7	1.7	2.0	2.0	2.0
5	2.0	2.0	2.0	2.3	2.3	2.3
2	2.3	2.3	2.3	2.7	2.7	2.7
1	2.6	2.5	2.6	3.0	3.0	3.0
0.5	2.9	2.8	2.9	3.4	3.2	3.4
0.2	3.2	3.1	3.2	3.8	3.6	3.8

2.2.3 Validation of Flood Estimates

Flood estimates for the much smaller catchments along the route of the proposed Expressway shown on the Catchment Area Plan contained in Appendix A were derived using an alternative rainfall based approach as per the recommendations of KCDC Guidelines (SKM, 2008; SKM, undated). The flood magnitudes were estimated by means of a HEC-HMS rainfall / runoff routing model which uses as inputs a prescribed 24 hour rainfall distribution, a 24 hour rainfall total and a curve number defining the runoff characteristics of the catchment. This is a less direct method than the regional flood frequency approach of McKerchar and Pearson (1989) (which uses measured runoff flows from a hydrologically similar regional catchment) but it is a valid alternative approach and more appropriate for small catchments.

The availability of these HEC-HMS model sourced flood estimates provided an opportunity to validate the flood estimates in Tables 2-2 and 2-3 for the Mangapouri and Te Manuao Catchments. Table 2-4 compares the flood estimates obtained in these investigations for the 1% AEP storm adjusted for possible climate change effects to 2090 with the flood estimates derived from the HEC-HMS rainfall/ runoff routing models.

Table 2-4 Comparison of flood estimates for 1% AEP flood adjusted for possible climate change effects to 2090 derived using alternative approaches for Mangapouri and Te Manuao Catchments

Catchment	**Flood Estimate (m^3/s)**	
	Regional Flood Frequency Method	**HEC-HMS Rainfall / Runoff Model**
Mangapouri at existing railway culvert	15.2	17.5
Te Manuao	3.0	3.2

The flood estimates from the two methods are fairly comparable for both catchments, in particular for the Te Manuao Catchment. The HEC-HMS rainfall runoff model forecasts a slightly higher flood estimate than the regional flood frequency method but the difference is not large.

This consistency between the two methods provides a fair degree of confidence in the flood estimates for other AEP values in Tables 2-1 and 2-2 for both catchments.

The use of regional hydrological characteristics for estimating flood magnitudes for small (< 5km^2) catchments has been queried by the Environmental Protection Agency's (EPA) Technical Reviewer.

The catchment area for the Mangaone Stream at the Ratanui gauging station (from which flood estimates for the Mangapouri Stream have been derived) is 9.2km^2 which is only about 3.9 times the size of the Mangapouri Catchment at the existing NIMT railway culvert. The scaling reduction according to catchment area using McKerchar and Pearson's (1989) Regional Flood Frequency method to derive flood estimates for the Mangapouri Stream from flood frequency values for the Mangaone Stream is not overly large. However it must be acknowledged that there are significant differences in catchment slope and land use. The Mangaone Catchment above the gauging station is a hill country one and with mixed land uses (indigenous forest, pine forest plantation, scrub and pastoral). In contrast the Mangapouri Catchment upstream of the railway line is generally part of flat alluvial plain, and apart from the racecourse used for pastoral purposes and low density residential development. The 24 hour design rainfall values for the Kāpiti Coast (SKM, 2009) suggest there is a slight rainfall gradient between the two catchments which reflects the orographic effects of the foothills bounding the coastal plain.

On the basis of the evidence then, the use of regional hydrological characteristics to obtain flood estimates for the small Mangapouri Catchment appears a reasonable, albeit conservative, approach. It is slightly more problematic down-scaling the flood estimates from the Mangaone Catchment to the even smaller Te Manuao Catchment (0.32km^2). However it is important that a consistent approach is applied across both catchments. The fact that the HEC-HMS rainfall / runoff model used for other small catchments affected by the proposed Expressway (Coles and Bird, 2013) predicted flood estimates for the 1% AEP flood adjusted for possible climate change effects to 2090 that are not too dissimilar to those from a regional flood frequency approach lends support the use of the latter approach.

Further support for use of a regional flood frequency approach is given by the work of McKerchar (1991b) and Pearson (1991). McKerchar (1991b) recommended that the mean annual flood for small ungauged catchments should be estimated using the contour maps of $Q_m/A^{0.8}$ (where Q_m is the mean annual flood and A is the catchment area) from the regional flood frequency method of McKerchar and Pearson (1989) until further lines of enquiry had been fully explored. In the case of the Mangaone Catchment at the Ratanui gauging station, the $Q_m/A^{0.8}$ ratio has a value of about 2.6 which closely matches the contour map values in McKerchar and Pearson (1989). Pearson (1991) recommended various Q_{100}/Q_m values for small catchments grouped according to 20% AEP 24 hour rainfall totals and average catchment slope. The Q_{100}/Q_m value for the Mangaone Catchment is about 3.0 which is very consistent with the 3.02 value recommended by Pearson (1991) for small catchments with a 20% AEP 24 hour rainfall total in the range of 105-155mm and an average catchment slope of less than 19°.

2.2.4 Flood Hydrographs

Figure 2-2 shows the assumed inflow hydrographs for the Mangapouri Stream for both existing and possible future (2090) climate conditions scaled according to the peak values given in Table 2-1. Meanwhile Figure 2-3 shows similar inflow hydrographs for the Te Manuao Catchment. The hydrograph shape is sourced from the 21 October 1998 storm event, the largest on record from the Mangaone at Ratanui hydrological gauging station.

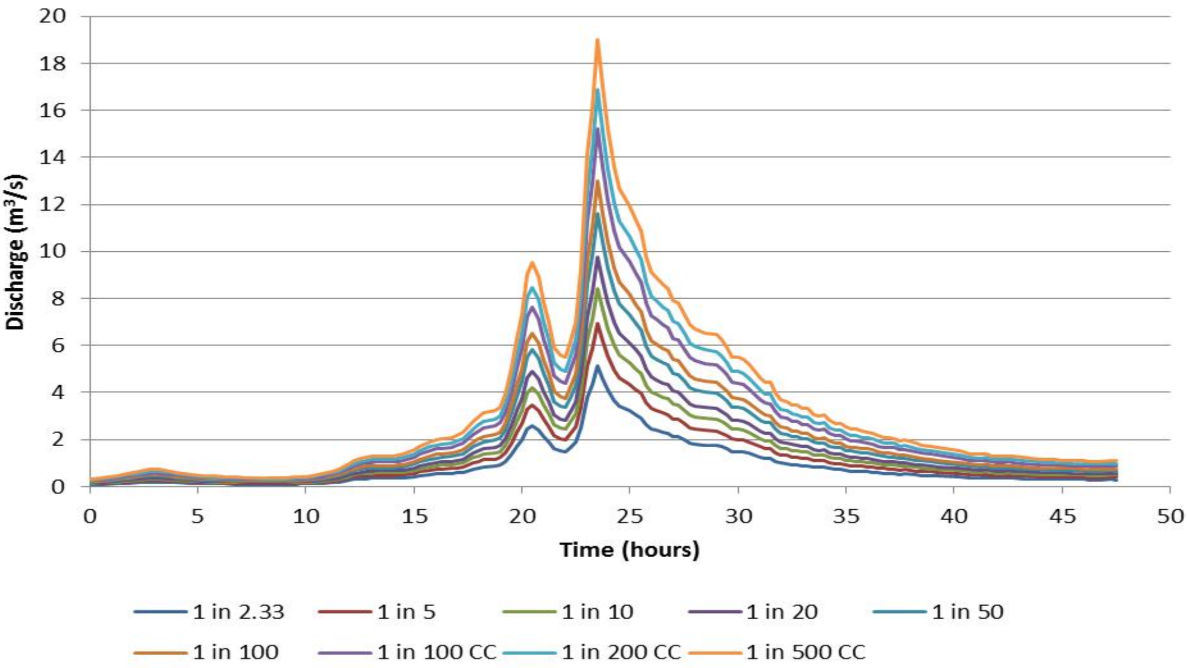

Figure 2-2 Inflow hydrographs to Mangapouri Catchment for various annual exceedance probabilities existing and possible future (to 2090) climate conditions

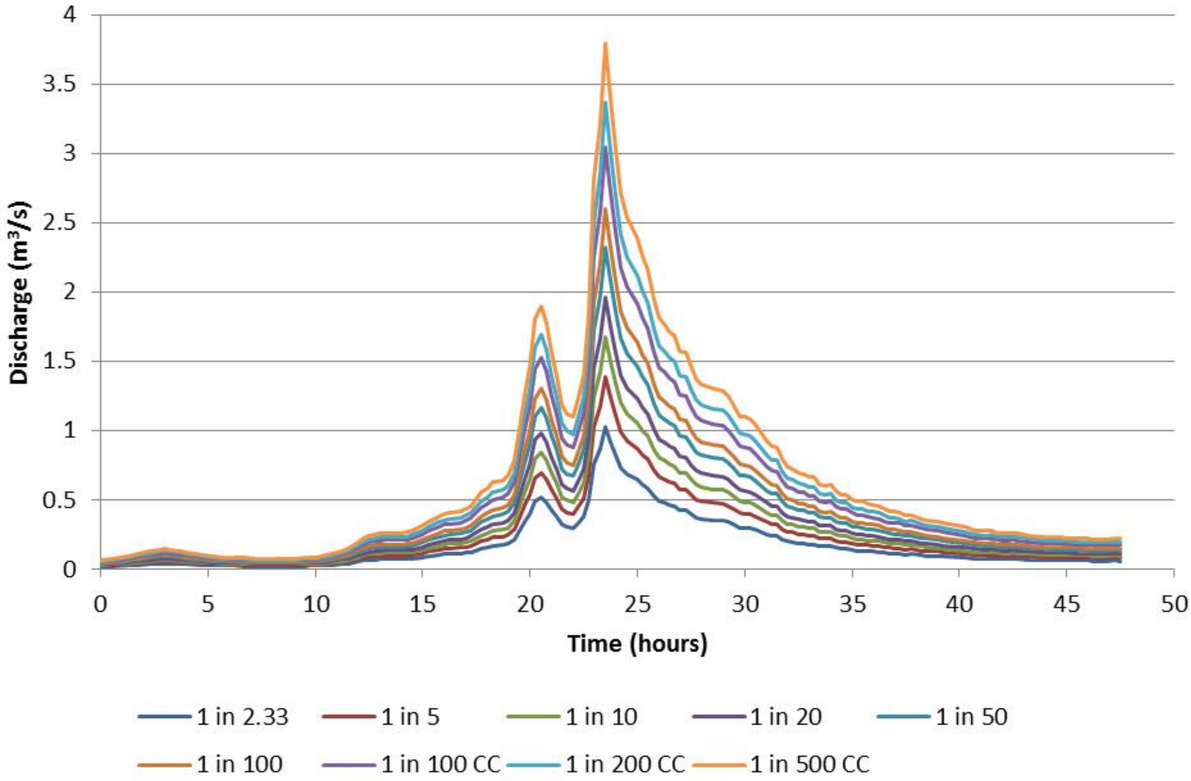

Figure 2-3 Inflow hydrographs to Te Manuao Catchment for various annual exceedance probabilities for existing and possible future (to 2090) climate conditions

The Environmental Protection Agency's (EPA) Technical Reviewer has also queried the choice of the flood hydrograph on which to base the design inflow hydrographs for the Mangapouri Stream. The 21 October 1998 flood hydrograph is the one with the largest peak discharge in the Mangaone Stream at Ratanui stream flow record. It is common practice to choose the flood event with the largest peak discharge in a record to use as a base hydrograph for translation to other nearby catchments, as long as the hydrograph shape is fairly typical. However the hydrograph for another significant flood could equally have been chosen, e.g. the 28 October 1998 one (7 days later than the selected one).

Inspection of the range of Mangaone Stream hydrographs shown in Figures 2-1 to 2-5 of the companion report on hydraulic investigations for the Expressway crossing of the Ōtaki River floodplain (Smith and Webby, 2013) shows that Mangaone Stream (and by implication Mangapouri Stream) flood events are often multi-peaked with two and sometimes even three distinct peaks reflecting discrete bursts of heavier rainfall occurring within the overall rainfall pattern.

The 21 October 1998 flood hydrograph for the Mangaone Stream exhibited two distinct peaks in the order of three hours apart. The choice of the hydrograph for this particular flood event to use as a base hydrograph for scaling flood hydrographs for the Mangapouri Stream was therefore reasonable and rational.

3. Hydraulic Performance in Current Situation

3.1 Hydraulic Behaviour of Mangapouri Stream in Current Situation

In the current situation, the Mangapouri Stream in the vicinity of the State Highway 1 / Rahui Road / NIMT railway line triangle essentially behaves as a system of two flood detention ponds in series. The first pond is formed by the shallow basin upstream of County Road and the NIMT railway line (with the railway embankment acting as the detention barrier) and bounded by the Te Manuao Catchment terrace on the north side and Rahui Road along the south side (Figure 3-1). The second pond is formed by the Pare-o-Matangi Reserve which occupies another shallow basin between the NIMT railway line and SH1 (as it climbs up to cross over the railway line) with the elevated road embankment acting as the detention barrier. Figure 3-2 shows the storage area / elevation relationships for both ponds.

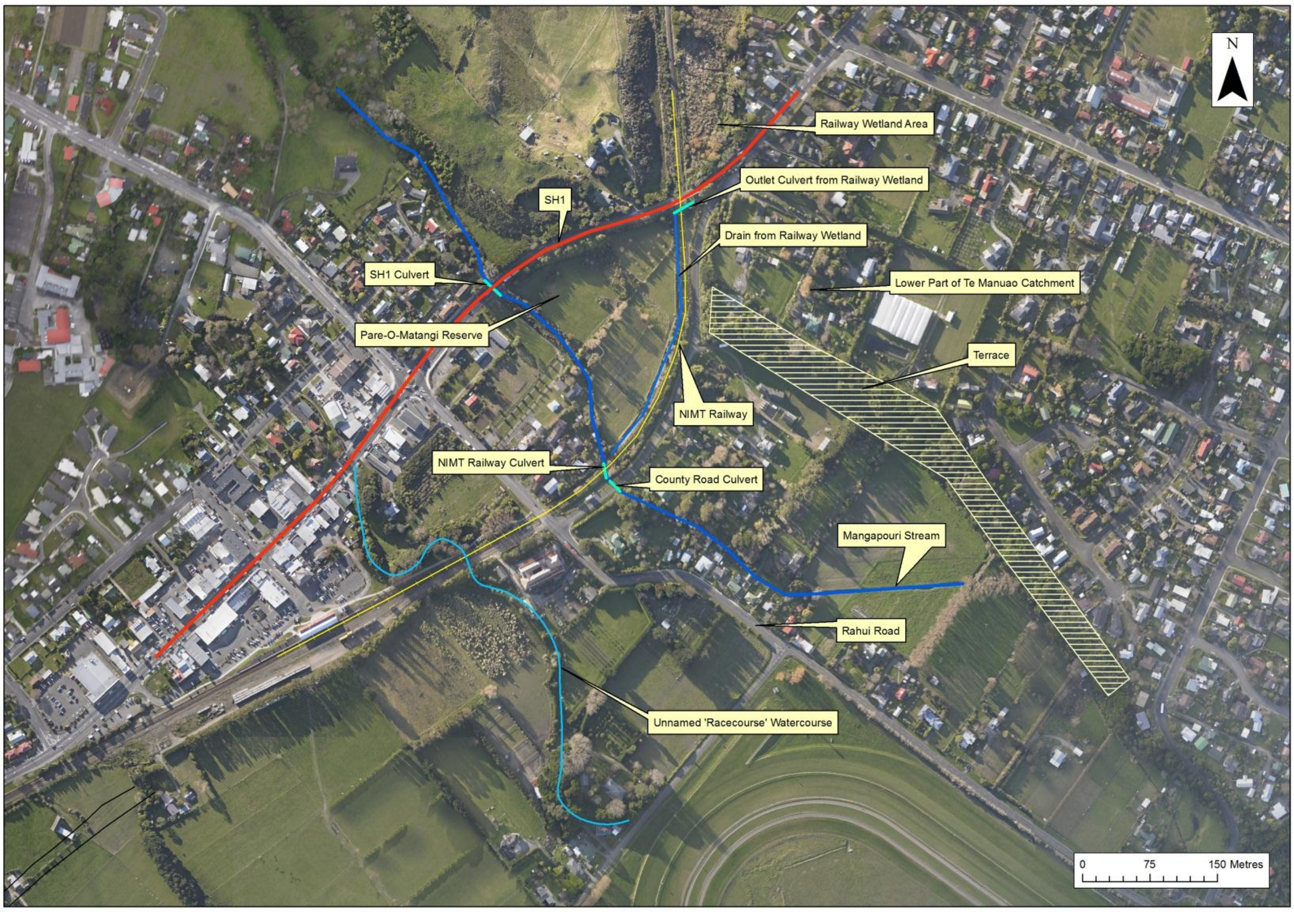

Figure 3-1 Current geometry of Mangapouri Stream in SH1 / Rahui Road / NIMT railway line triangle including lower end of Te Manuao Catchment and railway wetland area

Note that, while the upstream basin is a designated flood detention facility, the function of the Pare-o-Matangi Reserve as a secondary flood detention area does not appear to have previously been recognised. The upstream basin is the primary flood detention facility. The slightly depressed nature of the ground topography of the Pare-o-Matangi Reserve relative to transport links enclosing it and the culvert inlet and outlet means that if also functions as a flood detention facility.

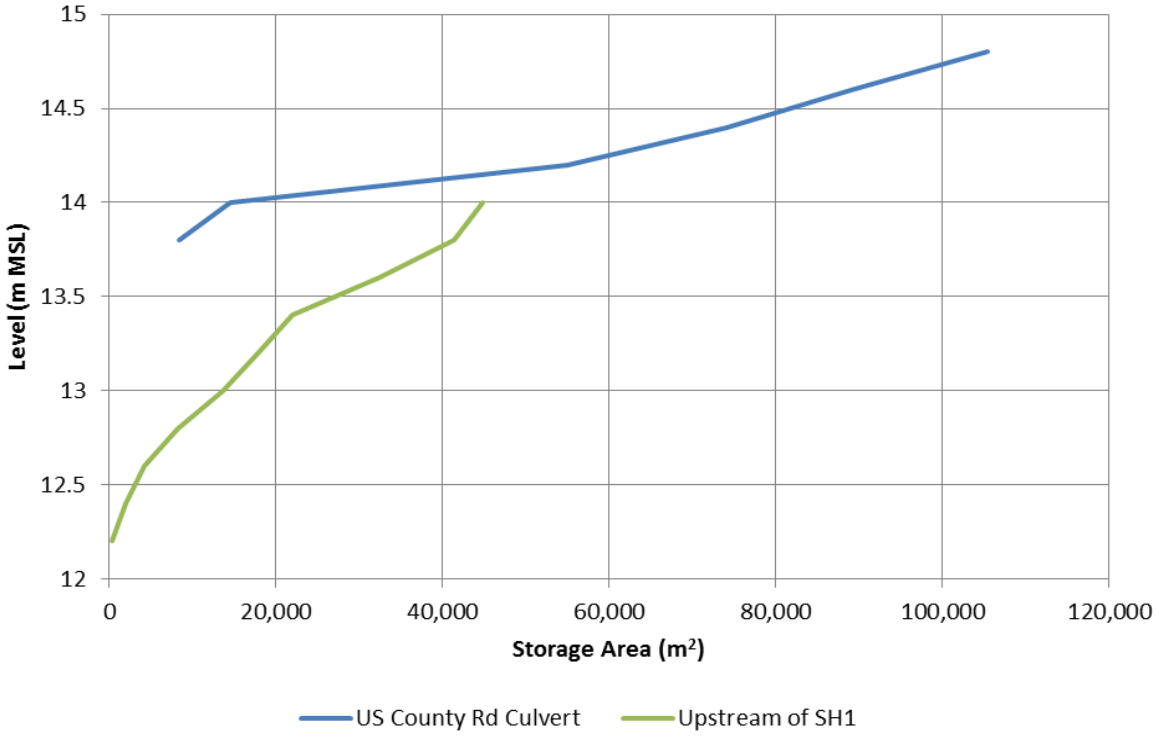

Figure 3-2 Storage area / elevation relationships for flood detention ponds upstream of County Road and the NIMT railway line, and the Pare-o-Matangi Reserve upstream of SH1 (based on LiDAR data)

The two detention ponds are connected by a 1.2m diameter culvert under County Road and a purposely throttled culvert under the NIMT railway line (see Table 3-1 for the dimensions of both culverts). From the initial scheme assessment, it was found that the combination of the two culverts throttles downstream flood flows to limit flood inundation through Ōtaki Township rather than just the railway culvert. The railway embankment would act as an overflow weir if flood levels in the upstream detention pond were not relieved by outflow over Rahui Road (refer to discussion of this later in Section 3.2) and rose above track level.

The second detention pond is drained by a culvert made up of twin 0.9m diameter pipes under SH1 (see Table 3-1 for the culvert dimensions). Similar to the railway embankment for the first detention pond, the road embankment acts as an overflow weir if flood levels in the second detention pond rise above road level. Figure 3-3 illustrates the combined culvert and road overflow weir level / discharge relationship for the SH1 culvert[4].

Table 3-1 summarises all the culvert types on the Mangapouri Stream in the SH1 / Rahui Road / NIMT railway line triangle in the current situation, along with their key dimensions and levels.

[4] This rating relationship was evaluated with the aid of a level / discharge relationship for the stream channel downstream of the culvert obtained from a previous HEC-RAS one-dimensional computational hydraulic model of the Mangapouri Stream (WRC, 1989).

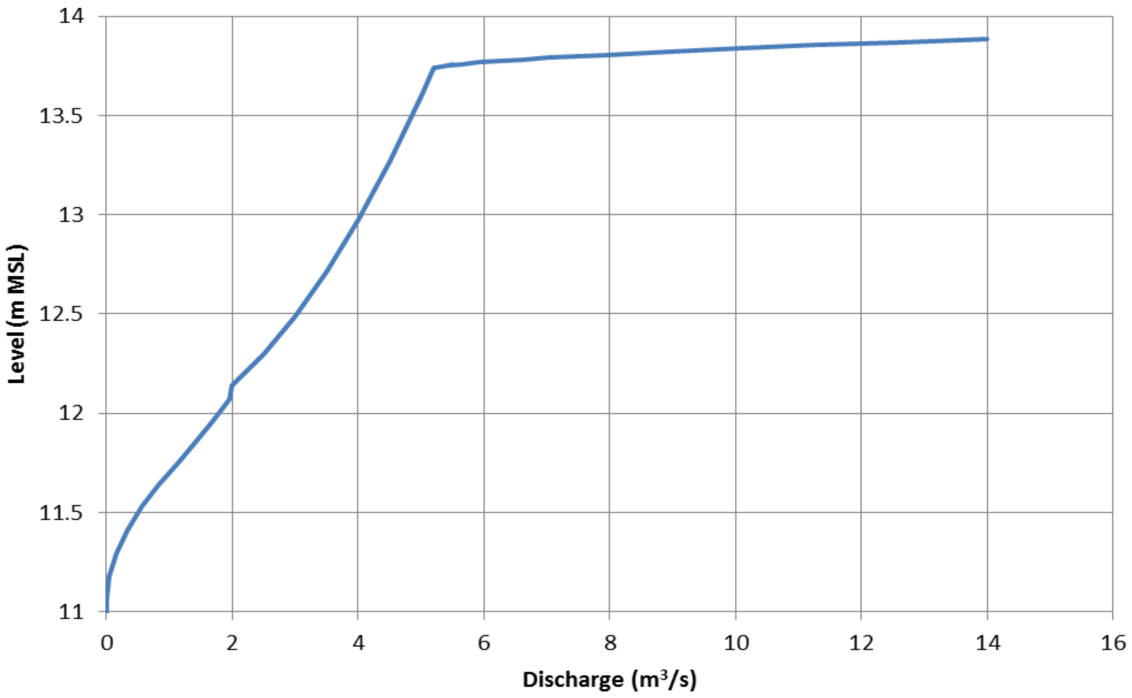

Figure 3-3 Pond level / discharge relationship for SH1 culvert and road overflow weir (discharge includes both culvert outflow and road overflow)

Table 3-1 Culvert types, dimensions and levels for current situation in Mangapouri Stream in SH1 / Rahui Road / NIMT railway line triangle

Location	Type	Size (m)	Invert Level (m MSL Wellington)		Length (m)	Slope (%)	Road / Track Level (m MSL Wellington)
			u/s	d/s			
County Rd [1]	circular	1.2 (dia)	11.97	12.01	19.3	negative	14.39 [2]
NIMT railway [1]	custom-built arch	0.95 x 1.2	12.08	11.98	12.2	0.82	16.28 [3] 15.4 [4]
Existing SH1 [1]	twin circular	0.9 (dia)	11.06	10.96	20	0.50	13.74
Railway wetland	circular	0.40 (dia)	17.34	17.31	8.0	0.38	19.46

[1] Details for these culverts obtained from Wellington Regional Council February 1998 report "*Ōtaki Floodplain Management Plan, Mangapouri Stream Upgrade, Hydraulic Modelling Report*", Report No. WRC/RI-T-97/48.
[2] Road levels further north from this culvert along County Road are lower than this level.
[3] Track level at location of railway culvert.
[4] Approximate track level at location of Rahui Road railway crossing.

3.2 Modifications to Computational Hydraulic Model of Current Situation

The one-dimensional MIKE11 computational hydraulic model was originally set up to mimic the detention pond behaviour under flood conditions of the current situation as described above. However a number of improvements were made to the existing model:

- As flood levels rise in the detention pond area upstream of County Road and the NIMT railway line above a level of about 14.75m MSL Wellington datum (14.4m NZ Vertical Datum), floodwaters will start to spill southwards over Rahui Road into the Racecourse Catchment. Rahui Road therefore performs a flood relief function which the model was modified to mimic in order to more accurately predict flood levels in the detention pond area.
- Previously any storm runoff contribution from the Te Manuao Catchment to the Mangapouri Stream was ignored. Storm runoff from this partly urbanised catchment to the north is inferred to flow as sheet flow across SH1 into the railway wetland area (Figure 3-1) and possibly also down County Road directly into the flood storage area upstream of the existing NIMT railway embankment and County Road. This catchment contribution from the Te Manuao catchment was therefore incorporated into the model.
- The route by which any storm runoff from the Te Manuao Catchment entered the Mangapouri Stream was also incorporated into the model. The railway wetland area to the north of the existing SH1 overbridge over the NIMT railway line (Figure 3-1) was therefore included in the model along with the culvert outlet under the railway line and the long drain which conveys wetland outflow into the Mangapouri Stream.

The overflow characteristics of Rahui Road were evaluated with a separate two-dimensional MIKE21 model of part of the flood storage area upstream of the existing NIMT railway embankment, Rahui Road itself and the floodplain area southwards beyond the unnamed watercourse draining the Racecourse Catchment (currently the floodplain to the south is unconstrained by any topographic obstacle as far as Chrystall's Bend stopbank along the north side of the Ōtaki River)[5]. This reflects the path that any overflow will tend to follow with the floodplain to the west partially blocked by the NIMT railway line which is slightly elevated above natural floodplain levels from the Rahui Road crossing southwards towards the unnamed watercourse. Figure 3-4 shows the pond level / discharge relationship for this overflow relief path for the primary flood storage area upstream of the existing railway embankment. This hydraulic rating relationship was incorporated into the MIKE11 model of the existing situation.

The railway wetland area was incorporated into the MIKE11 model as a third detention pond area. Figure 3-5 shows the storage area / elevation relationship for the wetland area. The railway wetland area is elevated approximately 6.5m above the Pare-o-Matangi Reserve which forms the second flood storage area along the Mangapouri Stream.

The culvert outlet from the wetland area and downstream drain along the western side of the existing NIMT railway embankment were also incorporated into the model to provide hydraulic connectivity with the Mangapouri Stream. The dimensions of the culvert outlet are summarised in Table 3-1.

[5] For simplicity this MIKE21model ignored any inflow contribution from the Racecourse Catchment (see map in Appendix A) and any outflow via the unnamed watercourse culvert under the NIMT railway line. The floodplain in the model was also artificially constrained by preventing any overflow over the railway line. Further details of the extent of the MIKE21 model are given in Appendix F.

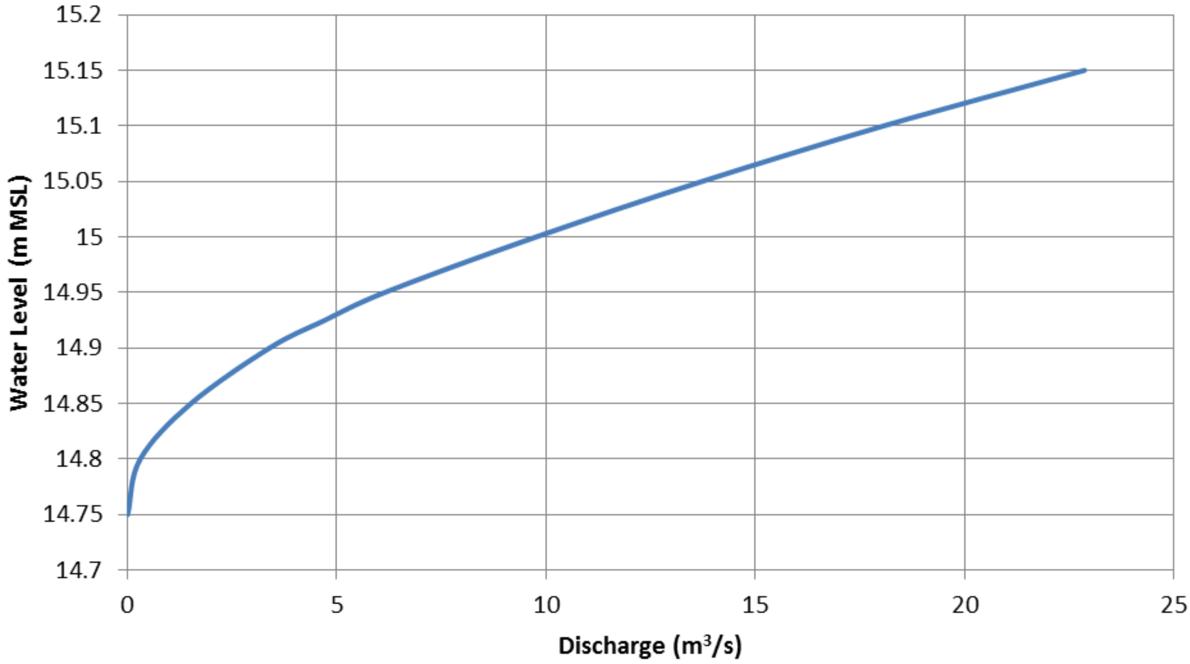

Figure 3-4 Pond level / discharge relationship for Rahui Road overflow from primary flood storage pond area upstream of NIMT railway line and County Road

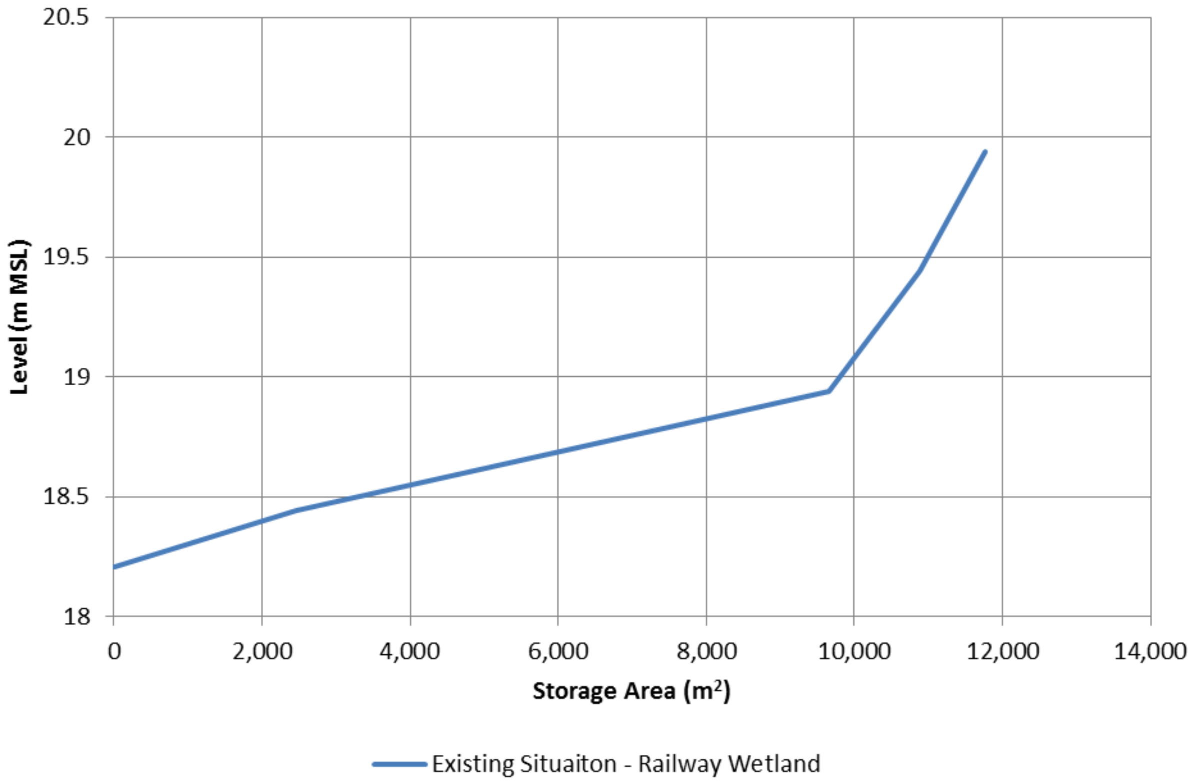

Figure 3-5 Storage area / elevation relationship for existing railway wetland area (based on LiDAR data)

If flood levels rise too high in the railway wetland area, they will overtop the railway embankment into an adjacent wetland to the west (between the railway line and a line of sandhills) and also overtop ground on the eastern side of the railway between it and County Road (this latter overflow path would spill floodwaters directly into the primary flood storage area upstream of the existing railway embankment). Both additional overflow paths were represented in the MIKE11 model as overflow weirs (weir levels sourced from LiDAR data).

3.3 Key Assumptions for Hydraulic Model Simulations of Current Situation

A number of key assumptions were made for the initial simulations with the modified hydraulic model. These were as follows:

- Firstly all of the surface runoff from the Te Manuao Catchment was assumed to be directed to the railway wetland area with none diverted via County Road into the flood storage area upstream of the existing railway embankment. This sensitivity of the model predictions to this assumption was subsequently tested in some further model simulations.
- Similarly all surface runoff from the Ōtaki Racecourse part of the Mangapouri Catchment was assumed to be directed via the drain on the eastern side of Te Roto Road into the Mangapouri Stream. The validity of this assumption was subsequently re-evaluated.
- When the flood storage area upstream of the existing railway embankment starts to fill, it was assumed that there would be no leakage through the track ballast. In reality there would be some leakage so that this assumption was a conservative one in that it implied the occurrence of higher flood levels in the primary flood storage area upstream of the railway embankment.
- The railway wetland area was initially assumed to be near empty with effectively nil storage prior to the occurrence of any flood (inspection of the wetland during the site visit indicated this to be a reasonable assumption).
- The model was not calibrated as would normally occur as there are no quantitative flood level and flow data available for calibration. The only anecdotal evidence available is an observation of the magnitude of flood inundation in the flood storage area upstream of the existing railway embankment during the 28 October 1998 flood which is discussed later in Section 3.6. However the channel roughness assumptions for the model are detailed below.

A Manning's n channel roughness value of 0.050 was applied to the main channel of the Mangapouri Stream in the MIKE11 model in line with the channel roughness value used for the HEC-RAS model of the entire stream used for the 1998 Wellington Regional Council investigations of channel capacity (WRC, 1998). However this assumption has negligible impact on the flood level and discharge predictions of the MIKE11 model as the model is effectively configured as a flood storage routing model where channel friction has no influence.

For the drain linking the railway wetland with the main stream channel, a slightly higher Manning's n channel roughness value was used. This choice of Manning's n value reflects the rough, overgrown character of the drain. This roughness value has no influence on predicted flood levels and outflows for the railway wetland at the head of the drain as the wetland again functions as a flood storage element in the MIKE11 model.

The frictional characteristics of the culverts linking the flood storage (detention) basins were defined using Manning's n roughness values carefully calculated for culverts made of concrete and flowing full. However, again these culvert roughness assumptions have negligible impact on the predicted flood levels and flows through the flood storage basin system as the culverts are short and their discharge capacities are governed by the flow contraction and expansion head losses at the culvert entrance and exit respectively.

For the two-dimensional MIKE21 model of the floodplain area to the south of Rahui Road (see Figure F-1 in Appendix F) used to establish the overflow characteristics of Rahui Road, a global surface roughness value of n = 0.040 was assumed.

3.4 Flood Level and Discharge Predictions for Current Situation

The following floods defined by the hydrographs in Figures 2-2 and 2-3 were routed through the triple detention pond system using the modified MIKE11 model:

- 42.9% (1 in 2.33) annual exceedance probability (AEP) flood based on existing climate conditions
- 20% (1 in 5) AEP flood based on existing climate conditions
- 10% (1 in 10) AEP flood based on existing climate conditions
- 5% (1 in 20) AEP flood based on existing climate conditions
- 2% (1 in 50) AEP flood based on existing climate conditions
- 1% (1 in 100) AEP flood based on existing climate conditions
- 1% (1 in 100) AEP flood adjusted for effects of possible future climate change to 2090
- 0.5% (1 in 200) AEP flood adjusted for effects of possible future climate change to 2090
- 0.2% (1 in 500) AEP flood adjusted for effects of possible future climate change to 2090

Table 3-2 summarises peak flood levels through the detention pond system predicted by the MIKE11 model for the different floods. Meanwhile Table 3-3 summarises peak flood discharges along the Mangapouri Stream. Tables 3-4 and 3-5 give the respective water balances for the railway wetland area and the primary flood storage area upstream of the existing railway embankment.

Figure B-1 to B-8 in Appendix B complement the tabulated peak flood level and discharge predictions in Tables 3-2 and 3-3.

Figure 3-6 shows the relationships between flood levels and flows for:

- the primary flood storage area upstream of the NIMT railway embankment (inflows, railway culvert outflows and Rahuii Road overflows); and
- the secondary flood storage area upstream of SH1 (sum of SH1 culvert outflows and overflows).

Figure 3-7 shows similar relationships between flood levels and inflows and outflows for the railway wetland pond.

Table 3-2 Predicted peak flood levels for existing situation in Mangapouri Stream

Flood Case (AEP %)	Peak Flood Level (m MSL Wellington datum)			
	Upstream of County Road culvert	Upstream of NIMT railway culvert [1]	Upstream of SH1 culvert	Railway wetland area
42.9	14.18	13.57	12.64	19.15
20	14.36	13.93	12.92	19.50
10	14.45	14.44	13.31	19.55
5	14.60	14.60	13.43	19.59
2	14.81	14.81	13.57	19.63
1	14.86	14.86	13.63	19.66
1 + CC to 2090	14.92	14.92	13.72	19.70
0.5 + CC to 2090	14.95	14.95	13.76	19.72
0.2 + CC to 2090	14.99	14.99	13.77	19.75

[1] No overtopping of railway embankment occurs although overtopping of Rahui Road occurs at about a level of 14.75m (MSL Wellington datum).

Table 3-3 Peak flood discharges for existing situation in Mangapouri Stream

Flood Case (AEP %)	Peak Flood Discharge (m^3/s)					
	Inflow from Mangapouri Catchment	Railway wetland inflow	NIMT railway culvert outflow	Rahui Rd overflow	SH1 culvert and overflow	Railway wetland outflow
42.9	5.13	1.02	2.97	0.00	3.35	0.40
20	6.92	1.38	3.61	0.00	3.90	0.60
10	8.40	1.68	4.42	0.00	4.56	1.00
5	9.79	1.92	4.59	0.00	4.75	1.34
2	11.64	2.33	4.74	0.45	4.95	1.92
1	13.02	2.60	4.79	1.96	5.05	2.31
1 + CC to 2090	15.20	3.04	4.73	4.53	5.17	2.77
0.5 + CC to 2090	16.90	3.37	4.60	6.37	5.51	3.08
0.2 + CC to 2090	19.00	3.79	4.58	8.98	6.12	3.47

Table 3-4 Water balance for railway wetland area

Flood Case (AEP %)	Peak Flood Discharge (m^3/s)					Attenuation Factor [2]
	Railway wetland inflow	Culvert outflow at overflow peak[1]	Railway overflow	County Rd overflow	Sum of outflows	
42.9	1.02	0.40	0.00	0.00	0.40	0.61
20	1.38	0.44	0.16	0.00	0.60	0.57
10	1.68	0.44	0.56	0.00	1.00	0.40
5	1.92	0.43	0.90	0.01	1.34	0.31
2	2.33	0.40	1.47	0.05	1.92	0.18
1	2.60	0.39	1.83	0.09	2.31	0.11
1 + CC to 2090	3.04	0.37	2.26	0.14	2.77	0.09
0.5 + CC to 2090	3.37	0.36	2.55	0.17	3.08	0.09
0.2 + CC to 2090	3.79	0.35	2.90	0.22	3.47	0.08

[1] Note peak culvert outflows start to decrease for floods larger than 20% AEP flood due to partial drowning of culvert outflows by high tailwater levels in downstream drain.
[2] This assumes that peak outflows from different outlets occur coincidentally which may only be approximately true.

Table 3-5 Water balance for primary flood storage area upstream of existing NIMT railway embankment

Flood Case (AEP %)	Peak Flood Discharge (m^3/s)						Attenuation Factor [1]
	Inflow from Mangapouri Catchment	Overflow from railway wetland	Sum of inflows	NIMT railway culvert outflow	Rahui Rd overflow	Sum of outflows	
42.9	5.13	0.00	5.13	2.97	0.00	2.97	0.42
20	6.92	0.00	6.92	3.61	0.00	3.61	0.48
10	8.40	0.00	8.40	4.42	0.00	4.42	0.47
5	9.79	0.01	9.80	4.59	0.00	4.59	0.83
2	11.64	0.05	11.69	4.74	0.45	5.19	0.56
1	13.02	0.09	13.11	4.79	1.96	6.76	0.48
1 + CC to 2090	15.20	0.14	15.34	4.73	4.53	9.26	0.40
0.5 + CC to 2090	16.90	0.17	17.07	4.60	6.37	10.98	0.36
0.2 + CC to 2090	19.00	0.22	19.22	4.58	8.98	13.56	0.29

[1] This assumes that peak inflows from different sources occur coincidentally and also peak outflows from different outlets occur coincidentally which may only be approximately true.

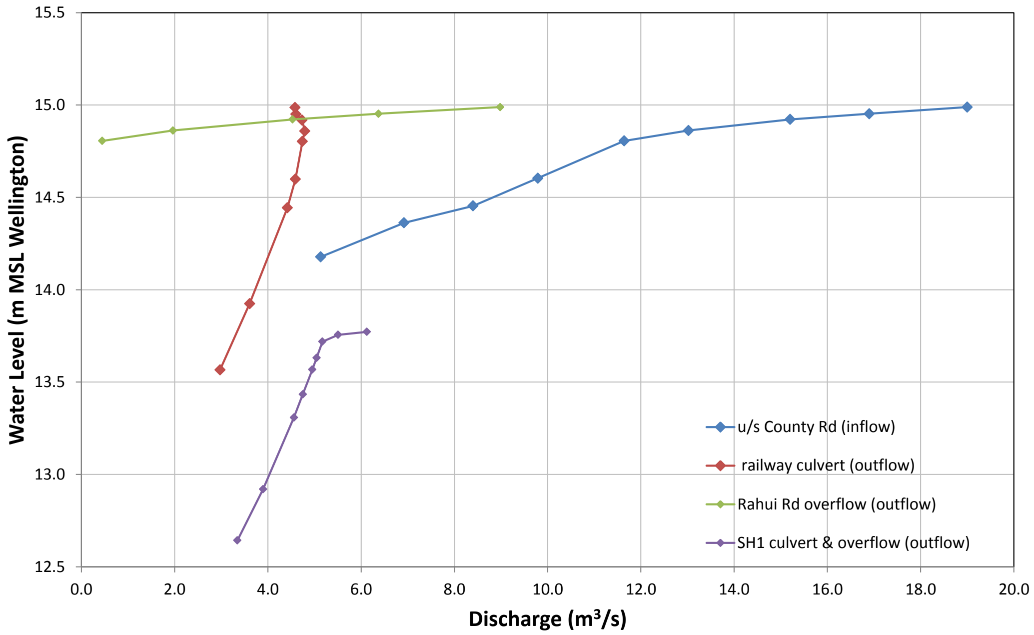

Figure 3-6 Pond level / inflow and outflow curves for Mangapouri Stream primary flood storage area upstream of NIMT railway embankment and County Road and secondary flood storage area upstream of SH1

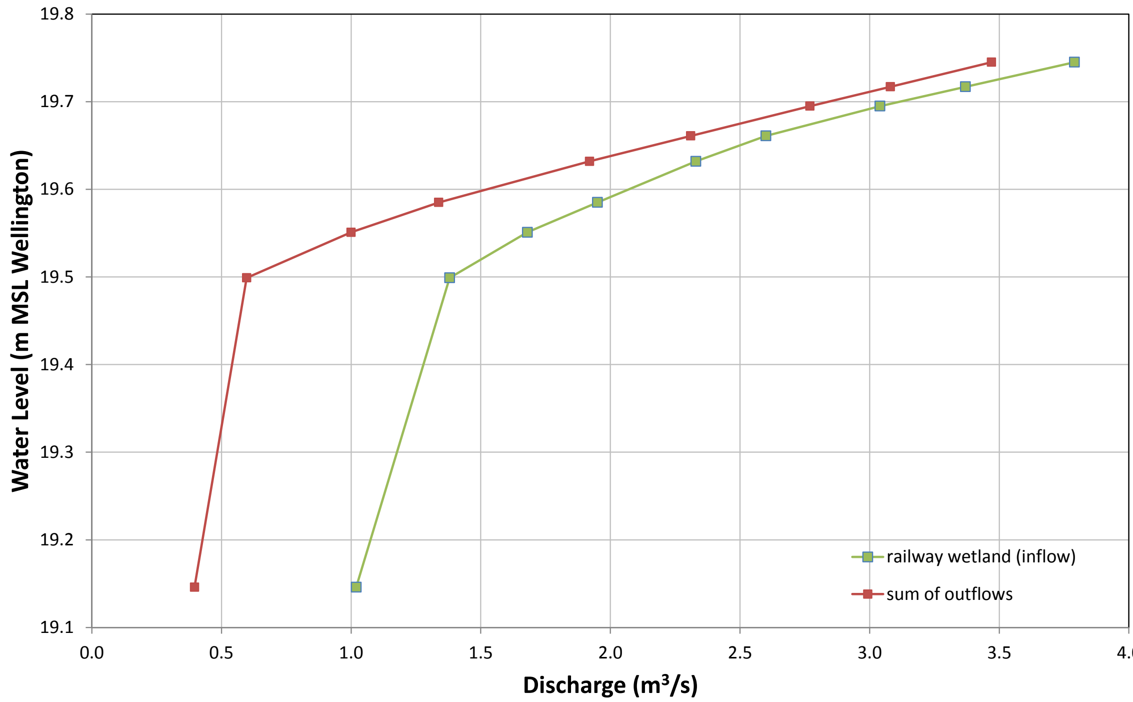

Figure 3-7 Pond level / inflow curves for railway wetland area

3.5 Observations on Hydraulic Performance for Current Situation

Figure B-5 in Appendix B confirms the initial assumption that the Mangapouri Stream from just upstream of County Road down to SH1 behaves as a twin detention pond system in series. The backwater profiles upstream of the NIMT railway embankment and culvert (chainage 751m) and upstream of SH1 and its culvert (chainage 1000m) are approximately horizontal.

Once County Road is overtopped by floodwaters between a 20% AEP and a 10% AEP flood, the County Road culvert gets drowned out (the peak flood levels upstream of the County Road culvert and upstream of the railway culvert in Table 3-2 become the same). The railway culvert then becomes the primary hydraulic control throttling flood flows past the railway embankment (Figure B-6 in Appendix B) with culvert outflows much smaller than pond inflows (Figure 3-6). The flood level hydrographs upstream of the County Road culvert and upstream of the railway culvert for the more extreme floods (Figures B-1 and B-2 in Appendix B) are effectively the same.

Rahui Road starts to overtop when the primary flood storage area upstream of the NIMT railway embankment fills up with floodwaters to a level of about 14.75m MSL Wellington datum (between a 5% AEP and 2% AEP flood in Table 3-2). After Rahui Road is overtopped and performs a flood relief function, flood levels in the flood storage area only rise very slowly for large increases in peak inflow. This is indicated by the sharp change in slope of the pond level / inflow curve (green coloured line) in Figure 3-6.

As the magnitude of the flood increases and flood inflows fill primary storage basin, the flood peak attenuation factor[6] reduces. The attenuation factor for the smaller floods considered is in the range of 47-56% and reduces to 29% for the most extreme flood (0.2% AEP adjusted for possible future climate change effects).

SH1 starts to overtop between a 1% AEP and a 0.5% AEP flood adjusted for possible future climate change effects. This is indicated by the sharp change in slope of the secondary pond level / outflow curve in Figure 3-6. Overtopping would occur with much smaller floods if the NIMT railway embankment upstream was not present and the railway culvert not throttled.

In the railway wetland area, flood levels are predicted to overtop the railway embankment between a 42.9% AEP and 20% AEP flood (based on the assumptions outlined in Section 3.3) as indicated by the overflow discharge values in Table 3-4. In practical terms this would occur initially by seepage through the railway track ballast and would probably result in the track being washed out. The predicted response is heavily influenced by the Te Manuao Catchment outflow assumption with the whole of the outflow directed towards the railway wetland. The sensitivity of the model predictions to this assumption is discussed later in Section 4.7.1.

As flood levels in the railway wetland area rise even further, the existing ground between the NIMT railway line and County Road may also start to overflow. However the flow volumes will be much smaller than those overtopping the railway embankment. As with the primary flood storage basin, the peak flood attenuation factor for the railway wetland reduces from about 60% for the 42.9% AEP and 20% AEP floods to about 8-9% for the most extreme floods considered (Table 3-4).

Figure 3-8 shows the predicted flood extent for the 1% AEP flood adjusted for possible future climate change effects to 2090 within the general area of the SH1 / Rahui Road / NIMT railway triangle. The variable shading of the flood extent indicates the magnitude of the flood depth. Similarly Figure 3-9 shows the predicted flood extent for the 0.2% AEP adjusted for possible future climate change effects in the same area.

[6] The flood peak attenuation factor is the ratio of the difference in the peak inflow and outflow to the peak inflow. It is a measure of how much the peak flood inflow is attenuated by flood storage.

As noted in Section 3.2, the simplified MIKE21 floodplain model used to establish the pond level / discharge rating relationship for Rahui Road overflow did not account for the inflow contribution from the Racecourse Catchment nor the outflow through the unnamed watercourse culvert under the NIMT railway line.

Despite these limitations of the simplified model, the following observations can be made from a comparison of Figures 3-8 and 3-9,:

- Within the primary flood storage basin upstream of the NIMT railway embankment, flood depths are fairly similar. This is not surprising given the very small increase in predicted peak flood level in the storage basin (0.07m) between the two flood cases.
- The extent of flood inundation in the same flood basin is very slightly greater at the upstream end for the 0.2% AEP flood adjusted for possible climate change effects.
- Within the secondary flood storage basin upstream of SH1, the flood depths are very similar which is again not surprising given the very small increase in peak flood level (0.05m) between the two flood cases.
- The extent of flood inundation in the secondary flood storage basin is very marginally increased around the houses along Rahui Road immediately to the west of the railway crossing.
- The Rahui Road overflow zone is slightly greater for the 0.2% AEP flood adjusted for possible climate change effects while the extent of flood spread is also greater. Flood depths are also slightly greater.

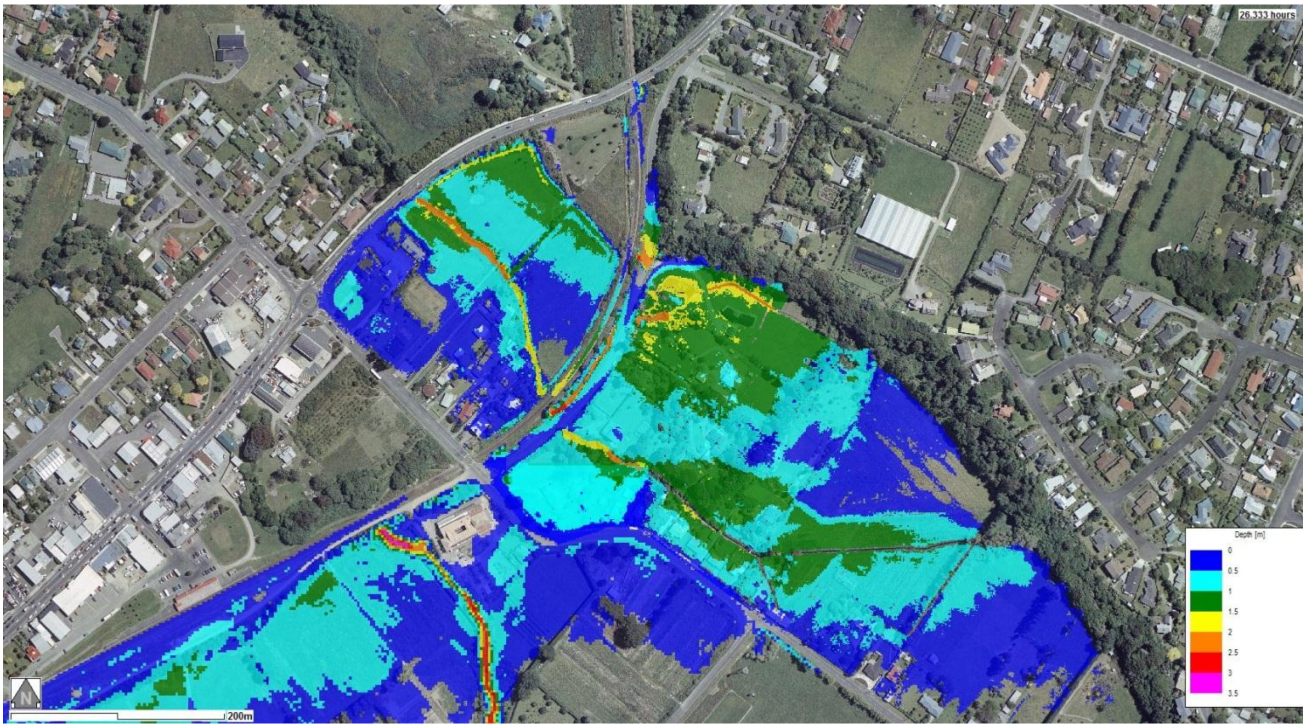

Figure 3-8 Predicted flood inundation extent for the 1% AEP flood adjusted for effects of possible future climate change to 2090 within the general area of the SH1 / Rahui Road / NIMT railway triangle

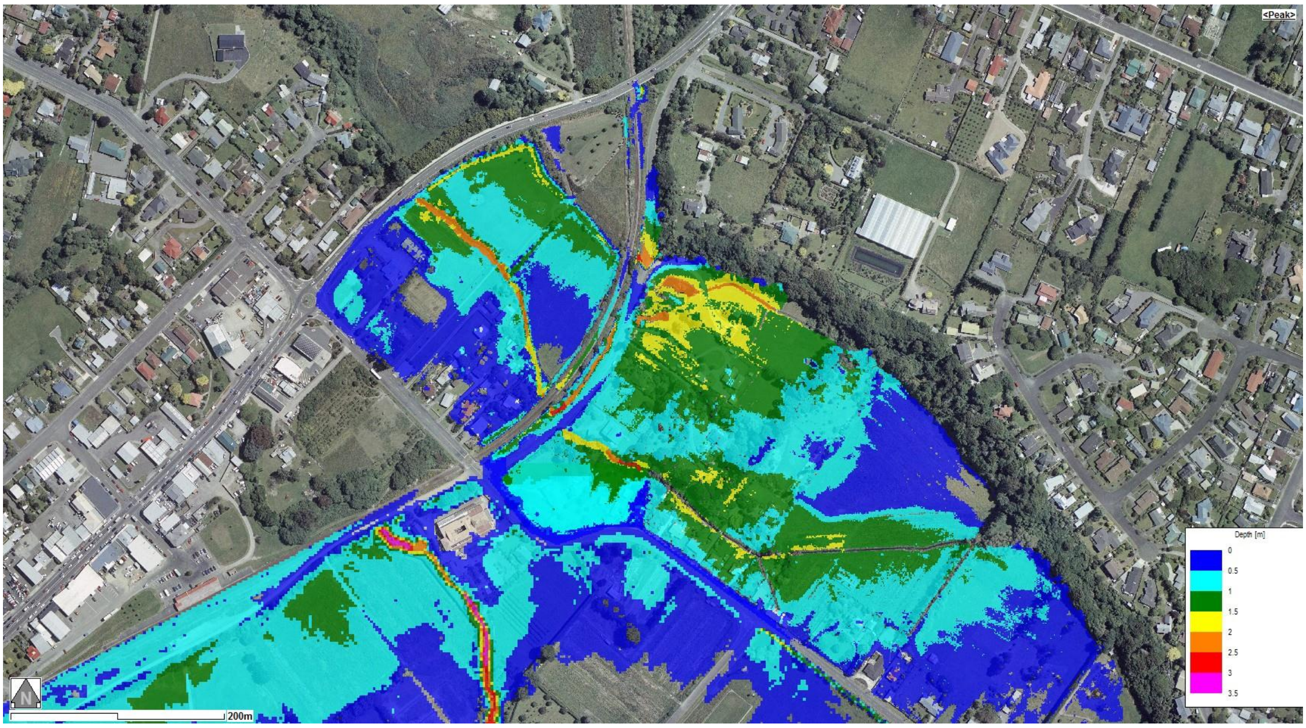

Figure 3-9 Predicted flood inundation extent for the 0.2% AEP flood adjusted for effects of possible future climate change to 2090 within the general area of the SH1 / Rahui Road / NIMT railway triangle

It should also be noted that the assumption that all surface runoff from the Racecourse part of the Mangapouri Catchment is diverted across Rahui Road into the primary flood storage basin is not necessarily correct. Field observations suggest that while a fair proportion of the surface runoff volume would follow this path via a culvert under Rahui Road, the limited capacity of the culvert means that some surface runoff is likely to flow across Te Roto Road towards the unnamed watercourse draining the Racecourse Catchment (refer to the catchment map in Appendix A). In reality the extent of inundation around the intersection of Rahui and Te Roto Roads may therefore be greater than that shown in Figures 3-8 and 3-9.

3.6 Checking Veracity of Flood Level Predictions Upstream of County Road

As a crude check on the veracity of the flood level predictions in Table 3-2, the property owner at 29 County Road provided anecdotal evidence at a recent PP2O Project Open Day in Ōtaki of floodwaters in the Mangapouri Stream inundating up to near the house on the adjacent property at 22 County Road in the 28 October 1998 flood (Mrs M Blaikie, pers. comm.).

The magnitude of the 28 October 1998 flood peak was inferred to be 22.0m^3/s at the Mangaone at Ratanui gauging station. The flood estimates for the Mangaone Stream at this location in Table2-1 indicate then that this flood was between a 20% AEP and a 10% AEP flood (≈ 14% AEP from interpolation of the tabulated flood frequency values). Assuming that the flood in the Mangapouri Stream had a similar frequency (or annual exceedance probability) as the flood in the Mangaone Stream, the flood levels in the range 14.36m to 14.45m MSL Wellington datum would have been expected upstream of the County Road culvert (these flood level values are sourced from Table 3-2 for the 20% and 10% AEP floods respectively upstream of the County Road culvert).

Inspection of ground levels in the vicinity of the house at 22 County Road indicates that these are in the range of 14.2-14.4m MSL Wellington datum. These ground levels roughly coincide with the predicted flood levels for floods in the 20% AEP to 10% AEP range. This provides a very approximate check on the veracity of the flood level predictions in Table 3-2.

The pattern of flood inundation shown in Figures 3-8 and 3-9 is very similar to that shown on the broad scale flood hazard layer incorporated in the Kāpiti Coast District Plan for Ōtaki. An excerpt of this flood hazard layer produced from information compiled by both GWRC and KCDC is included in Appendix D. The similarity of the patterns of inundation in Figures 3-8 and 3-9 and this broader scale map provide further confirmation of the veracity of the flood level predictions in Table 3-2.

Unfortunately no other anecdotal evidence or surveyed peak flood levels from other recent significant flood events have come to light during the course of these investigations that could be used to check the veracity of the model.

3.7 Effects of Flood Detention in Storage Basins for Current Situation

The 1998 Wellington Regional Council Report (WRC, 1998) gives dimensions and levels for the existing County Road and NIMT railway culverts. From the restricted size of the latter culvert, it can be inferred that previously a deliberate decision has been made by relevant local authorities to throttle the culvert in order to restrict downstream flood flows in the Mangapouri Stream and thereby provide protection to flood prone properties in Ōtaki Township (communications with GWRC and KNDC staff confirm this). However the effect of this past decision has been to expose a number of properties along County Road and Rahui Road to a slightly greater flood hazard than they would have been subjected to prior to the throttle being installed. Floor levels for these properties have been surveyed and compiled by KCDC and GWRC.

The area within the SH1 / Rahui Road / NIMT railway line triangle also functions as a secondary flood storage area as noted previously. Stored flood waters in this basin could also impact on properties along Rahui Road and SH1. The floor level data compiled by KCDC and GWRC also cover these properties.

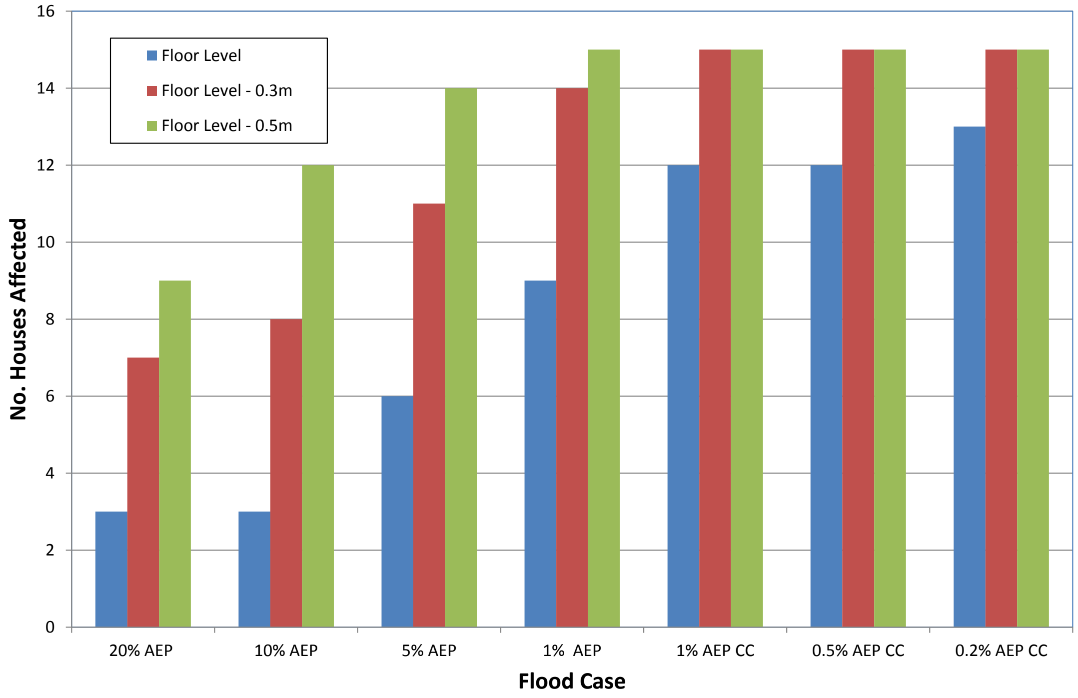

Figure 3-10 Number of flood affected houses in existing situation along County Road and Rahui Road upstream of NIMT railway culvert on Mangapouri Stream

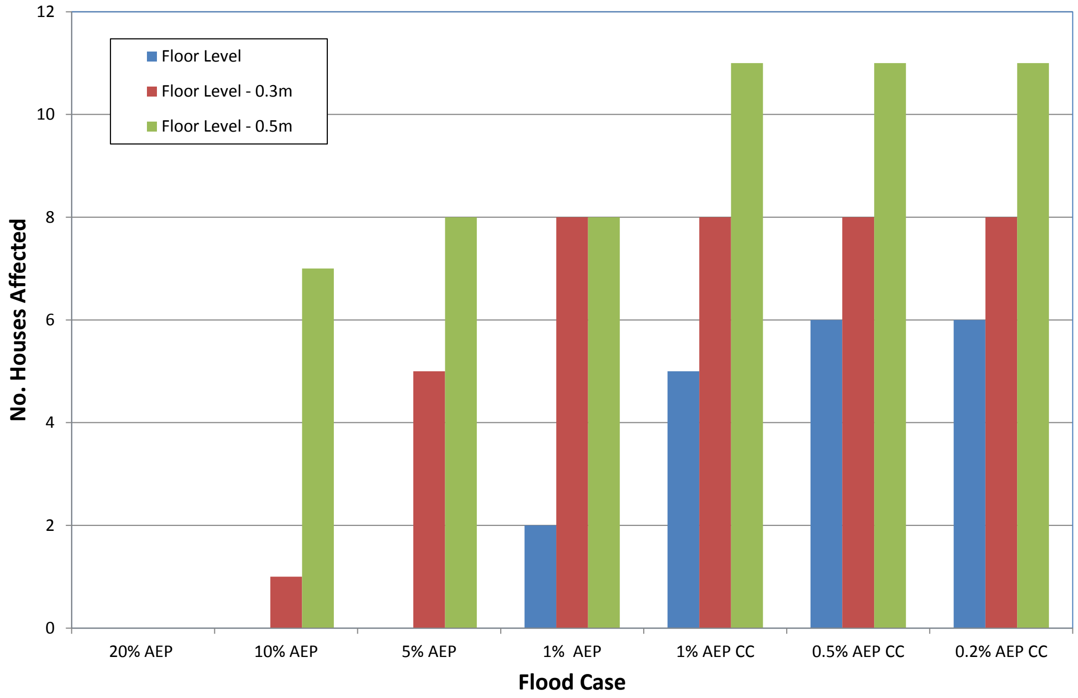

Figure 3-11 Number of flood affected houses in existing situation along SH1 and Rahui Road between NIMT railway culvert and SH1 culvert on Mangapouri Stream

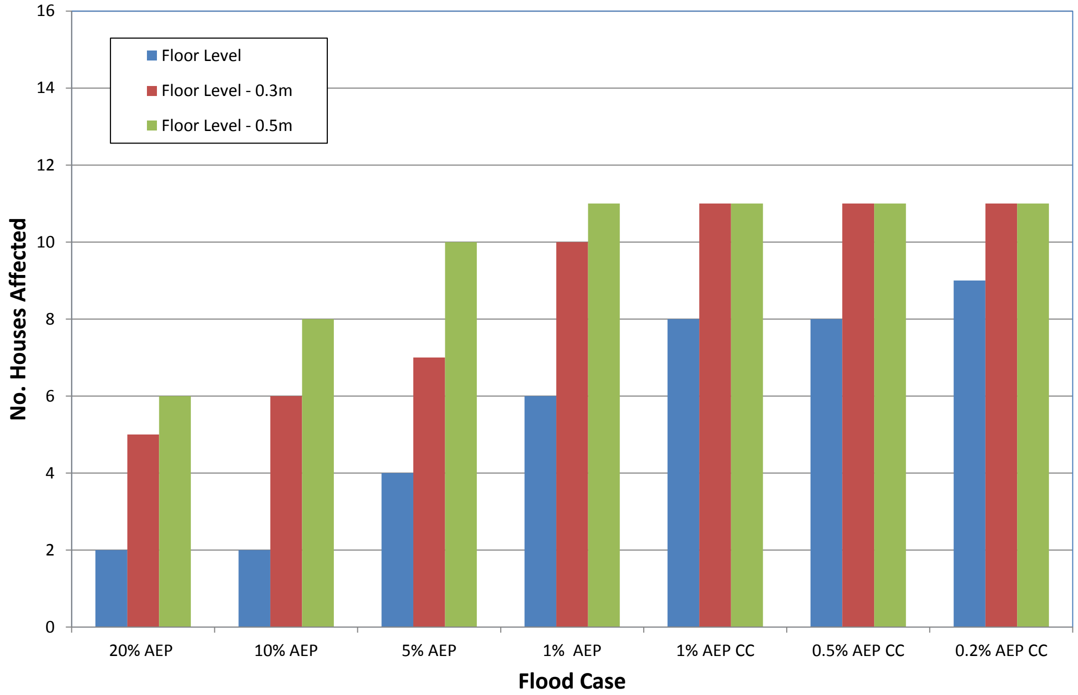

Figure 3-12 Number of flood affected houses in existing situation along County Road and Rahui Road upstream of NIMT railway culvert on Mangapouri Stream (excluding properties required for proposed Expressway)

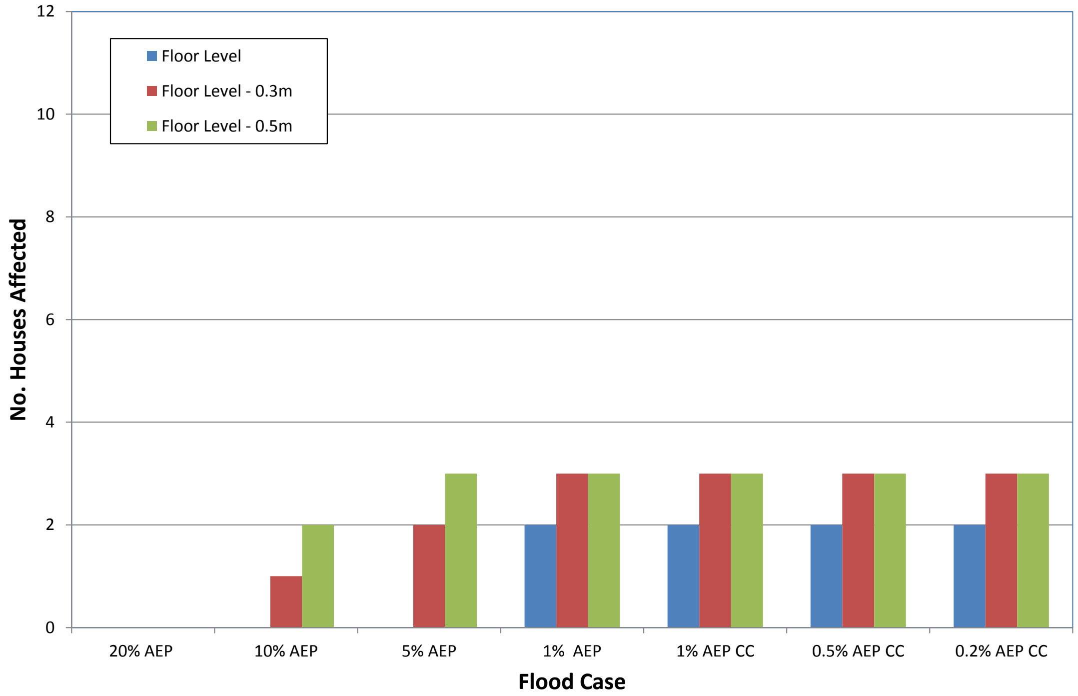

Figure 3-13 Number of flood affected houses in existing situation along SH1 and Rahui Road between NIMT railway culvert and SH1 culvert on Mangapouri Stream (excluding properties required for proposed Expressway)

The building floor levels were compared with the predicted flood levels in Table 3-2 to establish the number of affected houses for different sized floods. Figure 3-10 shows a bar chart of the number of affected houses within the primary flood storage area upstream of the NIMT railway embankment while Figure 3-11 shows a similar bar chart for the secondary flood storage area upstream of SH1. The count of affected houses in both bar charts is shown for three levels of freeboard:

- less than zero freeboard (peak flood level is either coincident with floor level or above)
- less than 0.3m freeboard (peak flood level is within 0.3m of floor level)
- less than 0.5m freeboard (peak flood level is within 0.5m of floor level)

However a number of properties will be impacted and removed by the proposed Expressway so that, to provide a valid comparison with the effects of the Expressway, these properties have been excluded from the count in Figures 3-10 and 3-11. Figures 3-12 and 3-13 show the results of this exclusion.

Comparison of Figure 3-12 with Figure 3-10 and Figure 3-13 with Figure 3-11 indicates that exclusion of those properties needing to be acquired for the PP2O Project reduces the number of flood affected houses. Exclusion of these properties has the greatest effect in the SH1 / Rahui Road / NIMT railway line triangle (Pare-o-Matangi Reserve) because only three properties out of a total of thirteen are likely to remain *in situ* (Figures 3-11 and 3-13).

Although exclusion of properties required for the PP2O Project upstream of the NIMT railway embankment does reduce the number of flood affected houses in the primary flood storage area on the Mangapouri Stream, the effect is much less significant (Figures 3-10 and 3-12). Two properties are inferred to have floor levels below flood level for the 20% AEP flood with five houses having floor levels with less than 0.3m freeboard (including the three with floor levels below flood level) and six houses with having floor levels with less than 0.5m freeboard. The number of flood affected houses in each freeboard category gradually increases as the flood magnitude increases. For the 1% AEP flood, six out of eleven houses have floor levels lower than the predicted peak flood level with ten houses having less than 0.3m freeboard and all eleven houses within the flood storage area having less than 0.5m freeboard. For the 1% AEP and 0.5% AEP floods adjusted for possible future climate change effects, the number of houses with floor levels lower than the predicted peak flood level increases to eight (nine in the case of the 0.2% AEP flood adjusted for possible future climate change effects) while all eleven houses have less than 0.3m freeboard.

Within the SH1 / Rahui Road / NIMT railway line triangle (Pare-o-Matangi Reserve), two out of three houses have floor levels lower than predicted peak flood level for floods larger than the 1% AEP flood while the remaining house has a freeboard of less than 0.3m for these floods.

3.8 Sensitivity of Peak Flood Level and Discharge Predictions to Alternative Assumptions

3.8.1 Storm Runoff Paths from Te Manuao Catchment

The limited pipe drainage network within the Te Manuao Catchment directs captured storm runoff to the railway wetland area. Previously it was assumed that other surface runoff from the catchment is also directed to the wetland area.

Inspection of ground level contour data for the lower part of the catchment (Figure 3-14) suggests however that a fair proportion of the surface runoff would flow either down SH1 and into County Road or over the edge of the terrace marking the boundary with the Mangapouri Catchment to the south. Surface runoff following this latter path would flow directly into the primary flood storage basin in the Mangapouri Stream.

Observations from the 7 March 2012 site reconnaissance identified a stormwater sump on the eastern side of County Road capturing road runoff (and possibly also some runoff from the Te Manuao Catchment) and directing it under the road into the drain between County Road and the existing NIMT railway line. The site reconnaissance was undertaken in fine weather but running water in the bottom of the sump was clearly audible indicating that it was also capturing a sizable volume of groundwater seepage (probably spring flow).

The sensitivity of the flood level and discharge predictions to the assumed drainage path for storm runoff from the Te Manuao Catchment was therefore tested by considering the effects of an even split between runoff directed to the railway wetland area and runoff directed to the primary flood storage in the Mangapouri Stream (the exact split is very difficult to estimate and could very well change with the magnitude of the storm event).

Table 3-6 summarises the peak flood level predicted by the MIKE11 model to this alternative Te Manuao Catchment runoff destination assumption. Meanwhile Table 3-7 summarises the peak flood discharge predictions. The bracketed values in Tables 3-6 and 3-7 are the previously predicted values from Tables 3-2 and 3-3.

Figure 3-14 Ground level contours in lower part of Te Manuao Catchment (contours shown in orange and yellow). Arrows show general direction of overland flow from lower Te Manuao Catchment.

A number of important observations can be made from the peak flood level and discharge predictions summarised in Tables 3-6 and 3-7:

- For the larger floods (1% AEP and larger), the effect of part diversion of Te Manuao Catchment flows into the primary storage basin on the Mangapouri Stream upstream of the NIMT railway embankment is to cause peak flood levels in the basin to increase only marginally (≈ 0.02m). This is because of the large area of the storage basin.
- However, for the same larger floods, peak flood levels in the secondary flood storage basin within the Pare-o-Matangi Reserve upstream of SH1would decrease significantly by 0.16-0.19m. This is due to the lower flow volumes entering the basin from the railway wetland.
- As a consequence of the marginally higher flood levels in the primary flood storage basin, Rahui Road overflow volumes increase quite significantly, ranging from 0.7-1.5m3/s for the 1% AEP and larger floods.
- Outflows through the SH1 culvert from the secondary flood storage basin are reduced due to the lower flow volumes entering the basin from the railway wetland.
- The existing railway line would start to be overtopped in a 1% AEP flood compared to between a 42.9% AEP and a 20% AEP flood if all of the Te Manuao Catchment outflow is assumed to directly enter the railway wetland.

Table 3-6 Predicted peak flood levels for existing situation in Mangapouri Stream with even split for diversion of Te Manuao Catchment runoff to railway wetland area and to primary flood storage basin in Mangapouri Stream (note bracketed values refer to base case flood level values from Table 3-2)

Flood Case (AEP %)	**Peak Flood Level (m MSL Wellington datum)**			
	Upstream of County Road culvert	**Upstream of NIMT railway culvert**	**Upstream of SH1 culvert**	**Railway wetland area**
20	14.39 (14.36)	14.19 (13.93)	13.01 (12.92)	18.78 (19.50)
5	14.67 (14.60)	14.66 (14.60)	13.34 (13.43)	19.09 (19.59)
1	14.88 (14.86)	14.88 (14.86)	13.47 (13.63)	19.47 (19.66)
1 + CC to 2090	14.93 (14.92)	14.93 (14.92)	13.53 (13.72)	19.53 (19.70)
0.2 + CC to 2090	15.01 (14.99)	15.01 (14.99)	13.61 (13.77)	19.58 (19.75)

Table 3-7 Peak flood discharges for existing situation in Mangapouri Stream with even split for diversion of Te Manuao Catchment runoff to railway wetland area and to primary flood storage basin in Mangapouri Stream (note bracketed values refer to base case flood discharge values from Table 3-3)

Flood Case (AEP %)	**Peak Flood Discharge (m^3/s)**					
	Inflow from Mangapouri Catchment [1]	**Railway wetland inflow**	**NIMT railway culvert**	**Rahui Rd overflow**	**SH1 culvert and overflow**	**Railway wetland outflow**
20	7.61 (6.92)	0.69 (1.38)	4.04 (3.61)	0 (0)	4.07 (3.9)	0.34 (1.38)
5	10.77 (9.79)	0.98 (1.92)	4.72 (4.59)	0 (0)	4.63 (4.75)	0.39 (1.95)
1	14.32 (13.02)	1.30 (2.60)	5.00 (4.79)	2.71 (1.96)	4.80 (5.05)	0.45 (2.60)
1 + CC to 2090	16.72 (15.20)	1.52 (3.04)	5.06 (4.73)	5.21 (4.53)	4.89 (5.17)	0.80 (3.04)
0.2 + CC to 2090	20.9 (19.0)	1.90 (3.79)	5.16 (4.58)	10.46 (8.98)	5.02 (6.12)	1.24 (3.79)

[1] Larger inflow volumes from Mangapouri Catchment for sensitivity test case compared to base case reflect the increase due to component of inflow from Te Manuao Catchment (zero for base case).

3.8.2 Effects of Culvert blockage

Culvert blockage by flood transported woody and vegetative debris is a common problem in drainage systems and natural watercourses. It is reasonable therefore to consider the effects of culvert blockage on predicted flood peak levels and discharges. It should be notes that culvert blockage does not mean complete blockage but only partial blockage (it would be extremely rare for a culvert to be totally blocked).

In the context of the Mangapouri Stream, the culvert most exposed to blockage is the County Road culvert which is the first one on the main stem of the stream. However, if this culvert became partially blocked by debris (either tree-sourced debris or urban detritus) during the rising stages of flood event, then floodwaters would simply head up prematurely before overtopping County Road. Consideration of blockage of the NIMT railway culvert is a more conservative scenario.

The existing NIMT railway culvert lies immediately downstream of the County Road culvert in series with it. The distance between the downstream end of the County Road culvert and the upstream end of the railway culvert is very small (~ 2m) so that there is much lower chance of the railway culvert getting blocked by flood transported debris. If the culvert did become partially blocked, then floodwaters would also head up prematurely before overtopping of Rahui Road started to occur.

Although there are some trees within the Pare-o-Matangi Reserve downstream of the railway culvert, the potential supply of woody debris and vegetative material is very limited. Therefore the chance of the SH1 culvert becoming partially blocked by flood-transported debris is even more unlikely.

Tables 3-8 and 3-9 summarise the peak flood level and discharge predictions of the MIKE11 model for the case of partial blockage (50 per cent blockage) of the NIMT railway culvert on the Mangapouri Stream. Again the bracketed values are the previously predicted for the base case from Tables 3-2 and 3-3.

A number of important observations can be made from the peak flood level and discharge predictions summarised in Tables 3-8 and 3-9:

- For floods larger than the 1% AEP flood, the effect of a 50 per cent blockage of the railway culvert is to cause peak flood levels in the primary storage basin upstream of the culvert to increase by 0.06-0.09m. For floods smaller than the 1% AEP flood, the increase in peak flood levels is much larger.
- Flood levels in the primary flood storage basin upstream of the railway culvert are constrained from increasing too much by increasing outflows over Rahui Road which partially compensate for the deceased capacity of the partially blocked railway culvert.
- Partial culvert blockage results in lower flows into the secondary flood storage basin within the Pare-o-Matangi Reserve upstream of SH1. Consequently flood levels in this basin for the larger flows will be much lower (0.5-0.7m) and SH1 culvert outflows will be significantly reduced (by 1.0-1.7m^3/s).
- As a consequence of the higher peak flood levels in the primary storage basin, there are even more substantial increases in Rahui Road overflow for the floods larger than the 1% AEP flood (4.0-4.7m^3/s).

Table 3-8 Predicted peak flood levels for existing situation in Mangapouri Stream with partial blockage of NIMT railway culvert

Flood Case (AEP %)	**Peak Flood Level (m MSL Wellington datum)**			
	Upstream of County Road culvert	**Upstream of NIMT railway culvert**	**Upstream of SH1 culvert**	**Railway wetland area**
20	14.69 (14.36)	14.69 (13.93)	12.39 (12.92)	19.50 (19.50)
5	14.87 (14.60)	14.87 (14.60)	12.68 (13.43)	19.59 (19.59)
1	14.95 (14.86)	14.94 (14.86)	12.93 (13.63)	19.66 (19.66)
1 + CC to 2090	14.99 (14.92)	14.99 (14.92)	13.05 (13.72)	19.7 (19.70)
0.2 + CC to 2090	15.05 (14.99)	15.05 (14.99)	13.21 (13.77)	19.75 (19.75)

Table 3-9 Peak flood discharges for existing situation in Mangapouri Stream with partial blockage of NIMT railway culvert

Flood Case (AEP %)	**Peak Flood Discharge (m^3/s)**					
	Inflow from Mangapouri Catchment	**Railway wetland inflow**	**NIMT railway culvert**	**Rahui Rd overflow**	**SH1 culvert and overflow**	**Railway wetland outflow**
20	6.92 (6.92)	1.38 (1.38)	2.17 (3.61)	0.00 (0.00)	2.74 (3.9)	1.38 (1.38)
5	9.79 (9.79)	1.95 (1.95)	2.28 (4.59)	2.28 (0.00)	3.43 (4.75)	1.95 (1.95)
1	13.0 (13.0)	2.60 (2.60)	2.32 (4.79)	5.92 (1.96)	3.91 (5.05)	2.60 (2.60)
1 + CC to 2090	15.2 (15.2)	3.04 (3.04)	2.35 (4.73)	8.88 (4.53)	4.14 (5.17)	3.04 (3.04)
0.2 + CC to 2090	19.0 (19.0)	3.79 (3.79)	2.38 (4.58)	13.67 (8.98)	4.4 (6.12)	3.79 (3.79)

4. Hydraulic Performance in Proposed Expressway Situation

4.1 Hydraulic Behaviour of Mangapouri Stream in Proposed Situation

Figure 4-1 shows an aerial photograph of the Mangapouri Stream in the SH1 / Rahui Road / NIMT railway line triangle with the layout of the proposed PP2O Expressway and realigned NIMT railway line superimposed. The old NIMT railway alignment would be abandoned allowing the Expressway to make use of that corridor to the south of Rahui Road and through the railway wetland north of the existing SH1 overbridge over the railway line.

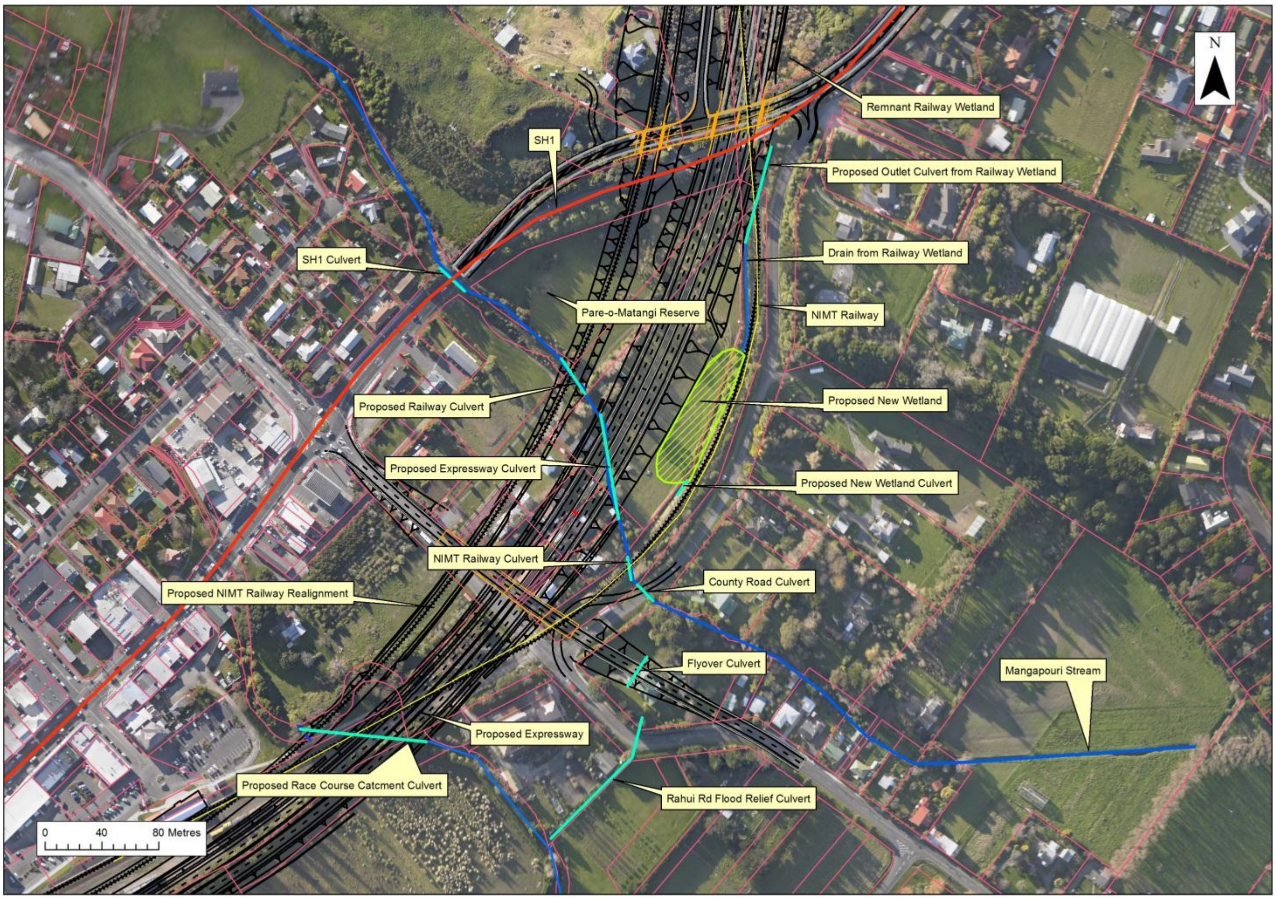

Figure 4-1 Aerial photograph of Mangapouri Stream in SH1 / Rahui Road / NIMT railway line triangle with layout of proposed Expressway and realigned railway line superimposed

As noted in Section 1.1, the site reconnaissance carried out on 7 March 2012 identified the desirability of retaining the existing NIMT railway culvert / County Road culvert system for throttling storm runoff from the Mangapouri Catchment. This was an alternative to the initial scheme assessment proposal to remove the existing railway culvert and use the new Expressway culvert and realigned railway culvert to replicate its current throttling function. The retention of the existing NIMT railway culvert / County Road culvert system means that the geometry of the primary flood storage basin on the Mangapouri Stream upstream of County Road and the existing railway embankment would remain fairly similar.

However there would be one significant change with the primary storage pond geometry. The location of the eastern approach embankment to the Rahui Road overbridge as shown in Figure 4-1 is such that it almost completely blocks the Rahui Road overflow path between the old Dairy Factory site to the west and the corner of Rahui Road and Te Roto Road in the east (refer to the Rahui Road overflow pattern in Figures 3-8 and 3-9). Figure 3-4 shows that the volume of overflow in the existing situation gets quite large as the storage basin fills up. The storage basin will fill up even more in the proposed situation if the overflow relief path is blocked and the inflow has nowhere else to go. To allow for this blockage of the overflow relief path in the proposed situation, it will be necessary to incorporate a gap (or gaps) in the overbridge approach embankment.

The gap in the Rahui Road approach embankment would best take the form of a large box culvert with the following characteristics:

- a deep enough section to ensure the occurrence of free surface flow conditions through it (rather than pressurised pipe flow conditions);
- a wide enough section to minimise the head loss through it;
- an invert set fairly low to achieve the required discharge capacity;
- excavation of the storage basin in front of the culvert to provide hydraulic connectivity with the main stream channel; and
- excavation of the shallow area around the culvert exit between the approach embankment and the old Rahui Road.

One other effect of the Rahui Road overbridge construction will be the slight loss of storage volume in the primary flood storage basin on the Mangapouri Stream upstream of County Road and the existing NIMT railway embankment. However this could be partially compensated for by excavation of the area between the stream and the overbridge approach embankment. Figure 4-2 shows the storage area / elevation relationship for the modified primary storage basin on the Mangapouri Stream (excluding any additional excavation) compared to the original area / elevation relationship shown in Figure 3-2.

Similarly the flood storage basin in the Pare-o-Matangi Reserve upstream SH1 will also be affected by loss of storage due to the new Expressway embankment and the realigned NIMT railway passing through it. Figure 4-2 also shows the storage area / elevation relationship for the modified storage basin in the Pare-o-Matangi Reserve compared to the original area / elevation relationship shown in Figure 3-2.

There will be negligible flood storage volume available between the proposed Expressway embankment and the realigned NIMT railway embankment. In any case, this area is required for attenuation treatment of storm runoff from the Expressway itself (the area is blocked off from the stream).

The pattern of Rahui Road overflow seen in Figures 3-8 and 3-9 for the existing situation is very wide and shallow. The wide approach from the primary flood storage area to the overflow zone ensures that head losses are minimal with this overflow relief path. By contrast in the proposed situation, the contraction of flood relief flows into a narrow gap through the Rahui Road overbridge approach embankment and subsequent expansion out of the narrow gap to the wide overflow crest formed by Rahui Road means that overflow head losses will be much greater and it will be impossible to match the overflow discharge characteristics of Rahui Road in the current situation (as defined by the pond level / discharge rating shown in Figure 3-4) without further mitigation.

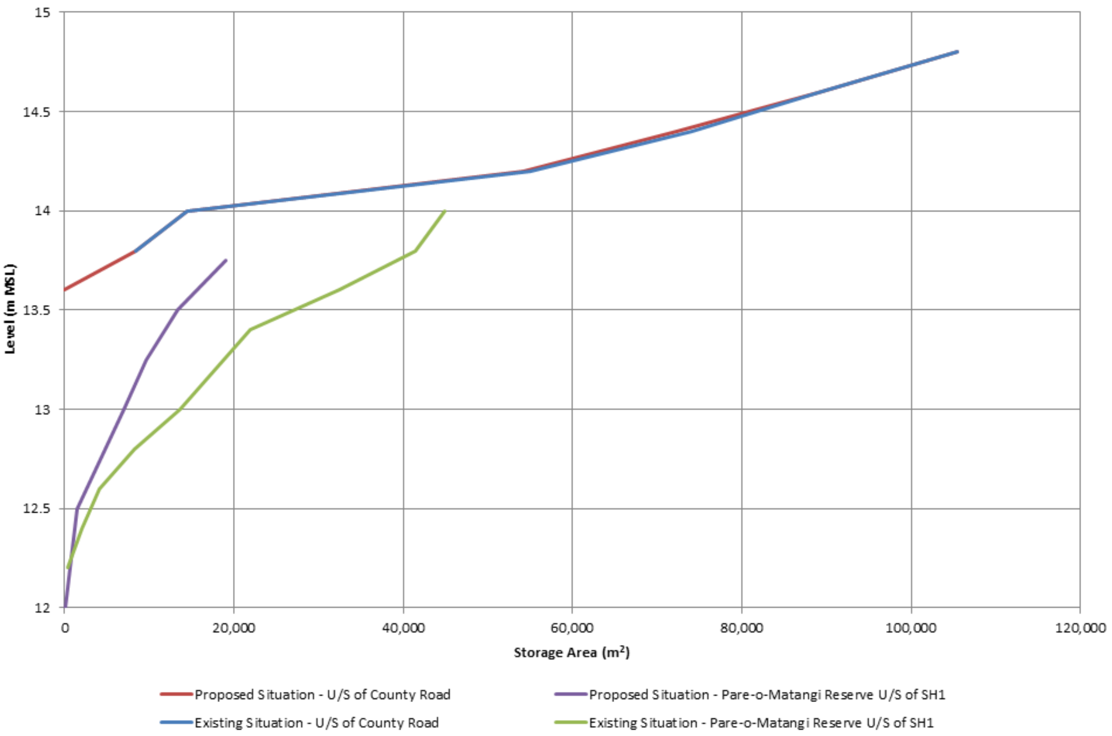

Figure 4-2 Storage area / elevation relationships for modified flood detention basins upstream of County Road and the NIMT railway line, and the Pare-o-Matangi Reserve upstream of SH1

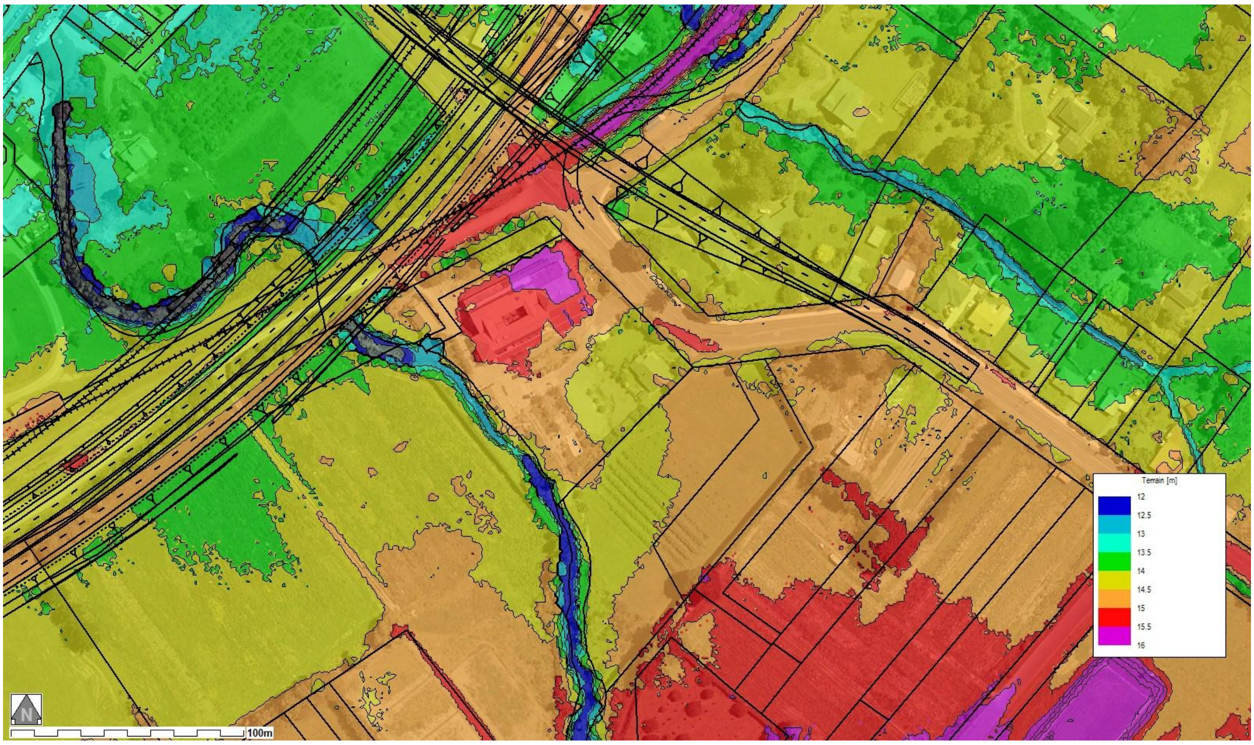

Figure 4-3 Topographic relief map for Rahui Road overflow zone with layout of proposed Rahui Road over-bridge superimposed

Figure 4-3 shows a topographic relief map for the Rahui Road overflow zone with the layout of the proposed Rahui Road over-bridge superimposed.

Preliminary trials with a modified version of the original MIKE11 for the Mangapouri Stream flood storage basin system coupled to a MIKE21 model of the Rahui Road overflow path representing the proposed Expressway situation indicated that the only way of emulating the current overflow discharge characteristics of Rahui Road was to incorporate a long relief culvert under Rahui Road to the unnamed watercourse that historically would have drained surface runoff from the racecourse area to the east. Figure 4-4 shows the route of this proposed relief culvert which has been selected to follow existing property boundaries to minimise disruption to their owners.

The unnamed watercourse into which this relief culvert is proposed to discharge currently conveys surface runoff via a 1.25m wide by 1.25m deep box culvert under the NIMT railway line and a 0.9m diameter culvert under SH1 to a dedicated soakage area on the grounds of Ōtaki College. As the existing railway line is being relocated to make way for the new Expressway, the existing railway culvert will need to be replaced with a 95m long, 1.35m diameter culvert under both the Expressway and the realigned railway line (Figure 4-4). The final sizing and route selection for this culvert will be a matter of detailed design.

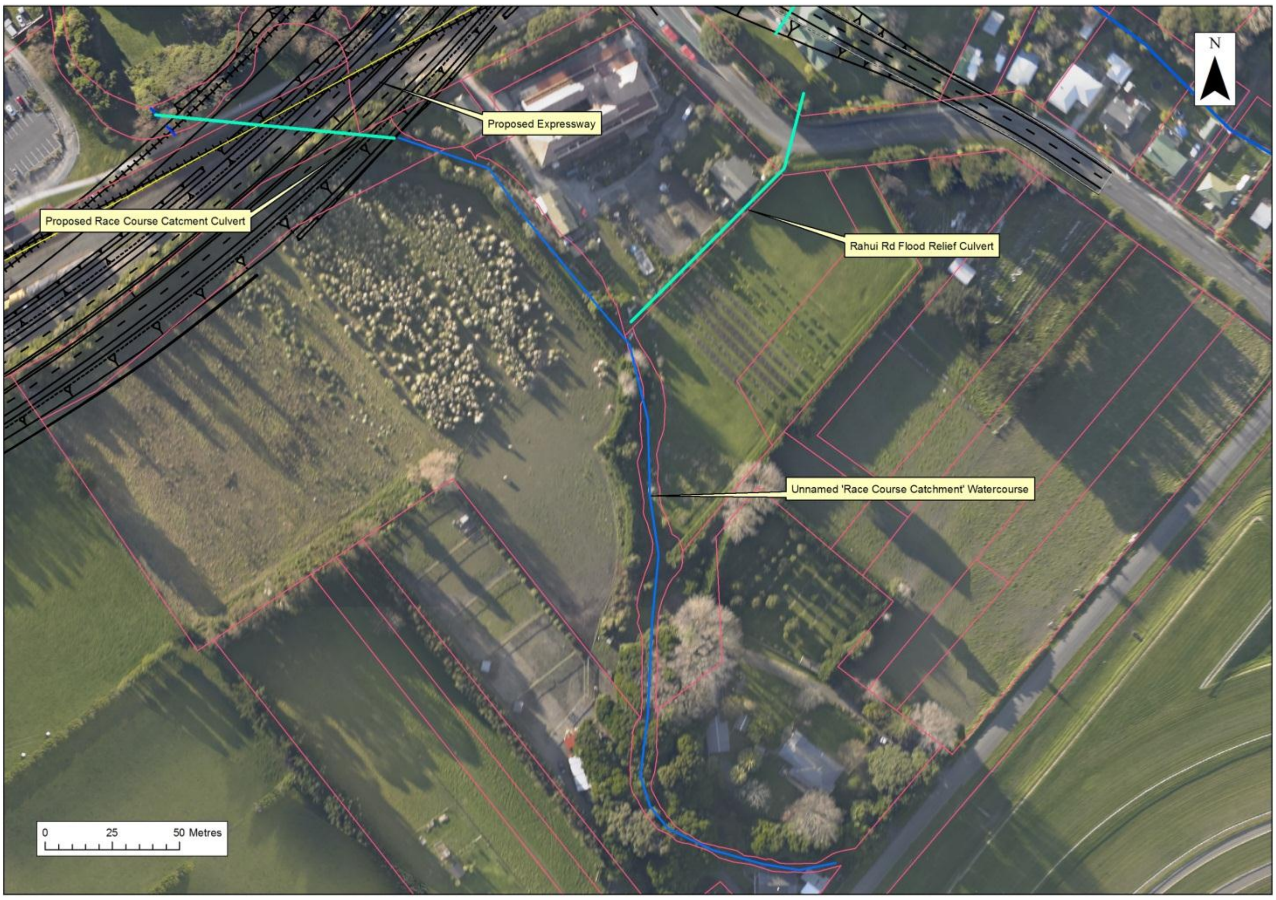

Figure 4-4 Aerial photograph showing drainage system for unnamed watercourse conveying storm runoff from part of Ōtaki Racecourse

It can be seen from the relief shading on the topographic plan in Figure 4-3 that road levels on Rahui Road are up to 0.4m higher around the bend where the proposed overflow relief culvert would be sited (Figure 4-4). One additional way of slightly improving the overflow discharge characteristics of the Rahui Road then would be to locally reshape the vertical profile of the road to lower the level from about 15.0-15.2m MSL Wellington datum to approximately the same level as that further west (14.6-14.8m MSL Wellington datum).

A third means of slightly enhancing the overflow discharge characteristics of the Rahui Road in the proposed situation is to locally lower the level of the link road connection that loops around under the Rahui Road overbridge adjacent to the eastern abutment. This link road connection overlies the existing NIMT railway line and current ground levels would need to be lowered by about 0.4m to achieve this effect. Floodwaters breaking out of the primary flood storage basin and following this overflow path would flow around the inside of the overbridge abutment and then eastwards along Rahui Road to the overflow zone.

In the initial scheme assessment, the new Mangapouri Stream culverts under the new PP2O Expressway and the relocated NIMT railway line were proposed to be relatively small so as to throttle flood flows in the stream. Now that the existing NIMT railway culvert is to be retained to preserve its current throttling function, the new Expressway and railway culverts can be structures with a much larger cross-sectional area. It is envisaged that they would be box culvert structures with the following characteristics:

- a width that approximately matches that of the existing stream;
- a depth that is large enough to ensure free surface flow conditions through the structure; and
- an invert that is deep enough to allow a surface layer of cobbles and large gravel material to be placed over it to form a natural stream bed through it.

The purpose of having a deep box culvert section is to prevent the structure from heading up under extreme flood conditions and to ensure as much natural light can enter it to encourage fish passage up the structure.

The route of the proposed Expressway passes through the railway wetland area as seen in Figure 4-5. The available storage volume for attenuating storm runoff from the Te Manuao Catchment will be significantly reduced. Figure 4-6 shows the residual storage volume remaining in the wetland after construction of the Expressway embankment. The face of the Expressway embankment will be used to form the western boundary of the remnant wetland.

To compensate for the loss of storage volume in the remnant railway wetland, it is proposed to make use of the “dead zone” between the old NIMT railway embankment and the new Expressway embankment to the south of the new local link road overbridges to form a second wetland area in series with the remnant railway wetland. The two wetland areas would be connected by a 75m long, 1m diameter pipe. Construction of the second wetland area would involve minimal excavation but would require:

- a 3.5m high bund at the downstream end to impound the wetland; and
- lining of the inside face of the existing railway embankment with an impervious material to form a watertight barrier.

The impoundment bund would incorporate a short approximately 15m long, 1m diameter outlet pipe to the Mangapouri Stream and an emergency overflow spillway.

Figure 4-7 shows the storage area / elevation relationship for the second wetland area.

Figure 4-5 Aerial photograph of railway wetland area and drainage system with layout of proposed Expressway superimposed

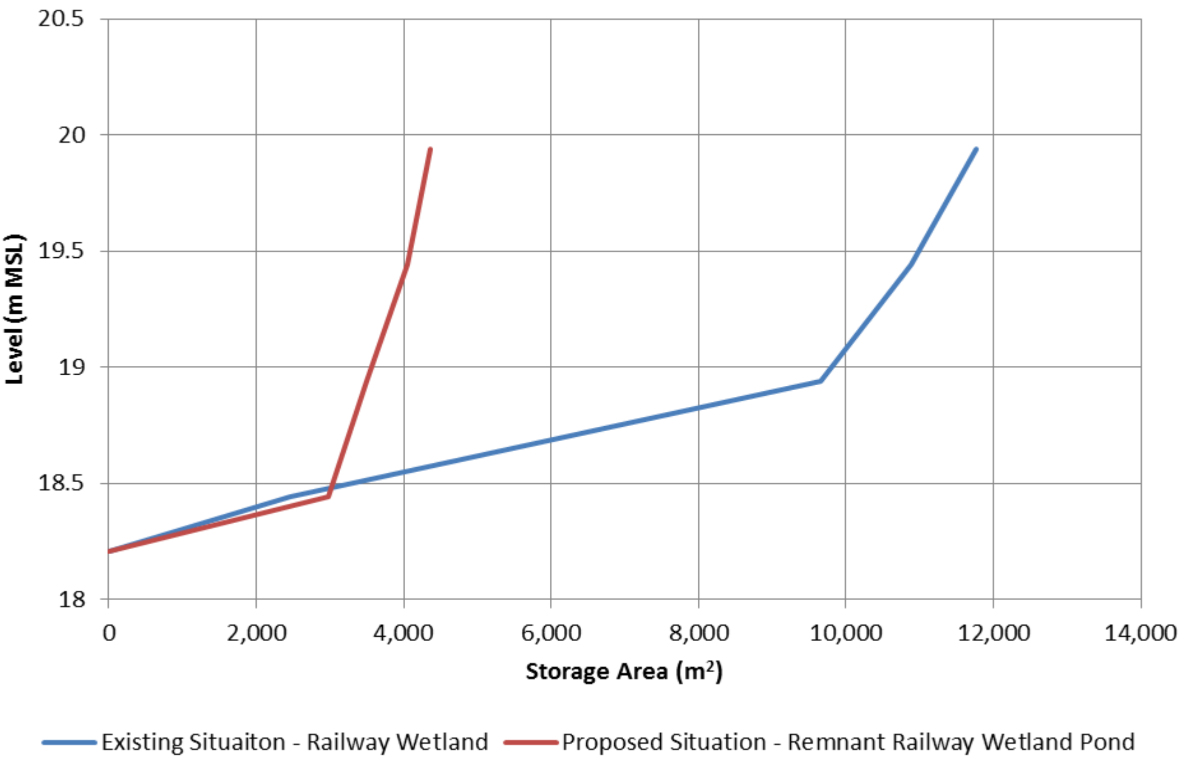

Figure 4-6 Storage area / elevation relationship for remnant railway wetland compared to equivalent relationship for existing railway wetland (based on LiDAR data)

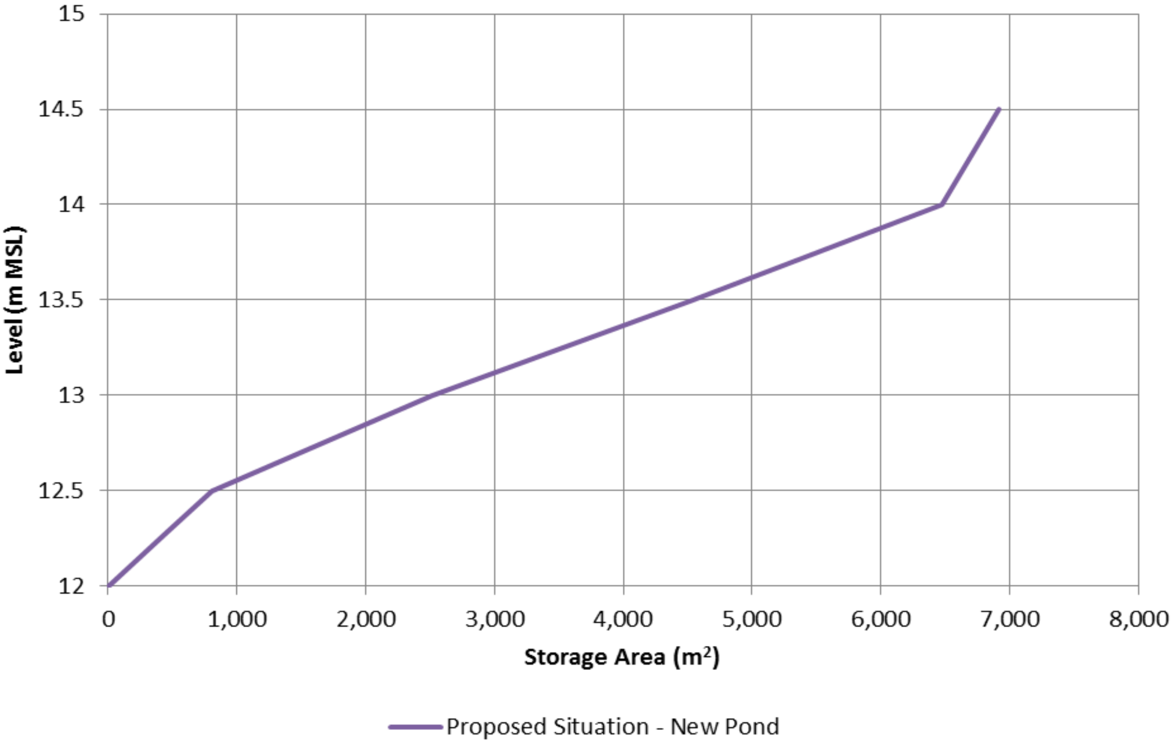

Figure 4-7 Storage area / elevation relationship for new wetland area between old railway embankment and proposed Expressway embankment (based on LiDAR data)

4.2 Adaptation of MIKE11 Model for Current Situation to Simulate Proposed Situation

The one-dimensional MIKE11 computational model outlined in Section 3.2 was further adapted to simulate the proposed situation in the Mangapouri Stream and railway wetland area.

The complexity of the overflow behaviour of the old Rahui Road with approach flow having to pass through a gap (or gaps) in the approach embankment to the Rahui Road overbridge and a supplementary relief culvert having to be provided under Rahui Road meant that a slightly different modelling approach was required to that used previously for the existing situation. This was underlined by the fact that flows through the relief culvert under Rahui Road would be affected by tailwater levels in the unnamed watercourse draining part of the Ōtaki Racecourse. Whereas a separate two-dimensional MIKE21 computational hydraulic model was used to quantify the overflow discharge characteristics of Rahui Road in terms of a pond level / discharge rating relationship (Figure 3-4) which was then incorporated in the MIKE11 model of the flood detention pond system for the existing situation, the proposed situation required a modified version of the MIKE11 model to be coupled to a MIKE21 model of the flood plain area to the south of Rahui Road including. The unnamed watercourse draining part of the Ōtaki Racecourse and discharging via a pipe system under SH1 was also incorporated as another coupled MIKE11 model component (the floodplain storage area upstream of the Expressway embankment on this watercourse was represented by the MIKE21 model)[7].

The MIKE11 model component incorporated the following modifications and features to assist in representing the proposed Expressway situation:

- modified area / elevation relationships for the primary and secondary flood storage basins along the Mangapouri Stream as per Figure 4-2
- a 60m long, 3m wide by 3m deep box culvert under the proposed Expressway on the Mangapouri Stream downstream of the existing railway culvert
- a 20m long, 3m wide by 3m deep box culvert under the realigned NIMT railway on the Mangapouri Stream downstream of the new Expressway culvert
- a modified storage area / elevation relationship for the remnant railway wetland area as per Figure 4-6
- a new wetland basin downstream of the remnant railway wetland one defined by the storage area / elevation relationship in Figure 4-7
- a 75m long, 1m diameter culvert draining the remnant railway wetland
- a 15m long, 1m diameter culvert outlet from the second wetland (downstream of the remnant railway wetland) to the Mangapouri Stream
- a 95m long, 1.35m diameter culvert under the proposed Expressway and realigned NIMT railway line on the unnamed watercourse draining the Racecourse Catchment
- the approximately 110m meandering length of channel between the downstream end of the new Expressway / railway culvert and the upstream end of the existing culvert under SH1 to the soakage area on the grounds of Ōtaki College
- a line of linkage elements along the northern side of the approach embankment to the Rahui Road overbridge (to connect to upstream end of the MIKE21 model of the floodplain area to the south)
- a linkage element upstream of the Expressway / railway culvert on the unnamed watercourse draining the Racecourse Catchment

The 3m wide by 3m high long box culverts under the Expressway and the realigned NIMT railway line along the Mangapouri Stream actually need to be over-deep sections to allow for a minimum 0.5m thick layer of cobbles along the invert of each culvert. The cobble layer is designed to facilitate fish passage through the culverts. This is not a requirement for any other culverts in the drainage system covered by this investigation.

The MIKE21 model component covered the area of the primary storage basin between the south bank of the Mangapouri Stream and the north side of the approach embankment to the Rahui Road overbridge, the area along the old Rahui Road between Te Roto Road and the new Expressway and the flood plain area to the south between Rahui Road and a proposed new secondary stopbank for the containment of Ōtaki River stopbank overflows (see Figure F-2 in Appendix F). The MIKE21 model also incorporated the following features:

- a 10m wide by 2m high box culvert[8] through the approach embankment to the Rahui Road overbridge

[7] The need to incorporate the drainage outlet for the Racecourse Catchment watercourse in the coupled MIKE11 / MIKE21 model for the proposed situation was not appreciated at the start of the investigation when the existing situation was being considered. The existing situation model ignored this drainage outlet in order to simplify the problem and reduce the complexity of the model. This and budgetary constraints precluded modification of the existing situation model so that it exactly similar to the proposed situation model.
[8] Various culvert widths were trialled. A 5m wide culvert induced head losses that were unacceptably high while a 20m wide "culvert" induced very minimal head losses. A 10m wide culvert represented a compromise size with acceptable head losses.

- a 115 long, 1.5m wide by 0.5m deep box section flood relief culvert under Rahui Road to the unnamed watercourse draining the Racecourse Catchment

The model effectively represented flood storage on the floodplain upstream of the new culvert on the unnamed Racecourse Catchment watercourse under the Expressway and realigned NIMT railway line required as a result of throttling of flood flows by that culvert. Details of the extent of the MIKE21 model are given in Appendix F.

Table 4-1 summarises details of all the culverts along the Mangapouri Stream and the remnant railway wetland drainage system while Table 4-2 summarises details of the culverts along the unnamed watercourse draining the Racecourse Catchment.

Table 4-1 Culvert types, dimensions and levels for proposed situation in Mangapouri Stream in SH1 / Rahui Road / NIMT railway line triangle (existing culvert data in black, new culvert data in red)

Location	Type	Size (m)	Invert Level (m MSL Wellington)		Length (m)	Slope (%)	Road / Track Level (m MSL Wellington)
			u/s	d/s			
County Rd [1]	circular	1.2 (dia)	11.97	12.01	19.3	negative	14.39 [2]
NIMT railway [1]	custom-built arch	0.95 x 1.2	12.08	11.98	12.2	0.82	16.28 [3] 15.39 [4]
Rahui Rd overbridge	box	10 x 2	13.5	13.5	≈ 20	0.00	≈ 18.5
Rahui Rd overflow relief	box	1.5 x 0.5	13.6	12.6	115	0.87	14.6
Expressway	box	3 x 3 [7]	11.40 [8]	11.10 [8]	60	0.50	16.37
Realigned railway	box	3 x 3 [7]	10.90 [8]	10.88 [8]	20	0.10	not known
Existing SH1 [1]	twin circular	0.9 (dia)	11.06	10.96	20	0.50	13.74
Remnant railway wetland outlet	circular	1.0	17.5	16.2	75	1.73	20 [5]
Second wetland outlet	circular	1.0	13.45	11.8	15	11.0	15.50 [6]

[1] Details for these culverts obtained from Wellington Regional Council February 1998 report "*Ōtaki Floodplain Management Plan, Mangapouri Stream Upgrade, Hydraulic Modelling Report*", Report No. WRC/RI-T-97/48.
[2] Road levels further north from this culvert along County Road are lower than this level.
[3] Track level on existing railway embankment at culvert location.
[4] Road level on upstream shoulder of Expressway embankment beneath Rahui Road overbridge.
[5] Ground level at entrance to remnant railway wetland outlet culvert.
[6] Crest level of bund impounding wetland through which outlet culvert passes.
[7] Depth dimension given for these culverts is the height between the surface of the assumed cobble bed layer and the culvert soffit. The depth of the box culvert sections needs to be at least 3.5m to accommodate a 0.5m thick cobble layer.
[8] These invert levels are for the top level of the cobble invert layer in the culverts.

The box culvert can be depressed with an invert level as low as 35.5m MSL Wellington datum to reduce the visual impact of it.

Table 4-2 Culvert types, dimensions and levels for proposed situation on unnamed watercourse draining part of Ōtaki Racecourse (existing culvert data in black, new culvert data in red)

Location	Type	Size (m)	Invert Level (m MSL Wellington)		Length (m)	Slope (%)	Road / Track Level (m MSL Wellington)
			u/s	d/s			
Combined Expressway / realigned railway	box	1.25 x 1.25	11.75	11.7	95	0.05%	15.19
Existing SH1	circular	0.9 (dia)	11.3	10.7	175	0.34%	13.59

The new box culvert under the Expressway on the unnamed watercourse draining part of the Ōtaki Racecourse has been assumed to be the same size as the existing culvert (1.25m x 1.25m). However this size is a non-standard size for precast box culvert units and could be replaced with a standard 1.5m diameter pipe section which approximately matches the discharge characteristics of the existing box culvert, taking account of the increased overall culvert length for the alignment shown in Figure 5-7. Alternatively a 1.35m diameter pipe could be used on an alignment perpendicular to the Expressway which would be shorter but would require a diversion of the downstream drainage channel.

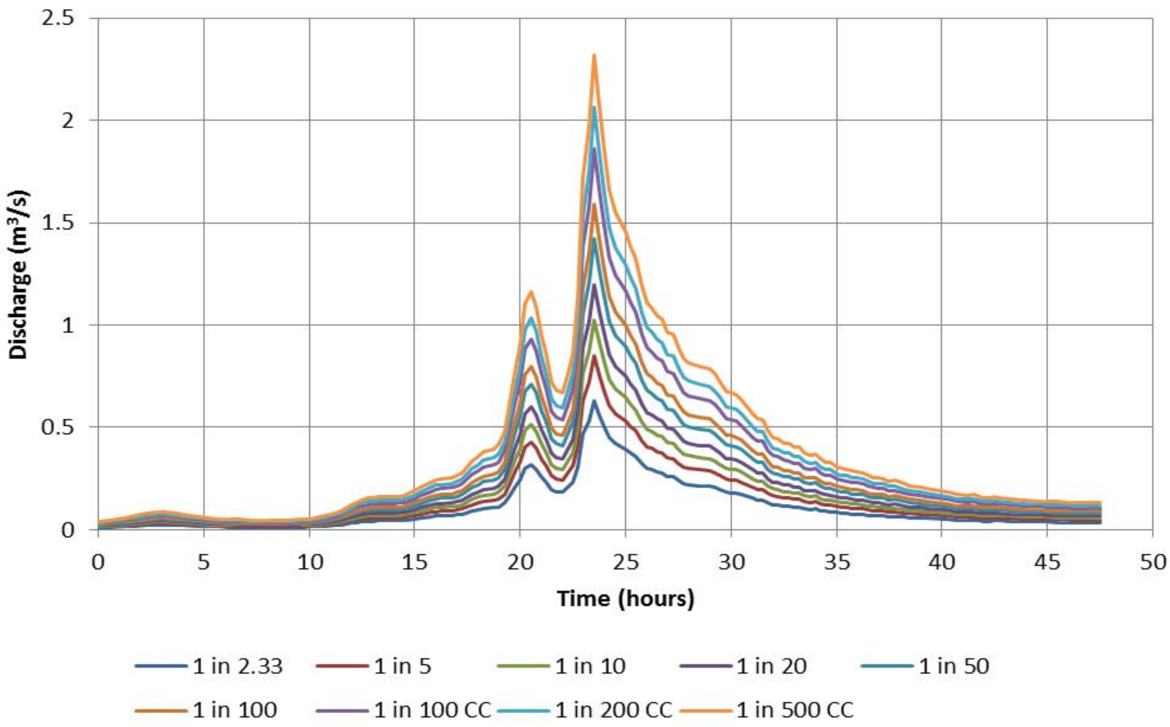

Figure 4-8 Inflow hydrographs to Racecourse catchment for various annual exceedance probabilities for existing and possible future (2090) climate conditions

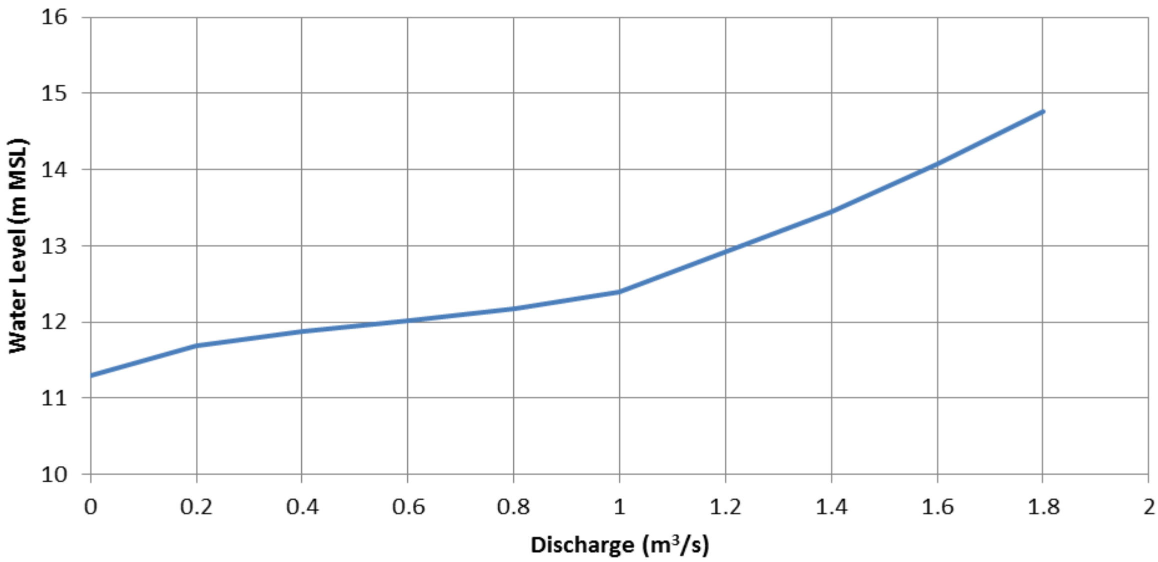

Figure 4-9 Headwater level / discharge rating relationship for 0.9m diameter pipe under SH1 on the unnamed watercourse draining the Racecourse Catchment

The coupled MIKE11 and MIKE21 models were run in parallel to route floods of various annual exceedance probabilities through the hydraulic system. Storm runoff from the part of the Ōtaki Racecourse drained by the unnamed watercourse for each flood case was defined by a separate flood hydrograph scaled according to catchment area $A^{0.8}$ as for the Te Manuao Catchment (Section 2.2.2 and Figure 2-3). The hydrographs for the Racecourse Catchment are shown in Figure 4-8.

The downstream boundary of the MIKE11 component of the coupled model on the unnamed watercourse draining the Racecourse Catchment was defined by means of a culvert rating for the 95m long 1.35m diameter pipe under SH1 leading to the soakage area on the grounds of Ōtaki College. Figure 4-9 shows the headwater level / discharge rating relationship defined for this culvert based on a fixed tailwater level at the outlet.

4.3 Key Assumptions for Hydraulic Model Simulations of Proposed Situation

As with the hydraulic model simulations for the existing situation, a number of similar key assumptions were made for the initial simulations with the combined MIKE11 / MIKE21 hydraulic model of the proposed expressway situation. These were as follows:

- Firstly all of the surface runoff from the Te Manuao Catchment was assumed to be directed to the remnant railway wetland area with none diverted via County Road into the flood storage area upstream of the original railway embankment. The sensitivity of model predictions to this assumption was subsequently tested in some further model simulations.
- All surface runoff from the Ōtaki Racecourse part of the Mangapouri Catchment was assumed to be directed via the drain system to the east of Te Roto Road into the Mangapouri Stream. The effect of this assumption was also subsequently re-evaluated.
- When the flood storage area upstream of the original railway embankment starts to fill, it was assumed that there would be no leakage through the track ballast. In the proposed situation, this is a very realistic

assumption as the western side of the railway embankment is required to be sealed to provide watertight containment for the new wetland area behind it.

- The remnant railway wetland area and the new downstream wetland area between the original railway embankment and the Expressway embankment were initially assumed to be near empty with effectively nil storage prior to the occurrence of any flood.
- Surface runoff from the small Te Roto Catchment south of the Racecourse Catchment (refer to the catchment map in Appendix A) and drainage via the associated culvert under the proposed Expressway and realigned NIMT railway line were ignored to reduce the complexity of the MIKE21 component of the combined model. The effect of this assumption was also subsequently checked.

The same Manning's n channel roughness values as outlined in Section 3.3 for the existing situation were assumed.

One significant difference between the MIKE11 components of the existing and proposed system models is the large box sections forming the long culverts under the Expressway and the realigned NIMT railway line on the main stream channel. These operate under free surface flow conditions and were represented in the MIKE11 models by open rectangular cross-sections. The box culverts will be constructed from over-deep box culvert sections with a loose cobble layer along the invert to facilitate fish passage. A Manning's n value of 0.020 to 0.025 was assumed to reflect the composite nature of the rough cobble bed and the smooth concrete sidewalls.

4.4 Flood Level and Discharge Predictions for Proposed Situation

The same range of floods outlined in Section 3.4 was used to route through the proposed hydraulic system centred around the Mangapouri Stream and described by the combined MIKE11 / MIKE21 computational hydraulic model. The results of the model simulations were compared with those predicted by the MIKE11 model of the existing situation for the flood conditions.

Table 4-3 summarises peak flood levels through the detention pond system predicted by the MIKE11 model for the different floods. Meanwhile Table 4-4 summarises peak flood discharges along the Mangapouri Stream. Tables 4-5 and 4-6 give the respective water balances for the railway wetland area and the primary flood storage area upstream of the existing railway embankment. Table 4-7 summarises peak flood levels and discharges on the unnamed watercourse draining the Racecourse Catchment.

Figure C-1 to C-15 in Appendix C complement the tabulated peak flood level and discharge predictions in Tables 4-3 to 4-7.

4.5 Observations on Hydraulic Performance for Proposed Situation

Figure C-7 in Appendix C shows backwater profiles along the Mangapouri Stream for the proposed situation. These confirm that the stream continues to behave approximately as a twin detention pond system in series as in the existing situation. In particular the County Road and old railway culverts behave in the same manner as they are unchanged from the existing situation. Peak flood levels along the stretch of stream between the outlet from the old railway culvert and the SH1 culvert are slightly sloping due to the effects of confinement by the new Expressway and railway culverts.

Figure 4-10a compares the Rahui Road overflow pond level / discharge rating relationship for the proposed situation (including the outflow contribution from the low level flood relief culvert under Rahui Road) with that for the existing situation. The invert level of the flood relief culvert has been set fairly low so that it comes into operation in much lower floods (the 10m wide culvert through the Rahui Road approach embankment has also been set fairly low and a connection with the Mangapouri Stream excavated in front of it to facilitate operation of the flood relief culvert). However the flood relief culvert has been purposely limited in size so that the volume of outflow released through it is constrained.

Figure 4-10a is complemented by Figures 4-10b to e which illustrate the response of the primary flood detention basin to the 1% AEP flood adjusted for the effects of possible climate change to 2090 in the proposed situation compared to the existing situation. Figure 4-10b compares flood level hydrographs for the two situations with the peak flood level for the proposed situation 0.04m lower than the peak flood level for the existing situation. Figure 4-10c compares outflow hydrographs through the old railway culvert with the form of the discharge hydrograph preserved in the proposed situation but the peak marginally lower than that for the existing situation (this reflects the marginally lower peak detention basin level in the proposed situation). Figure 4-10d compares the the outflow hydrographs for the Rahui Road overflow with the two flow components in the case of the proposed situation (Rahui Road overflow and the low-level culvert outflow). Figure 4-10e is another version of Figure 4-10d except that the two outflow components for the proposed situation have been summed together. In the proposed situation the Rahui Road outflow peak is ~1m3/s lower than the peak in the existing situation. However the outflow starts much earlier and is quickly throttled to about 0.9m^3/s by the restricted size of the low-level culvert under Rahui Road.

Figure 4-10f compares the outflow through the culvert under the Expressway draining the Racecourse Catchment with the combined outflow over Rahui Road from the primary flood detention basin in the proposed situation for the design 1% AEP flood adjusted for possible climate change effects to 2090. This illustrates the positive effect of flood storage upstream of the Expressway on the unnamed watercourse draining the Racecourse Catchment. The combined Rahui Road outflow (from road overflow and culvert flow) and the runoff from the Racecourse Catchment with peak discharges[9] of about 3.7m^3/s and 1.8m^3/s respectively for the design flood are reduced significantly to a peak outflow of about 1.8m^3/s through the Expressway culvert.

The net effect of the modified Rahui Road overflow discharge relationship is that lower flood levels are predicted in the primary flood storage basin on the Mangapouri Stream upstream of the old railway embankment in the proposed situation (Table 4-3) for all except the two largest floods. The predicted flood level for the 0.5% AEP flood adjusted for possible climate change effects is only 0.02m above that for the existing situation but the predicted flood level for the 0.2% AEP flood adjusted for possible climate change effects is about 0.12m above that for the existing situation. Although the latter result might be perceived to be an adverse outcome, it only affects the same number of houses as in the existing situation as discussed subsequently in Section 4.6. It also needs to be emphasised that, under such flood conditions, there would be widespread inundation elsewhere through Ōtaki Township as indicated by the blue and brown shading in the composite GWRC/ KCDC flood inundation map in Figure D-1 in Appendix D.

The combination of a slightly lower peak outflow and a slightly lower peak flood level for the primary flood detention basin on the Mangapouri Stream in the 1% AEP flood adjusted for possible climate change in the proposed situation compared to the existing situation is a result of the low level outlet culvert under Rahui Road releasing additional flow volume out of the pond early in a significant flood and prior to the peak.

[9] These peak inflows do not necessarily coincide time wise.

Table 4-3 Predicted peak flood levels for proposed situation in Mangapouri Stream (data for current situation in brackets)

Flood Case (AEP %)	Peak Flood Level (m MSL Wellington datum)					
	Upstream of County Road culvert	Upstream of old railway culvert	Upstream of Expressway culvert	Upstream of old SH1 culvert	Remnant railway wetland area	Second wetland area
42.9	14.07 (14.18)	13.50 (13.57)	12.77	12.72 (12.64)	18.33 (19.15)	14.22
20	14.25 (14.36)	13.60 (13.93)	12.97	12.92 (12.92)	18.48 (19.50)	14.37
10	14.38 (14.45)	14.08 (14.44)	13.25	13.20 (13.31)	18.60 (19.55)	14.48
5	14.47 (14.60)	14.46 (14.60)	13.49	13.45 (13.43)	18.73 (19.59)	14.57
2	14.67 (14.81)	14.67 (14.81)	13.65	13.60 (13.57)	18.92 (19.63)	14.70
1	14.79 (14.86)	14.79 (14.86)	13.75	13.70 (13.63)	19.07 (19.66)	14.78
1 + CC to 2090	14.88 (14.92)	14.88 (14.92)	13.81	13.76 (13.72)	19.31 (19.70)	14.93
0.5 + CC to 2090	14.97 (14.95)	14.97 (14.95)	13.82	13.77 (13.76)	19.51 (19.72)	15.04
0.2 + CC to 2090	15.11 (14.99	15.11 (14.99)	13.85	13.78 (13.77)	19.80 (19.75)	15.15

Table 4-4 Peak flood discharges for proposed situation in Mangapouri Stream (data for current situation in brackets)

Flood Case (AEP %)	Peak Flood Discharge (m^3/s)					
	Inflow from Mangapouri Catchment	Railway wetland inflow	old railway culvert outflow	Rahui Rd overflow	SH1 culvert and overflow	Railway wetland system outflow
42.9	5.13	1.02	2.84 (2.97)	0.00 (0.00)	3.52 (3.35)	0.79 (0.40)
20	6.92	1.38	3.03 (3.61)	0.00 (0.00)	3.89 (3.90)	1.07 (0.60)
10	8.40	1.68	3.62 (4.42)	0.00 (0.00)	4.39 (4.56)	1.26 (1.00)
5	9.79	1.92	4.24 (4.59)	0.00 (0.00)	4.77 (4.75)	1.45 (1.34)
2	11.64	2.33	4.51 (4.74)	0.50 (0.45)	5.00 (4.95)	1.69 (1.92)
1	13.02	2.60	4.58 (4.79)	0.51 (1.96)	5.15 (5.05)	1.87 (2.31)
1 + CC to 2090	15.20	3.04	4.53 (4.73)	2.97 (4.53)	5.81 (5.17)	2.13 (2.77)
0.5 + CC to 2090	16.90	3.37	4.20 (4.60)	5.05 (6.37)	6.14 (5.51)	2.34 (3.08)
0.2 + CC to 2090	19.00	3.79	4.33 (4.58)	6.89 (8.98)	6.60 (6.12)	2.52 (3.47)

Table 4-5 Water balance for railway wetland drainage system in proposed situation (data for current situation in brackets)

Flood Case (AEP %)	Peak Flood Discharge (m^3/s)			Attenuation Factor
	Railway wetland inflow	Outflow from remnant wetland	Outflow from second wetland	
42.9	1.02	0.96 (0.40)	0.79	0.23 (0.61)
20	1.38	1.21 (0.60)	1.07	0.22 (0.57)
10	1.68	1.43 (1.00)	1.26	0.25 (0.40)
5	1.92	1.62 (1.34)	1.45	0.24 (0.31)
2	2.33	1.87 (1.92)	1.69	0.27 (0.18)
1	2.60	2.06 (2.31)	1.87	0.28 (0.11)
1 + CC to 2090	3.04	2.33 (2.77)	2.13	0.30 (0.09)
0.5 + CC to 2090	3.37	2.49 (3.08)	2.34	0.31 (0.09)
0.2 + CC to 2090	3.79	2.64 (3.47)	2.52	0.34 (0.08)

Table 4-6 Water balance for primary flood storage area upstream of old railway embankment (data for current situation in brackets)

Flood Case (AEP %)	Peak Flood Discharge (m^3/s)					Attenuation Factor
	Inflow from Mangapouri Catchment	Old railway culvert outflow	Rahui Rd overflow	Relief culvert outflow	Sum of outflows	
42.9	5.13	2.84 (2.97)	0.00 (0.00)	0.85	3.69 (2.97)	0.28 (0.42)
20	6.92	3.03 (3.61)	0.00 (0.00)	0.92	3.95 (3.61)	0.43 (0.48)
10	8.40	3.62 (4.42)	0.00 (0.00)	0.91	4.53 (4.42)	0.46 (0.47)
5	9.79	4.24 (4.59)	0.00 (0.00)	0.89	5.13 (4.59)	0.48 (0.83)
2	11.64	4.51 (4.74)	0.50 (0.45)	0.93	5.94 (5.19)	0.49 (0.56)
1	13.02	4.58 (4.79)	0.51 (1.96)	0.92	6.01 (6.76)	0.54 (0.48)
1 + CC to 2090	15.20	4.53 (4.73)	2.97 (4.53)	0.91	8.35 (9.26)	0.45 (0.40)
0.5 + CC to 2090	16.90	4.20 (4.60)	5.05 (6.37)	0.90	10.15 (10.98)	0.40 (0.36)
0.2 + CC to 2090	19.00	4.33 (4.58)	6.89 (8.98)	0.89	12.11 (13.56)	0.36 (0.29)

Table 4-7 Predicted peak flood levels and discharges for proposed situation in unnamed watercourse draining Racecourse Catchment

Flood Case (AEP %)	Peak Flood Level (m MSL Wellington)		Peak Flood Discharge (m³/s)	
	Upstream of Expressway Culvert	Upstream of Old SH1 Culvert	Expressway Culvert	Old SH1 Culvert
42.9	12.92	12.79	1.25	1.18
20	13.29	13.11	1.42	1.29
10	13.57	13.36	1.49	1.38
5	13.83	13.59	1.6	1.46
2	14.08	13.82	1.79	1.54
1	14.26	13.97	1.84	1.57
1 + CC to 2090	14.8	14.45	1.84	1.59
0.5 + CC to 2090	14.94	14.57	1.84	1.75
0.2 + CC to 2090	15.08	14.7	1.89	1.78

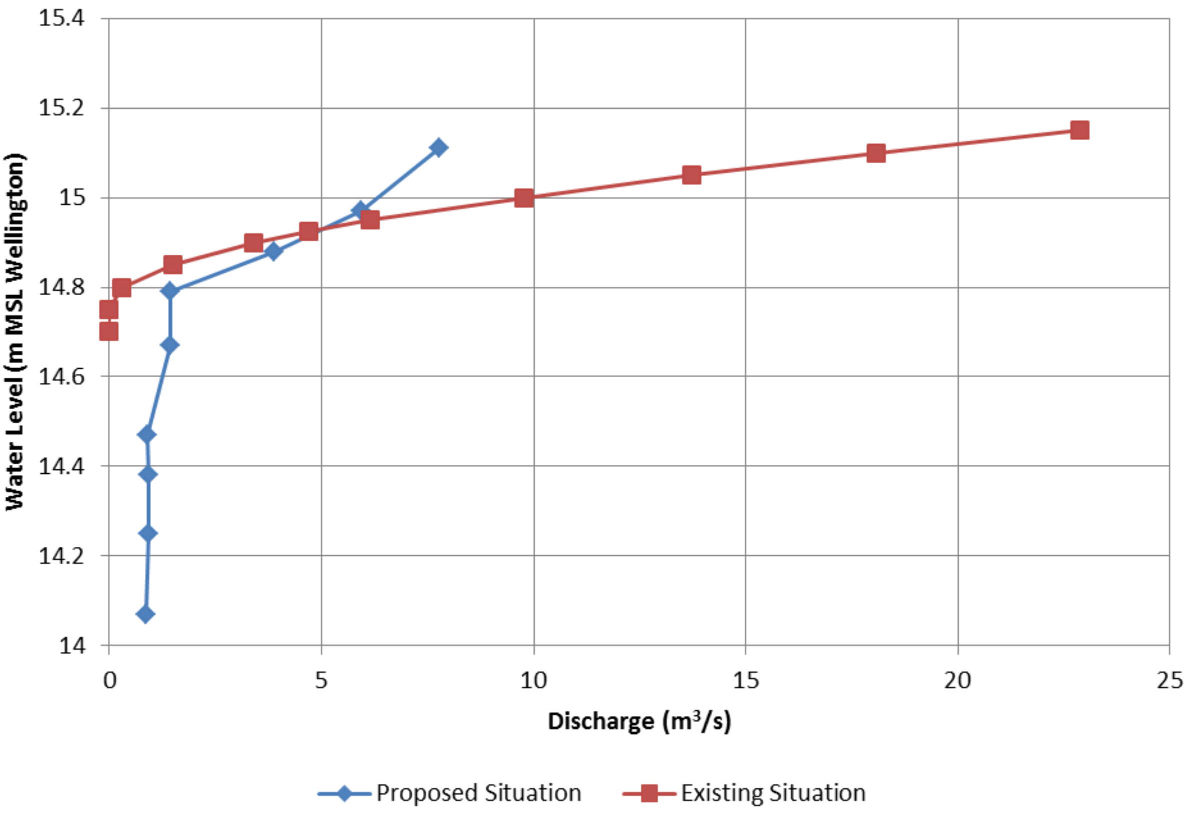

Figure 4-10a Primary storage pond / discharge rating relationship for Rahui Road overtopping / combined Rahui Rd overtopping and flood relief culvert (proposed situation only)

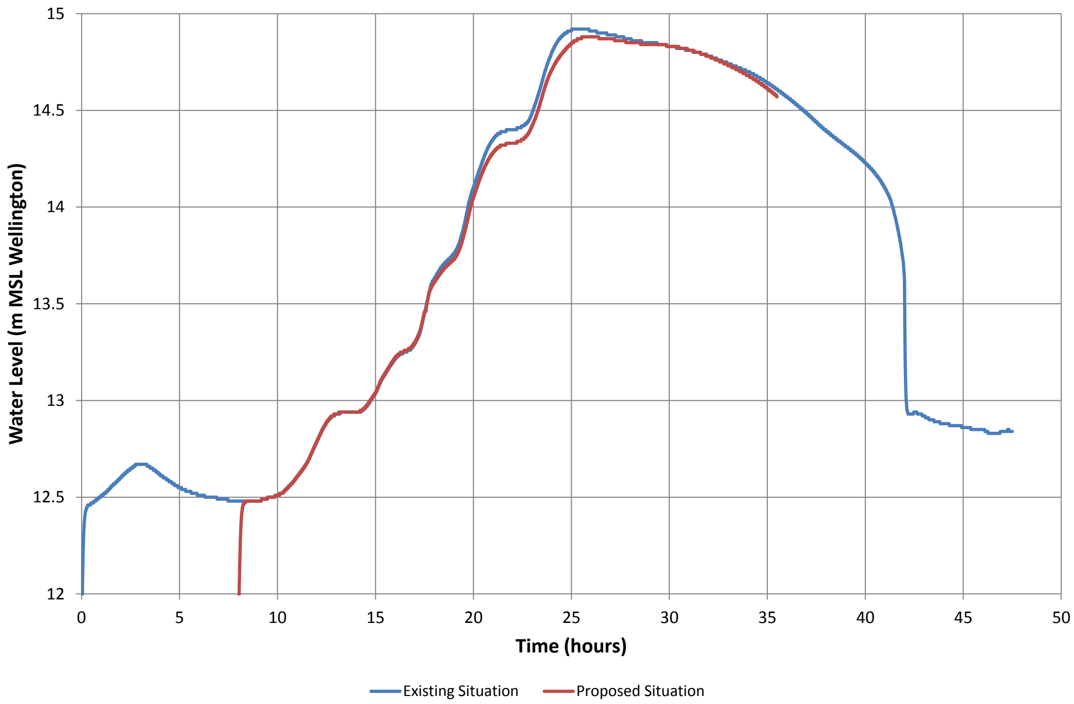

Figure 4-10b Comparison between existing and proposed situations of stage hydrographs in primary flood detention upstream of old railway culvert for 1% AEP flood adjusted for possible future climate change effects to 2090

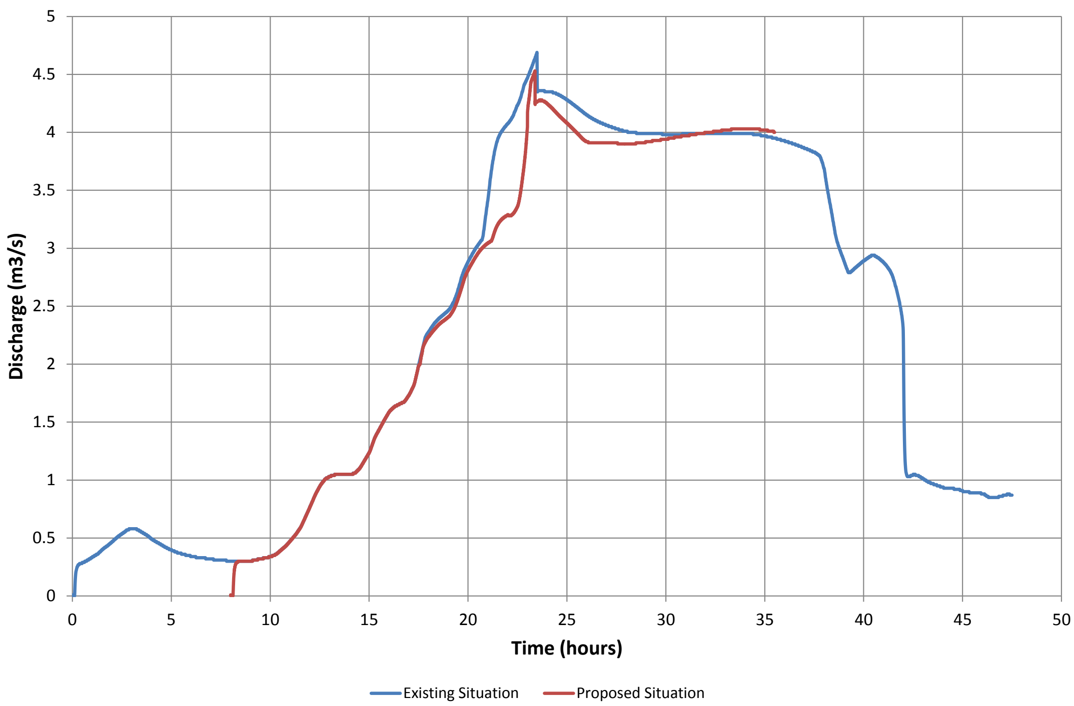

Figure 4-10c Comparison between existing and proposed situations of outflow hydrographs from primary flood detention through railway culvert for 1% AEP flood adjusted for possible future climate change effects to 2090

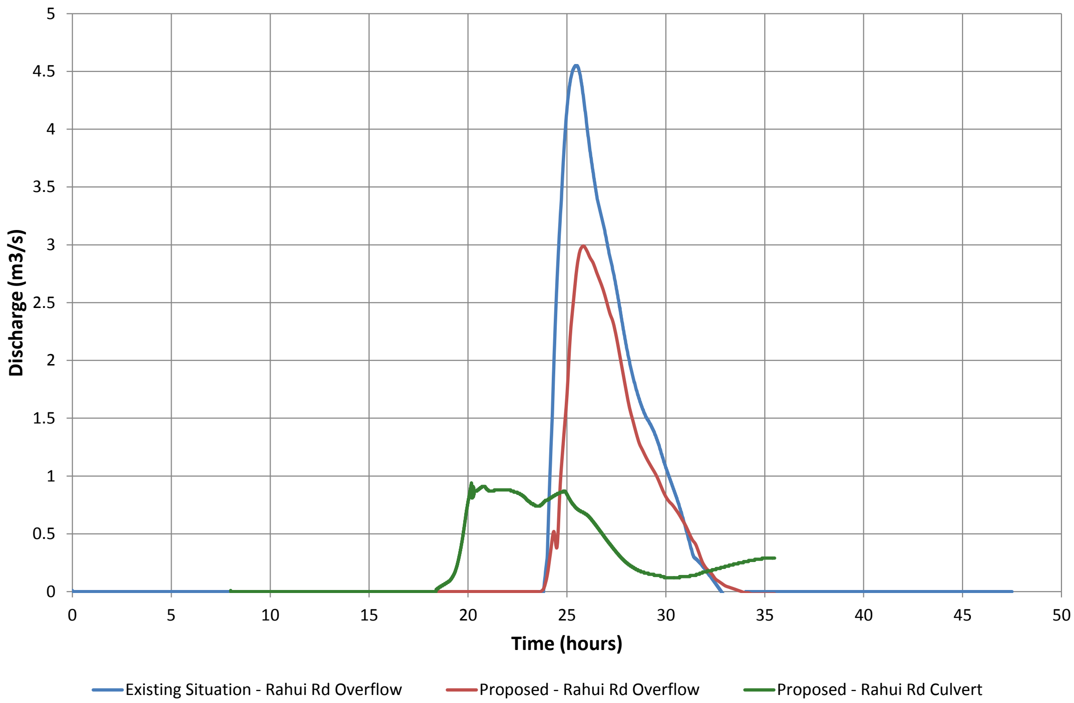

Figure 4-10d Comparison between existing and proposed situations of outflow hydrographs from primary detention basin over Rahui Road for 1% AEP flood adjusted for possible future climate change effects to 2090 (road overflow and culvert outflow separated for proposed situation)

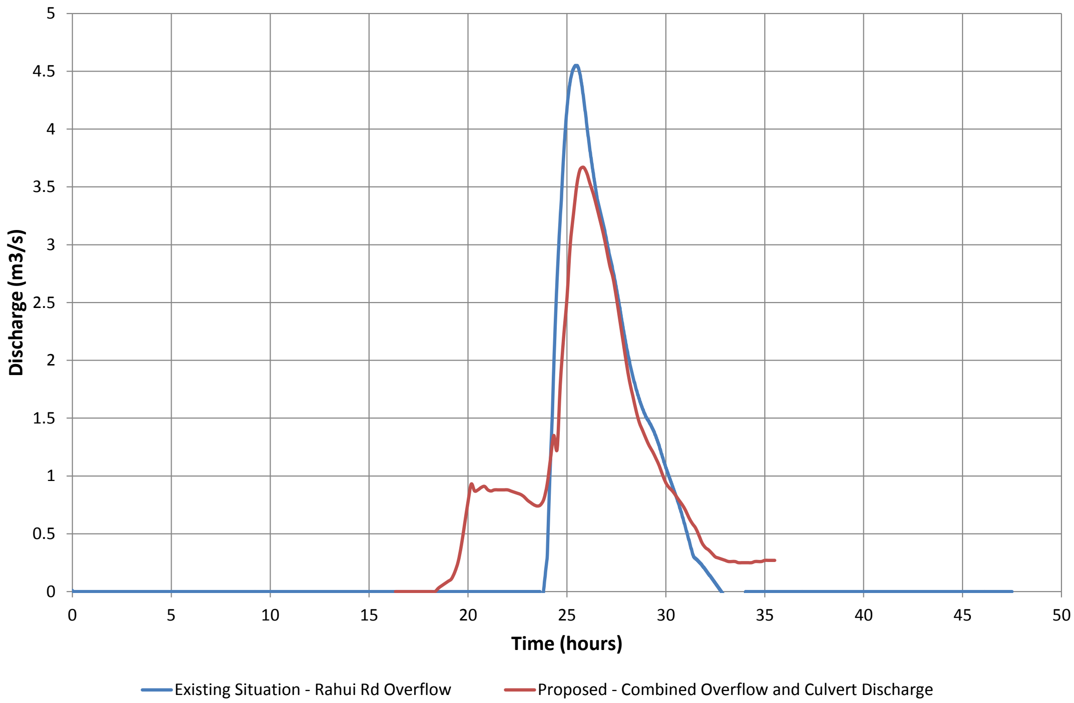

Figure 4-10e Comparison between existing and proposed situations of outflow hydrographs from primary detention basin over Rahui Road for 1% AEP flood adjusted for possible future climate change effects to 2090 (road overflow and under road culvert outflow summed for proposed situation)

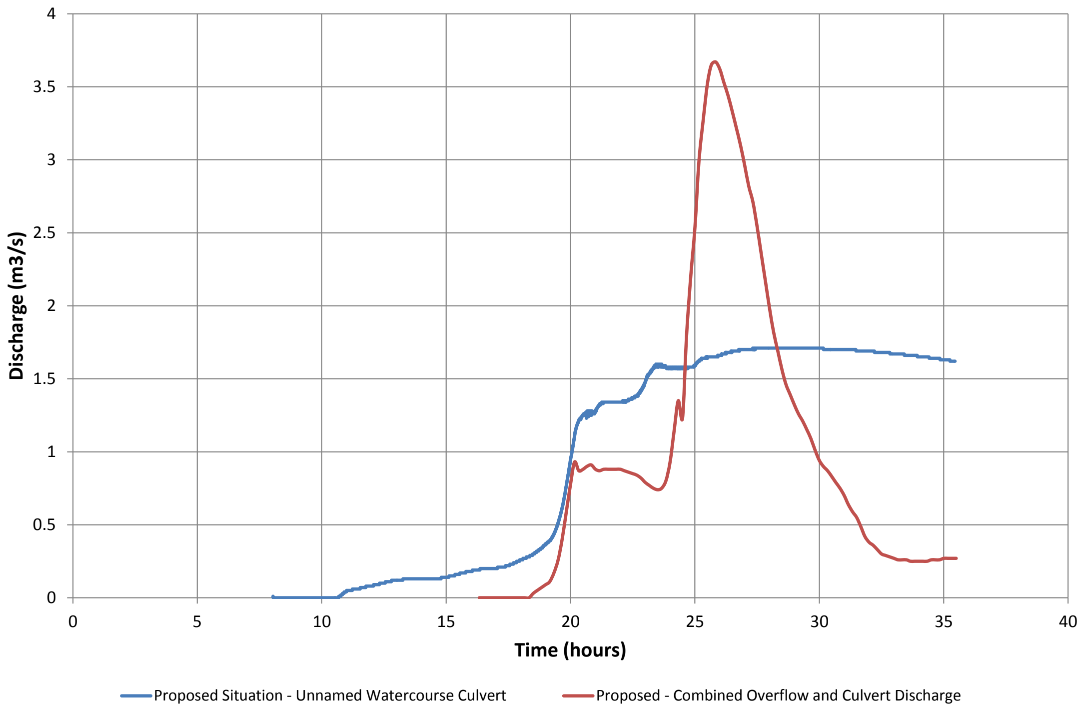

Figure 4-10f Comparison of outflow hydrographs from flood storage area draining Racecourse Catchment with from primary detention basin over Rahui Road (combined road and culvert flow) in proposed situation for 1% AEP flood adjusted for possible future climate change effects to 2090

The predicted peak flood levels and discharges given in Tables 4-3 to 4-7 are based on the assumptions that all Te Manuao Catchment flows are directed to the remnant railway wetland rather than the primary flood storage basin, and that all surface runoff from the Racecourse part of the Mangapouri Catchment enters the primary storage basin. As noted previously, the assumptions are not necessarily correct (they are examined further with aid of sensitivity tests in Section 4.7.

It was noted in Section 4.2 that flood levels in the primary storage basin on the Mangapouri Stream would butt up against the Expressway embankment directly beneath the Rahui Road overbridge where County Road loops round under it to link in with the old Rahui Road. The level of the upstream shoulder of the Expressway there is at 15.39m MSL Wellington datum (14.95m NZVD 2009) so that freeboard there for the 1% AEP flood adjusted for possible climate change effects would be about 0.5m and about 0.3m for the 0.2% AEP flood adjusted for possible climate change effects. This is a critical detail to be checked in the final design of the Expressway.

Figures 4-11 and 4-12 shows predicted flood depths and extent of inundation for the 1% AEP and 0.2% AEP floods adjusted for possible climate change effects within the general area of the SH1 / Rahui Road / old railway embankment triangle and the Rahui Road overflow zone. As noted previously, in contrast to the existing situation flood inundation maps in Figures 3-8 and 3-9, Figures 4-11 and 4-12 take account of the inflow contribution from the upstream Racecourse Catchment and the outflow via the 1.35m diameter culvert under the Expressway on the unnamed watercourse as seen in Figure 4-4.

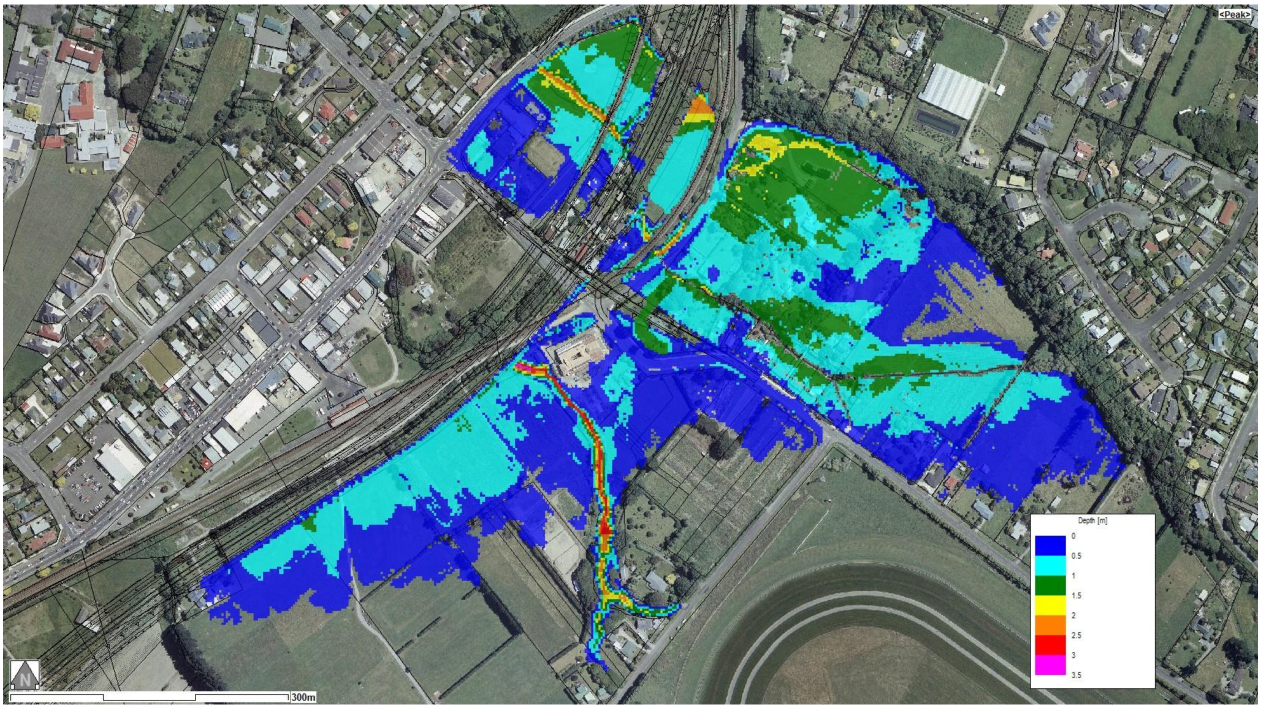

Figure 4-11 Predicted flood inundation extent for the 1% AEP flood adjusted for effects of possible future climate change to 2090 within the general area of the SH1 / Rahui Road / NIMT railway triangle for the proposed situation

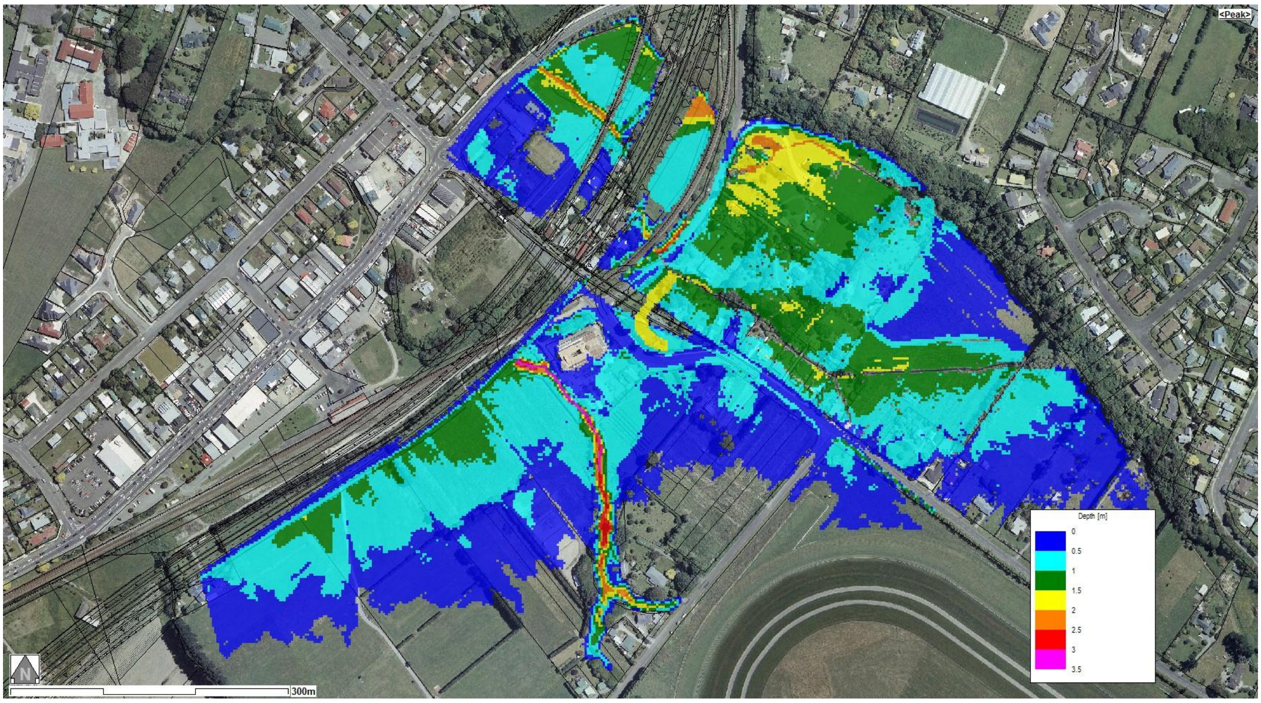

Figure 4-12 Predicted flood inundation extent for the 0.2% AEP flood adjusted for effects of possible future climate change to 2090 within the general area of the SH1 / Rahui Road / NIMT railway triangle for the proposed situation

The flood storage inundation patterns shown in Figures 4-11 and 4-12 are much as expected. The extent of inundation and magnitude of the flood depths in the primary storage basin and along the upstream side of the Expressway to the south of Rahui Road are greater for the larger flood in Figure 4-12. This particular figure also confirms the uncertainty identified with respect to the path of surface runoff from the northern part of the Ōtaki Racecourse (assumed to be within the Mangapouri Catchment area) with overland flow shown across the intersection of Te Roto Road with Rahui Road and spreading into the unnamed watercourse. The extent of inundation in the Pare-o-Matangi Reserve is constrained by the physical boundaries of the reserve (including the new railway embankment) and flood inundation depths are not significantly different between the two flood cases. The floodplain area on the downstream side of the Expressway was not included within the MIKE21 floodplain model although the MIKE11 model predictions of flood levels upstream of the SH1 culvert on the unnamed watercourse imply that widespread inundation of this area would start to occur between a 5% AEP and 2% AEP flood even in the existing situation.

The culvert under the Expressway on this unnamed watercourse has been deliberately sized to match as closely as possible the discharge characteristics of the existing 1.25m wide by 1.25m deep culvert under the NIMT railway line. The level of the upstream shoulder of the Expressway at this culvert location is 15.19m MSL Wellington datum (14.75m NZVD 2009) so that the predicted flood levels in Table 4-7 indicate that the freeboard for the 1% AEP flood adjusted for possible climate change effects would be about 0.4m and about 0.2m for the 0.2% AEP flood adjusted for possible climate change effects. The level of the Expressway at this culvert location is also a critical detail that needs to be checked during final design to ensure that premature overtopping of the road does not occur.

Note that the freeboard at this location (0.39m from Table 4-2) for the 1% AEP flood adjusted for possible climate change effects does not meet the freeboard requirements of the NZ Transport Agency's *Bridge Manual* (Transit NZ, 2003) for culverts. However, as the ponded floodwaters are likely to be fairly still, this reduced amount of freeboard should be acceptable (a lower freeboard standard has already been recommended in the companion overview report (Webby and Smith, 2013) for the Expressway at the old NIMT railway culvert location immediately to the north). The 0.5% AEP flood adjusted for possible climate change effects, a much more infrequent event, would still not overtop the road at this location with the current road level set at 15.19m MSL Wellington datum.

The outflow from the culvert under the Expressway on this unnamed watercourse discharges via the old SH1 culvert to a soakage area on the grounds of Ōtaki College (the watercourse does not continue through the school grounds to the Mangapouri Stream as it did in pre-development days). As noted before, Figure 4-10f illustrates the significant throttling effect of the Expressway culvert on the outflow past Rahui Road (combined road overflow and culvert outflow) from the primary detention area on the Mangapouri Stream as well as the runoff from the Racecourse Catchment. Table 4-7 indicates the old SH1 culvert would cause further minor attenuation of the peak outflow from the Expressway culvert although overtopping of the old SH1 might be expected to occur in floods larger than about a 5% AEP flood from inspection of ground contours.

Diversion of flow from the primary flood detention basin on the Mangapouri Stream into the unnamed watercourse draining the Racecourse Catchment would not increase the frequency with which the soakage area on the ground of Ōtaki College is utilised as this is determined by whenever the unnamed watercourse operates in a sufficiently large rainfall event. In moderate flood events, the volume of storm runoff discharged to the soakage area would increase due to the additional diversion from the primary flood detention basin (e.g. in a 5% AEP flood, the runoff volume would be approximately doubled). However, in the 1% AEP flood adjusted for possible climate change effects, approximately the same volume of flood waters would be discharged to the Ōtaki College soakage area. The inlet to the culvert under Rahui Road which causes the increased volume of storm runoff diverted to the Ōtaki College soakage area in moderate flood events could be reconfigured to increase the threshold flood level in the primary flood detention basin at which runoff diversion starts to occur (from that assumed in this investigation). This would reduce the diverted runoff volume in moderate flood events without compromising the performance of the Rahui Road overflow system in the design flood event.

Peak flood levels in the secondary flood storage basin in the Pare-o-Matangi Reserve upstream of SH1 (which is much reduced in size due the Expressway construction and NIMT railway realignment) are lower for floods smaller than the 5% AEP flood and slightly higher for floods larger than this. For the two largest floods considered, the differences are within 0.01m as by then overtopping of the road has occurred. For the intermediate sized floods, the flood level increases are slightly larger. The reason for this change relative to the existing situation is primarily the loss of flood storage within the basin as seen in Figure 4-2. This is despite the increased attenuation efficiency of the twin wetland system on the remnant railway wetland branch which markedly attenuates inflows from the Te Manuao Catchment relative to those for the existing situation for all floods larger than the 2% AEP flood (Table 4-5).

As part of the landscaping of the Pare-o-Matangi Reserve associated with construction of the new Expressway, a low bund[10] could be formed along the boundaries of the remaining properties of the corner of SH1 and Rahui Road. The purpose of this bund would be to prevent the ingress of floodwaters from the secondary storage pond within the Reserve onto these properties. This proposed mitigation measure makes the slightly increased flood levels in the Pare-o-Matangi Reserve acceptable.

The deficiency in performance of the secondary flood storage basin upstream of the old SH1 culvert could possibly also be remedied by reducing very slightly the size of the outlet culverts from the remnant railway wetland and the second downstream wetland (or setting the invert levels of the entrances to coth outlet culverts slightly higher). The remnant railway wetland has peak flood levels substantially lower than those for the existing situation (Table 4-3) for all except the largest flood considered (flood levels would start to overtop the Expressway at about a level of 20.0m MSL Wellington datum). There is potential capacity for marginally higher flood levels in the second downstream wetland on this branch.

Again, as noted before, these predictions for the remnant railway wetland system are based on the assumption of all Te Manuao Catchment flows entering the remnant railway wetland without any being diverted to the primary Flood storage basin on the Mangapouri Stream which is not necessarily correct. The sensitivity tests reported in Section 4.7 explore the effects of this assumption on the wider system including the remnant railway wetland.

The response of the hydraulic system described by the combined MIKE11 / MIKE21 model to flood inflows is quite dynamic and the peak flood discharge values in Table 4-4 (and peak flood level values in Table 4-3) are not coincident. This gives rise to a range of different trends relative to the peak discharge values for the existing situation. While old railway culvert discharge values are reduced (due to the lower upstream flood levels and the backwater effect of the stream through the new Expressway and railway culverts), the combined SH1 culvert and road overflow values are slightly higher for the 5% AEP and larger floods (which is consistent with the peak flood level trends). Peak outflows for the railway wetland system in the proposed situation are reduced compared to those in the existing situation. Rahui Road peak total outflows are higher for floods smaller than the 1 % AEP flood and lower for the 1 % AEP and larger floods due to the nature of the Rahui Road pond level / discharge relationship for the proposed situation.

Some of the peak discharge values reflect short term peaks as shown by the discharge hydrograph figures in Appendix C.

[10] This bund would have a maximum height of about 0.9m but for most of its length it would no more than 0.5m high.

4.6 Effects of Flood Detention in Storage Basins for Proposed Situation

In Section 3.7, the effect of ponded flood levels in the two Mangapouri Stream flood storage basins on surrounding properties was examined. Figures 3-12 and 3-13 showed the number of house affected if flood levels were:

- coincident with floor level (zero freeboard);
- within 0.3m of floor level (0.3m freeboard); or
- within 0.5m of floor level (0.5m freeboard).

The houses counted in this analysis were only those that would remain following construction of the proposed Expressway.

Figures 4-13 and 4-14 show the corresponding graphs to Figures 3-12 and 3-13 for the proposed situation based on the flood levels given in Table 4-3.

Comparison of Figures 4-13 and 3-12 for the primary flood storage basin upstream of the old railway embankment indicates that there is a slight reduction in the number of houses affected for the three smaller floods shown (20%, 10% and 5% AEP) but generally no change for the 1% AEP and 1% and 0.5% AEP floods adjusted for possible climate change effects. For the 0.2% AEP flood adjusted for possible climate change effects, there is an increase from nine to ten in the number of houses with inundated floor levels.

It is important to emphasise that these effects, even though they are reduced in the proposed situation in the case of some floods compared to the existing situation, are entirely a consequence of the deliberate decision in the past by the responsible local authorities to restrict the size of the existing railway culvert in order to throttle down-stream flood flows.

In the case of the 0.5% AEP flood adjusted for possible climate change effects, the proposed situation will result in a peak flood level within the primary flood storage basin (and hence floor level inundation depths) 0.02m higher than in the existing situation. For six of the affected houses, the relative increases in floor level inundation would be very small as the predicted inundation depths in the existing situation are already large (0.27-0.94m). For the other two affected houses, the relative increases in floor level inundation with the Expressway would be much larger as the predicted inundation depths in the existing situation are very low (less than 0.05m) although the actual increases would remain low in the proposed situation (less than 0.07m).

In the case of the 0.2% AEP flood adjusted for possible climate change effects, the proposed situation will result in a peak flood level within the primary flood storage basin (and hence floor level inundation depths) 0.12m higher than in the existing situation. As with the 0.5% AEP flood adjusted for possible future climate change effects, for six of the affected houses, the relative increase would be modest as the predicted inundation depths in the existing situation are already large (0.31-0.98m). For the four other affected houses, the relative increase in floor level inundation with the Expressway would be more significant as the predicted inundation depths in the existing situation are low. The inundation depths would increase from less than 0.00-0.09m in the existing situation to 0.06-0.21m in the proposed situation.

Similarly comparison of Figures 4-14 and 3-13 for the secondary flood storage basin upstream of the SH1 culvert indicates no real change in terms of the number of houses affected by the different floods considered except for the 10% AEP flood (the total number of houses within the basin area is very small). However, as noted in Section 4.5, construction of a low bund around the perimeter of these remaining properties on the corner of SH1 and Rahui Road as part of landscaping of the Pare-o-Matangi Reserve would be a suitable means of mitigating the effects of flood detention within the Reserve. The bund would stop the ingress of floodwaters stored within the Reserve onto these properties.

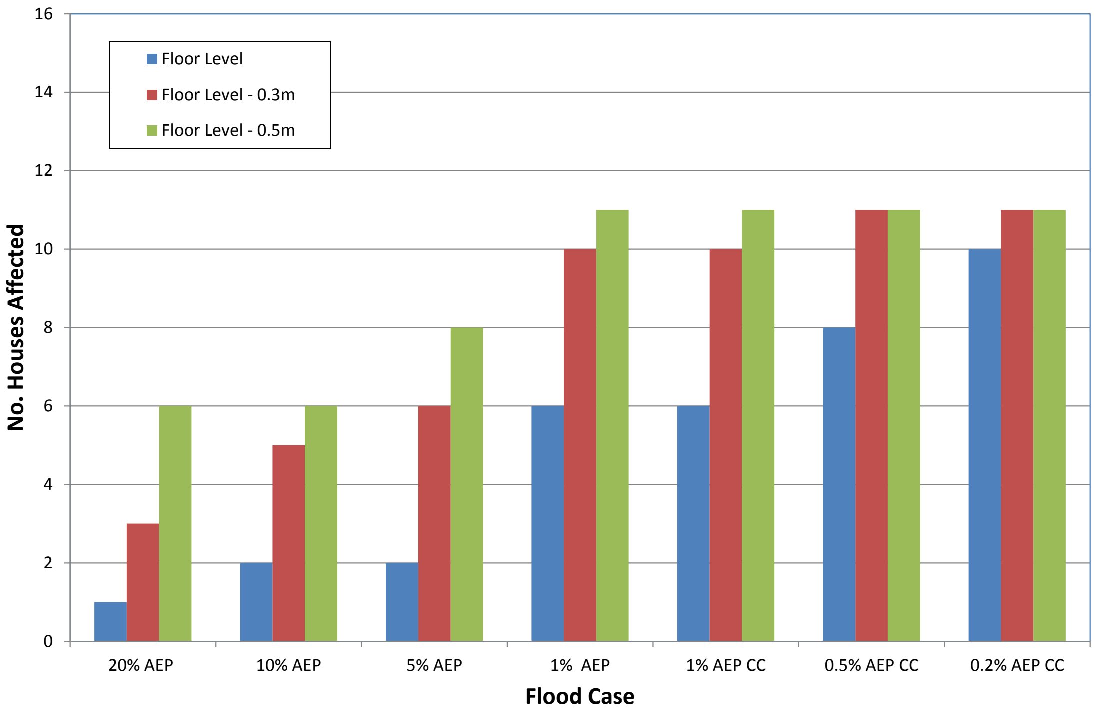

Figure 4-13 Number of flood affected houses in proposed situation along County Road and Rahui Road upstream of old railway culvert on Mangapouri Stream (excluding properties required for Expressway)

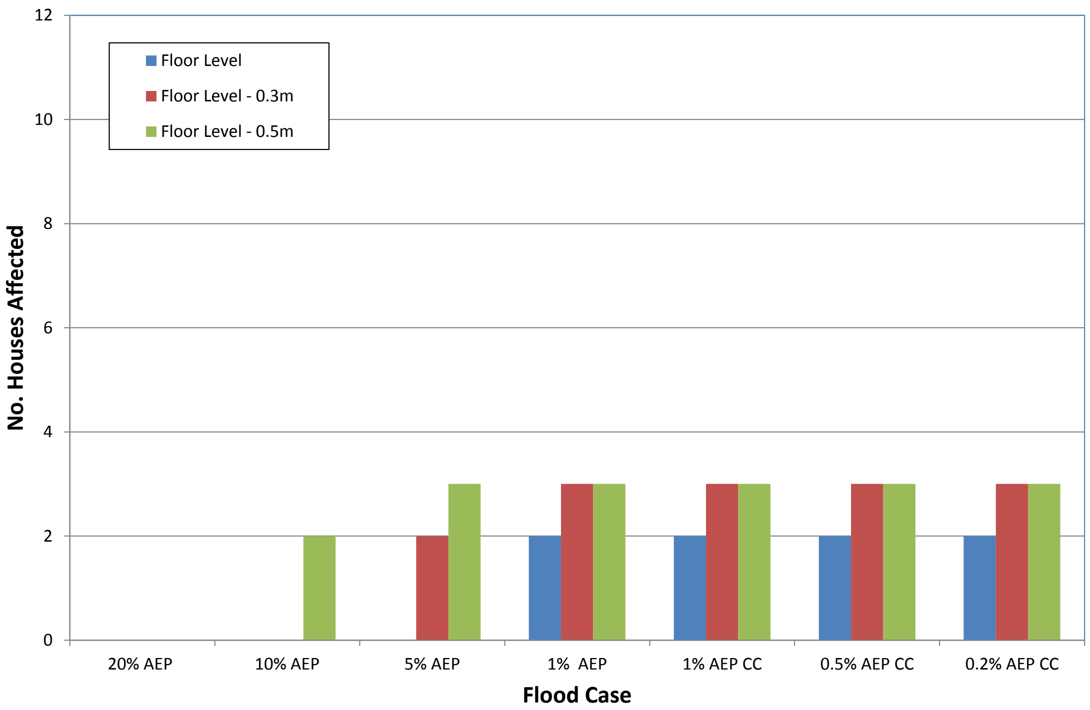

Figure 4-14 Number of flood affected houses in existing situation along SH1 and Rahui Road between old railway culvert and SH1 culvert on Mangapouri Stream (excluding properties required for Expressway)

4.7 Sensitivity of Peak Flood Level and Discharge Predictions to Alternative Assumptions

4.7.1 Storm Runoff Paths from Te Manuao Catchment

In Section 3.8.1, consideration was given to the effects of uncertainty in the actual path of excess storm runoff from the Te Manuao Catchment in the existing situation. Previously it had been assumed that all surface runoff from this particular catchment was directed to the railway wetland area. However the sensitivity test evaluated the effect of an even split between runoff going to the railway wetland area and runoff going directly to the primary flood storage basin on the Mangapouri Stream.

The sensitivity test has been applied to the proposed situation with consideration given to a limited number of floods only. Table 4-8 summarises the peak flood level predictions for this test with the bracketed values relating to the base case scenario (all runoff going to the remnant railway wetland) from Table 4-3. Table 4-9 summarises the peak flood discharge predictions for the proposed situation with the bracketed values again relating to the base case scenario from Table 4-4.

Table 4-8 Predicted peak flood levels for proposed situation in Mangapouri Stream with even split for diversion of Te Manuao Catchment runoff to railway wetland area and to primary flood storage basin in Mangapouri Stream (note bracketed values refer to base case flood level values from Table 4-3)

Flood Case (AEP %)	**Peak Flood Level (m MSL Wellington datum)**					
	Upstream of County Road culvert	**Upstream of old railway culvert**	**Upstream of Expressway culvert**	**Upstream of old SH1 culvert**	**Remnant railway wetland area**	**Second wetland area**
20	14.3 (14.25)	13.71 (13.6)	12.84 (12.97)	12.79 (12.92)	18.18 (18.48)	14.05 (14.37)
5	14.52 (14.47)	14.51 (14.46)	13.37 (13.49)	13.32 (13.45)	18.31 (18.73)	14.2 (14.57)
1	14.83 (14.79)	14.83 (14.79)	13.56 (13.75)	13.52 (13.70)	18.44 (19.07)	14.34 (14.78)
1 + CC to 2090	14.92 (14.88)	14.91 (14.88)	13.65 (13.81)	13.6 (13.77)	18.53 (19.31)	14.42 (14.93)
0.2 + CC to 2090	15.2 (15.11)	15.2 (15.11)	13.79 (13.85)	13.75 (13.78)	18.7 (19.8)	14.55 (15.15)

Table 4-9 Peak flood discharges for proposed situation in Mangapouri Stream with even split for diversion of Te Manuao Catchment runoff to railway wetland area and to primary flood storage basin in Mangapouri Stream (note bracketed values refer to base case flood discharge values from Table 4-4)

Flood Case (AEP %)	**Peak Flood Discharge (m^3/s)**					
	Inflow from Mangapouri Catchment	**Railway wetland inflow**	**old railway culvert outflow**	**Rahui Rd overflow**	**SH1 culvert and overflow**	**Railway wetland outflow**
20	7.61	0.69	3.22 (3.03)	0 (0)	3.64 (3.89)	0.5 (1.07)
5	10.75	0.96	4.48 (4.24)	0 (0)	4.58 (4.77)	0.75 (1.45)
1	14.32	1.3	4.77 (4.58)	1.18 (0.51)	4.88 (5.15)	1 (1.87)
1 + CC to 2090	16.72	1.52	4.84 (4.53)	4.07 (2.97)	5.48 (5.81)	1.16 (2.13)
0.2 + CC to 2090	20.895	1.895	4.56 (4.33)	8.24 (6.89)	5.29 (6.6)	1.42 (2.52)

The effect of a proportion of the Te Manuao Catchment flows entering the primary flood storage basin on the Mangapouri Stream directly is to cause:

- increased peak flood levels in the primary flood storage basin upstream of the old railway embankment;
- reduced peak flood levels in the secondary flood storage basin upstream of the Ste Highway 1 culvert;
- reduced peak flood levels in the remnant railway wetland and the second wetland downstream;
- increased Rahui Road overflows (sum of road overflow plus flood relief culvert outflow);
- reduced remnant railway wetland system outflows;
- increased old railway culvert outflows; and
- reduced SH1 culvert outflows.

The magnitude of the increases and decreases in peak flood levels and discharges relative to the base case scenario are very small. In particular, the increases in peak flood level in the primary storage basin are much less than the minimum design freeboard value of 0.3m recommended previously for the Expressway in the SAR Appendix E Report (Webby *et al*, 2011).

4.7.2 Effects of Culvert Blockage

In Section 3.8.2, the effects of partial (50 per cent) blockage of the old railway culvert were considered with respect to the existing situation. The same sensitivity test was applied to the proposed situation.

Tables 4-10 and 4-11 summarise the predicted peak flood level and discharge values resulting from the sensitivity test with the bracketed values representing the corresponding values from the base case scenario (no blockage) in Tables 4-3 and 4-4.

Table 4-10 Predicted peak flood levels for proposed situation in Mangapouri Stream with partial blockage of old railway culvert (note bracketed values refer to base case flood level values from Table 4-3)

Flood Case (AEP %)	**Peak Flood Level (m MSL Wellington datum)**					
	Upstream of County Road culvert	**Upstream of old railway culvert**	**Upstream of Expressway culvert**	**Upstream of old SH1 culvert**	**Remnant railway wetland area**	**Second wetland area**
20	14.47 (14.25)	14.27 (13.6)	12.49 (12.97)	12.44 (12.92)	18.47 (18.48)	14.37 (14.37)
5	14.77 (14.47)	14.77 (14.46)	12.77 (13.49)	12.72 (13.45)	18.73 (18.73)	14.58 (14.57)
1	14.92 (14.79)	14.92 (14.79)	13.00 (13.75)	12.95 (13.70)	19.06 (19.07)	14.79 (14.78)
1 + CC to 2090	15.10 (14.88)	15.09 (14.88)	13.14 (13.81)	13.09 (13.77)	19.30 (19.31)	14.93 (14.93)
0.2 + CC to 2090	15.4 (15.11)	15.39 (15.11)	13.34 (13.85)	13.29 (13.78)	19.80 (19.80)	15.16 (15.15)

Table 4-11 Predicted peak flood discharges for proposed situation in Mangapouri Stream with partial blockage of old railway culvert (note bracketed values refer to base case flood discharge values from Table 4-4)

Flood Case (AEP %)	**Peak Flood Discharge (m^3/s)**					
	Inflow from Mangapouri Catchment	**Railway wetland inflow**	**old railway culvert outflow**	**Total Rahui Rd overflow**	**SH1 culvert and overflow**	**Railway wetland outflow**
20	6.92	1.38	1.89 (3.03)	0 (0)	2.87 (3.89)	1.07 (1.07)
5	9.79	1.92	2.22 (4.24)	0.27 (0)	3.51 (4.77)	1.46 (1.45)
1	13.02	2.6	2.31 (4.58)	3.99 (0.51)	3.96 (5.15)	1.87 (1.87)
1 + CC to 2090	15.2	3.04	2.41 (4.53)	6.29 (2.97)	4.19 (5.81)	2.14 (2.13)
0.2 + CC to 2090	19.0	3.79	2.56 (4.33)	10.64 (6.89)	4.54 (6.6)	2.53 (2.52)

The effects of partial blockage of the old railway culvert are similar to that for a proportion of the Te Manuao Catchment flows entering the primary flood storage basin on the Mangapouri Stream upstream of the old railway embankment. However the railway culvert outflows are significantly reduced (rather than increased as in the Te Manuao Catchment outflow sensitivity test) and the increases in peak flood level in the primary flood storage basin upstream of the railway culvert are greater than for the previous sensitivity test. The increases in peak flood level are no larger than the recommended minimum design freeboard value from the SAR Appendix E Report (Webby *et al*, 2011).

As noted in Section 3.8.2, the likelihood of the old railway culvert becoming partially blocked is very low due to the shielding effect of the County Road culvert immediately upstream.

4.7.3 Effects of Reducing Size of Remnant Railway Wetland Branch Culverts

Tables 4-12 and 4-13 show that reducing the size of the outlet culverts on the remnant railway wetland system from a nominal 1m diameter to a 0.9m diameter has minimal effect on flood levels within the flood storage basin in the Pare-o-Matangi Reserve upstream of the SH1 culvert. This is at the expense of increasing flood levels in both wetlands on this system. The nominal 1m diameter outlet culvert size therefore appears to be close to an optimal size.

Table 4-12 Predicted peak flood levels for proposed situation in Mangapouri Stream with reduced culvert size on remnant railway wetland system (note bracketed values refer to base case flood level values from Table 4-3)

Flood Case (AEP %)	**Peak Flood Level (m MSL Wellington datum)**					
	Upstream of County Road culvert	**Upstream of old railway culvert**	**Upstream of Expressway culvert**	**Upstream of old SH1 culvert**	**Remnant railway wetland area**	**Second wetland area**
1	14.79 (14.79)	14.78 (14.79)	13.75 (13.75)	13.71 (13.7)	19.23 (19.07)	14.85 (14.78)
1 + CC to 2090	14.88 (14.88)	14.88 (14.88)	13.81 (13.81)	13.76 (13.77)	19.54 (19.31)	15.01 (14.93)
0.2 + CC to 2090	15.11 (15.11)	15.1 (15.11)	13.84 (13.85)	13.78 (13.78)	20.13 (19.8)	15.33 (15.15)

Table 4-13 Predicted peak flood discharges for proposed situation in Mangapouri Stream with reduced culvert size on remnant railway wetland system (note bracketed values refer to base case flood discharge values from Table 4-4)

Flood Case (AEP %)	**Peak Flood Discharge (m^3/s)**					
	Inflow from Mangapouri Catchment	**Railway wetland inflow**	**old railway culvert outflow**	**Rahui Rd overflow**	**SH1 culvert and overflow**	**Railway wetland outflow**
1	13.02	2.6	4.6 (4.58)	0.41 (0.51)	5.15 (5.15)	1.77 (1.87)
1 + CC to 2090	15.2	3.04	4.55 (4.53)	2.94 (2.97)	5.77 (5.81)	2.01 (2.13)
0.2 + CC to 2090	19	3.79	4.35 (4.33)	6.8 (6.89)	6.44 (6.6)	2.3 (2.52)

4.8 Alternative Solution to Flood Relief Culvert Under Rahui Road

As an alternative to the combination of the 10m wide dry culvert through the Rahui Road overbridge approach embankment (to maintain connectivity between the primary flood storage basin on the Mangapouri Stream and the Rahui Road overflow zone) and the low level, limited size flood relief culvert under Rahui Road, it would be possible to replace the approach embankment with a more open concrete structure supported on piers. However this alternative is likely to be more expensive as well as being visually less attractive. It would also still partially block the full width of the Rahui Road overflow zone and would therefore be likely to result in increased flood levels in the primary flood storage basin to some degree.

5. Detailed Response to Comments on Initial Scheme Assessment from GWRC and KCDC

5.1 Response to Comments from GWRC

Table 5-1 summarises the key comments made by GWRC in their review of the initial scheme assessment and our responses to these comments based on the content of this report.

5.2 Response to Comments from KCDC

Similarly Table 5-2 summarises the key comments made by KCDC in their review of the initial scheme assessment) and our responses to these comments based on the content of this report.

Table 5-1 Key comments from GWRC and our responses to them

Comment	**Our Response**
Sensitivity tests should be undertaken, particularly on the model inflows, given the uncertainty present in the hydrology	The hydraulic response of the flood storage basin system in the Mangapouri Stream in the vicinity of the proposed Expressway to a wide range of flood magnitudes (from 42.9% AEP to 1% AEP based on current climate conditions and from 1% AEP to 0.2% AEP for possible future climate change effects to 2090) has been examined in this report. By covering such a wide range of floods with a progressively increasing peak discharge value and defining the response of the each individual storage basin in terms of peak level / inflow or peak level / outflow rating relationships, the annual exceedance probability (AEP) is effectively being removed as a parameter identifying the extremity of a flood. Instead the sensitivity of the system response to the absolute value of the peak discharge is being evaluated. It should be noted that the peak level response of the primary flood storage basin upstream of County Road in both the existing and proposed situations (Figures 3-6 and 4-7 respectively) is very flat for the more extreme floods due to Rahui Road acting as a flood relief "valve". If the absolute value of the peak discharge is underestimated (or overestimated) for the very low AEP floods, then the predicted peak flood level will only be very slightly underestimated (or overestimated), i.e. by a few centimetres only. Apart from the uncertainty in the actual magnitude of the peak discharge estimates for the various AEP floods, the other key uncertainty related to the flood hydrology is the path of the Te Manuao Catchment outflows. We have examined the sensitivity of the distribution of these outflows by considering two alternative scenarios, one where the total runoff volume is directed to the railway wetland (or the remnant wetland in the case of the proposed situation) and another one where the runoff volume is evenly distributed between the railway wetland and the primary flood storage basin upstream of County Road. The latter sensitivity test is discussed in Sections 3.8.1 with respect to the existing situations and in Section 4.7.1 with respect to the proposed situation.

Comment	**Our Response**
Additional justification for the use of a freeboard value of 300mm should be provided, particularly in relation to the uncertainty present in the hydrology, the effect of culvert blockages, and the addition of the Te Manuao Catchment flow	The initial scheme assessment recommended a minimum design freeboard value of 300mm for the new Expressway culvert based on the assumption that this culvert would take over the flood flow throttling function of the existing NIMT railway culvert after this latter culvert was removed. As noted in this report, the design philosophy has changed such that it is now proposed to retain the old railway culvert and embankment even though the NIMT railway is to be relocated to the west side of the Expressway. The old railway culvert will therefore continue to perform its flood flow throttling function. The minimum design freeboard assumption of 300mm remains valid however as the ponded floodwaters in the primary flood storage basin upstream of County Road will continue to be impounded by a short section of the Expressway immediately under the Rahui Road overbridge (where County Road loops around under the bridge to connect with Rahui Road). The choice of such a low design freeboard value is reasonable in this context as the surface of the ponded floodwaters will be flat and still with no turbulence generated waves present except locally around the railway culvert.
Confirmation if properties on the left bank around the Expressway are being removed as part of construction	Existing properties at 24, 26, 28, 30, 32, 34, 36, 38 and 40 Rahui Road to the west of the existing railway crossing will need to be acquired to allow for Expressway and Rahui Road overbridge construction. In addition, properties at 42 and 50 Rahui Road to the east of the existing railway crossing will also need to be acquired to allow for Expressway and Rahui Road overbridge construction. The impact of flood ponding in the storage basins upstream of County Road and SH1 on these properties has therefore been excluded from the effects assessment in this report.

Comment	**Our Response**
Location of stormwater detention ponds for Expressway runoff should be shown in relation to flood extent Outline if they have been taken into account in the hydraulic modelling as a loss of flood storage area	The main stormwater attenuation pond for Expressway runoff is located in the centre of the dual carriageway road to the north of the Mangapouri Stream Crossing. This is illustrated in the companion report on the assessment of stormwater effects (Coles and Bird, 2012). The attenuation pond area has been specifically excluded from flood storage in the Mangapouri Stream for the proposed situation. It is not needed as flood storage in any case as the sizes of the Expressway and realigned railway culverts are such that they operate under a free surface flow regime and do not head up.
Additional discussion on whether or not Rahui Road will act as a "safety valve" for flood levels in the primary flood storage basin upstream of the old railway embankment	Road levels for the Expressway at the crossing of the Mangapouri Stream are more than 1m higher than the level of Rahui Road. However, as the Expressway is climbing north of where it passes under the Rahui Road overbridge, the critical location for comparison of road levels with the level of the Rahui Road overflow zone is directly underneath the Rahui Road overbridge. The Expressway level on the upstream side at this location is still about 0.2m higher than the level of the Rahui Road overflow zone. Therefore Rahui Road will still act as a flood relief "valve" in the proposed Expressway situation.
Effects of partial culvert blockage by flood transported woody and vegetative debris should be included Consider the likelihood of alternative blockage scenarios	This is considered in Section 3.8.2 of this report with respect to the existing situation and in Section 4.7.2 with respect to the proposed situation. The potential for the occurrence of alternative culvert blockage scenarios is also considered in Section 3.8.2 of this report.

Comment	**Our Response**
Discussion on changes in flow velocities caused by the Expressway construction should be included Discussion on whether or not increases in velocity are likely to lead to scour and whether erosion mitigations measures are necessary	Since it is now proposed to retain the existing NIMT railway culvert in order to preserve its current flood flow throttling function, the proposed Expressway will have minimal change on the current flow regime in the Mangapouri Stream. As the new Expressway and railway culverts downstream of the existing railway culvert will be sized to approximately match the width of the existing stream channel and bee deep enough to operate under a free surface flow regime, flow velocities along the Mangapouri Stream through the culvert will be largely unchanged from the present situation. These flow velocities are very unlikely to lead to scour and erosion issues. The only area of potential scour and erosion concern in the proposed situation is the area around the exit from the flood relief culvert under Rahui Road. Scour and bank protection will need to be provided at this location to protect the bed of the watercourse and the bank opposite the exit point.
Discussion on whether deposition of sediment in ponding areas created by the Expressway is likely to occur should be included Discussion also of methods of mitigation to ensure flood risk is not increased over life of Expressway	Floodwaters in a stream like the Mangapouri will convey a significant amount of suspended sediment. This will be the same in both the existing and proposed situations. It is inevitable that, due to the ponding of floodwaters in the sequence of flood storage basins in the system, some deposition of suspended sediment will occur on inundated areas. This will tend to get washed away by subsequent rainfall events. It will only occur very infrequently for floods larger than about a 10% AEP one. The changes in geometry to the different flood storage basins in the proposed situation are very minor will not exacerbate the potential for suspended sediment deposition. Due to the infrequency of flood events large enough to cause the occurrence of sediment deposition, the potential for flood risk to increase as a consequence of loss of storage from sediment deposition is extremely low.
Discussion of changes in the drainage of ponding areas upstream of the Expressway such as the time to drain and whether standing water is left	The geometry of the main flood storage basins is such that they will drain fairly easily with only minimal residual depression storage remaining post-flood. This applies to both the existing and proposed situations. Inspection of the water level hydrographs for both situations in Appendices B and C indicates that the drainage time for the flood storage basins on the Mangapouri Stream is generally less than 24 hours, assuming the shape of the assumed flood hydrograph is typical. The drainage times for the wetlands draining Te Manuao Catchment flows are slightly longer.

Table 5-2 Key comments from KCDC and our responses to them

Comment	**Our Response**
The design flows for the analysis are derived from available gauged data for the Mangaone Stream using a regional flood frequency scaling approach. The flows used in the report correlate with those from previous KCDC modelling of this area.	Noted
The overflow over Rahui Road is stated as starting to occur at approximately 14.7m. Recent LiDAR data suggests that this could be lower, possibly at 14.4m.	The LiDAR sourced data used for this work was made available by KCDC. We have noted that the levels associated with this data are in terms of the NZ Vertical Datum (2009). Our hydraulic analyses have all been carried out based on levels expressed in terms of the Mean Sea Level Wellington (1953) Datum. The relationship between the two level datums is outlined in Section 1.5. The lowest levels of the Rahui Road overflow zone are about 14.3m in terms of the NZ Vertical Datum (2009). Applying the appropriate datum correction, this level translates to a level of about 14.75m in terms of the Mean Sea Level Wellington (1953) Datum.

Comment	**Our Response**
The area upstream of the existing railway line is an important flood storage area. The culvert under the railway is a throttle that helps limit flooding downstream. In the proposed design the throttle is moved downstream to the Expressway culvert resulting in increased catchment area from the Te Manuao Catchment contributing to the inflows to the flood storage area.	As noted in this report, the design philosophy with respect to throttling flood flows out of the primary flood storage basin on the Mangapouri Stream has changed. It is now proposed to retain the existing railway culvert in order to preserve its current flood flow throttling function. The effects of Te Manuao Catchment flows into the storage basin system have been given very careful consideration in this extended analysis. Although the limited (piped) stormwater drainage system within the Te Manuao Catchment transfers captured storm runoff directly to the railway wetland to the west of SH1, the potential for excess storm runoff to enter the primary flood storage basin upstream of the existing railway line (via overland flow down SH1 and County Road) instead of entering the railway wetland is very real. Two alternative runoff distribution scenarios have been examined; on in which all Te Manuao Catchment flows are directed to the railway wetland area and the other in which there is an even split in the flow distribution between the railway wetland and the primary flood storage basin upstream of the existing railway line (for which the embankment will be retained after the railway is relocated in the proposed situation.
The assessment of flood impacts has not considered the change in land use associated with the proposed Expressway. This has been assumed to be mitigated through storage ponds and swales. However in the Mangapouri Catchment it will be difficult to provide attenuation outside of the floodplain. The drainage plans show the attenuation to be within the storage area upstream of the Expressway.	The stormwater effects of the proposed Expressway on the Mangapouri Stream and required mitigation measures have received detailed consideration in the companion report by Coles and Bird (2012). This report has carefully assessed the volumes of storm runoff and their treatment to minimise the impact on the Mangapouri Stream. The attenuation pond outflows to the stream are predicted to be very low. We have been very careful not to double count areas used for treating road-sourced stormwater and areas using for attenuating natural catchment storm runoff.

6. Conclusions

In its present form, the Mangapouri Stream in the vicinity of SH1, the NIMT railway line, Rahui Road and County Road behaves effectively as a system of interconnected flood detention ponds or storage basins under flood conditions. The system includes the railway wetland in the area to the north which captures storm runoff from the neighbouring Te Manuao Catchment and releases it via a drainage system into the Mangapouri Stream. The barriers forming the flood storage basins are the elevated transport links (principally the NIMT railway line and SH1) and the associated culverts through them on the main stream channel. In particular the NIMT railway culvert has been purposely throttled to limit flood flows and assist in the prevention of flooding downstream through Ōtaki Township.

Historically the Mangapouri Stream in this locality flowed across a natural floodplain (which was an extension of the much larger Ōtaki River floodplain). However as the floodplain has been developed over time, the natural drainage patterns have been heavily modified. In addition to the construction of the two transport links referred to before, there have been a number of other human interventions that have contributed to these changed drainage patterns:

- Construction of the Ōtaki Racecourse has truncated the head of the unnamed watercourse that would have naturally drained much of the racecourse part of the floodplain. Instead surface runoff from the northern part of the racecourse is now captured by drains along the northern side and diverted under Rahui Road via a culvert into the primary storage basin area on the Mangapouri Stream.
- The unnamed watercourse that has had its head truncated by the racecourse drains via culverts under the NIMT railway line and SH1. The latter culvert feeds storm runoff to a soakage area on the grounds of Ōtaki College. The original watercourse beyond this soakage area which historically linked up with the Mangapouri Stream has been completely eliminated.
- As outlined above the NIMT railway culvert has been deliberately restricted in size to throttle flood flows although the County Road culvert immediately upstream performs this function for smaller floods until it gets overtopped.
- The limited piped stormwater drainage system in the neighbouring Te Manuao Catchment feeds captured storm runoff to the railway wetland area where the runoff volumes are attenuated and slowly released via an outlet culvert and drain along the western side of the NIMT railway line into the Mangapouri Stream.

The hydraulic response of the whole flood storage basin system in the Mangapouri Stream is very finely balanced and further modifications to the system can potentially change the behaviour significantly and have much wider effects than just in the local vicinity of them. There are also a number of major uncertainties that affect the hydraulic response of the system:

- The amount of surface runoff that enters the primary storage basin on the Mangapouri Stream from the northern part of the Ōtaki Racecourse via the man-made drainage system rather than flowing overland to the original unnamed watercourse that historically would have drained that part of the floodplain is uncertain.
- The amount of surface runoff from the neighbouring Te Manuao Catchment instead of flowing overland into the railway wetland area is also uncertain.

The first source of uncertainties would have a positive benefit in that less runoff would be diverted to the primary flood storage basin on the Mangapouri Stream resulting in slightly reduced flood levels. The second source of uncertainty has been assessed by means of a sensitivity test which has shown that, while flood levels in the primary flood storage basin on the Mangapouri Stream would be increased, the magnitude of the increases would only be marginal.

Without mitigation, the proposed PP2O Expressway will have a number of major impacts on the hydraulic of interconnected flood storage basins on the Mangapouri Stream:

- The new eastern approach embankment to the new Rahui Road overbridge will block the present Rahui Road overflow flood relief path.
- Construction of the new Expressway and realigned NIMT railway line through the Pare-o-Matangi Reserve will cause a loss of storage volume in the secondary flood storage basin upstream of the SH1 culvert.
- Construction of the new Expressway and realigned NIMT railway line will also require the Mangapouri Stream to be confined by culverts through the Pare-o-Matangi Reserve.
- Construction of the new Expressway through the railway wetland area will cause a significant loss of storage volume from the wetland.
- Construction of the new Expressway and realigned NIMT railway line will require a new and longer culvert to maintain the drainage path for the unnamed watercourse draining the Racecourse Catchment.

Based on the results of the further investigations presented in this report, the following mitigation measures are proposed to preserve as closely as possible the delicate balance of the current hydraulic response of the storage basin system under flood conditions:

- The existing railway embankment and its associated culvert on the Mangapouri Stream will be retained in order to preserve the flood detention function of the primary flood storage basin.
- A dry culvert will be incorporated within the eastern approach embankment to the Rahui Road overbridge to maintain hydraulic connectivity between the primary flood storage basin and the (old) Rahui Road overflow zone. The area in front of the culvert will need to be excavated to ensure the downstream Rahui Road flood relief facilities come into operation at the desired flood magnitude.
- A limited size, low level flood relief culvert will be provided under Rahui Road to allow a small volume of floodwaters to be discharged to the unnamed watercourse which drains the Racecourse Catchment.
- Localised reshaping of the vertical profile of the old Rahui Road to remove a local high point will be undertaken to provide a uniform crest level through the Rahui Road overflow zone.
- The new culvert under the Expressway and realigned NIMT railway line which replaces the existing railway culvert will be sized to limit flows through it to no more than the present discharge capacity. The slightly elevated Expressway road formation will allow floodwaters to head up in front of the new culvert and utilise the rough land area upstream for flood storage purposes.
- The new Expressway and realigned NIMT railway culverts on the Mangapouri Stream will be nearly as wide as the existing stream channel and deep enough so that both continue to operate under a free surface flow regime in extreme flood conditions.
- A low bund will be constructed around the remaining properties along Rahui Road and SH1 backing on to the Pare-o-Matangi Reserve to mitigate the effects of slightly increased flood levels in the Reserve. The bund would form part of the landscaping within the Reserve.

- The loss of flood storage in the railway wetland will be rectified by making use of the dead space between the old railway embankment and the new Expressway embankment just to the north of the Mangapouri Stream Crossing to form a second wetland area in series with the remnant railway wetland.
- The outlet culverts on the remnant railway wetland system will be sized to maximise the attenuation efficiency of the system in order to reduce outflows to the Mangapouri Stream.

The hydraulic model simulations of these mitigation measures have shown that:

- Flood levels in the primary storage basin on the Mangapouri Stream would be marginally lower than those in the existing situation for all except the two largest floods considered (the 0.5% AEP and 0.2% AEP floods adjusted for possible change effects to 2090). However the number of houses affected would be the same as in the existing situation.
- The flood levels in the primary storage basin would impact on a number of houses within the primary flood storage basin area in that flood levels exceed floor levels or are within 0.5m of floor levels. In terms of the former criterion, the number of affected houses with the Expressway would be slightly lower than in the existing situation for the smaller floods considered (six in the case of the 1% AEP flood adjusted for possible future climate changes effects in the proposed situation compared to eight in the existing situation). However the number of affected houses would be the same (eight) for the 0.5% AEP flood and increased by one (ten) for the 0.2% AEP flood (both floods also adjusted for possible future climate change effects).
- Where the predicted flood level for the 0.5% AEP flood adjusted for possible future climate change effects exceeds house floor levels in the primary flood storage basin with the Expressway, the 0.02m increase in floor level inundation would be very small in a relative sense for six of the affected properties as the predicted inundation depths in the existing situation are already large (0.27-0.94m). For the other affected houses, the relative increases in floor level inundation with the Expressway would be much larger as the predicted inundation depths in the existing situation are very low (less than 0.05m) although the actual increases would remain low in the proposed situation (less than 0.07m). We would expect the resulting flood damage costs to be similar in the case of each affected house between the existing and proposed situations[11].
- Where the predicted flood level for the 0.2% AEP flood adjusted for possible future climate change effects exceeds house floor levels in the primary flood storage basin with the Expressway, the 0.12m increase in floor level inundation would be modest in a relative sense for six of the affected properties as the predicted inundation depths in the existing situation are already large (0.31-0.98m). For the other affected houses, the relative increases in floor level inundation with the Expressway would be more significant as the predicted inundation depths in the existing situation are low. The inundation depths would increase from less than 0.00-0.09m in the existing situation to 0.06-0.21m in the proposed situation. We would expect the resulting flood damage costs to be similar for the six houses where the relative increases in floor level inundation are modest and slightly greater for the other houses where the relative increases in floor level inundation are more significant.
- Flood levels within the Pare-o-Matangi Reserve (upstream of the SH1 culvert) would be marginally higher for some of the intermediate sized floods considered (2% AEP flood up to the 1% AEP floods adjusted for possible change effects to 2090). However this would only impact on the same number of buildings as at present (excluding those houses which need to be acquired for the Expressway Project). The increased

[11] Flood damage costs for inundated buildings are typically expressed in terms of different floor level inundation depth bands, e.g. -0.1 to 0m, 0 to 0.05m, 0.05 to 0.5m and 0.5 to 2.0m.

flood levels would be acceptable provided the proposed low bund around the perimeter of the remaining properties on Rahui Road and SH1 backing onto the Reserve is constructed. The magnitude of the peak outflows from this secondary storage basin area would be only slightly higher than for the existing situation due to the throttling effect of the SH1 culvert.

- The attenuation efficiency of the remnant railway wetland system is significantly improved compared to that of the present situation such that outflows to the Mangapouri Stream are much reduced.
- Diversion of flow from the primary flood detention basin on the Mangapouri Stream into the unnamed watercourse draining the Racecourse Catchment would not increase the frequency with which the soakage area on the ground of Ōtaki College is utilised as this is determined by whenever the unnamed watercourse operates in a sufficiently large rainfall event.
- In moderate flood events, the volume of storm runoff discharged to the soakage area would increase due to the additional diversion from the primary flood detention basin on the Mangapouri Stream (e.g. in a 5% AEP flood, the runoff volume would be approximately doubled). However, in the 1% AEP flood adjusted for possible climate change effects, approximately the same volume of flood waters would be discharged to the Ōtaki College soakage area.
- The inlet to the culvert under Rahui Road which causes the increased volume of storm runoff diverted to the Ōtaki College soakage area in moderate flood events could be configured to increase the threshold flood level in the primary flood detention basin at which runoff diversion starts to occur (from that assumed in this investigation). This would reduce the diverted runoff volume in moderate flood events without compromising the performance of the Rahui Road overflow system in the design flood event.

It needs to be emphasised that, for the larger floods considered (1% AEP flood and larger) in both the existing and proposed situation, there is likely to be widespread flood inundation across the floodplain on which Ōtaki Township is sited as demonstrated by the flood hazard map incorporated in the Kāpiti Coast District Plan (see excerpt of this in Figure D-1 in Appendix D). This flood inundation would arise from surface runoff exceeding the capacity of the existing piped stormwater and open channel drainage systems.

A range of sensitivity tests has been carried out to test the sensitivity of the hydraulic response of the system to the uncertainties in the hydrological inputs and to potential culvert blockages. These have demonstrated that a 300mm design freeboard allowance for the system is suitable.

In summary then, the effects of the proposed PP2O Expressway crossing of the Mangapouri Stream and its ancillary features are minimal and acceptable. In very rare floods such as the 0.5% AEP and 0.2% AEP floods adjusted for possible change effects to 2090 where the peak flood levels would be slightly greater than in the existing situation, the number of properties affected would be either the same or marginally increased. However there would be widespread flood inundation elsewhere through Ōtaki Township as noted above[12].

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[12] It is acknowledged that the approach used here for assessing the hydraulic (flood hazard) effects of the Expressway on houses in the primary flood storage basin on the Mangapouri Stream, whether these effects are acceptable and whether mitigation is required, differs slightly from the approach used in other locations and in the companion report assessing the stormwater effects of the Project (Coles and Bird, 2013).

Because the primary flood storage basin on the Mangapouri Stream is a dedicated flood storage facility designed to relieve flood risks downstream through Ōtaki Township, it has been treated as a special case. A wider range of floods other than the 1% AEP flood adjusted for possible future climate change effects has been considered. Since the flood effects are predicted to be slightly reduced in the case of the 1% AEP flood adjusted for possible future climate change effects and slightly worse in the case of the rarer 0.5% and 0.2% AEP floods also adjusted for possible future climate change effects (flood level increases of 0.02m and 0.12m respectively) with widespread flooding elsewhere through Ōtaki Township, the effects of the Project are considered to be minimal and acceptable and that, therefore, no additional mitigation is required.

For the "Assessment of Stormwater Effects" report (Coles and Bird, 2013), the standard flood test applied throughout the Project area has been the 1% AEP flood adjusted for possible future climate change effects. In the case of the affected farm shed within the Gear / Settlement Heights flood ponding area (see Figures 22 and 23 in Coles and Bird (2013)), the increase in flood level due to the Expressway is 0.3m. Due to the higher probability of occurrence of the 1% AEP flood adjusted for possible future climate change effects compared to the 0.5% and 0.2% AEP floods and the significantly greater increase in depth of flood inundation for this affected farm shed, exploring mitigation with the affected landowner in this particular case is recommended.

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