NZ TRANSPORT AGENCY
WAKA KOTAHI

Peka Peka to North Ōtaki Expressway
Hydraulic Investigations for Expressway Crossing of Ōtaki River and Floodplain

Quality Assurance Statement

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Revision Schedule

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NZ Transport Agency

Contents

List of Abbreviations

AEE	Assessment of Environmental Effects
AEP	Annual Exceedance Probability
DS	Downstream
GWRC	Greater Wellington Regional Council
KCDC	Kāpiti Coast District Council
LiDAR	Light Detection and Ranging[1]
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
PP2O	Peka Peka to North Ōtaki
RMA	Resource Management Act
RoNS	Roads of National Significance
SAR	Scheme Assessment Report
SH1	State Highway 1
TRB	True Right Bank (as viewed looking downstream in direction of river or stream flow)
US	Upstream

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[1] This is an airborne laser remote sensing technology used for the acquisition of detailed and accurate topographic survey data.

1. Introduction

1.1 Rationale for Investigations

The township of Ōtaki is protected by the Chrystall's Bend stopbank along the north side of the Ōtaki River as shown in Figure 1-1. The stopbank provides a 1% annual exceedance probability (AEP) level of protection for floods based on current climate conditions. However the stopbank has been constructed with a wider crest to facilitate future upgrading if ever it is decided in the future to raise the design level of protection or restore the current level of protection to account for the effects of changing climate conditions.

In the event of the occurrence of a flood larger than the design standard, the Chrystall's Bend stopbank would be overtopped (and possibly also breached if the level of overtopping was sufficiently large and lasted for a long enough time). The stopbank overtopping flows would flow across the Ōtaki River floodplain to the north of the Ōtaki River and inundate parts of Ōtaki Township. However most of the overtopping flow volume would follow a secondary flow path along the landward side of the stopbank. These flood inundation patterns are illustrated in Figure 1-2 which depicts the predicted extent of inundation across the floodplain in the existing situation for the 0.2% annual exceedance probability (AEP) flood adjusted for possible climate change effects to 2090.

The proposed Peka Peka to North Ōtaki (PP2O) Expressway will cross the Ōtaki River floodplain to the north of the river directly through the secondary flow paths for stopbank overtopping flow as seen in Figure 1-2. The expressway will be constructed as a raised embankment which will act as a barrier to the passage of floodplain flows resulting from stopbank overtopping. Figure 1-3 shows the predicted extent of flood inundation for the earlier scheme phase of the proposed expressway for the 0.2% AEP flood adjusted for possible future climate change effects prior to more detailed hydraulic modelling of additional mitigation measures. The predicted flood inundation pattern is partially mitigated in this case by the provision of a 20m wide by 1.5m deep dry "culvert" structure through the road embankment on the landward side of the Chrystall's Bend stopbank (this is where the embankment rises up in a southerly direction to reach the required level for the bridge crossing of the Ōtaki River).

The provision of this culvert structure represented an initial scheme option for exploring means of mitigating the effects of the expressway as a barrier to floodplain flows and establishing preliminary design levels for the road embankment. However it was recognised at the time of these initial investigations that the work was incomplete as the flood inundation pattern seen in Figure 1-3 was clearly unsatisfactory and required further detailed investigations. In particular it was noted in the case of the 0.2% AEP flood adjusted for possible climate change effects to 2090 that:

- the elevated expressway embankment, acting as a barrier to floodplain flows resulting from stopbank overtopping, would allow floodwaters to spread further north into the Mangapouri Stream primary flood storage basin area north of Rahui Road and east of the existing NIMT railway line;
- the vertical profile of the expressway was not high enough to prevent floodplain flows from spilling over the road embankment; and

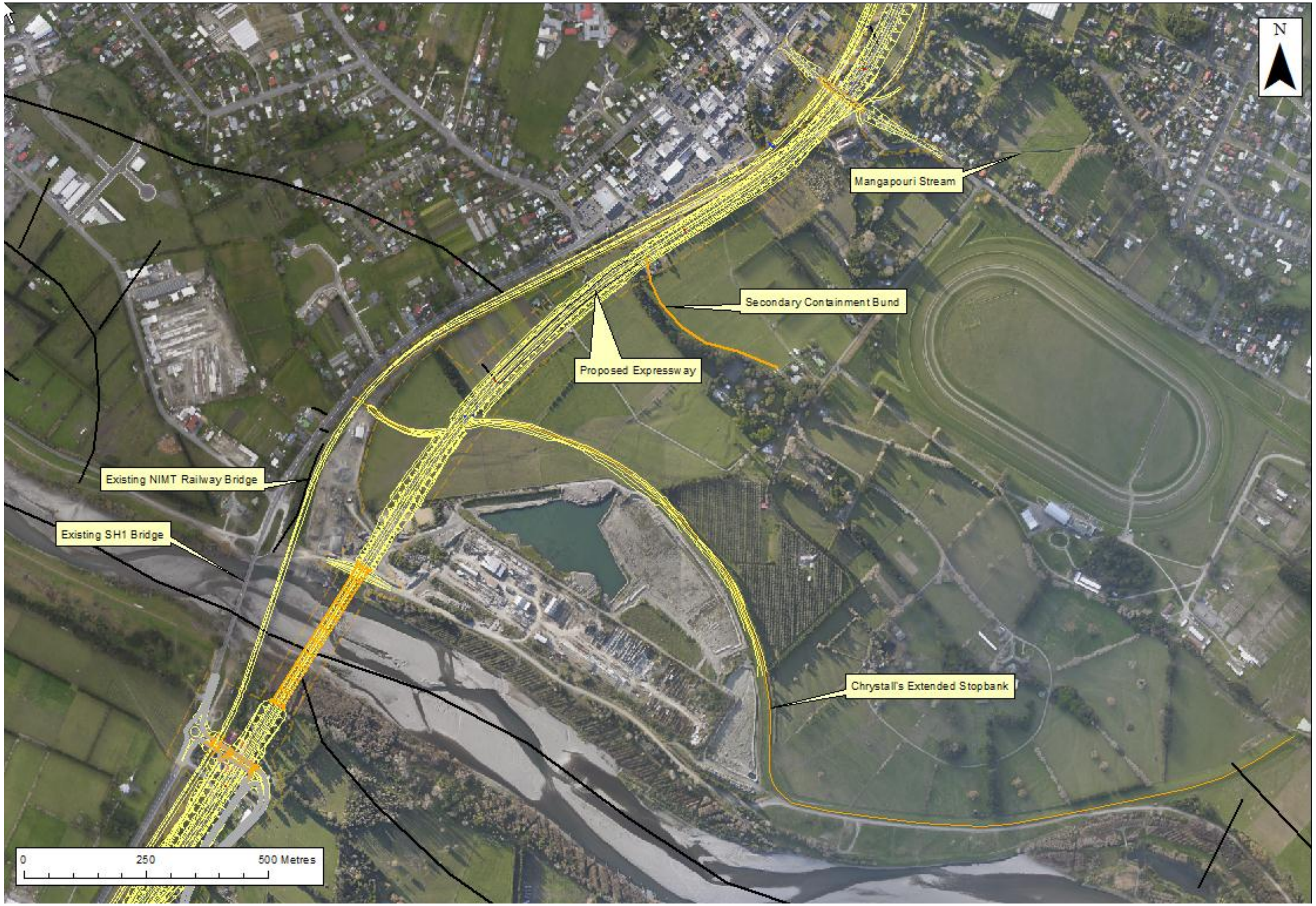

Figure 1-1 Aerial view of Ōtaki River and floodplain in vicinity of existing and proposed river crossings

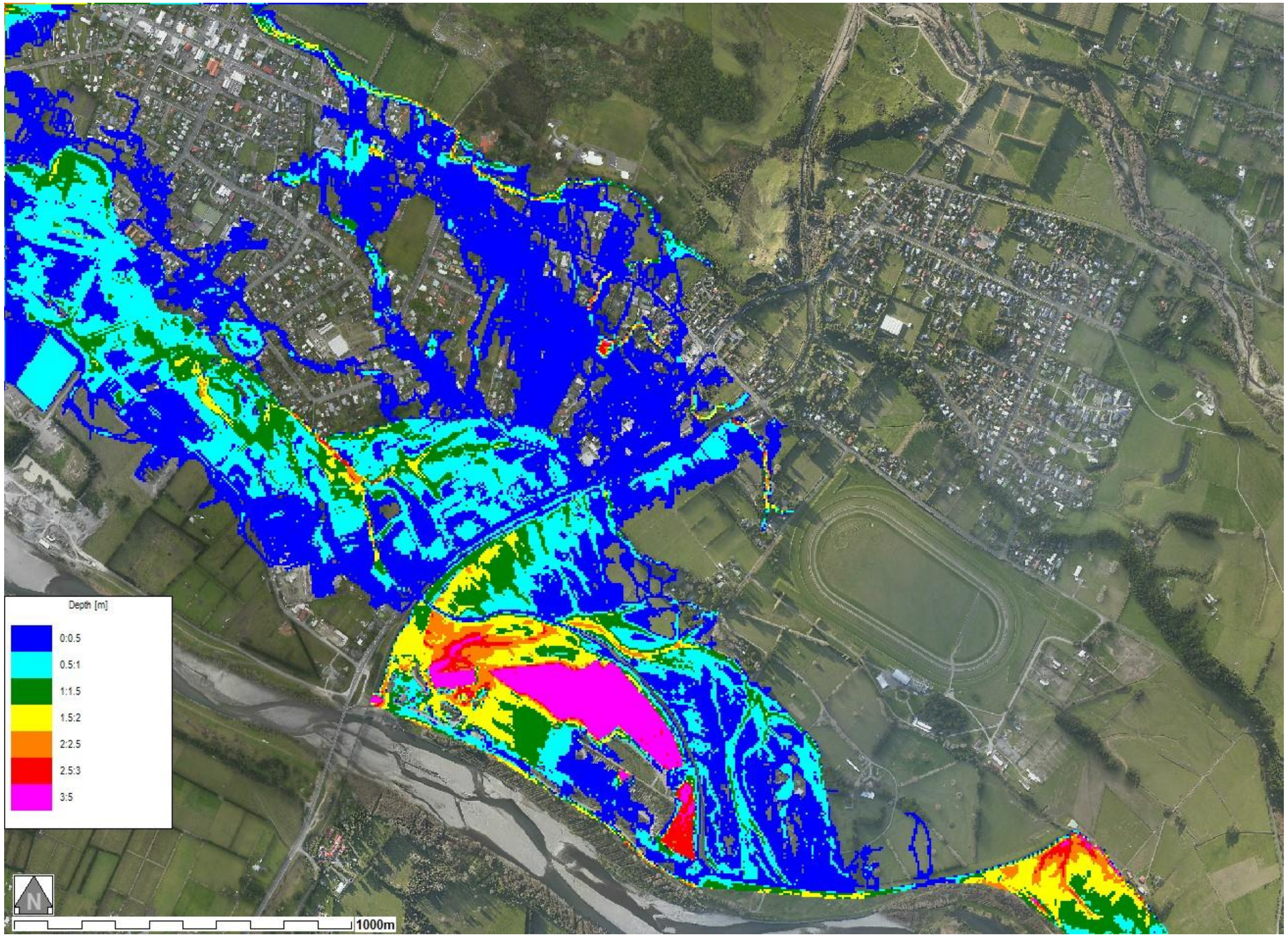

Figure 1-2 Extent of flood inundation for existing situation on Ōtaki River floodplain resulting from stopbank overtopping in 0.2% AEP flood adjusted for possible effects of future climate change

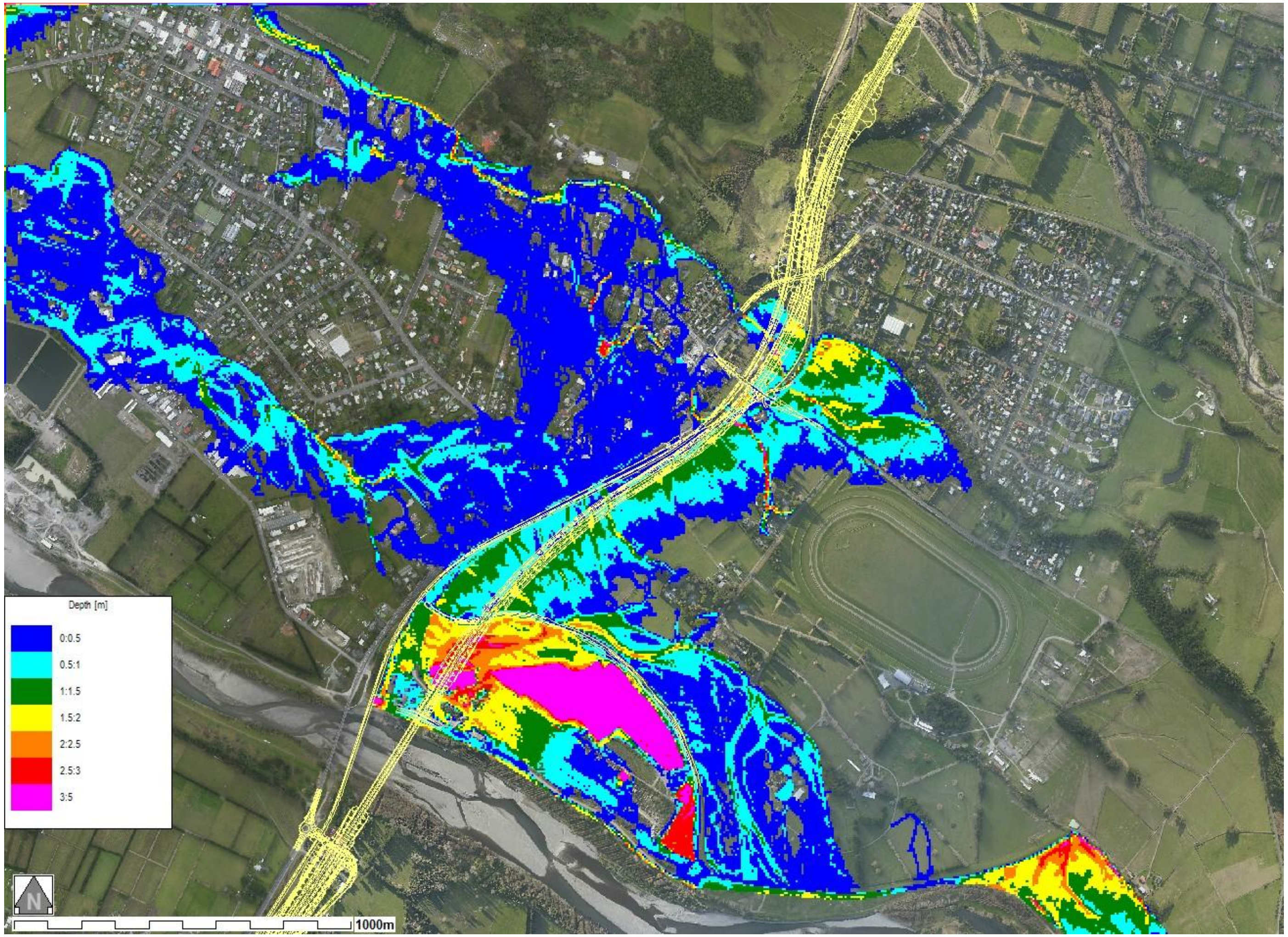

Figure 1-3 Extent of flood inundation for proposed expressway situation on Ōtaki River floodplain resulting from stopbank overtopping in 0.2% AEP flood adjusted for possible effects of future climate change (20m wide culvert only incorporated in expressway embankment with no other mitigation measures)

- the vertical profile of the expressway, being higher at the southern end and lower at the northern end, would potentially also direct a greater volume of floodwaters through Ōtaki Township than in the existing unconstrained floodplain situation.

It should be noted that the hydraulic modelling simulations used to produce Figures 1-2 and 1-3 considered no simultaneous storm runoff contributions to the flood inundation pattern across the floodplain from the Mangapouri Stream and other small local catchments.

This report presents the results of the investigations into additional mitigation measures to address the above matters in order to reduce the effects of the proposed expressway on existing stopbank overtopping flood hazards to an acceptable level and minimise the risk to public safety. The results of these investigations are also summarised in the overview assessment of hydraulic effects report (Webby and Smith, 2013) covering all the major watercourses crossed by the proposed PP2O Expressway. The overview report addresses the effects of the proposed expressway on floods in the Ōtaki River which are not specifically covered in this report.

1.2 Feedback on Initial Investigations from GWRC and KCDC

GWRC provided feedback on our initial investigations and also identified the spread of stopbank overtopping flows (in a flood larger than the stopbank design flood) into the primary storage basin area for the Mangapouri Stream as a significant issue. They noted that they "*would not be willing to agree to the diversion of Ōtaki River floodplain flows into the Mangapouri Stream*". They suggested for this stopbank flood overtopping scenario that consideration should also be given to:

- coincident flood peaks in the Ōtaki River and the Mangapouri Stream; and
- the effects of potential stopbank breaching (to be consistent with hydraulic modelling investigations carried out on the Waikanae River for the Mackays to Peka Peka Expressway Project immediately to the south).

GWRC noted the provision of a 20m wide dry culvert in the northern approach embankment to the Ōtaki River Crossing as a means of helping to mitigate the effects of the proposed expressway blocking the passage of stopbank overtopping flows across the floodplain (the dry culvert providing continuity for the main secondary flow path along the landward side of Chrystall's Bend stopbank). They suggested that consideration should therefore be given to the potential effects of partial blockage by woody and vegetative debris under flood conditions of this normally dry culvert. They were also interested in other effects of the expressway and dry culvert including:

- changes in flow velocity across the floodplain relative to the existing situation;
- potential sediment deposition in low velocity ponding areas;
- potential erosion of the floodplain surface due to excessively high flow velocities; and
- any reduction in the time to drain the floodplain relative to the existing situation.

KCDC deferred to GWRC on the initial investigations undertaken for the expressway crossing of the Ōtaki River and Floodplain as they considered these watercourses to be outside their specific jurisdiction.

1.3 Scope of Stopbank Overtopping Investigations

As noted in Section 1.1 and in the feedback from GRWC outlined in Section 1.2, the assumed configuration for the proposed PP2O Expressway embankment across the Ōtaki River floodplain without any mitigation would cause floodwaters in a stopbank overtopping event (an Ōtaki River flood larger than the stopbank design flood) to spread northwards into the Mangapouri Stream, thereby exacerbating the existing flood risk to properties in the Rahui Rd / County Rd area. This is unacceptable to GWRC as the flood protection authority and to NZTA as a responsible development agency.

The pattern of flood spread resulting from this flood scenario (see Figure 1-3) suggests a potential solution – a secondary flood containment bund extending up the floodplain approximately perpendicular to the Expressway embankment and partway along it. This would prevent stopbank overflows spreading further north into the Mangapouri Stream Catchment. It may also be necessary to complement this mitigation measure by:

- increasing the size of the dry culvert through the embankment which provides continuity for the existing secondary flow path along the floodplain parallel to the river immediately to the north of the stopbank; and
- re-shaping the vertical profile of the expressway embankment between the Chrystall's bend stopbank and the new flood containment bund so that, when road overtopping does occur, it occurs preferentially within a dedicated overflow zone at an appropriate flood threshold.

The flood containment bund solution initially appeared the most practical and promising one. However the other treatment measures described above were viewed as potentially complementary.

The further detailed investigations reported in this report were focussed therefore on examining the suitability of these mitigation measures in combination with each other. In addition consideration was also given to the additional potential effects identified by GWRC:

- changes in flow velocity across the floodplain relative to the existing situation;
- potential sediment deposition in low velocity ponding areas;
- potential erosion of the floodplain surface due to excessively high flow velocities; and
- any reduction in the time to drain the floodplain relative to the existing situation.

Appropriate outputs from the detailed hydraulic modelling were produced to enable these points to be specifically addressed in a quantitative manner.

Consideration was also given to the effects of stopbank breaching at the location of greatest stopbank overtopping to be consistent with similar investigations carried out on the Waikanae River for the Mackays to Peka Peka Expressway Project.

The effects of concurrent flood peaks in the Ōtaki River and the Mangapouri Stream become irrelevant if the suggested secondary flood containment bund in the middle of the floodplain proves successful as it would separate the floodplain into two components. The effects of floodplain inundation resulting from flood flows spreading overland from the Mangapouri and Racecourse Catchments are considered in a companion report (Smith and Webby, 2013).

1.4 Methodology for Floodplain Investigations

The investigations described in this report used a computational hydraulic modelling approach to assess the effects of the proposed expressway across the Ōtaki River floodplain and to optimise suitable mitigation measures to reduce these effects.

Specifically a MIKEFLOOD[2] model previously developed for the GWRC for flood hazard investigations across the floodplain (GWRC, 2007) was adapted and enhanced for the purposes of these investigations. The MIKEFLOOD model incorporated two linked components that were run simultaneously in parallel:

- a one-dimensional MIKE11[2] computational hydraulic model component representing the Ōtaki River and used for simulating flow behaviour within the main river channel; and
- a two-dimensional MIKE21[2] computational hydraulic model component representing the off-channel flood storage basin occupied by the Stresscrete concrete factory and the Ōtaki River floodplain and used for simulating flow behaviour across these two-dimensional surfaces.

1.5 Calibration of GWRC MIKE11 Model of Ōtaki River

The GWRC (2007) report on the flood hazard investigations for the Ōtaki River floodplain does not provide any details of the original calibration of the MIKE11 component (representing the Ōtaki River) of the MIKEFLOOD model. We have sought comment from GWRC on this matter and they have given the following response based on information provided by the MIKEFLOOD model developer (S Westlake, GWRC, pers. comm.):

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[2] MIKE11 and MIKE21 are internationally recognised computational hydraulic modelling software packages developed by the Danish Hydraulic Institute (DHI) and designed for simulating flow behaviour in complex river and floodplain systems. They are both widely used in New Zealand. MIKEFLOOD is an overarching software shell which incorporates both packages and enables linear watercourses to be linked to two-dimensional water bodies or surfaces.

> The Otaki River channel component of the model was calibrated to the March 1990 flood event (peak flow of 1170 m^3/s, a little over a 5 year flood) at the time of the initial model build in 1992. The model was also verified against the 975 m^3/s flood (about a 2.5 year event) of August 1991. The model *"produced a good match between recorded and modelled flood levels"* (Manssen, 1994), although those model results can no longer be found. All of the March 1990 levels were predicted to within 0.61 m, and 60% were within 0.2 m (Manssen, 1997). An overflow channel through Riverslea Orchard (upstream of the railway on the left bank) was calibrated to a small event of February 1992. The remainder of the model was uncalibrated.
>
> Despite larger flood events occurring in October 1998 (1289 m^3/s peak flow, about an 8 year event) and January 2005 (1549 m^3/s peak flow, about a 25 year event), no flood level information was collected for those events and the model has not been recalibrated since the original calibration.

It is unfortunate that the supporting documentation for the MIKE11 model calibration appears to have been lost. We have inspected the model as provided by GWRC and noted the Manning's n channel roughness values obtained from model calibration. Table 1-1 summarises the ranges of these Manning's n values for different reaches of the main river channel.

Table 1-1 Ranges of Manning's channel roughness values for different reaches of Ōtaki River from calibrated MIKE11 model

River Channel Reach	**Manning's n Channel Roughness Range**	**Nature of Reach**
2.6km long reach at end of Ōtaki Gorge	0.068 – 0.070	Confined rocky gorge
6.5km long reach from exit of gorge to existing NIMT railway bridge	0.054 – 0.068	Steeply sloping semi-braided river channel reach (bed slope ≈ 0.48%)
60m long reach past existing NIMT railway and SH1 road bridges	0.088	Short semi-braided river channel reach past existing transport link crossings
2.6km long reach downstream of existing SH1 road bridge	0.040 – 0.054	Steeply sloping semi-braided river channel reach (bed slope ≈ 0.26%)
1.2km long reach upstream of river mouth	0.033 – 0.038	Tidally effected reach incorporating gravel to sand bed transition

The Manning's n channel roughness values in Table 1-1 obtained from the MIKE11 model calibration reflect the nature of each river reach as well the intensity of sediment motion expected under significant flood conditions. They appear to be realistic values for a steep gravel bed river such as the Ōtaki although the values within the lower gorge reach and immediately downstream of the gorge exit are relatively high. This is upstream of the area of interest for this particular assessment.

We have also noted that the existing NIMT railway and SH1bridges across the Ōtaki River are represented in the MIKE11 model as cross-sections excluding the area occupied by the bridge piers and with a high Manning's n value to simulate the head loss induced by the piers. Some blockage at the railway bridge by debris raft formation on the piers is represented by an assumption of over-size peers.

The flood used for calibration of the MIKE11 model was a reasonably large one. The reported match between measured and predicted peak flood levels for the 1,170m^3/s flood is reasonable given the likely accuracy of the observed flood levels obtained from flood debris marks.

As part of the GWRC (2007) floodplain hazard investigations, the MIKE11 model calibration was checked against a single inferred peak flood level upstream of the NIMT railway line on the left bank for the January 2005 flood (approximately a 5% AEP flood based on current climate conditions). The predicted flood level was 0.46m higher than the inferred flood level and the difference was attributed to the amount of debris blockage at the rail bridge allowed for in the model being greater than actually occurred in the flood. We note also that the riverbed in the model was refined using 2006 river cross-section survey data which could have been an additional contributing factor as 2006 mean riverbed levels were higher than 1991 mean bed levels between Chrystall's Bend and the river mouth (Gardner, 2011).

We are satisfied on the basis of the available evidence that the MIKE11 model has been satisfactorily calibrated.

However the lack of surveyed peak flood level data for major flood events than can be used for ongoing verification of the MIKE11 model calibration remains a concern. This underlines the importance of such data being acquired in the future after any major flood event. This is particularly the case when riverbed levels are known to be constantly increasing over time.

1.6 Principle of Hydraulic Neutrality

An elevated transport link constructed across a floodplain interferes with the natural drainage function of such a feature. Adequate provision must therefore be made for relief measures within the elevated link to allow the safe passage of floodplain through it or over it.

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 are kept away from residential properties and instead redirected towards uninhabited rural areas.

Application of this principle of hydraulic neutrality is demonstrated by the proposed inclusion of a wide dry culvert through the expressway embankment, the incorporation of a secondary flood containment bund to prevent the spread of floodplain flows towards the Mangapouri Stream and the reshaping of the vertical profile of the road embankments to form a flood relief weir.

1.7 Topographic Data

Topographic data for the general Ōtaki River floodplain area 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.

Bed levels for the Ōtaki River in the MIKE11 model were sourced from a 2006 river cross-section survey (GWRC, 2007).

1.8 Level Datum

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 then, 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 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 Hydrology

2.1 Previous Flood Estimates

For the initial hydraulic modelling investigations, the flood hydrology of the Ōtaki River was not revisited. Instead the same flood estimates used by GWRC in recent flood hazard investigations for the floodplain (GWRC, 2007) were adopted. These flood estimates are reasonably similar to the results of a subsequent review of the flood hydrology of the Ōtaki River carried out by NIWA for GWRC (McKerchar, 2009)[3].

In the initial hydraulic modelling investigations, the flood estimates used by GWRC (2007) were also adjusted to account for the effects of possible future climate change to 2090 based on MfE (2010) guidelines. Table 2-1 summarises these flood estimates for current and possible future climate conditions along with those from McKerchar (2009).

Table 2-1 Flood estimates for Ōtaki River

Annual Exceedance Probability (%)	**Flood Estimate (m^3/s)**		
	Current climate conditions from review by McKerchar (2009)	**Current climate conditions as assumed by GWRC (2007)**	**Adjusted for effects of possible future climate change to 2090**
50	900	n/a [1]	n/a [1]
20	1,160	n/a [1]	n/a [1]
5	1,500	n/a [1]	n/a [1]
2	1,710	n/a [1]	n/a [1]
1	1,870	1,810	2,120
0.5	2,030	n/a [1]	n/a [1]
0.2	n/a [1]	2,130	2,490

[1] not available

The same flood estimates used in the initial hydraulic modelling investigations and by GWRC (2007) were again used for the further detailed hydraulic modelling investigations reported in this report.

It can be seen from Table 2-1 that the 1% AEP flood adjusted for possible climate change effects to 2090 is approximately the same as the 0.2% AEP flood estimate for current climate conditions.

2.2 Concurrency of Floods in Mangaone Stream and Ōtaki River

In view of GWRC's suggestion to consider the effects of concurrent floods of similar annual exceedance probability values in the Ōtaki River and Mangapouri Stream, the relative magnitude of concurrent historic floods from the Ōtaki River and the Mangaone Stream (from which flood estimates for the ungauged Mangapouri Stream were derived – see Smith and Webby (2013)) was examined. Figures 2-1 to 2-5 compare the discharge hydrographs for the four largest Ōtaki River floods since 1993 with the corresponding discharge hydrographs for the Mangaone Stream and the discharge hydrograph for the largest Mangaone Stream flood (20-21 October 1998) with the corresponding discharge hydrograph for the Ōtaki River. The graphs in these

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[3] This review was based on the estimated annual maxima series for 54 years from 1955-2008 with a Gumbel distribution.

figures use two different vertical axis scales to accommodate the order of magnitude differences between flows in the two watercourses – the left hand vertical axis corresponds to the scale for Mangaone Stream flows (blue hydrograph) while the right hand vertical axis corresponds to the scale for Ōtaki River flows.

It can be seen from Figures 2-1 to 2-5 that the peak flow in the Ōtaki River always lags the peak flow in the Mangaone Stream. As Mangapouri Stream flows are much more likely to reflect Mangaone Stream flows, the same conclusion applies to relative timing of peaks in the Ōtaki River and Mangapouri Stream.

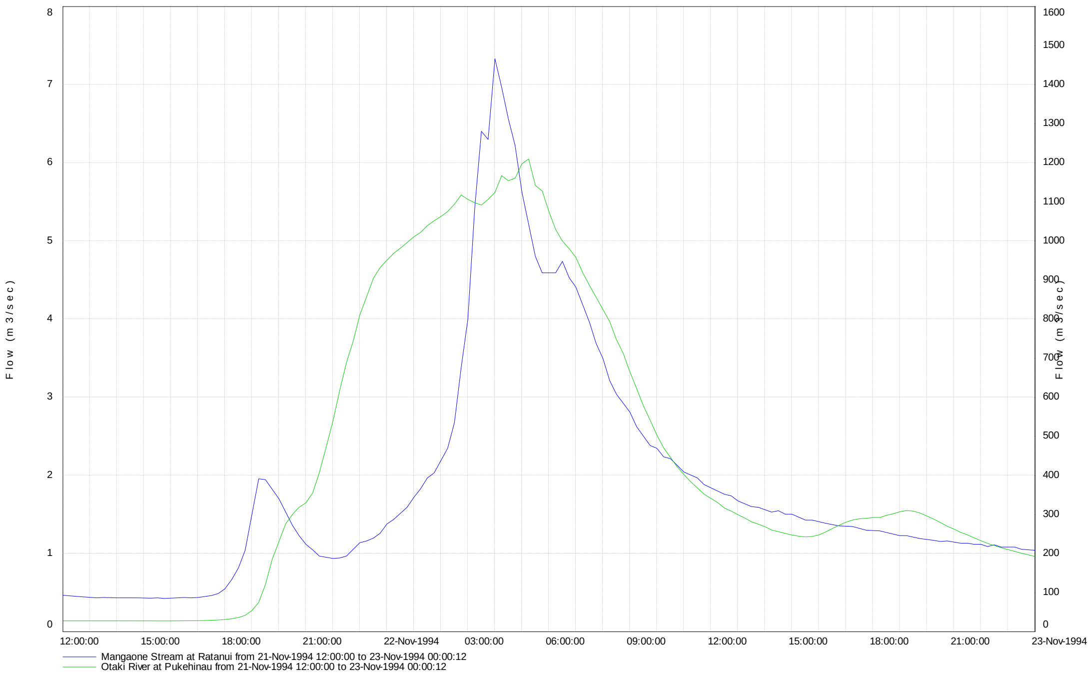

Figure 2-1 Concurrent flood events in the Mangaone Stream and Ōtaki River on 22 November 1990 (Mangaone Stream flow on left axis – blue line, Ōtaki River flow on right axis – green line)

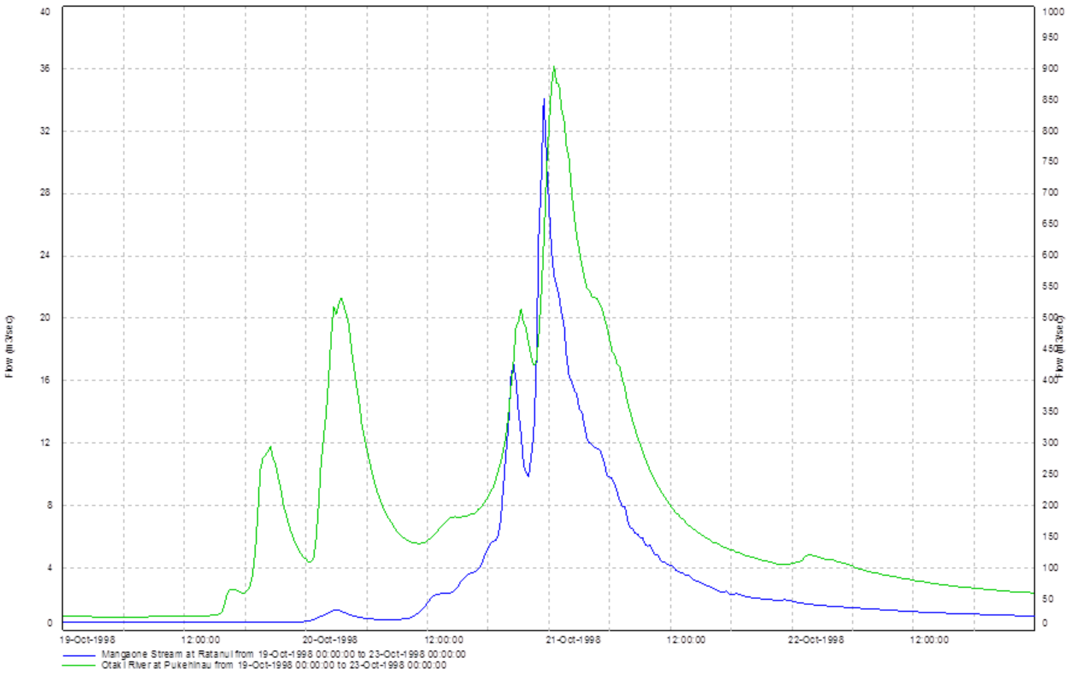

Figure 2-2 Concurrent flood events in the Mangaone Stream and Ōtaki River on 20-21 October 1998 (Mangaone Stream flow on left axis – blue line, Ōtaki River flow on right axis – green line)

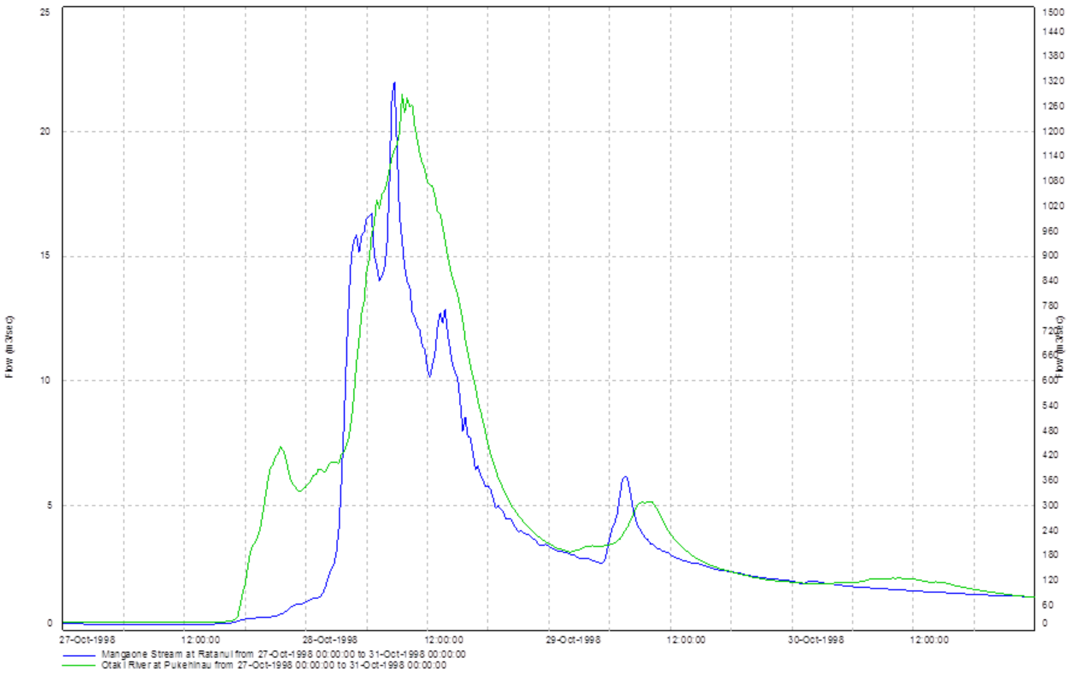

Figure 2-3 Concurrent flood events in the Mangaone Stream and Ōtaki River on 28 October 1998 (Mangaone Stream flow on left axis – blue line, Ōtaki River flow on right axis – green line)

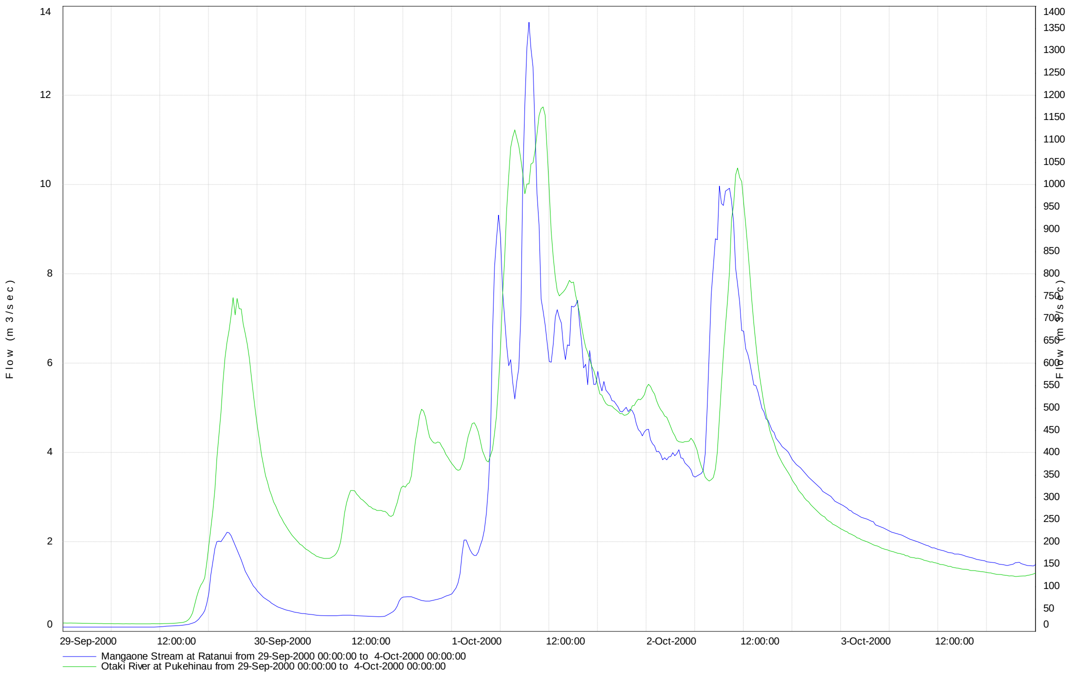

Figure 2-4 Concurrent flood events in the Mangaone Stream and Ōtaki River on 30 September to 1 October 2000 (Mangaone Stream flow on left axis – blue line, Ōtaki River flow on right axis – green line)

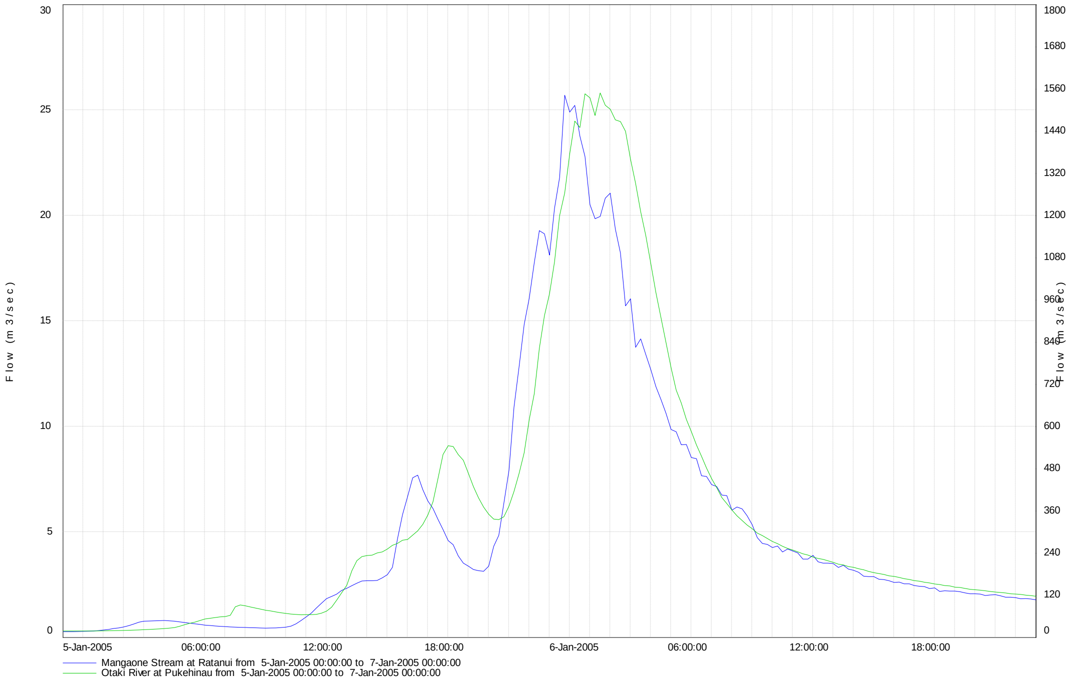

Figure 2-5 Concurrent flood events in the Mangaone Stream and Ōtaki River on 5-6 January 2005 (Mangaone Stream flow on left axis – blue line, Ōtaki River flow on right axis – green line)

Table 2-1 compares the peak flow values in both watercourses for the floods shown in Figures 2-1 to 2-5 along with the estimated annual exceedance probability values that these correspond to and the lag times between the peaks.

Table 2-1 Summary of characteristics of concurrent floods in Ōtaki River and Mangaone Stream

Date	**Ōtaki River**		**Mangaone Stream**		**Lag Time between Peaks**[1] **(hours)**
	Peak Flow (m^3/s)	**Estimated AEP (%)**	**Peak Flow (m^3/s)**	**Estimated AEP (%)**	
5-6 Jan 2005	1549	4.2	25.7	7.4	1.75
28 Oct 1998	1289	12	22.0	15	0.75
22 Nov 1994	1210	17	7.3	83	1.25
30- Sept -1 Oct 2000	1175	20	13.6	53	1.75
20-21 Oct 1998	904	50	34.1	2	1.00

[1] Difference between the time of peak discharge in the Ōtaki River at the Pukehinau gauging station and the time of peak discharge in the Mangaone Stream at the Ratanui gauging station expressed in hours.

The following observations can be made from the data in Table 2-1:

- Although the same storm events commonly affect both the larger Ōtaki and much smaller Mangaone and Mangapouri Catchments, the annual exceedance probability values of the resulting floods in each watercourse are usually quite different.
- Extreme floods in the Ōtaki River with a low annual exceedance probability value generally give rise to less extreme floods (with a higher annual exceedance probability value) in the Mangaone Stream (probably reflecting a significant orographic-induced rainfall gradient across the Ōtaki Catchment in widespread storm events), and hence by implication, the Mangapouri Stream.
- The most extreme flood in the Mangaone Stream with a 2% annual exceedance probability of occurrence corresponded with only a 50% annual exceedance probability flood in the Ōtaki River.
- Flood peaks in the Ōtaki River always tend to lag flood peaks in the Mangaone Stream (and hence by implication, in the Mangapouri Stream).

Based on these observations it is not considered appropriate to consider concurrent floods with the same annual exceedance probability value in both the Ōtaki River and the Mangapouri Stream. However the assumption of coincidence in time of flood peaks in both watercourses would be reasonable but conservative.

2.3 Consideration of Over-Design Flood

GWRC have recommended that consideration be given to evaluating the effects of an over-design flood such as one 1.5 times the magnitude of the 1% AEP flood adjusted for possible future climate change effects. While this may be appropriate for very small catchments, it is not necessarily appropriate for larger catchments. For the Ōtaki River, extrapolation of the flood frequency data from McKerchar (2009) in Table 2-1 (which has considerable uncertainty) indicates that a flood 1.5 times the magnitude of the 1% AEP flood adjusted for possible future climate change effects could have an annual exceedance probability in the order of 0.02% (1 in 5,000). This exceeds the Ultimate Limit State design flood standard required for bridges of this importance by the NZ Transport Agency's *Bridge Manual* (Transit NZ, 2003).

A flood of such magnitude is also well in excess of the current design standard for the Chrystall's Bend stopbank providing flood protection to Ōtaki Township. It would almost certainly result in breaching of the stopbank as a consequence of overtopping.

For the purposes of this assessment, consideration has been given to evaluating the effects of stopbank overtopping with and without breaching by the 0.2% AEP flood adjusted for possible future climate change effects to 2090. These effects on the Ōtaki River floodplain (including Ōtaki Township) have been evaluated for both the existing situation (refer Sections 4.2 and 4.3) and the proposed situations (refer Sections 5.3 and 5.4).

3. Treatment Philosophy for Expressway Crossing of Floodplain

3.1 Treatment Philosophy for Ōtaki River Bridges

The existing SH1 bridge across the Ōtaki River partially constricts the river channel and causes a slight backwater effect[4] upstream. The NIMT railway bridge immediately upstream of the SH1 bridge has a longer overall length and does not appear to contribute to this backwater effect. The maximum 330m length of the Expressway crossing of the Ōtaki River, comprising two parallel bridges, has been selected to approximately match that of the existing NIMT railway bridge and thereby ensure adequate hydraulic performance. The pier to pier span length has been set at 30m (based on structural considerations) giving a total of 11 spans.

The Ōtaki River drains a fairly large catchment which extends back to the main east / west divide of the Tararua Ranges. The catchment includes extensive forest cover so that there is a very high likelihood of large volumes of woody debris being flushed out of the catchment under extreme flood conditions with some of the debris snagging on the piers of the proposed upstream Expressway bridge, thereby inducing the formation of a debris raft and causing increased pier head losses (the wide spacing of the piers would limit the size of any debris raft on a pier). For this reason it is appropriate to adopt at least a minimum design freeboard value of 1.2m for the bridges based on the guidelines of the NZ Transport Agency's *Bridge Manual* (Transit NZ, 2003). The piers of the two bridges will be aligned so that those on the upstream bridge will have a sheltering effect on those of the downstream bridge.

However the reach of the Ōtaki River from Chrystall's Bend to the river mouth, which the existing road and rail bridges cross and which the Expressway bridges will also cross, is a known aggradational reach. Gravel extraction is actively exercised as a management tool to try and maintain riverbed levels to a desired profile, thereby ensuring that the design flood standard for the Chrystall's Bend stopbank is not eroded and the flood risk to Ōtaki Township is not exacerbated by bed aggradation[5]. To monitor the effects of gravel extraction, regular cross-section surveys are undertaken to ensure that the mining of gravel bed material is sustainable.

Gardner (2011) analysed changes in mean bed level and the volume of gravel bed material in the Ōtaki River based on river cross-section surveys in 1991, 2006 and 2011. He calculated that mean bed levels in the reach from Chrystall's Bend to the river mouth had mostly increased in the range 0-0.3m over the period 1991 to 2011 with increases of 0.3-0.5m at some cross-sections and decreases at a few cross-sections.

Gardner (2011) also found that, between 2006 and 2011, mean bed level changes in part of the Ōtaki River reach from Chrystall's Bend down to about where the Expressway bridges will cross the river (cross-section 380) were roughly in balance - some increases up to 0.12m and some decreases up to -0.23m. However in the remainder of the reach downstream of the Expressway crossing point, he found that mean bed levels had mostly increased in the range 0-0.15m with increases at some cross-sections of 0.15-0.37m and decreases at other cross-sections of up to -0.3m and at one section up to -0.6m. On balance though, the mean bed level

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[4] A backwater effect in this context means that upstream flood levels along the river are slightly elevated due to the bridge constriction compared to the situation without the bridge present. The effect diminishes with increasing distance upstream.

[5] GWRC hold the resource consents for gravel extraction and license others to undertake this with constraints on the volume of gravel bed material that is allowed to be extracted.

increases dominated over the decreases over the whole of the reach resulting in a net increase in the gravel bed volume (implying a net aggradation trend of the riverbed).

The design freeboard allowance for the two Expressway bridges therefore needs to allow for the effects of gradually occurring bed aggradation in addition to the effects of potential debris raft formation on the bridge piers. Based on the minimum freeboard requirements of the NZ Transport Agency's *Bridge Manual* (Transit NZ, 2003) for the latter factor and the recent aggradational history of the Ōtaki River with an increasing bed level trend, it would be appropriate to adopt a slightly higher freeboard standard for the two Expressway bridges than the *Bridge Manual* value. We would recommend a minimum freeboard standard of 1.7m derived from the 1.2m allowance from the *Bridge Manual* and the maximum mean bed level increase between 1991 and 2011 of 0.5m.

In view of the longevity of the projected design life for the Expressway bridges and the importance of these structures, it is appropriate for the Serviceability Limit State Flood to be at least the 0.2% AEP flood based on current climate conditions. This flood is approximately the same as the 1% AEP flood adjusted for possible future climate change effects to 2090. This design standard is in accordance with the requirements for the serviceability limit state flood of the NZ Transport Agency's *Bridge Manual* (Transit NZ, 2003).

3.2 Treatment Philosophy for Expressway Embankment Crossing of Floodplain

In a stopbank overtopping scenario, floodwaters from the Ōtaki River spill across the floodplain predominantly following a secondary flow path along the landward side of the Chrystall's bend stopbank and parallel with the river. There would be some lateral spread of floodwaters into residential parts of Ōtaki Township.

Construction of the proposed PP2O Expressway on a raised embankment across the floodplain will interfere with the main secondary flow path as the embankment would act as a flood detention barrier. The most important treatment objective for the expressway crossing of the floodplain was to incorporate some means of providing continuity for this main secondary flow path. Other additional treatment objectives were:

- if possible, reduce the impact of stopbank overtopping flows on Ōtaki Township, particularly residential areas; and
- contain the spread of stopbank overtopping flows into the Mangapouri Stream.

Given the context of the proposed expressway, it is not possible to pre-define a suitable design flood standard or design freeboard value for the expressway embankment. These parameters can only be determined by carrying out a range of flow simulation trials exploring the effects of different embankment geometries and complementary mitigation measures for a stopbank overtopping event. The detailed hydraulic modelling investigations described in this report represent a continuation of the evaluation process to establish these parameters (begun with initial hydraulic modelling investigations during the earlier scheme development) and to optimise the proposed mitigation measures.

4. Hydraulic Performance in Current Situation

4.1 Hydraulic Behaviour in Main River Channel

Figure 4-1 shows peak flood level along the main channel of the Ōtaki River predicted by the one-dimensional MIKE11 component of the combined MIKEFLOOD river and floodplain model for the existing situation and the following floods:

- 1% AEP flood for current climate conditions (1,810m^3/s)
- 0.2% AEP flood for current climate conditions (2,130m^3/s)
- 0.2% AEP flood adjusted for the effects of possible future climate change to 2090 (2,490m^3/s)

The peak flood level profiles in Figure 4-1 progressively rise as the magnitude of the peak flood discharge increases.

The locations of the existing NIMT railway and State Highway 1 bridge crossings along the river are included in Figure 4-1. The SH1 bridge has a shorter span relative to the NIMT railway bridge (and also the proposed twin expressway bridges) and causes a backwater effect upstream with the peak flood level profiles locally elevated with respect to the average bed level profile.

The SH1 bridge has a variable soffit level of between about 14.8m (MSL Wellington datum) at either end and about 15.2m (MSL Wellington datum) mid-span while the NIMT railway bridge has a constant soffit level of about 15.4m (MSL Wellington datum). Comparison of the peak flood level profiles in Figure 4-1 with these soffit levels indicates that:

- a 0.2% AEP flood would just start to touch the soffit of the NIMT railway bridge; and
- a flood somewhere between a 0.2% AEP flood and a 0.2% AEP flood adjusted for possible climate change effects to 2090 would just start to touch the soffit of the SH1 road bridge.

Some heading up on both bridges would occur for floods larger than these (this effect has not been modelled). Flood- transporting woody debris catching on the bridge superstructure and forming a debris raft, which is a very real threat in the Ōtaki River due to the nature of the catchment, would exacerbate this behaviour. The effect of surcharging on either or both bridges would increase the height of stopbank overtopping.

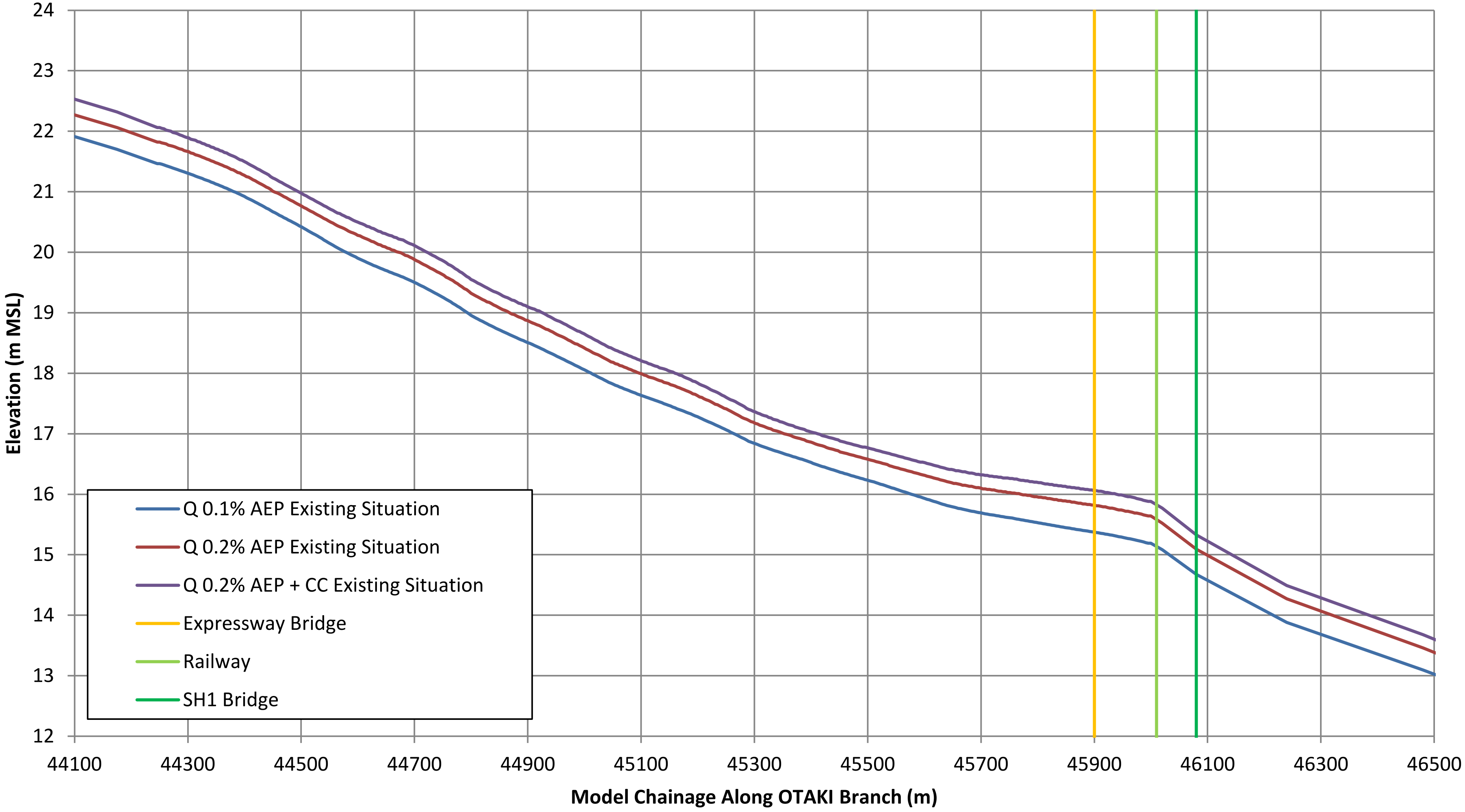

Figure 4-1 Predicted peak flood levels along Ōtaki River for range of floods in existing situation

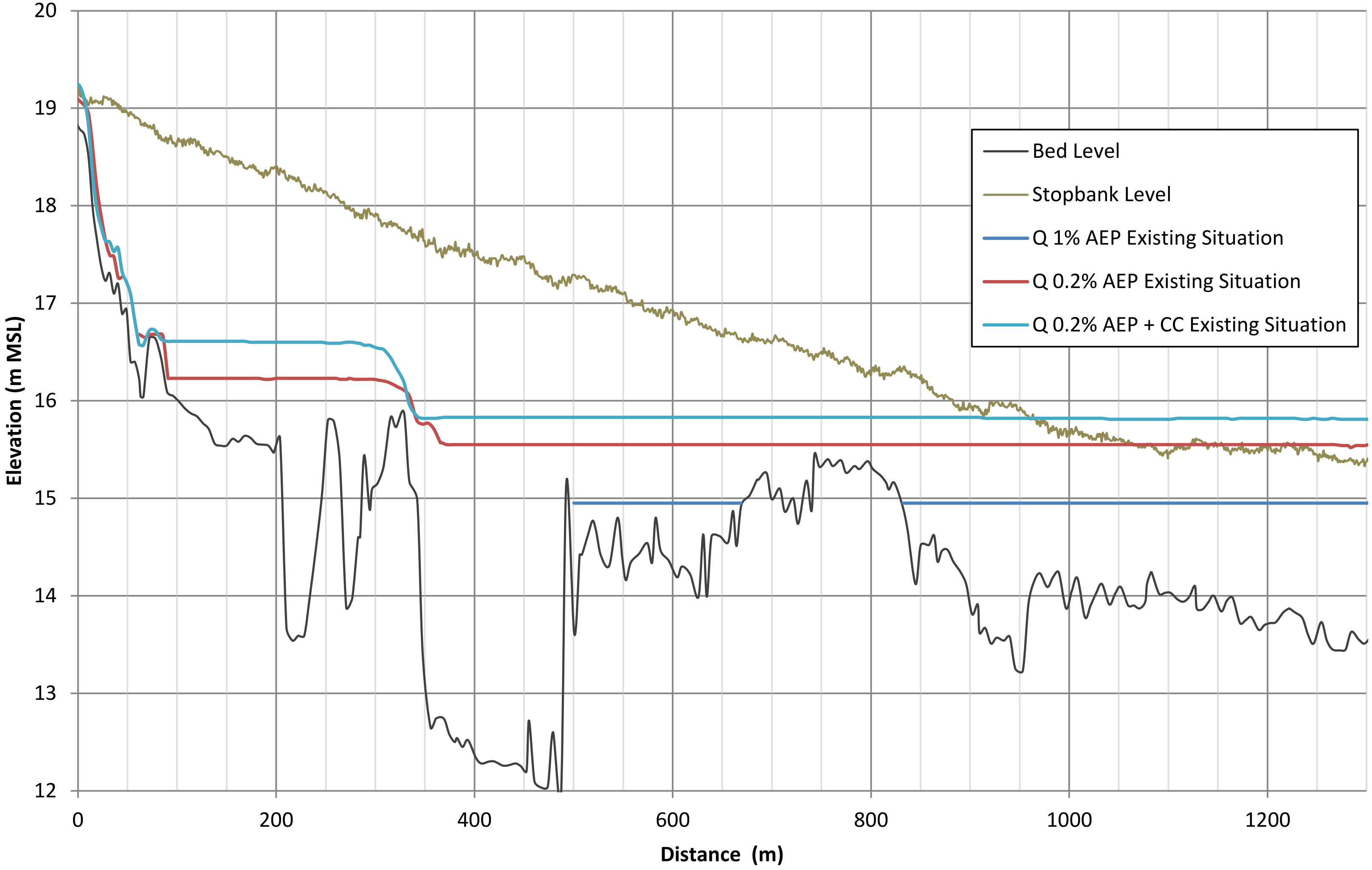

Figure 4-2 Predicted peak flood levels along Chrystall's Bend stopbank past concrete products factory for range of floods in existing situation (left hand axis coincides with where stopbank veers way from river, right hand axis corresponds to location of NIMT railway embankment)

As flood levels in the main river channel increase with the magnitude of the discharge, floodwaters gradually backfill the shallow semi-enclosed basin occupied by the Stresscrete concrete products factory on the right bank upstream of the NIMT railway bridge. The backfilling of the basin starts from the downstream end of the basin but, with larger floods, also occurs from spill over higher ground at the upstream end of the basin[6]. This basin was incorporated in the two-dimensional MIKE21 component of the combined MIKEFLOOD river and floodplain model. The model predicted this basin to behave effectively as an off-channel flood storage basin with an approximately horizontal water surface. This is shown in Figure 4-2 for the same range of floods as in Figure 4-1.

Figure 4-2 also includes the crest level profile of the Chrystall's' Bend stopbank along the right (north) bank of the Ōtaki River (Figure 1-1) and a "bed" profile through the middle of the off-channel flood storage basin. The stopbank crest level and the basin "bed" level profiles were both sourced from LiDAR data which explains the irregularity of them.

Figure 4-2 indicates that:

- the stopbank would have a freeboard of about 0.6m in a 1% AEP flood at the downstream end adjacent to the NIMT railway embankment at distance 1300m (the railway embankment itself forms a return leg back to the river for the stopbank flood defence for Ōtaki Township);
- the stopbank would just start to be overtopped by a 0.2% AEP flood; and
- the stopbank would be overtopped by up to about 0.5m at the downstream end by a 0.2% AEP flood adjusted for possible future climate change effects.

4.2 Hydraulic Behaviour across Floodplain

Figure 1-2 in Section 1 shows the predicted flood extent across the floodplain for a 0.2% AEP flood adjusted for possible climate change effects overtopping the Chrystall's Bend stopbank. The flood inundation map also shows peak flood depths in different ranges denoted by colour shading.

The 0.2% AEP flood adjusted for possible climate change effects overtops the Chrystall's Bend stopbank in a couple of locations:

- over a distance of about 350m upstream of where the stopbank deviates to skirt around the perimeter of the concrete factory basin (overtopping by up to 0.25m); and
- over a distance of about 350m upstream of the downstream end of the stopbank immediately adjacent to the NIMT railway embankment (overtopping by up to 0.45m).

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[6] The river bank along the outer edge of this shallow basin is stabilised by a roadway and by grass and trees so that it is clearlya permanent feature. However the external peer reviewer reported observing during a site visit in November 2012 stockpiles of gravel along the bank beside the road. He suggested that these could have been included in the terrain represented in the MIKE21 component of the MIKEFLOOD model and that, if they were present, they could have influenced the flow patterns into the basin. Careful inspection of the ground contours along the river bank generated from the 2010 LiDAR data suggests that there could have been one or at most two small isolated stockpiles of gravel but not a continuous line of them. We have therefore discounted the possibility of any significant effect on flow patterns.

Stopbank overtopping flows predominantly follow a secondary flow path parallel to the Ōtaki River along the landward side of Chrystall's Bend stopbank. However there is some lateral spread of floodwaters into Ōtaki Township to the east of the NIMT railway line and to the west of State Highway 1. Peak flood depths across the floodplain are typically in the range of 0.5-1m along the main secondary flow path parallel with the river and 0-0.5m through Ōtaki Township.

Complementary to the flood inundation map in Figure 1-2, Figure 4-3 shows a map of peak flow velocities within the concrete factory basin and across the floodplain. Peak flow velocities are typically in the range of 0.5-1m/s except, downstream of State Highway 1 within the main secondary flow path, there are pockets of higher velocities following old overflow channels.

Figure 4-4 shows peak flood levels across the floodplain along a curved section immediately upstream of the proposed alignment of the expressway embankment. These profiles are for the 0.2% AEP flood and the 0.2% AEP flood adjusted for possible climate change effects. Figure 4-4 also includes a ground level profile along the curved section together with marked locations for key features (e.g. Chrystall's Bend stopbank and Rahui Road). The ground level profile enables peak flood depths across the floodplain to be inferred. The peak flood level profiles generally slope down (i.e. the peak flood depths reduce) with distance from the Chrystall's Bend stopbank.

Note that the peak flood depth and peak flow velocity maps in Figures 1-2 and 4-3 ignore any concurrent flood in the Mangapouri Stream on the northern edge of the floodplain. This approach has been deliberately used so that the proposed situation (where the floodplain is split into two discrete components) is directly comparable with the existing situation and valid difference maps between the two situations showing peak flood depth and velocity differences across the floodplain for a Chrystall's Bend overtopping flow condition can be constructed.

4.3 Effects of Stopbank Breach in Existing Situation

The peak flood depth map in Figure 1-2 and peak flow velocity map in Figure 4-3 for the 0.2% AEP flood adjusted for the possible climate change effects overtopping the Chrystall's Bend stopbank implicitly assume that the stopbank can sustain the level and duration of overtopping without breaching.

Detailed inspection of peak flood levels along the Ōtaki River at the two stopbank overtopping locations identified above determined that the critical location with the highest risk of stopbank breaching (due to the magnitude of the depth of overtopping) in the existing situation was immediately upstream of the NIMT railway embankment. It is difficult to know, if a stopbank breach did occur, how wide the breach might develop to and how long it would take to achieve its full width.

Based on the depth of stopbank overtopping at this location, a 150m wide breach[7] was assumed with an initial average invert level of 15.45m (MSL Wellington datum) coincident with stopbank crest level and a final average invert level of 13.7m, giving an average maximum breach depth below stopbank crest level of 1.75m. Breach erosion was assumed to be initiated at the time of maximum stopbank overtopping while full development was assumed to occur after a period of 1 hour based on typical breach development times for the rapid phase of

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[7] This particular breach width was selected because the depth of overtopping reduced to less than 0.3m from the maximum value of 0.45m over this distance at the critical overtopping location. A stopbank overtopping depth of greater than 0.3m is considered to significantly increase the risk of occurrence of a stopbank breach.

breach erosion in earth-fill embankment dams (Singh and Scarlatos, 1988). The actual breach development time in this context is unlikely to have much influence on the magnitude of the peak breach outflow as the peak flood level in the flood storage basin which drives the breach outflow would not have dropped much over the assumed period of breach development.

Figure 4-5 compares the estimated breach outflow hydrograph for the assumed stopbank breach scenario with the corresponding stopbank overtopping flow hydrograph (no breach scenario) for the same length of stopbank. The breach outflow hydrograph can be seen to have a peak value nearly twice as large as the peak of the stopbank overtopping flow hydrograph. The volume of breach outflow in the stopbank breach scenario is partially constrained by the pre-existing depth of floodwaters on the downstream side of the stopbank from overtopping flows (i.e. the breach outflow is partially drowned).

Figures 4-6 and 4-7 show peak flood depth and peak flow velocity maps respectively for an assumed stopbank breach of 150m width at the critical location comparable to Figures 1-2 and 4-3 for the no stopbank breach scenario.

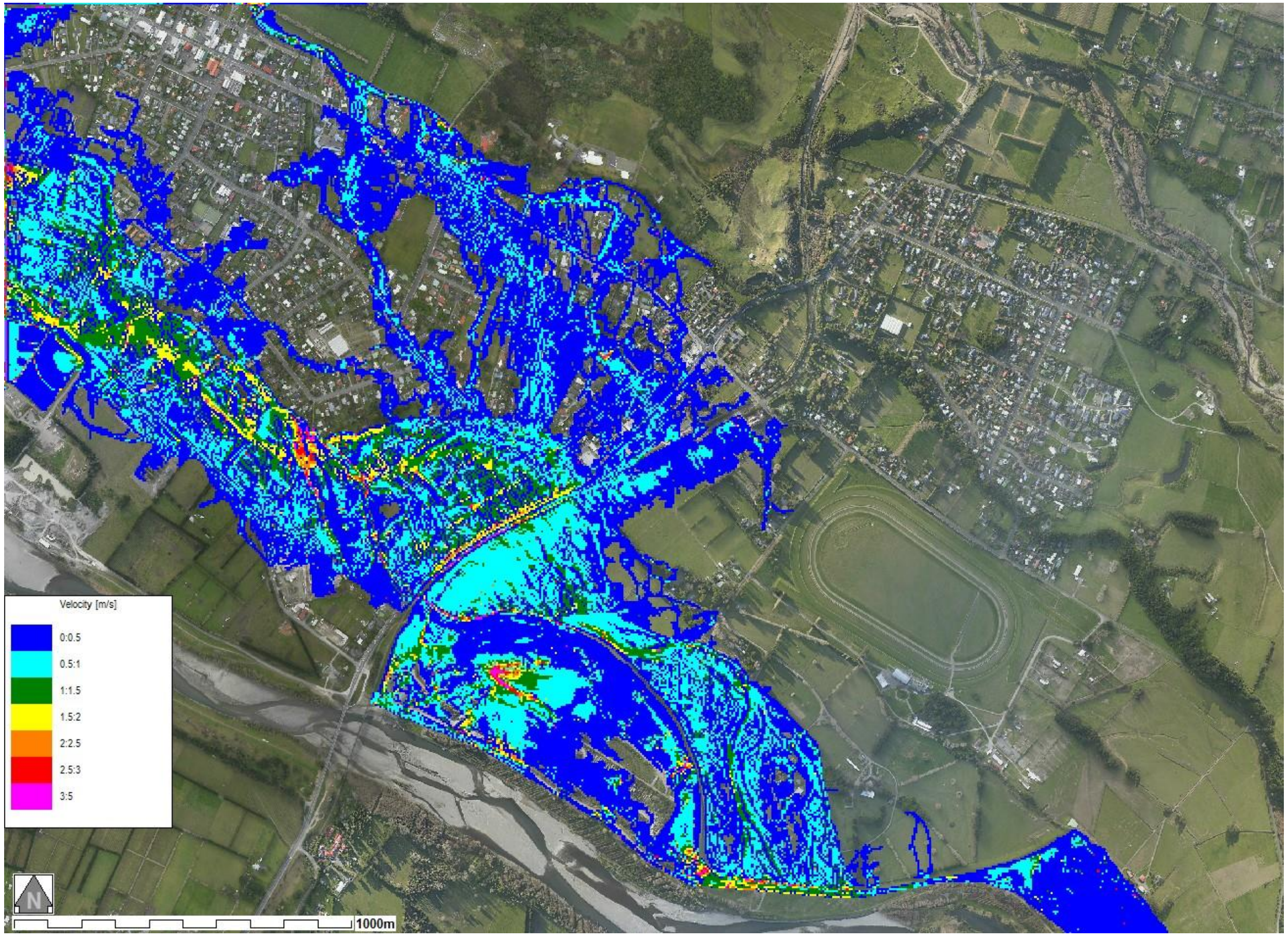

Figure 4-3 Peak flow velocities across Ōtaki River floodplain for existing situation resulting from stopbank overtopping in 0.2% AEP flood adjusted for possible effects of future climate change (no concurrent flood in Mangapouri Stream)

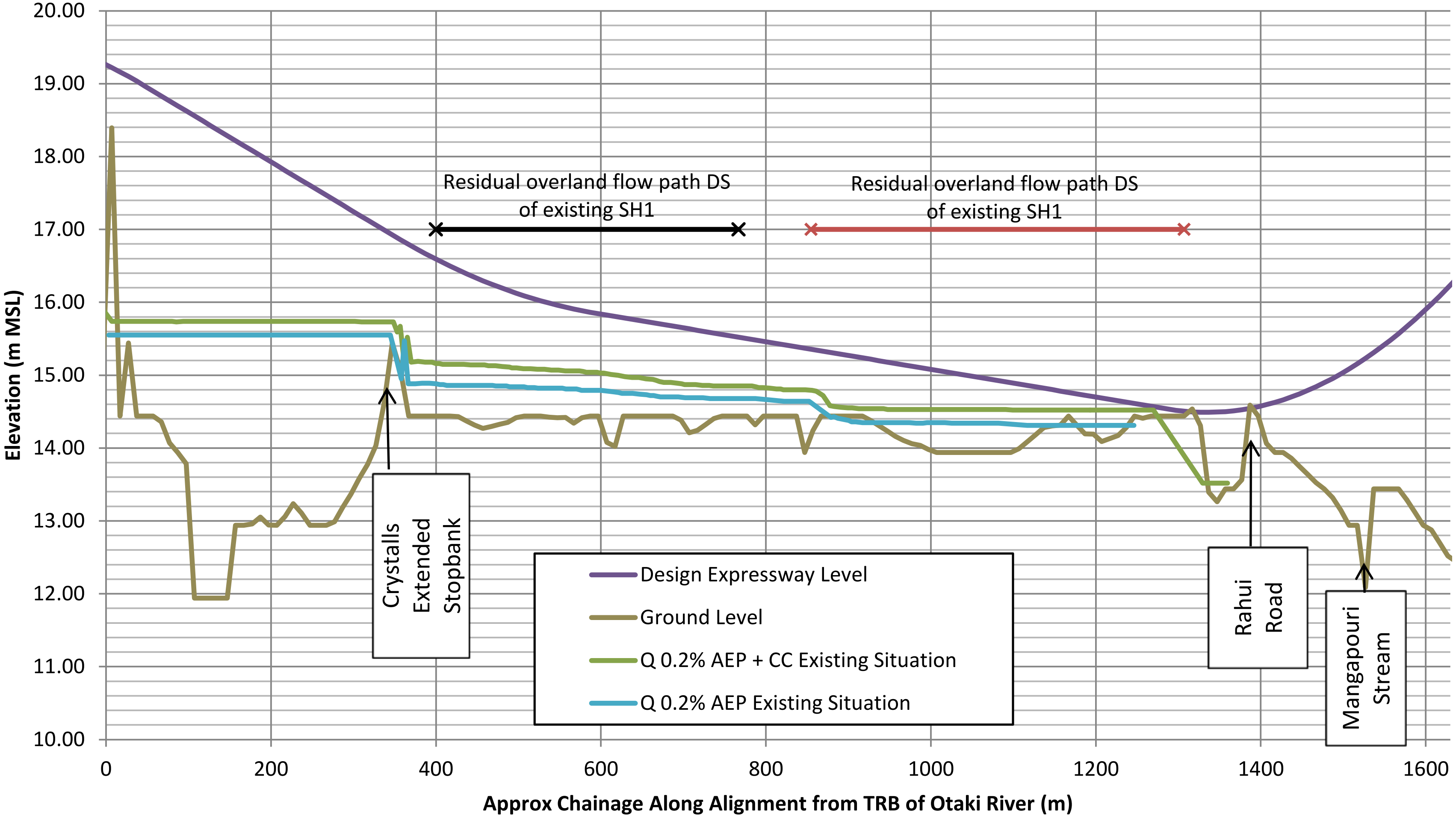

Figure 4-4 Predicted flood levels across the Ōtaki River floodplain along a curved line immediately upstream of proposed expressway for floods overtopping Chrystall's Bend stopbank in existing situation (i.e. no expressway embankment present)

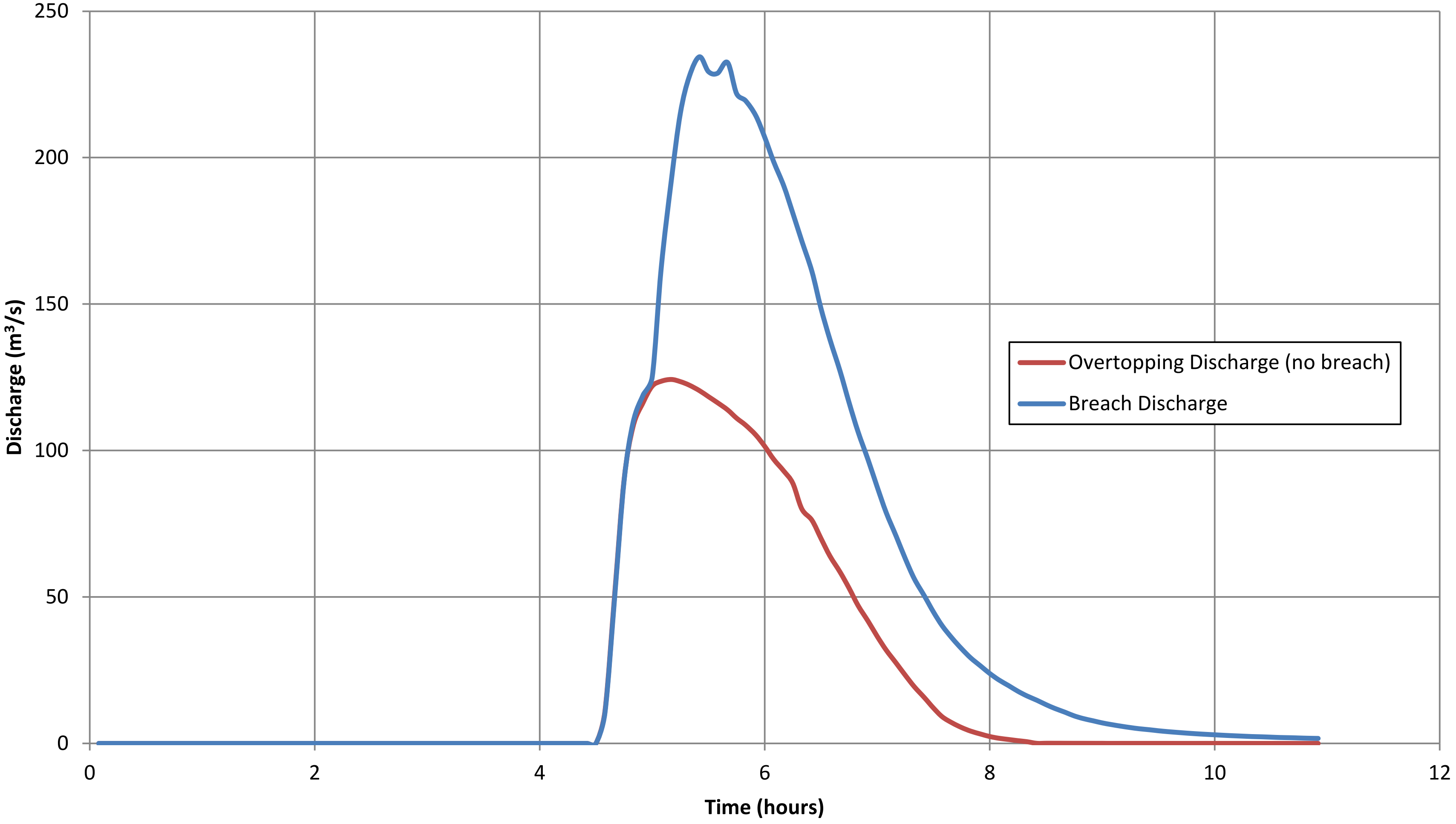

Figure 4-5 Comparison of estimated breach outflow hydrograph for the assumed stopbank breach scenario with corresponding stopbank overtopping flow hydrograph (no breach scenario) for the same length of stopbank (0.2% AEP flood adjusted for the possible climate change effects to 2090 in Ōtaki River)

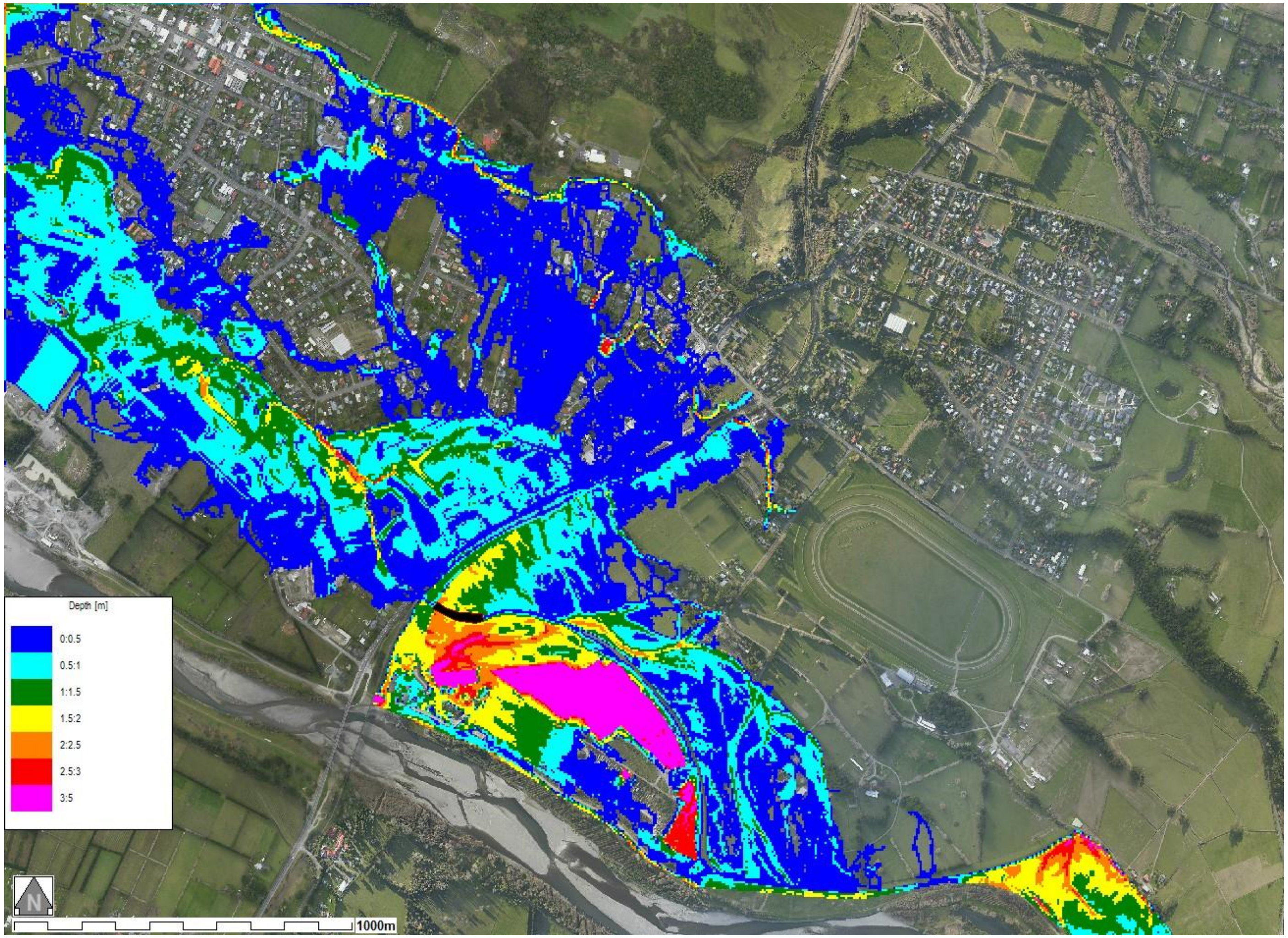

Figure 4-6 Peak flood depths across Ōtaki River floodplain for existing situation resulting from stopbank overtopping and breaching in 0.2% AEP flood adjusted for possible effects of future climate change (no concurrent flood in Mangapouri Stream)

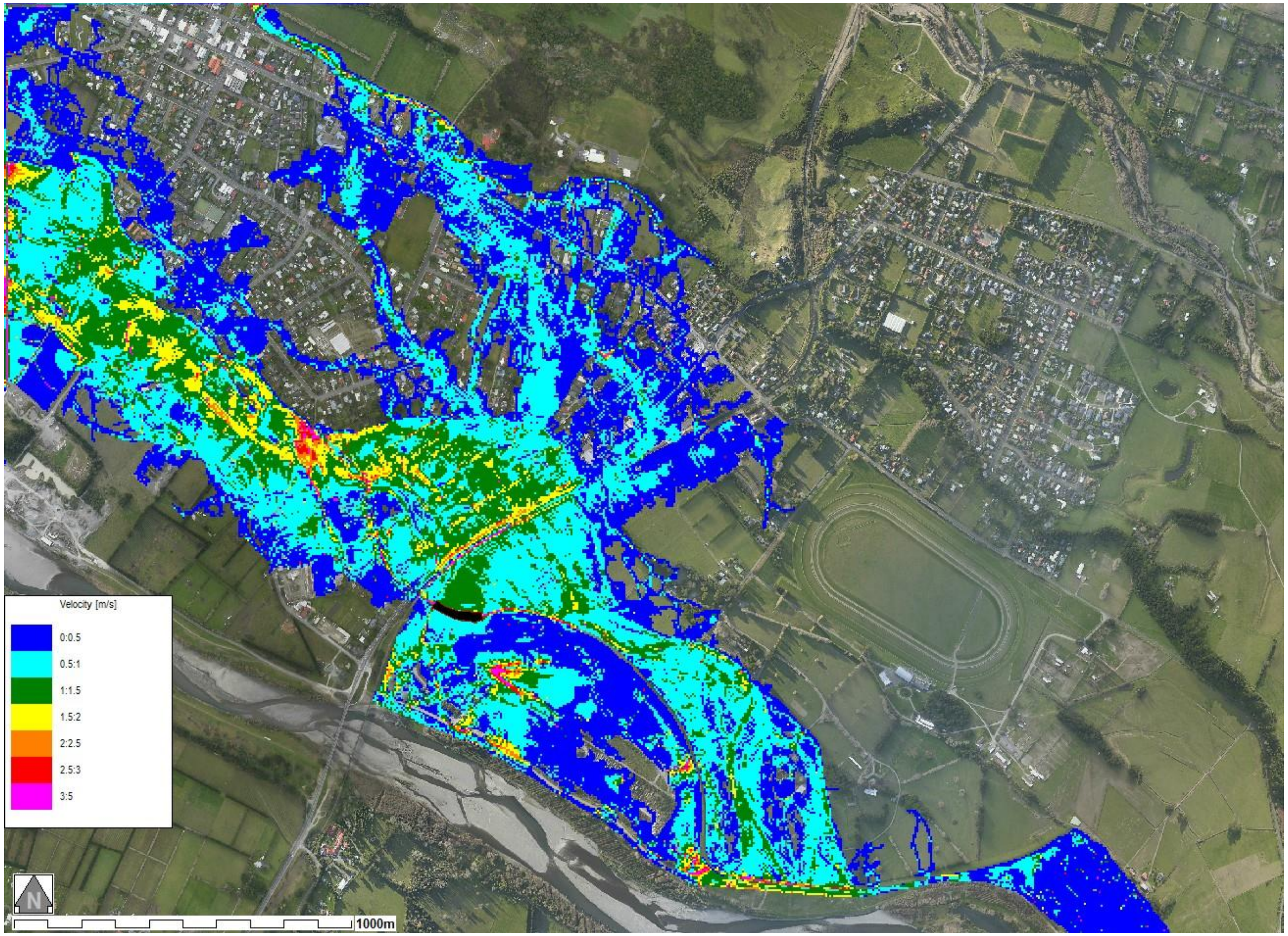

Figure 4-7 Peak flow velocities across Ōtaki River floodplain for existing situation resulting from stopbank overtopping and breaching in 0.2% AEP flood adjusted for possible effects of future climate change (no concurrent flood in Mangapouri Stream)

Figure 4-6 shows that the extent of flood inundation across the floodplain for this stopbank breach scenario is very similar to that in the comparable no breach scenario (Figure 1-2). The main secondary flow path on the landward side of the stopbank system remains the dominant flow path. The lateral spread of floodwaters through Ōtaki Township follows the same flow paths as in the no stopbank breach situation with only marginally greater flow depths.

Peak flood depths are typically in the range of 0.5-1.0m across the floodplain with depths up to 2m immediately in front of the NIMT railway embankment nearest the Chrystall's Bend stopbank. Peak flood depths through Ōtaki Township are predominantly in the range of 0-0.5m.

Peak flow velocities across the floodplain down to State Highway 1 and through Ōtaki Township are predominantly in the 0.5-1m/s range as in the no stopbank breach scenario in Figure 4-3. Peak flow velocities downstream of State Highway 1 along the old overflow channels evident are more accentuated than in the no stopbank breach scenario with values as high as 2-2.5m/s in small pockets. Peak flow velocities are also higher through Ōtaki Township with values as high as 0.5-1m/s along old overflow channels.

5. Hydraulic Performance in Proposed Expressway Situation

5.1 Proposed Mitigation Options

As noted in Section 1.3, the following mitigation measures were trialled to mitigate the effects of the proposed expressway embankment on stopbank overtopping flows flowing across the Ōtaki River floodplain:

- a secondary flood containment bund projecting upstream of the expressway embankment roughly parallel with the main river channel;
- a dry culvert through the expressway embankment immediately to the north of the Chrystall's Bend stopbank; and
- reshaping the vertical alignment of the expressway embankment between the Chrystall's Bend stopbank and the secondary flood containment bund to form a preferential weir overflow path across the roadway for stopbank overtopping flows.

The location of these mitigation measures is illustrated in Figure 5-1.

5.2 Hydraulic Behaviour in Main River Channel

As with Figure 4-1 for the existing situation, Figure 5-2 shows predicted peak flood level along the main channel of the Ōtaki River in the proposed expressway situation for the following floods:

- 1% AEP flood for current climate conditions (1,810m^3/s)
- 0.2% AEP flood for current climate conditions (2,130m^3/s)
- 0.2% AEP flood adjusted for the effects of possible future climate change to 2090 (2,490m^3/s)

It should be noted that these flood level profiles already account for the effect of pier-induced head losses on the existing NIMT railway and SH1 road bridges.

Comparison of Figures 5-2 and 4-1 indicates that the proposed twin parallel expressway bridges crossing the Ōtaki River have no real effect on the backwater profiles along the main river channel. The bridge abutments have been set back from the edge of the active river channel so that the total span length matches that of the existing NIMT railway bridge and therefore does not induce any backwater effect upstream. The lenticular-shaped piers supporting the superstructure of each bridge however are widely spaced to minimise the total number of them (30m spacing). The pier head losses with such a wide spacing are minimal (~ 0.01-0.02m per bridge). However these head losses would increase if the bridge piers snagged flood-transported woody debris (the downstream NIMT rail and SH1 road bridges with their lower soffit levels pose more of a risk with respect to this particular hazard).

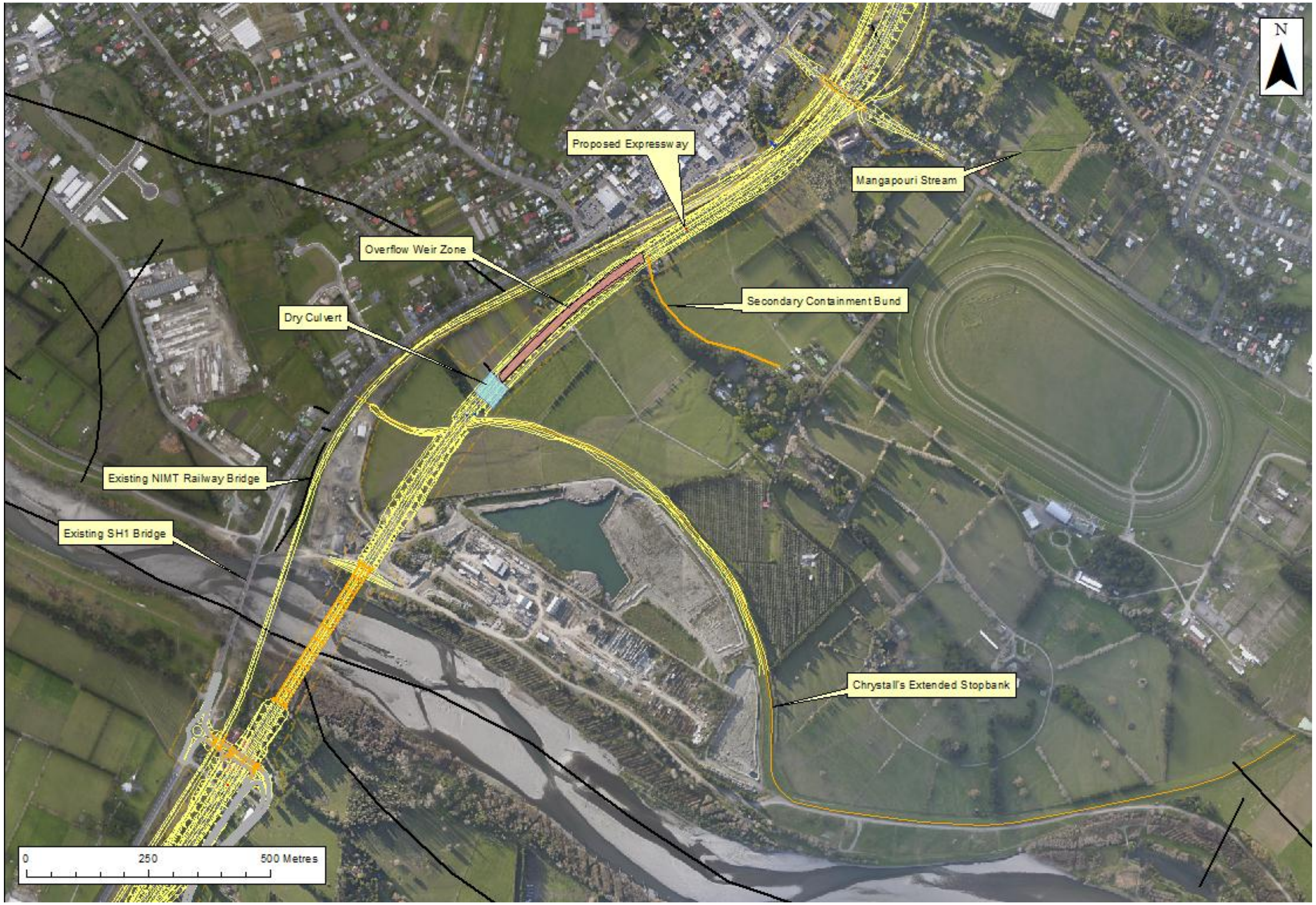

Figure 5-1 Proposed treatment measures to mitigate effects of PP2O Expressway embankment on stopbank overtopping flows flowing across Ōtaki River floodplain

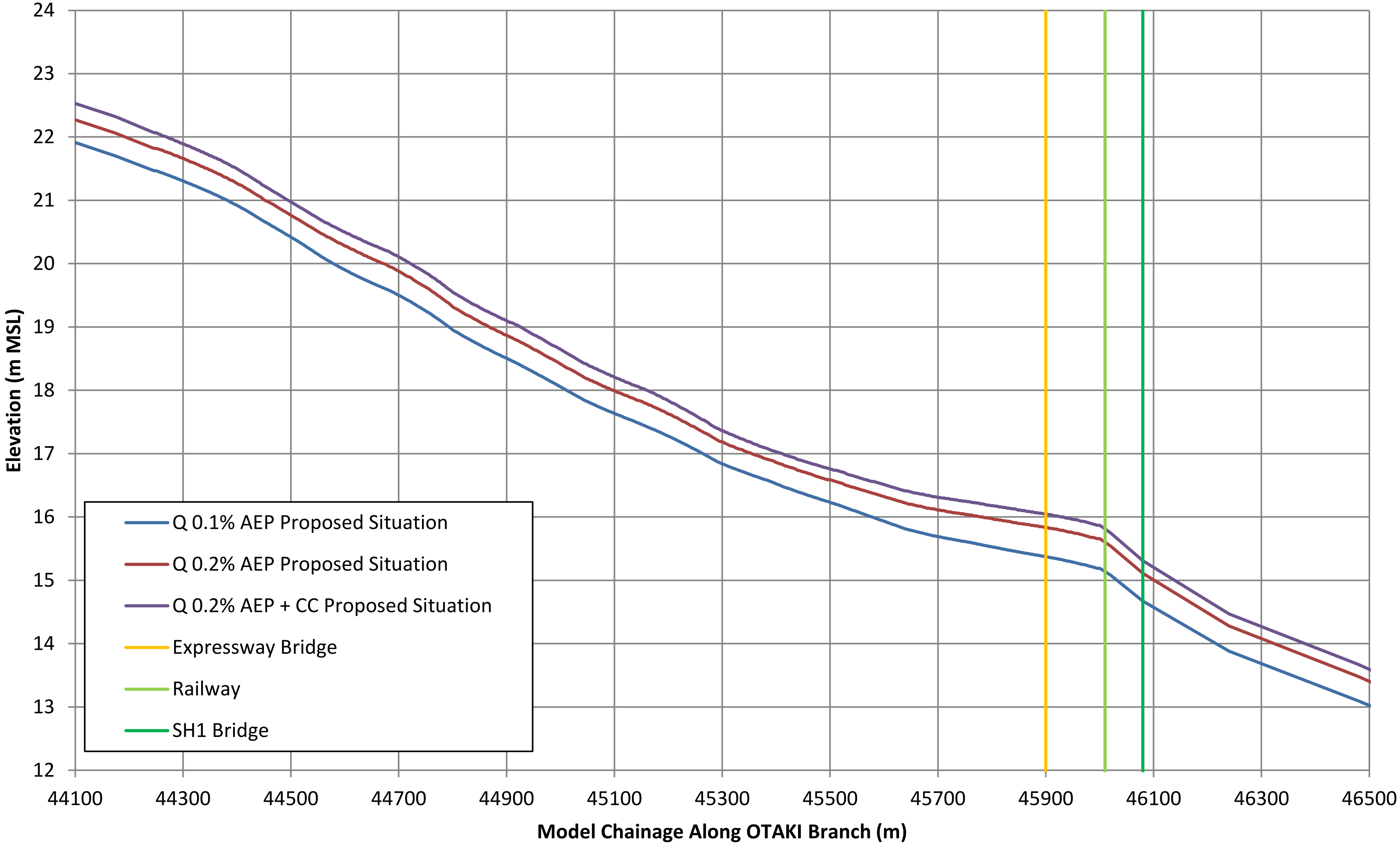

Figure 5-2 Predicted peak flood levels along Ōtaki River for range of floods in proposed situation

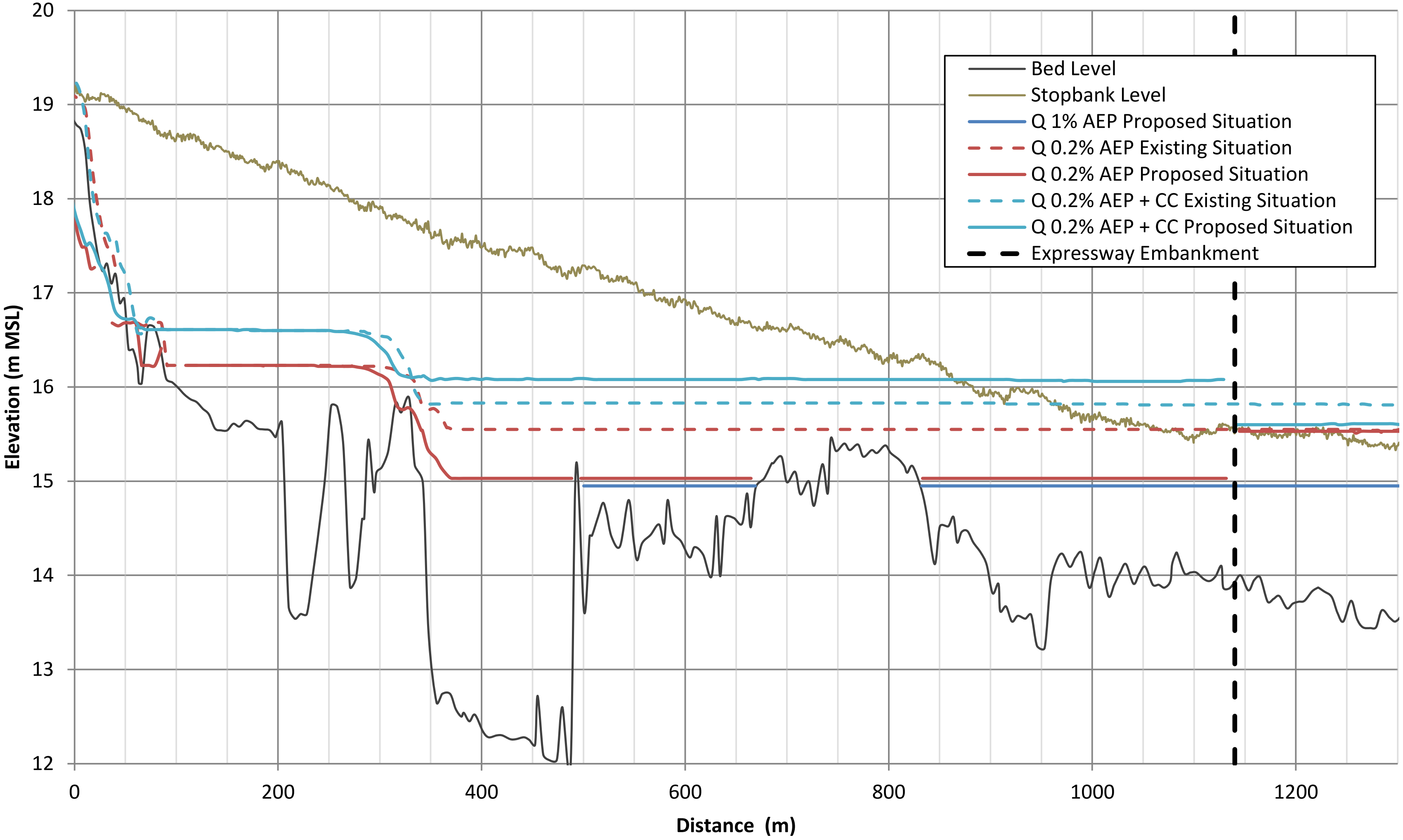

Figure 5-3 Predicted peak flood levels along Chrystall's Bend stopbank past concrete factory for range of floods in proposed situation (left hand axis coincides with where stopbank veers way from river, right hand axis corresponds to location of NIMT railway embankment)

The piers on the two parallel Expressway bridges will be aligned so that each pier on the upstream bridge will have a partial sheltering effect on the corresponding pier on the downstream bridge. However it would be conservative to assume that the individual head losses induced by the pier shape on each bridge are cumulative. However any additional pier head losses induced by snagged woody debris would only be likely to affect the piers on the upstream bridge. The piers on the downstream bridge would be unlikely to be affected by snagged woody debris due to the sheltering effect of the piers on the upstream bridge. The design freeboard standard for a bridge is intended to provide some allowance for debris-induced pier head losses.

Irrespective of the small magnitude of the bridge pier head losses in this context, the backwater effect of any pier head losses would rapidly diminish with distance upstream due to the steepness of the bed of the Ōtaki River. It can therefore be concluded that the piers on the twin Expressway bridges would not increase upstream flood levels (except in the immediate vicinity of the bridge) and thereby reduce the flood standard of the Chrystall's Bend stopbank.

The northern approach embankment to the twin bridge crossings of the Ōtaki River bisects the off-channel storage basin occupied by the concrete factory. The effect of this is to partially dam the floodwaters in the basin such that a water level differential is created across the expressway embankment as seen in Figure 5-3. Water levels in the off-channel storage basin remain approximately horizontal on either side of the expressway embankment. However the magnitude of the water level differential across the embankment increases with the magnitude of the flood.

Figure 5-3 also includes the crest level of the part of Chrystall's Bend stopbank around the perimeter of the off-channel storage basin. Figure 5-3 indicates that:

- the stopbank would still contain the 1% AEP flood with a freeboard of about 0.6m;
- the stopbank would just start to be overtopped by a 0.2% AEP flood over a distance of about 100m upstream of the expressway embankment and between the expressway embankment and the NIMT railway embankment;
- due to the way the concrete factory flood storage basin fills from the main river channel, the expressway embankment acts as a partial dam and causes flood levels upstream of the embankment in a 0.2% AEP flood to be about 0.4m lower than those downstream between the expressway embankment and the NIMT railway embankment;
- the stopbank would be overtopped by up to 0.45m in a 0.2% AEP flood adjusted for possible climate change effects over a distance of about 200m upstream of the expressway embankment; and
- the stopbank would be overtopped by up to 0.2m in a 0.2% AEP flood adjusted for possible climate change effects between the expressway embankment and the NIMT railway embankment.

Compared to the existing situation, the effects of the proposed PP2O Expressway crossing of the Ōtaki River are only minor. The depth of overtopping of the existing Chrystall's Bend stopbank upstream of the approach embankment to the bridge crossing is slightly increased only for the 0.2% AEP flood adjusted for possible climate change effects to 2090.

5.3 Hydraulic Behaviour across Floodplain

Figure 5-4 shows peak flood level profiles for the proposed situation along a curved section across the floodplain immediately upstream of the alignment of the expressway embankment. These profiles are for the same floods as in Figure 4-4 for the existing situation – a 0.2% AEP flood and a 0.2% AEP flood adjusted for possible climate change effects to 2090.

The peak flood level profiles shown in Figure 5-4 are based on the optimised geometry for the different flood mitigation measures trialled:

- a 350m long secondary flood containment bund in the location shown in Figure 5.1;
- a 40m wide dry culvert through the expressway embankment located approximately as shown in Figure 5-1; and
- a road overflow weir section along the expressway embankment measuring approximately 300m long with a minimum crest level of 15.3m (MSL Wellington datum) and rising up to about 15.8m (MSL Wellington datum) to the north of the line of the secondary flood containment bund (as seen in Figure 5-4) and then falling again beyond this high point.

Figure 5-4 shows that with the optimised overflow weir geometry, stopbank overtopping flows arising from a 0.2% AEP flood (approximately equal to a 1% AEP flood adjusted for possible climate change effects to 2090) would be able to be passed through the expressway embankment without the embankment being overtopped. However stopbank overtopping flows arising from a 0.2% AEP adjusted for possible climate change effects would overtop the expressway embankment by about 0.3m.

The level of service for the expressway embankment would therefore be at least the 0.2% AEP flood with a design freeboard value in the order of 0.7m (the actual freeboard may in fact be less than this value once the vertical profile of the new expressway is adjusted to accommodate the overflow weir section).

Note that the modified vertical profile for the expressway shown in Figure 5-11 is an interim modification and has yet to be formally incorporated in the final design concept. It has been modelled geometrically on the basis of the results of the computational hydraulic model simulations to confirm that it is in fact feasible to modify the vertical alignment in this manner. It may be possible to refine the alignment further by shifting the whole of the overflow weir section southwards towards the Ōtaki River crossing so that high point of the weir section at the north end coincides with the line of the secondary containment bund.

Figure 5-5 shows a map of peak flood inundation depths across the floodplain for the proposed expressway situation incorporating the above mitigation measures for stopbank overtopping resulting from a 0.2% AEP flood adjusted for possible climate change effects.

Figure 5-6 shows a peak flood depth difference map between the proposed (Figure 5-5) and existing situations (Figure 1-2) across Ōtaki River floodplain resulting from stopbank overtopping by a 0.2% AEP flood adjusted for possible future climate change effects. This indicates that peak flood levels through Ōtaki Township are reduced compared to those for the existing situation. The optimised mitigation measures outlined above therefore represent an improvement on the current situation.

Figure 5-7 shows a map of peak flow velocities across the floodplain for stopbank overtopping flows in a 0.2% AEP flood adjusted for possible climate change effects. Figure 5-8 shows a peak flow velocity difference map comparing the peak flow velocity patterns and magnitudes in Figures 5-7 and 4-3 for the proposed and existing situations respectively.

As with Figure 5-6, Figure 5-8 shows that peak flow velocities from stopbank overtopping flows spreading laterally through Ōtaki Township are slightly lower than in the existing situation for this flood case. This is balanced by slightly higher flow velocities across the uninhabited part of the floodplain upstream of the expressway embankment.

In general the optimised mitigation measures as outlined above with the proposed expressway in place represent an improvement on the current situation, particularly in respect of residential population areas.

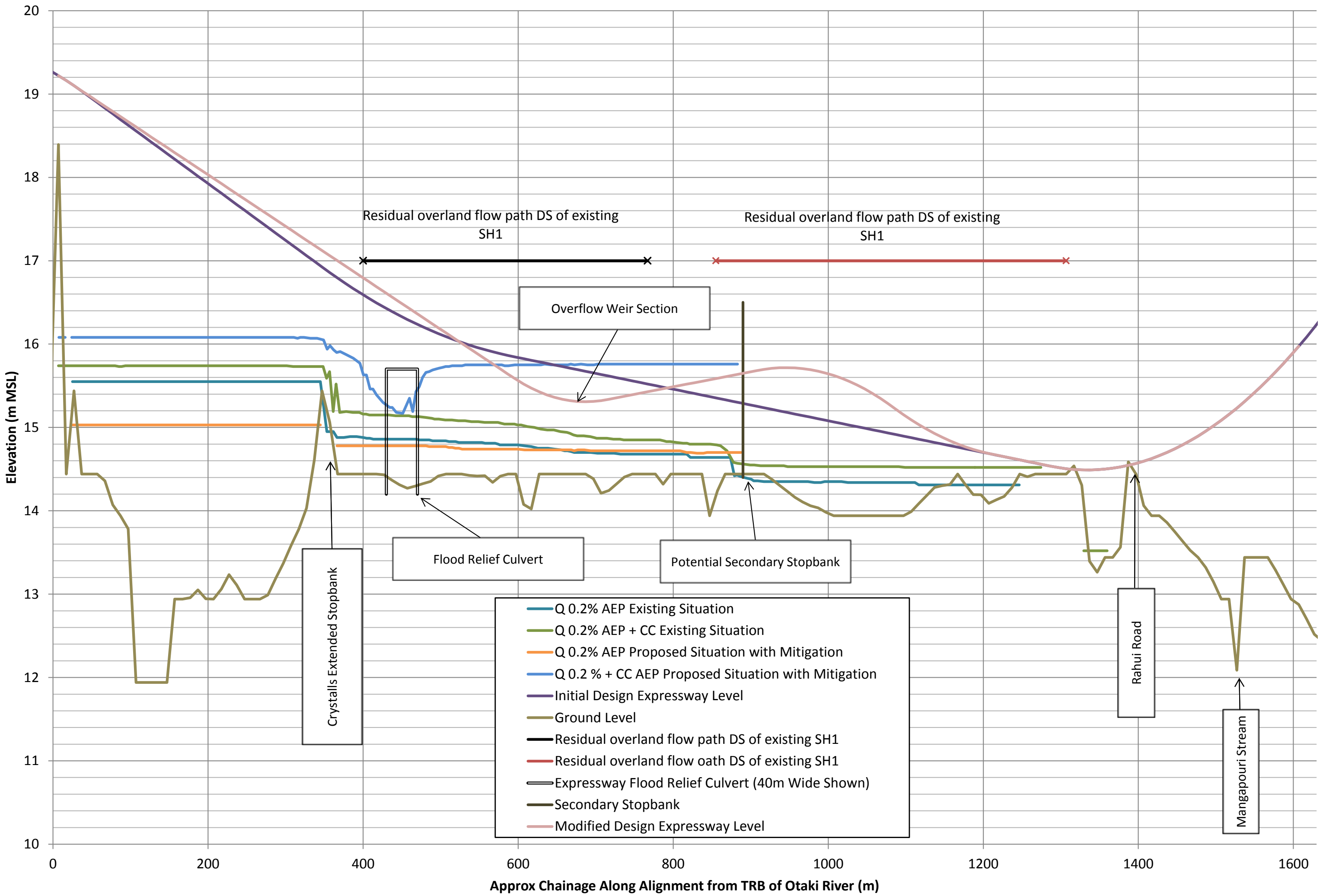

Figure 5-4 Predicted flood levels across the Ōtaki River floodplain along a curved line immediately upstream of expressway embankment for floods overtopping Chrystall's Bend stopbank in proposed situation

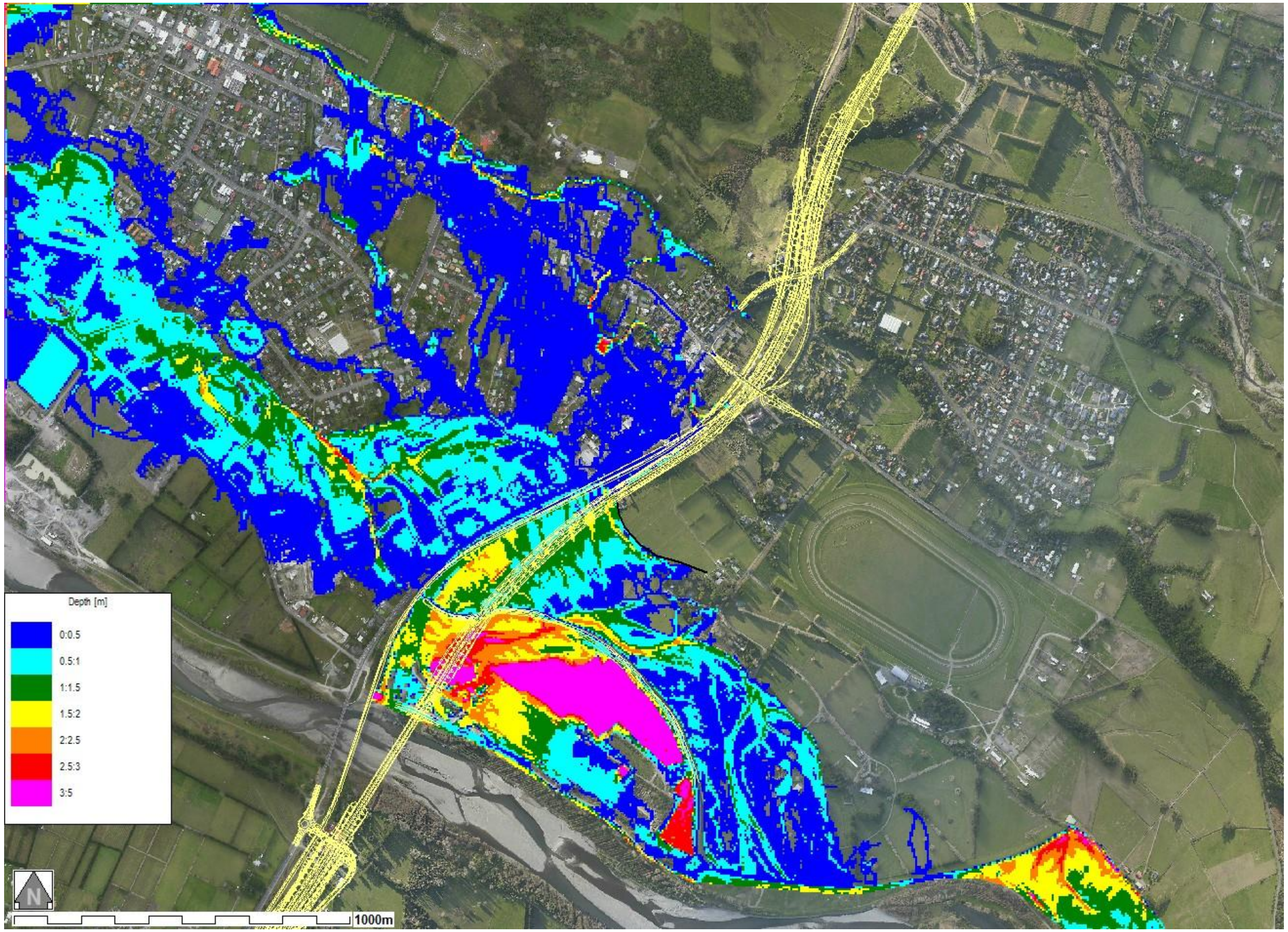

Figure 5-5 Peak flood inundation depths for proposed situation on Ōtaki River floodplain resulting from stopbank overtopping in 0.2% AEP flood adjusted for possible effects of future climate change (no concurrent flood in Mangapouri Stream)

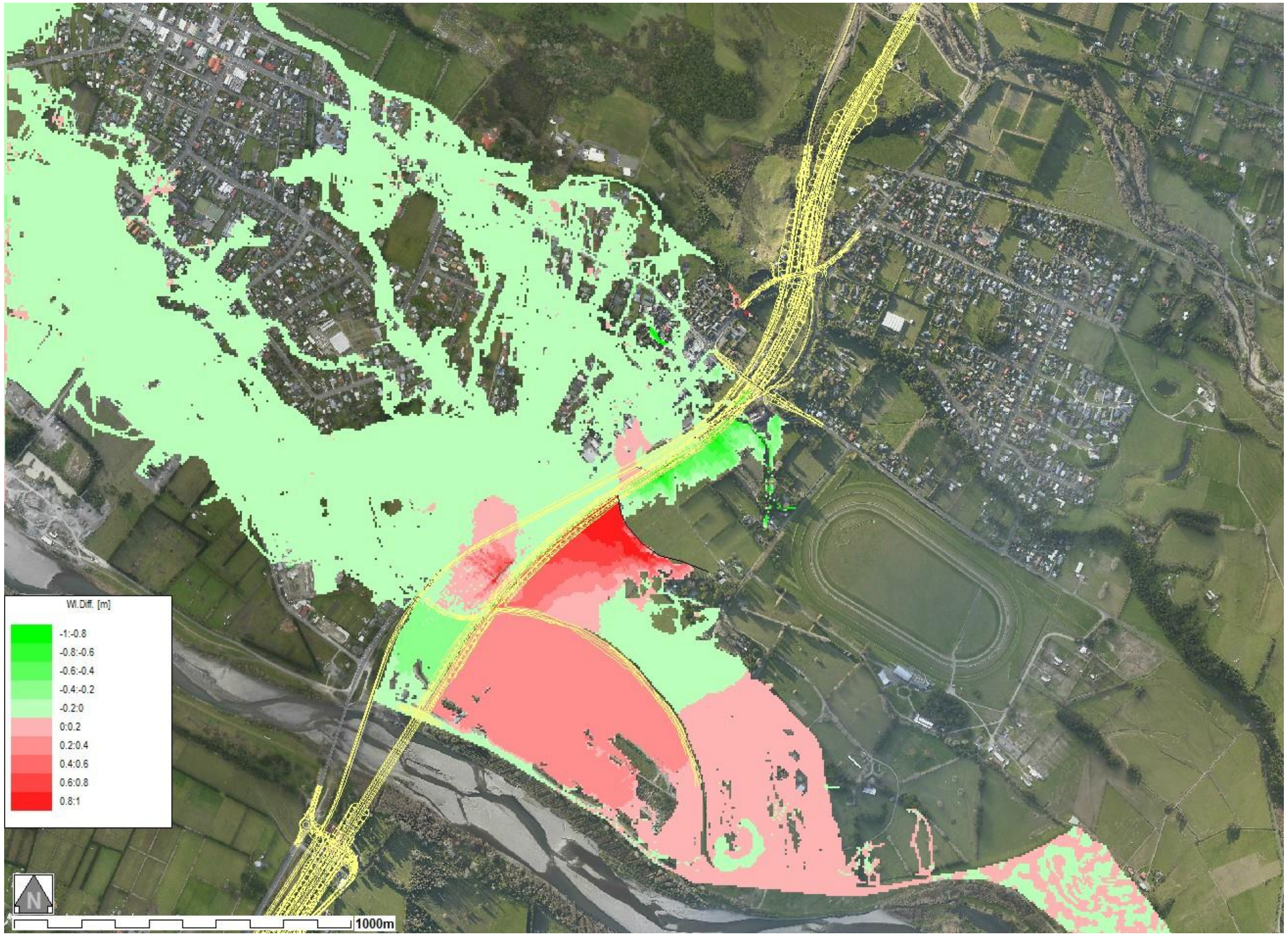

Figure 5-6 Peak flood depth differences between proposed and existing situations on Ōtaki River floodplain resulting from stopbank overtopping in 0.2% AEP flood adjusted for possible effects of future climate change - no concurrent flood in Mangapouri Stream (pink shading indicates areas of increased flow depths, green shading indicates areas of decreased flow depths)

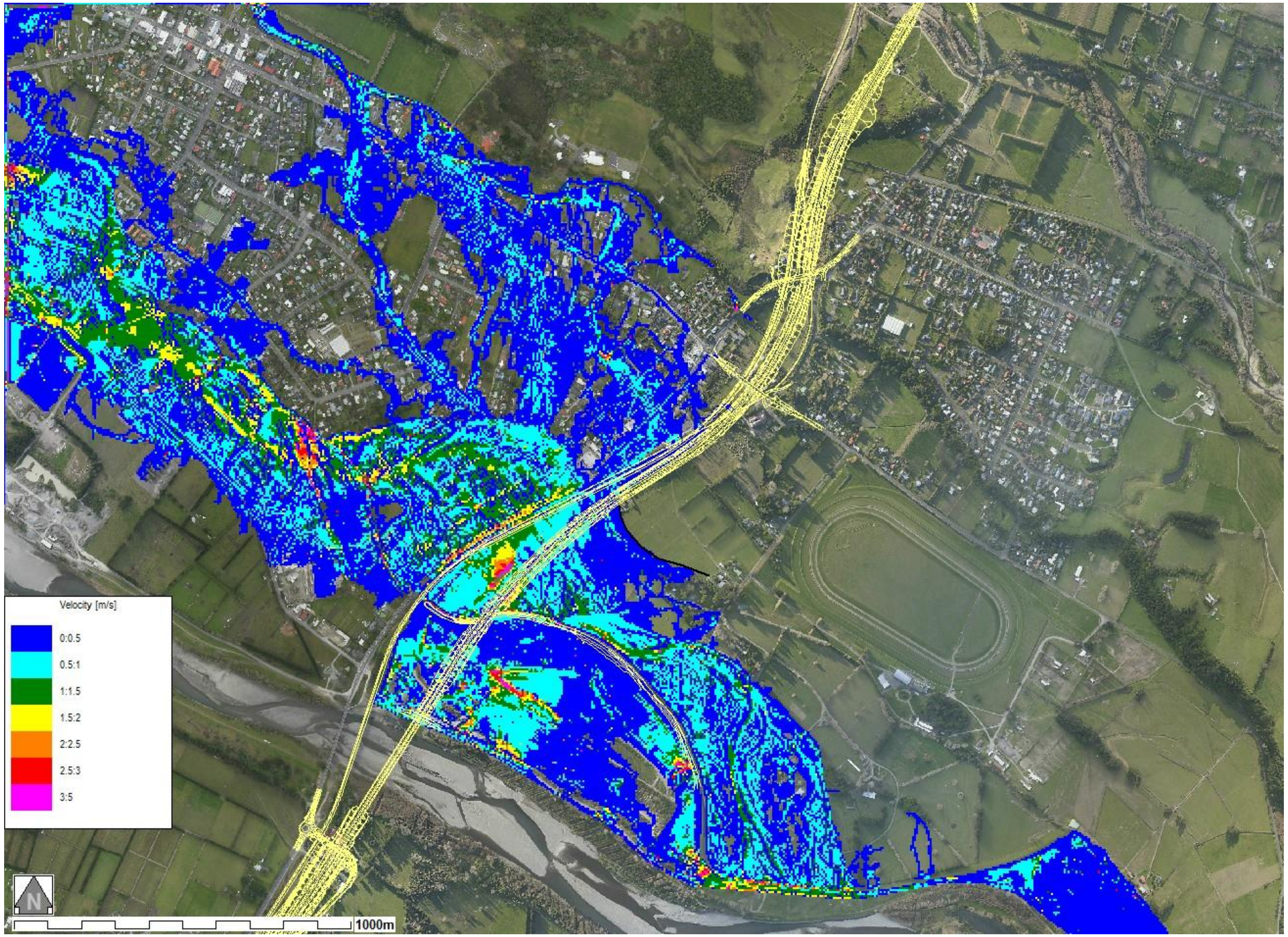

Figure 5-7 Peak flow velocities for proposed situation on Ōtaki River floodplain resulting from stopbank overtopping in 0.2% AEP flood adjusted for possible effects of future climate change (no concurrent flood in Mangapouri Stream)

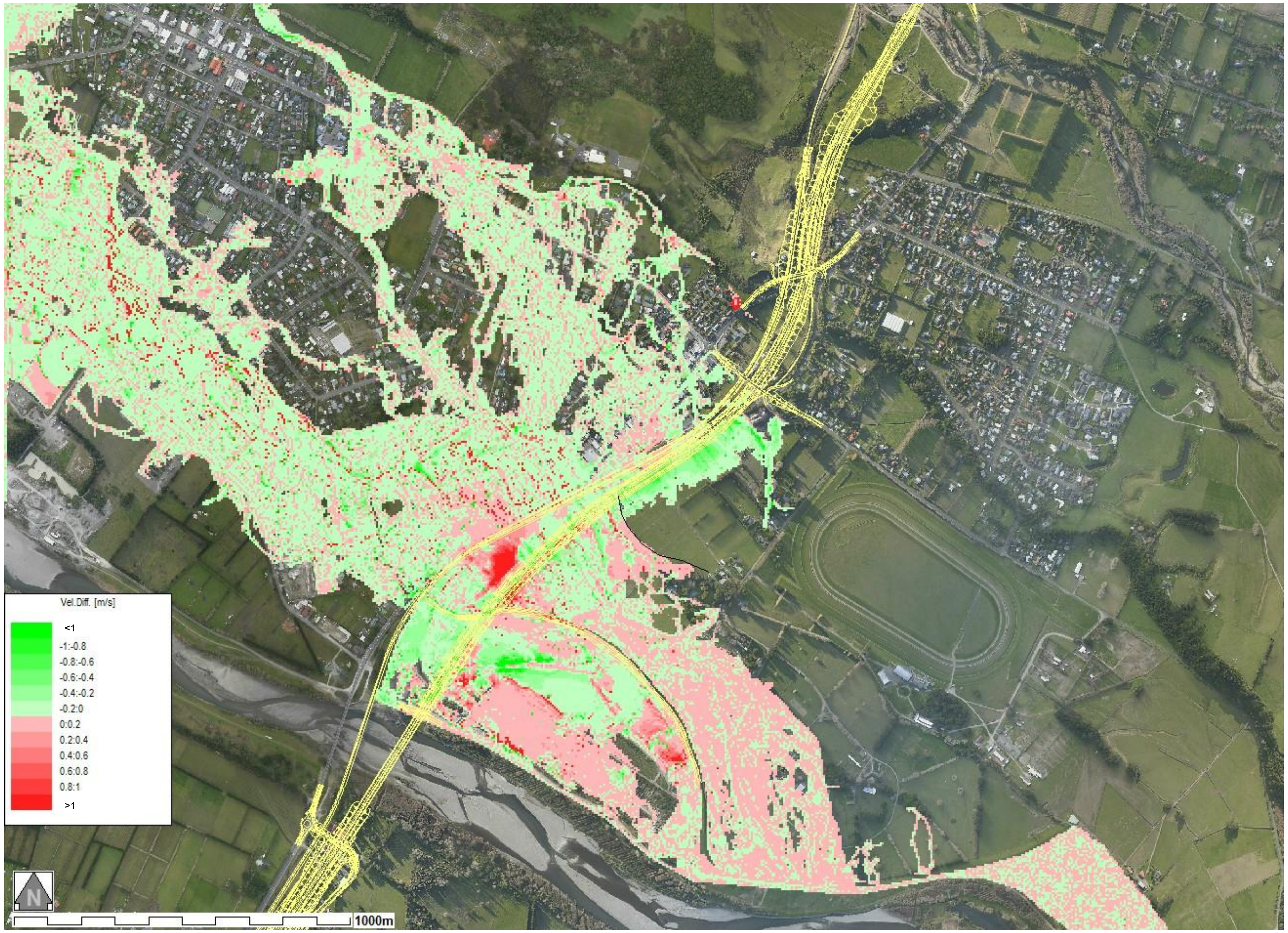

Figure 5-8 Peak flow velocity differences between proposed and existing situations on Ōtaki River floodplain resulting from stopbank overtopping in 0.2% AEP flood adjusted for possible effects of future climate change - no concurrent flood in Mangapouri Stream (pink shading indicates areas of increased flow velocities, green shading indicates areas of decreased flow velocities)

5.4 Effects of Stopbank Breach in Proposed Situation

Detailed inspection of peak flood levels along the Ōtaki River at the various stopbank overtopping locations in the proposed situation determined that the critical location with the highest risk of stopbank breaching (due to the magnitude of the depth of overtopping) would be immediately upstream of the proposed expressway embankment. Again it is difficult to know, if a stopbank breach did occur, how wide the breach might develop to and how long it would take to achieve its full width.

Based on the depth of stopbank overtopping at this location, a 150m wide breach[8] was assumed with an initial average invert level of 15.6m (MSL Wellington datum) coincident with stopbank crest level and a final average invert level of 14.7m, giving an average maximum breach depth below stopbank crest level of only 0.9m. The assumed final average breach invert level is influenced by natural ground levels on the landward side of the stopbank which are significantly higher than those at the assumed stopbank breach location in the existing situation (immediately upstream of the NIMT railway embankment). This is advantageous in the proposed situation as it means that the assumed breach would not erode as deep as in the existing situation and breach outflow volumes would be lower.

Again breach erosion was assumed to be initiated at the time of maximum stopbank overtopping while full development was assumed to occur after a period of 1 hour based on typical breach development times for the rapid phase of breach erosion in earth-fill embankment dams (Singh and Scarlatos, 1988). The actual breach development time in this context may not have much influence on the magnitude of the peak breach outflow as the peak flood level in the flood storage basin which drives the breach outflow would not have dropped much over the assumed period of breach development.

Figure 5-9 shows a peak flood depth map across the floodplain for an assumed 150m wide stopbank breach at the critical location in the proposed expressway situation comparable to the map in Figure 4-6 for the existing situation. Figure 5-10 shows a peak flood depth difference map comparing the flood inundation patterns and depths for the proposed and existing situations. Negative differences indicate lower peak depths in the proposed situation while positive differences indicate higher peak depths.

As with Figure 5-6 comparing the proposed and existing situations for the no stopbank breach scenario, Figure 5-10 shows reduced flood levels across the floodplain and through Ōtaki Township downstream of the proposed expressway, except for a localised area of increased flow depths around the dry culvert outlet. The area to the north of the secondary flood containment bund upstream of the expressway is no longer inundated so shows up as an area of reduced peak flow depths in the proposed situation. The main area of increased peak flow depths across the floodplain is in the storage area formed by the secondary flood containment bund upstream of the expressway embankment.

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[8] This particular breach width was selected because the depth of overtopping reduced to less than 0.3m from the maximum value of 0.45m over this width at the critical overtopping location.

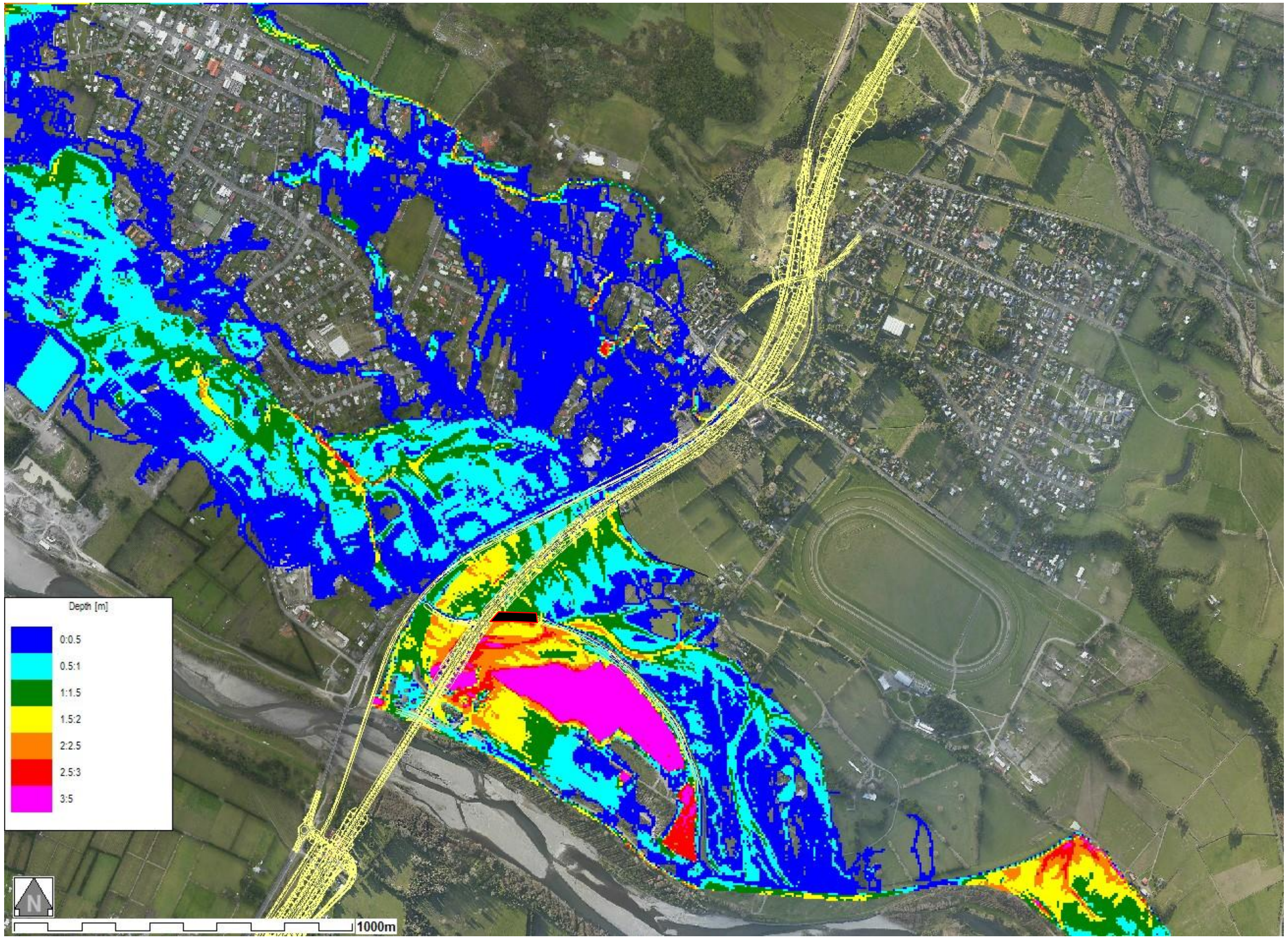

Figure 5-9 Peak flood depths across Ōtaki River floodplain for proposed situation resulting from stopbank overtopping and breaching in 0.2% AEP flood adjusted for possible effects of future climate change (no concurrent flood in Mangapouri Stream)

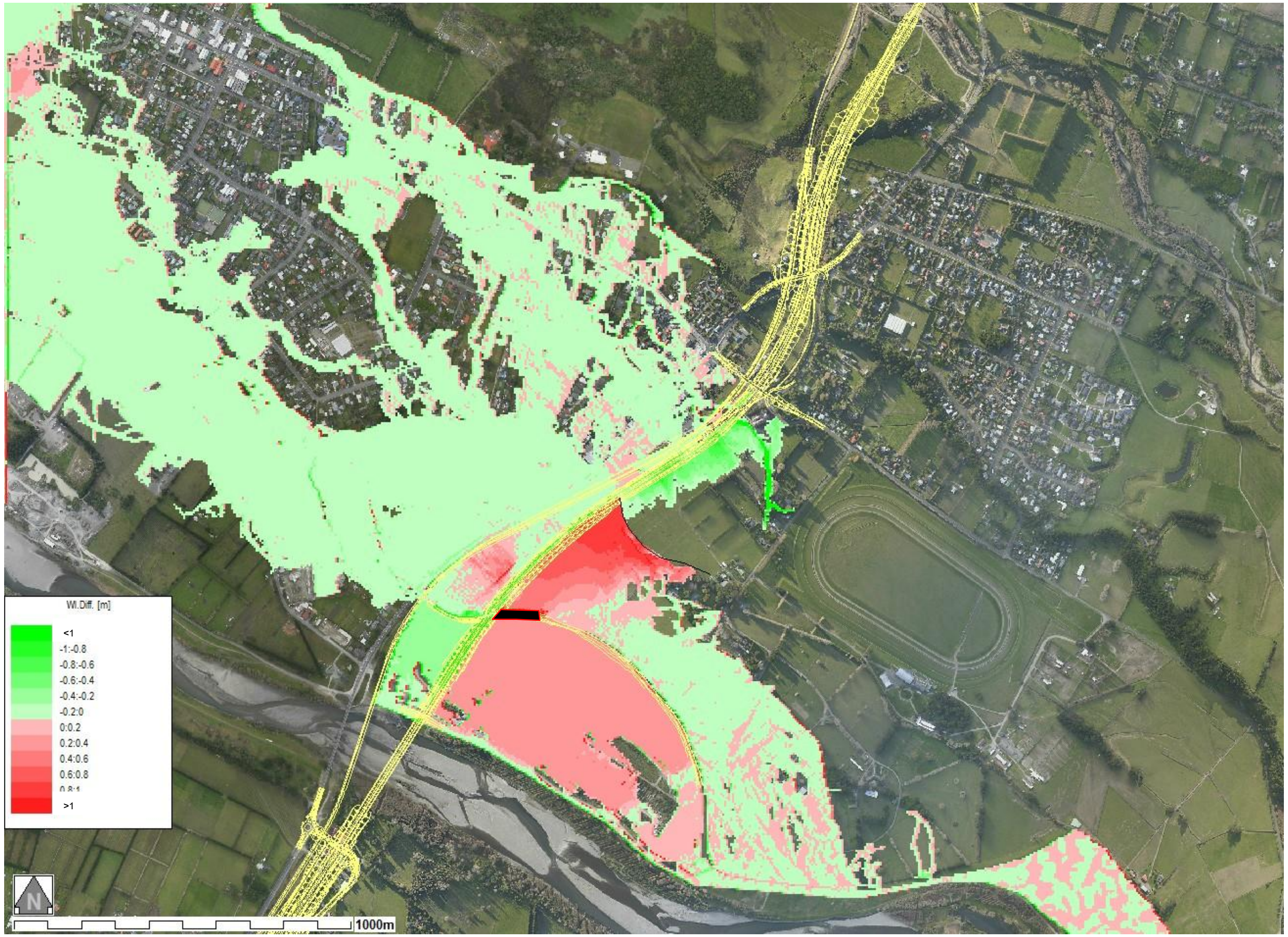

Figure 5-10 Peak flood depth differences between proposed and existing situations on Ōtaki River floodplain resulting from stopbank overtopping and breaching in 0.2% AEP flood adjusted for possible effects of future climate change - no concurrent flood in Mangapouri Stream (pink shading indicates areas of increased flow depths, green shading indicates areas of decreased flow depths)

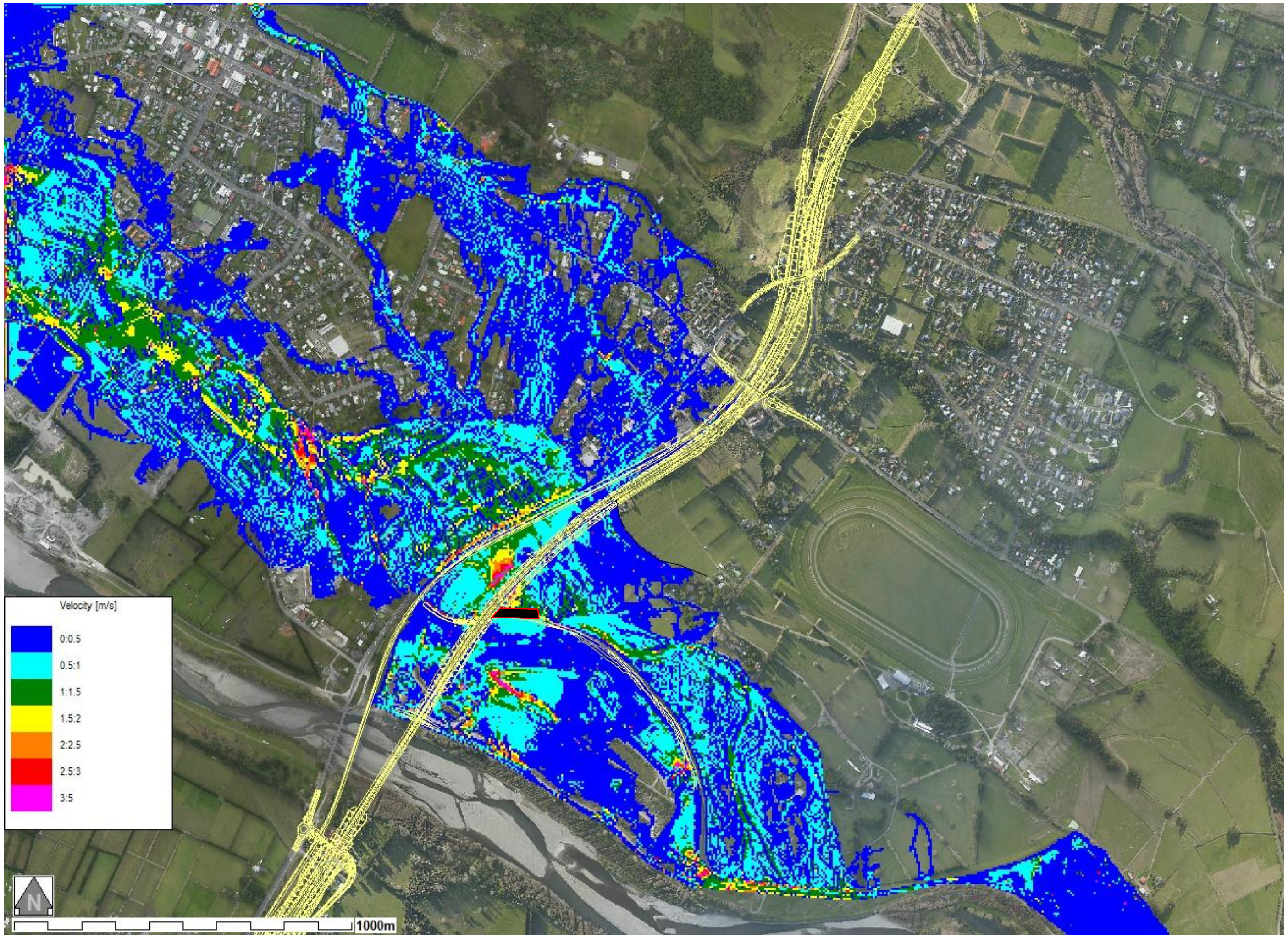

Figure 5-11 Peak flow velocities across Ōtaki River floodplain for proposed situation resulting from stopbank overtopping and breaching in 0.2% AEP flood adjusted for possible effects of future climate change (no concurrent flood in Mangapouri Stream)

Figure 5-12 Peak flow velocity differences between proposed and existing situations on Ōtaki River floodplain resulting from stopbank overtopping and breaching in 0.2% AEP flood adjusted for possible effects of future climate change - no concurrent flood in Mangapouri Stream (pink shading indicates areas of increased flow velocities, green shading indicates areas of decreased flow velocities)

Figure 5-11 shows a peak flow velocity map across the floodplain for an assumed 150m wide stopbank breach at the critical location in the proposed expressway situation comparable to the map in Figure 4-7 for the existing situation. Figure 5-12 shows a peak flow velocity difference map comparing the flow velocity patterns and magnitudes for the proposed and existing situations. Negative differences indicate lower peak velocities in the proposed situation while positive differences indicate higher peak velocities.

Figure 5-12 shows reduced peak flow velocities across most of the floodplain upstream and downstream of the expressway embankment for the proposed situation.

The reductions in peak flow depths and flow velocities across the floodplain in the proposed situation for the stopbank breach scenario again underline the positive benefits of the proposed mitigation measures relative to the existing situation.

5.5 Consideration of Other Effects

5.5.1 Partial Culvert Blockage

In order for a partial blockage of a culvert in a watercourse by flood-transported woody debris to occur, the following criteria need to be satisfied:

- there has to be an abundant supply of woody debris material available to be transported;
- the flow depths need to be deep enough to transport the available woody debris material; and
- the culvert structure needs to incorporate a number of narrow cells that would make it prone to blockage.

In this particular context, none of these criteria would appear to be satisfied with respect to the dry culvert through the proposed expressway embankment. Although the Ōtaki Catchment is heavily forested with an abundant supply of woody debris material, any such material conveyed by the river will be confined to the main channel river and will not spill over onto the floodplain. The floodplain itself is mainly used for pastoral purposes with the number trees forming shelterbelts and hedges insufficient to supply enough wind-blown woody material within the primary overland flow path to block the dry culvert. The flow depths across the floodplain are also not particularly deep and would be insufficient to transport large tree branches if these were in fact available. The proposed dry culvert through the expressway embankment is very wide and would probably need to be formed as a two or three span bridge structure with piers. The wide cells formed by the abutments and piers would not make the structure very prone to blockage.

The potential for partial blockage by flood-transported woody debris of the dry culvert through the proposed expressway embankment is therefore considered to be negligible.

5.5.2 Sediment Deposition in Ponding Areas

Sediment deposition across the Ōtaki River floodplain would only occur if the Chrystall's Bend stopbank was overtopped. Any deposition would primarily be in the storage area confined by the secondary flood containment bund upstream of the proposed expressway. The duration of flood inundation would be relatively short so that the volume of any deposition would be small. It would be washed off the vegetation into the floodplain surface by subsequent rainfall events.

However, for the stopbank to be overtopped in the first instance, the flood event causing this would have a very low probability of occurrence (0.2% AEP or smaller). Therefore, although the potential for deposition of fine suspended sediment on the floodplain due to ponding of sediment laden floodwaters by the expressway embankment cannot be discounted, it would be extremely rare.

As stopbank overflows and maximum floodplain flow velocities are similar in the existing and proposed situations, there would not be any significant change in the amount of sediment deposition between the two cases.

5.5.3 Erosion of Floodplain Surfaces Due to High Flow Velocities

The peak flow velocities approaching and through the dry culvert under the expressway would be insufficient to cause erosion of the floodplain surface. However the peak flow velocities would be exacerbated relative to the existing situation at the culvert outlet so that some erosion of the floodplain surface there could be expected. The amount of surface erosion would be limited by the short duration of the flood inundation (2-3 hours). As with the potential for sediment deposition, it would also be an extremely rare occurrence because of the low annual exceedance probability of a flood that would overtop the Chrystall’s Bend stopbank.

The higher maximum flow velocities in the vicinity of the culvert outlet would not threaten the integrity of the Expressway embankment due to its shear bulk. Any erosion damage to the floodplain surface or to the embankment due to these high flow velocities, if it occurred, would be easily reparable.

5.5.4 Drainage Times for Ponding Areas

Figure 5-13 compares stage hydrographs between the proposed and existing situations for the 0.2% AEP flood adjusted for possible future climate change effects at a location in the far corner of the flood storage area formed by the secondary flood containment bund upstream of the proposed expressway embankment. This is the area that would take the longest time to drain.

In the existing situation, the duration of inundation is in the order of only a couple of hours. Although the depths of inundation are significantly greater in the proposed situation, the duration of inundation is only slightly longer.

Consequently drainage times for stopbank overtopping flows flowing over the floodplain would be only slightly longer than in the existing unconstrained floodplain situation.

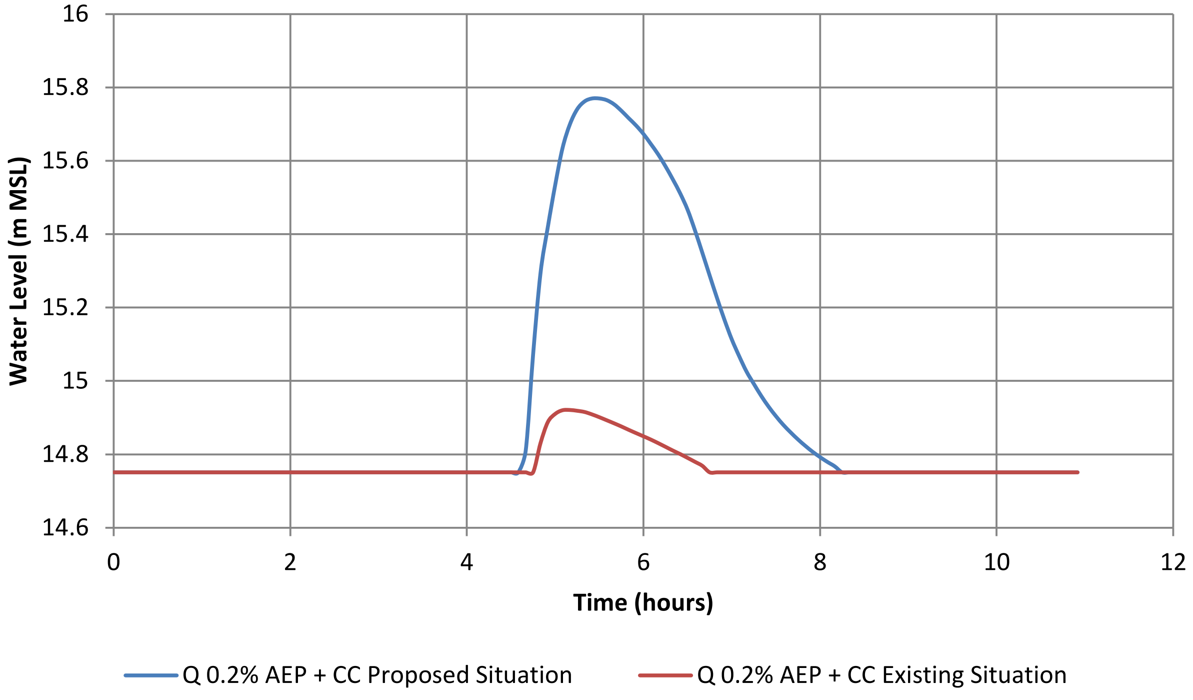

Figure 5-13 Stage hydrographs at a location in corner of storage area formed by secondary flood containment bund upstream of proposed expressway embankment for a 0.2% AEP flood adjusted for possible climate change effects overtopping Chrystall's Bend stopbank

5.5.5 Concurrent Flood in Mangapouri Stream

GWRC have queried what the effects of a concurrent flood in the Mangapouri Stream would have on the extent and depth of flood inundation across the Ōtaki River floodplain. The MIKE21 component of the MIKEFLOOD model is too coarse to accurately represent the Mangapouri Stream and, to properly incorporate it, the stream channel would need to be represented as a separate one-dimensional MIKE11 component. This would have required stream cross-section data which were not available.

Therefore to provide an approximate indication of the effects of a concurrent flood in the Mangapouri Stream with stopbank overtopping from the Ōtaki River, we have rerun both the existing situation and proposed situation MIKEFLOOD models for the case of a 0.2% AEP flood in the Ōtaki River coinciding with a 1% AEP flood in the Mangapouri Stream (both floods adjusted for the effects of possible future climate change to 2090). The 1% AEP flood in the Mangapouri Stream would significantly exceed the capacity of the existing stream channel so the inaccurate representation of the channel by the MIKE21 component of the MIKEFLOOD model is not a major issue. The MIKE21 component of the model will overestimate the extent of flood inundation caused by floodwaters from the Mangapouri Stream although the flood inundation pattern across the floodplain will be masked by the dominant influence of stopbank overtopping flows from the Ōtaki River.

The model simulations for the existing and proposed situations assumed that stopbank overtopping by the 0.2% AEP flood in the Ōtaki River adjusted for possible climate change effects did not result in stopbank breaching.

In the existing situation, floodwaters from such a flood overtopping the Chrystall's Bend stopbank would spread across the floodplain to reach Rahui Road upstream of the NIMT railway line, thereby swelling floodwaters in the Mangapouri Stream contained by the primary flood detention basin in that stream. Floodwaters spreading across the floodplain from the Ōtaki River would also flow into the Mangapouri Stream downstream of the existing SH1 culvert after first overtopping Mill Road.

In the case of the Mangapouri Stream, a 1% AEP flood in the Mangapouri Stream adjusted for possible climate change effects in the existing situation would overtop Rahui Road and start spreading southwards and westwards. While this would be very likely to precede the peak of Ōtaki River sourced floodwaters overtopping the Chrystall's Bend stopbank, the flood recession in the Mangapouri Stream would be long enough for floodwaters from the two sources to intercept to the south of Rahui Road and east of the existing SH1.

In the proposed situation, floodwaters spreading across the floodplain from the Ōtaki River would be prevented from intercepting floodwaters sourced from the primary flood detention basin on the Mangapouri Stream by the proposed secondary flood containment bund on the eastern side of the Expressway embankment. However stopbank overtopping floodwaters from the Ōtaki River and floodwaters breaking out of the Mangapouri Stream downstream of the existing SH1 culvert would still intercept to the west of the Expressway, after the former had first overtopped Mill Road.

In the proposed situation, floodwaters spreading across the floodplain from the Ōtaki River would also enter the Mangapouri Stream downstream of the existing SH1 culvert after overtopping Mill Rd. However the proposed secondary containment bund would prevents these floodwater from reaching and flowing over Rahui Road to swell floodwaters stored in the primary flood detention basin on the Mangapouri Stream.

Figures 5-14 and 5-15 show the results of the model simulations for this flood scenario for the existing and proposed situations respectively. Comparison of the two figures suggests that the extent of flood inundation to the west of the Expressway / SH1 corridor is very similar with perhaps a slight reduction in the inundation extent in the proposed situation along the Mangapouri Stream over the first 300-400m downstream of the existing SH1 culvert. From the intensity of the colour shading it would also appear that peak flood inundation depths would be marginally lower over this part of the floodplain in the proposed situation.

To the east of the Expressway / SH1 corridor, the two flow sources are separated by the secondary flood containment bund. The extent of flood inundation in both situations is again very similar with floodwaters from the Mangapouri Stream spreading southwards towards where the secondary containment bund is located in the proposed situation. Peak flood depths within the ponding area formed by the secondary containment bund and the Expressway embankment in the proposed situation are deeper than in the existing situation as would be expected. However these depths are not exacerbated by the overland flow from the Mangapouri Stream because of the separation function of the secondary containment bund.

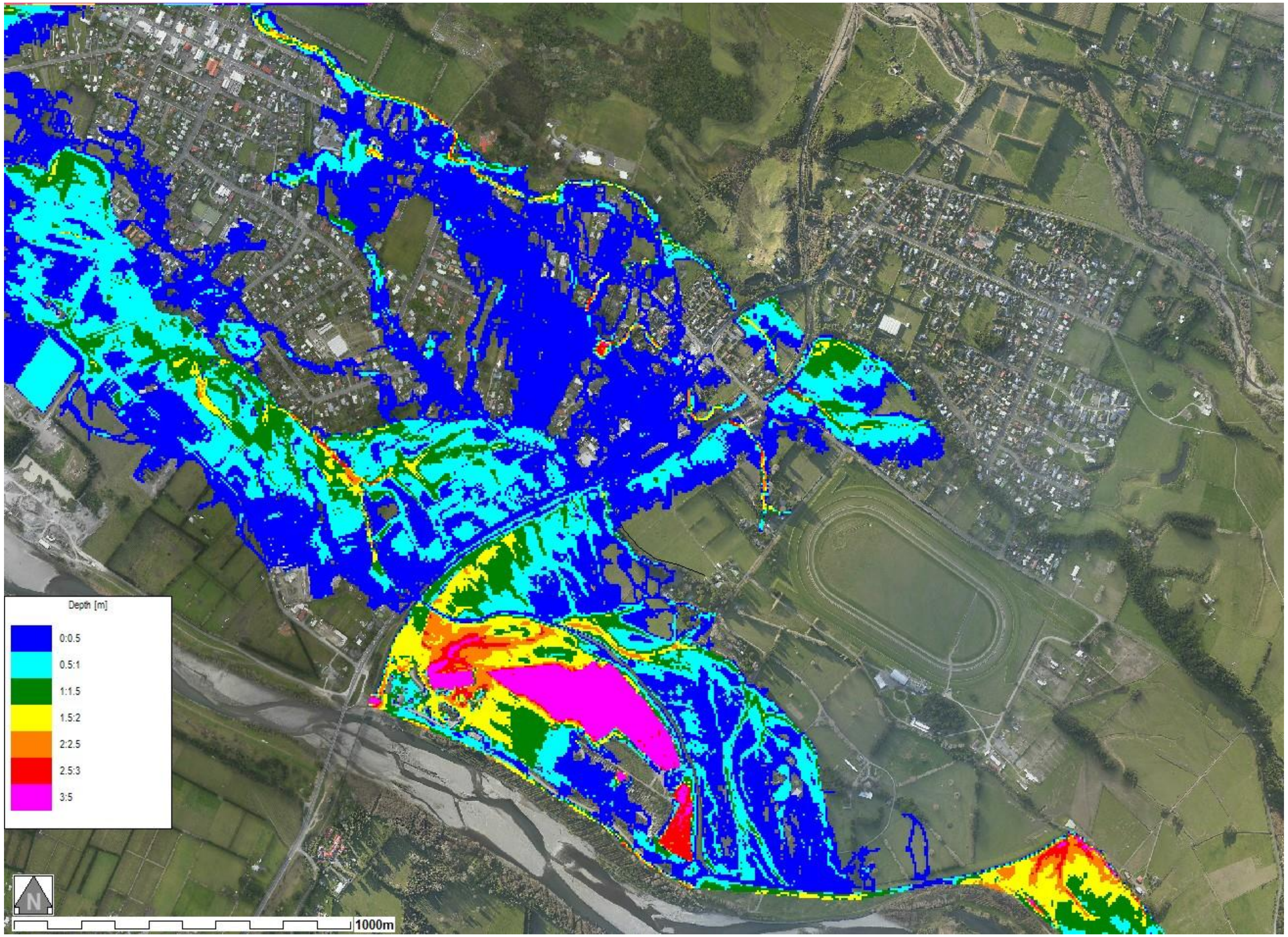

Figure 5-14 Peak flood inundation depths for existing situation on Ōtaki River floodplain resulting from stopbank overtopping in 0.2% AEP flood with concurrent 1 % AEP flood in Mangapouri Stream (both floods adjusted for possible effects of future climate change)

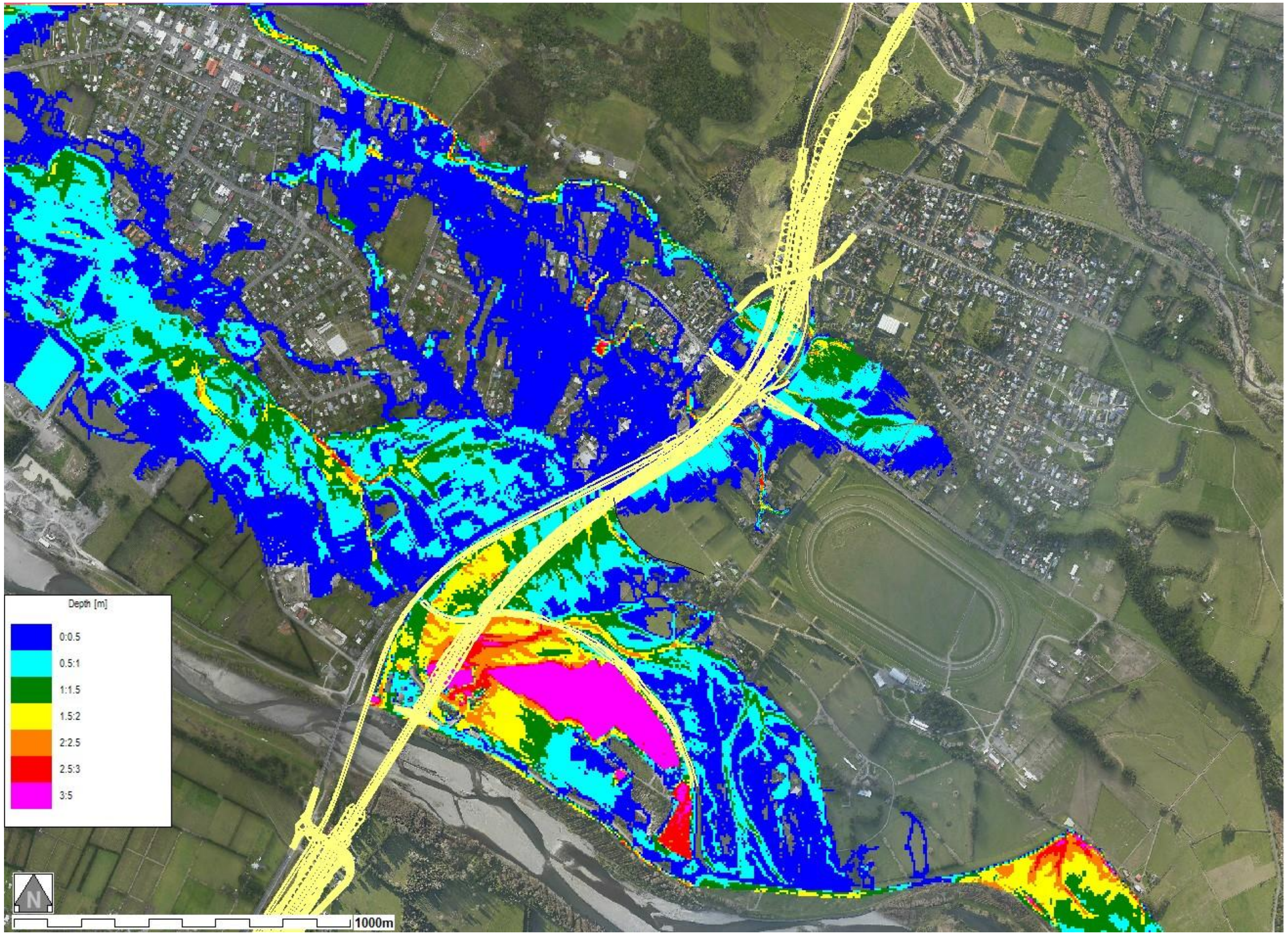

Figure 5-15 Peak flood inundation depths for proposed situation on Ōtaki River floodplain resulting from stopbank overtopping in 0.2% AEP flood with concurrent 1 % AEP flood in Mangapouri Stream (both floods adjusted for possible effects of future climate change)

Comparison of the flood inundation extent shown in Figure 5-15 for the proposed situation with the flood inundation extent shown in Figure 5-5 for the same stopbank overtopping flood scenario but without consideration of a concurrent flood in the Mangapouri Stream indicates that the only changes in flood extent are:

- within the primary and secondary flood detention basin areas of the Mangapouri Stream; and
- in the area to the south of Rahui Road and to the east of the Expressway embankment inundated by floodwaters overflowing Rahui Road from the primary flood detention basin on the Mangapouri Stream.

It can be concluded that the effect of a concurrent flood in the Mangapouri Stream with a large flood in the Ōtaki River overtopping the Chrystall's Bend stopbank has only a minor effect on the extent of flood inundation through Ōtaki Township to the west of the Expressway / SH1 corridor.

5.6 Secondary Flood Containment Bund Requirements

Figure 5-14 shows a graph of predicted flood level profiles for different flood scenarios along the alignment of the proposed secondary flood containment bund (see Figure 5-1 for proposed location). The graph in Figure 5-1 can be used to gauge the dimensional requirements for the containment bund.

Figure 5-15 indicates that the containment bund would need to be about 350m in length. It would not need to be a particularly high structure. Allowing for a minimum freeboard of 300mm, the crest level would need to be set at a minimum level of about 16.05m (MSL Wellington datum). This means that the containment bund would have a maximum height above existing ground levels of about 1.75m although, for much of its length, it would have a much lower height (less than 1.45m).

Construction of the proposed secondary flood containment bund could interfere with natural drainage patterns for surface runoff so that it is important that appropriately located culverts passing under the expressway embankment are provided to convey any runoff to the downstream (western) side of the expressway.

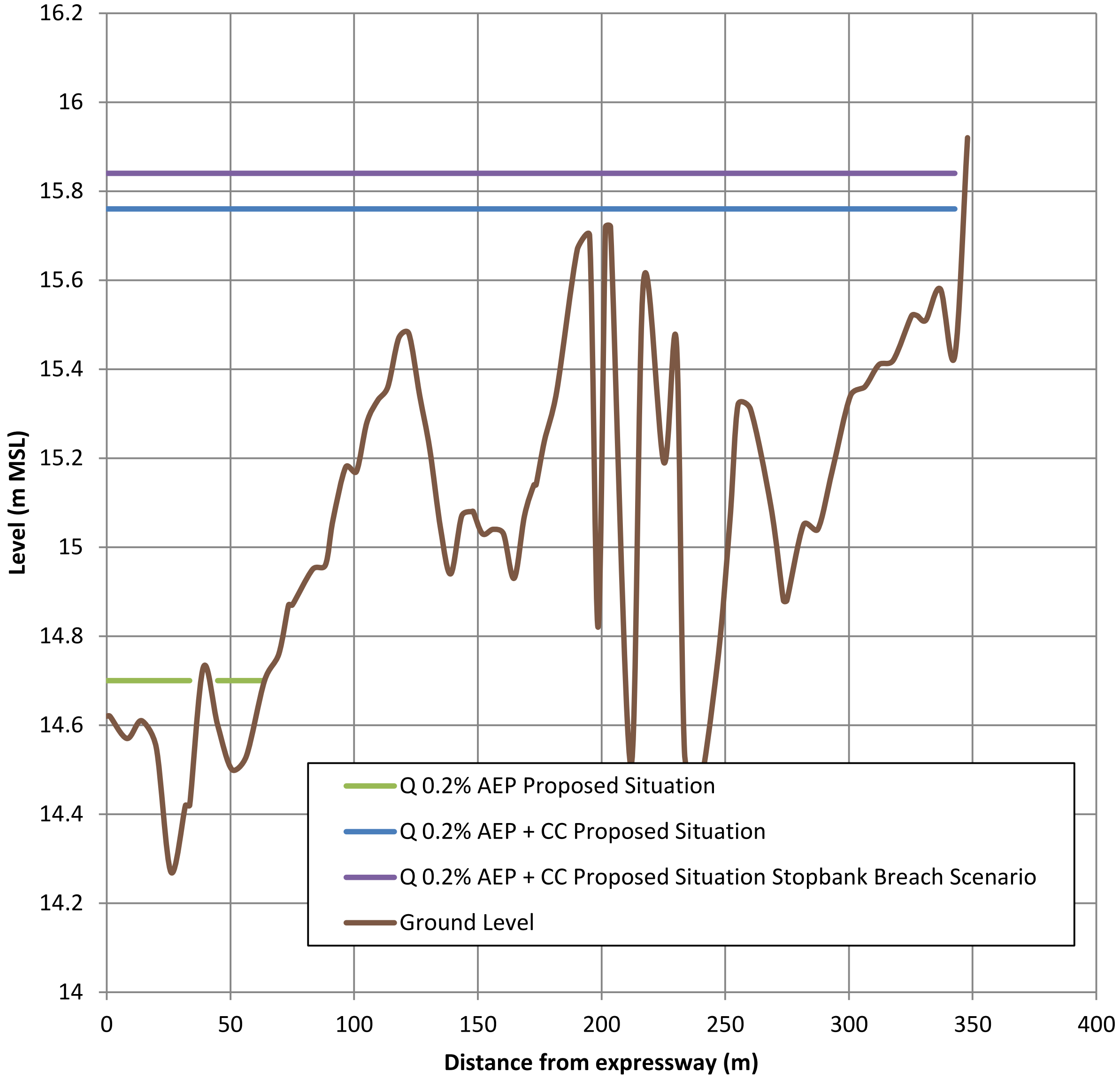

Figure 5-14 Predicted flood level profiles along alignment of proposed secondary flood containment bund on Ōtaki River floodplain for floods overtopping Chrystall’s Bend stopbank

6. Response to Comments by GWRC

Table 6-1 summarises the key comments made by GWRC in their review of the initial investigations for the proposed expressway carried out to set design levels for the new road at each waterway crossing and our responses to these comments. Our responses are based on the content of this report.

Table 6-1 Key comments from GWRC and our response to them

Comment	**Our Response**
The diversion of Ōtaki River floodplain flows into the Mangapouri Stream is unacceptable.	The proposed mitigation measures including a secondary flood containment bund, a 40m wide dry culvert through the expressway embankment and an overflow relief weir along part of the expressway are able to contain stopbank overtopping flows and prevent them from spreading into the Mangapouri Catchment. The secondary containment bund in particular would separate out and prevent the mixing of stopbank overtopping flows sourced from the Ōtaki River and Mangapouri Stream breakout flows.
Consideration should be given to coincident flood peaks in the Ōtaki River.	The proposed secondary flood containment bund isolates the effects of Ōtaki River stopbank overtopping flows from the effects of Mangapouri Stream breakout flows. This negates the need for consideration of coincident flood peaks in both watercourses. However, notwithstanding this comment, it is not appropriate to consider concurrent floods in the Ōtaki River and the Mangapouri Stream with the same annual exceedance probability value. Extreme floods in the Ōtaki River always give rise to less extreme floods in the Mangaone Stream (and by implication the Mangapouri Stream) based on measured flow records. Also flood peaks in the Ōtaki River generally lag those in the Mangaone Stream (and by implication the Mangapouri Stream) by about 1-2 hours. It would be reasonable but conservative to assume that the times of peak flood discharge in both watercourses were coincident. Flood inundation patterns across the Ōtaki River floodplain resulting from breakout of flood flows from the Mangapouri Stream are described in a companion report (Smith and Webby, 2013).
Consideration should be given to the effects of stopbank breaching.	This matter is addressed in Sections 4-3 and 5-4 of this report.

Comment	**Our Response**
Consideration should be given to the potential effects of partial blockage of culverts by flood-transported woody debris.	This matter is addressed in Section 5-5 of this report.
Consideration should be given to other potential effects: - sediment deposition in flood ponding areas - Erosion of floodplain surfaces by high velocity flows - changes in the drainage times of ponding areas	These matters are addressed in Section 5-5 of this report.

7. Conclusions

The bed of the Ōtaki River is aggrading downstream of Chrystall's Bend to the river mouth although gravel extraction is undertaken to manage this trend. Gradually increasing bed levels in this river reach will affect flood levels past the proposed Expressway bridges (as well as the existing NIMT railway and SH1 road bridges). The design freeboard allowance for the Expressway bridges therefore needs to allow for periodic increase of bed level in addition to the increased head losses resulting from potential debris raft formation on the bridge piers. A minimum design freeboard allowance of 1.7m to allow for these factors is considered appropriate.

The piers on the twin parallel Expressway bridges across the Ōtaki River will be aligned so that each pier on the upstream bridge will have a partial sheltering effect on the corresponding pier on the downstream bridge. The head losses induced by the piers on each bridge are minimal (~ 0.01-0.02m) with their wide spacing (30m) and lenticular shape and can be conservatively assumed to be cumulative between the two bridges. Additional pier head losses would be induced by snagged woody debris material although these would only affect the piers on the upstream bridge due to their alignment with and sheltering effect on the corresponding piers on the downstream bridge. The design freeboard standard for a bridge is intended to provide some allowance for debris-induced pier head losses.

Irrespective of the small magnitude of the bridge pier head losses in this context, the backwater effect of any pier head losses would rapidly diminish with distance upstream due to the steepness of the bed of the Ōtaki River. It can therefore be concluded that the piers on the twin Expressway bridges would not increase upstream flood levels (except in the immediate vicinity of the bridge) and thereby reduce the flood standard of the Chrystall's Bend stopbank.

The flat area on the north bank of the Ōtaki River where Ōtaki Township is sited is a natural floodplain. A stopbank system along the north side of the river provides a 1% annual exceedance probability standard of flood protection to Ōtaki Township based on current climate conditions.

This stopbank system protecting Ōtaki Township will be overtopped by floods in the Ōtaki River larger than the stopbank design flood standard. Stopbank overtopping flows would predominantly follow a secondary flow path over the floodplain roughly parallel with the main river channel. However there will also be some lateral spreading of floodwaters through Ōtaki Township. The extent of flood inundation over the floodplain and the peak depths of flood inundation would be dependent on the magnitude of the flood event in the Ōtaki River which results in the occurrence of stopbank overtopping.

The construction of an elevated embankment to carry the proposed expressway will bisect the floodplain and form a barrier to the natural drainage of stopbank overtopping flows flowing over the floodplain. The embankment will therefore cause floodwaters to back up behind it and could also allow them to spread laterally into the Mangapouri Stream Catchment along the northern edge of the floodplain.

In order to minimise the effects of the proposed expressway on stopbank overtopping flows flowing over the Ōtaki River floodplain, it will be necessary to provide a means of evacuation through the embankment for floodwaters ponded behind the embankment barrier. In particular the following mitigation measures as shown in Figure 5-1 are recommended to be implemented:

- a 350m long, approximately 1.75m high secondary containment bund projecting upstream from the expressway embankment and following a natural terrace line (located about 550m along the expressway embankment from the Chrystall's Bend stopbank);
- a 40m wide, 1.5m high dry culvert through the expressway embankment (located about 50m along the expressway embankment from the Chrystall's Bend stopbank); and
- an approximately 300m long overflow weir section formed by the vertical profile of the road between the dry culvert and the line of the secondary stopbank with a crest level of about 15.3m (MSL Wellington datum) – the road profile would need to rise up to a high point of about 15.8m (MSL Wellington datum) to the north of the line of the secondary containment bund to provide a lateral constraint for the weir section.

The secondary containment bund will prevent the lateral spread of ponded floodwaters into the Mangapouri Stream Catchment. The dry culvert will provide the primary means of evacuation for ponded floodwaters behind the expressway embankment while the overflow weir will provide a secondary means of evacuation.

In terms of peak flow depths and velocities, these mitigation measures would be able to reduce the effects of the proposed expressway from stopbank over-topping sourced floodplain flows on populated areas to less than those that would occur in the current floodplain situation. However, upstream of the expressway embankment, peak flood inundation depths would be increased due to the partial damming effect of the embankment while peak flow velocities would be reduced except in the localised area approaching and through the dry culvert. These latter effects would only impact on land currently used for pastoral purposes.

It should also be emphasised that the occurrence of these effects would be extremely rare given the very low annual exceedance probability of Ōtaki River floods which would overtop the stopbank system protecting Ōtaki Township. However the potential for occurrence cannot be dismissed.

The potential for partial blockage by flood-transported woody debris of the dry culvert through the proposed expressway embankment is considered to be negligible because of the width of the structure and the limited supply of woody debris material across the floodplain. The potential for deposition of fine suspended sediment on the floodplain due to ponding of sediment laden floodwaters by the expressway embankment cannot be discounted but would be extremely rare. The peak flow velocities approaching and through the dry culvert under the expressway on the very rare occasions that it did operate would be insufficient to cause erosion of the floodplain surface but could cause surface erosion at the culvert outlet. Drainage times stopbank overtopping flows flowing over the floodplain would be only slightly longer than in the existing unconstrained floodplain situation.

On balance then the effects of the proposed expressway on stopbank overtopping flows flowing over the Ōtaki River floodplain are no more than minor. In fact the impact on populated areas will be less than in the existing situation. The effects will only be greater in rural areas away from people. The effects will also be temporary and extremely rare due to very low annual exceedance probability of Ōtaki River floods which would overtop the protective stopbank system.

The potential for stopbank breaching increases with the depth of overtopping. In the case of the current situation, the critical location for stopbank overtopping (and potential breaching) is immediately upstream of where the Chrystall's Bend stopbank butts into the NIMT railway embankment and a 0.2% AEP flood adjusted for possible future climate change effects to 2090 would overtop the stopbank by up to 0.45m. However, in the case of the proposed expressway situation, the critical location for stopbank overtopping (and potential breaching) is immediately upstream of where the Chrystall's Bend stopbank butts into the new expressway embankment and a 0.2% AEP flood adjusted for possible future climate change effects to 2090 would also overtop the stopbank at that location by up to 0.45m. A similar length of stopbank is considered to be potentially at risk in either case but ground levels behind the stopbank (which control the level that a stopbank breach would erode down to) in the proposed situation are significantly higher than those at the likely breach location in the existing situation. This means that the outflow volumes for potential stopbank breach in the proposed situation would be likely to be significantly less than in the existing situation. As a consequence of this, peak flow depths across most of the floodplain including downstream of the expressway embankment would be lower in the proposed situation.

The effect of the expressway embankment also forming a barrier through the off-channel storage area occupied by the Stresscrete concrete factory is to reduce the depth of stopbank overtopping of the Chrystall's Bend stopbank between the expressway embankment and the NIMT railway embankment by a 0.2% AEP flood adjusted for possible future climate change effects. This in turn would reduce the risk of stopbank breaching in that location in the proposed situation.

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