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

Quality Assurance Statement

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NZ Transport Agency

Contents

List of Abbreviations

AEE	Assessment of Environmental Effects
AEP	Annual Exceedance Probability
chge	Chainage
DS	Downstream
EPA	Environmental Protection Agency
GEV	Generalised Extreme Value (a statistical distribution used to fit flood maxima series data)
GWRC	Greater Wellington Regional Council
h: v	horizontal: vertical
IPO	Inter-decadal Pacific Oscillation
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
PE3	Log Pearson 3 (a statistical distribution used to fit flood maxima series data)
PP2O	Peka Peka to North Ōtaki
RMA	Resource Management Act
RoNS	Roads of National Significance
SAR	Scheme Assessment Report
SH1	SH1
TRB	True Right Bank (as viewed looking downstream in direction of river or stream flow)
US	Upstream
DS	Downstream

[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

State Highway 1 (SH1) and the North Island Main Trunk (NIMT) Railway run parallel to each other as the pass through Te Horo Village with the railway line to the west (and nearest to the foothills of the Tararua Ranges). In a geomorphological sense, both transport routes are crossing the alluvial fan of the Mangaone Stream as they pass though the village. Drainage pattern across the alluvial fan appear to have been significantly modified over time and constrained in their location to facilitate development of the fan for residential, pastoral and horticultural purposes. In fact, anecdotal evidence indicates that the Mangaone Overflow, located 250m south of the SH1 and NIMT railway crossings of the main Mangaone Stream (Figure 1-1), approximately follows the original course of the stream to the coastal dune barrier behind Te Horo Beach.

An alluvial fan in its natural state may often have several distributor channels starting to convey catchment runoff over the surface of the fan from the head to the base. These are represented in the present situation by the now constrained northern breakout flood path and School Road Drain seen in Figure 1-1. Towards the existing SH1 and NIMT railway transport links, the course of these distribution channels has been changed so that flood flows conveyed by them are channelled via a man-made drainage system to the Mangaone Overflow and Mangaone Stream culverts. The topographic relief map in Figure 1-1 does in fact provide evidence for the original course of some of these distributor channels (the lighter coloured green meandering lines within the darker areas of green).

The NIMT railway line is elevated above ground level across the alluvial fan surface so that, when a significant flood occurs, floodwaters pond upstream of the embankment. This can be seen in the photograph on the front cover which shows the aftermath of the 28-October-1998, (viewed looking east across the SH1 and the NIMT railway crossings of the main stream channel – photograph provided courtesy of Greater Wellington Regional Council). SH1 through Te Horo Village is a known flooding hotspot with floodwaters inundating the road every few years. The near at-grade vertical alignment of the road is probably a contributing factor to this behaviour. The flood hazard map in the Kāpiti Coast District Plan (see Appendix A) confirms the exposure of SH1 and the NIMT railway line in this area to existing flood hazards caused by floodwaters following the course of several overland flow paths across the alluvial fan surface.

The route of the proposed Expressway lies on the foothills (i.e. upstream) side of the two existing transport routes (Figure 1-1) and will therefore be exposed to the same flood hazards. In order to achieve a minimum level of service with respect to these flood hazards, the expressway will need to be elevated as a raised embankment with an adequate conveyance capacity for flood flows through the embankment along the main stream channel and existing overland flow paths.

However, the situation is further complicated by the presence of an east/west local link road (connecting School Road on the east side of the Expressway with Te Horo Beach Road on the west side) which crosses the Expressway via an overbridge. The local link road has to cross the main stream channel twice as well as having to pass through existing overland flow paths. Again adequate flood capacity for these crossings will need to be provided.

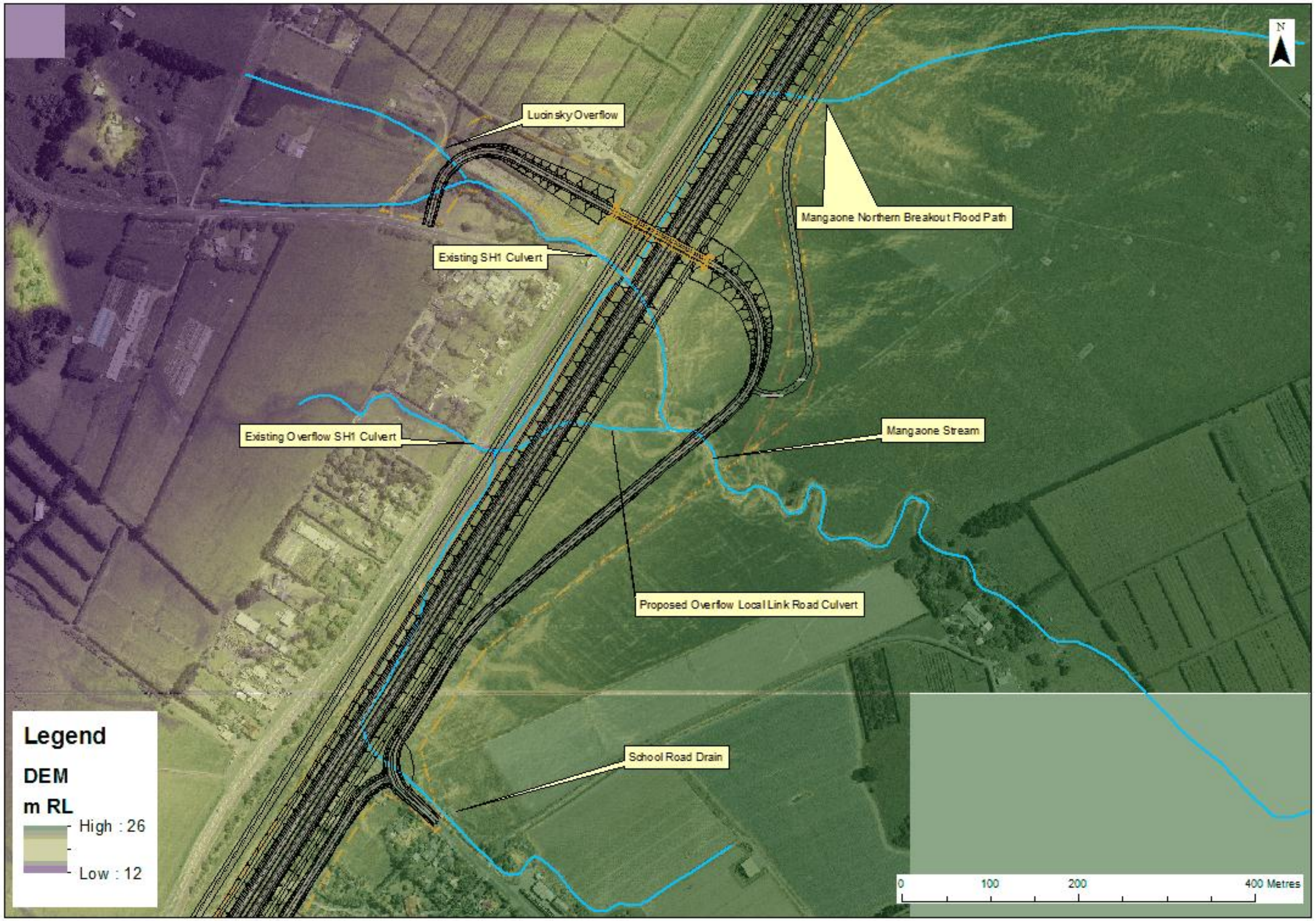

Figure 1-1 Topographic relief map of Mangaone Stream alluvial fan and floodplain area with route of proposed expressway superimposed

For the initial scheme design, design levels were set for the proposed vertical alignment for the expressway and culvert sizes through the expressway embankment were defined with the aid of a one-dimensional computational hydraulic model of the Mangaone Stream and overflow system. The model incorporated storage volumes upstream of the expressway embankment to reflect the flood ponding behaviour that will occur in significant flood events. However, it was recognised at the time that flood flow patterns across the alluvial fan would be two-dimensional in nature (i.e. horizontal flow velocities across the fan have two primary components rather than only one primary component in a single direction), and that a two-dimensional hydraulic modelling approach would provide more certainty to the prediction of flood inundation patterns and depths.

This report presents the results of further computational hydraulic modelling investigations for the Mangaone Stream alluvial fan and floodplain system using a two-dimensional modelling approach. 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 Expressway.

1.2 Feedback on Initial Investigations from GWRC and KCDC

Greater Wellington Regional Council (GWRC) provided feedback on the initial investigations for the scheme development. They raised a number of concerns about the one-dimensional computational hydraulic model used to predict flood patterns as well as concerns about the flood inundation predictions:

- they observed that there was minimal information on the development and calibration of the model;
- they also noted that the description of the model did not provide sufficient information to determine where ponding areas were located;
- they noted that there was no information on how the flood inundation maps for both the existing and proposed situations had been produced;
- they noted a number of issues with the predicted flood inundation patterns that caused uncertainty about their accuracy and whether they could actually be an artefact of the modelling or mapping techniques rather than real;
- they expressed a wish to see the predicted flood extents further downstream of SH1 along the Mangaone Overflow, the main stream channel and the Lucinsky Overflow in both the existing and proposed situations compared to what had been shown initially; and
- they suggested that sensitivity tests should be undertaken with regard to the model inflows given the uncertainty in the flood estimates.

From an effects assessment perspective, GWRC made a number of other comments on the preliminary investigations:

- the flood inundation map should show ranges of peak flood depths in addition to the areal extent of inundation;
- a map showing changes in peak flood depth between the existing and proposed situations should also be included to highlight the effects of the proposed expressway on flood levels;

- a map showing predicted flow velocities across the alluvial fan and floodplain system should be included for both the existing and proposed situations; and
- a map showing changes in peak flow velocities between the existing and proposed situations should also be included to highlight the effects of the proposed expressway on flow directions and velocities.

GWRC were also interested in other effects of the Expressway including:

- potential sediment deposition in low velocity ponding areas;
- potential erosion of the floodplain surface due to increased 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 Mangaone Stream alluvial fan and floodplain system as, except for the School Road Drain, they considered this alluvial fan and floodplain watercourse system to be outside their specific jurisdiction.

1.3 Scope and Methodology for Detailed Investigations

The preliminary investigations for the initial scheme design used a more detailed and truncated version of an existing one-dimensional MIKE11[2] computational hydraulic model of the Mangaone Stream alluvial fan and floodplain system previously developed by GWRC (and made available for the purposes of these investigations). The model was used in order to:

- examine the effects of the Expressway on existing flood patterns and levels across the alluvial fan and floodplain system for the Mangaone Stream and Overflow;
- determine appropriate culvert sizes in order to provide continuity for existing overland flow paths across the alluvial fan and floodplain surface and to mitigate any adverse effects of the Expressway; and
- set design levels for the Expressway.

The analyses using the modified MIKE11 model of the Mangaone Stream alluvial fan and floodplain system considered the 1% annual exceedance probability (AEP) flood adjusted for the possible effects of future climate change to 2090 as a base case but also evaluated the sensitivity of the initial scheme design to the 0.5% AEP flood adjusted for the possible effects of future climate change.

The purpose of the more detailed investigations then was to replicate the preliminary investigations using an alternative two-dimensional computational hydraulic modelling approach in order to provide more confidence in the assessment of effects of the Expressway and local link road crossings of the Mangaone Stream alluvial fan and floodplain system. The primary tool for these more detailed investigations was an even more extensive modification of the previous MIKE11 model of the Mangaone Stream alluvial fan and floodplain system in which the one-dimensional overland flow paths within an extended area of interest were replaced with a two-dimensional representation of the nearly flat ground surface.

[2] MIKE11 is an internationally recognised computational hydraulic modelling software package developed by the Danish Hydraulic Institute (DHI) and designed for simulating flow behaviour in complex river and floodplain systems. It is widely used in New Zealand

Examination of the original MIKE11 model branch structure and the flood inundation patterns shown on the Kāpiti Coast District Plan flood hazard map (see Appendix A) indicated that a suitable approach would be to incorporate a two-dimensional floodplain surface into the model covering an area extending from about 1.4km upslope from SH1 to about 1.25km downslope from SH1 (where a natural hydraulic control occurs through a gap in a line of inland sand-hills along Te Horo Beach Road) and covering a width of about 1.5km (Figure 1-2). In this manner the MIKE11 model was transformed to a MIKEFLOOD[3] model. The latter model incorporated two linked components that were run simultaneously in parallel:

- a one-dimensional MIKE11[3] computational hydraulic model component representing the main channel of the Mangaone Stream including the Expressway / NIMT railway / SH1 culvert system, the Mangaone Overflow including the Expressway / NIMT railway / SH1 culvert system and the School Road Drain, and used for simulating flow behaviour within these primary channels; and
- a two-dimensional MIKE21[3] computational hydraulic model component representing the Mangaone Stream alluvial fan and floodplain surface over the area shown in Figure 1-2 and used for simulating flow behaviour across this two-dimensional nearly flat surface.

The MIKE11 model component also included culverts on the east / west local link road (Mangaone Stream –east side of the Expressway, Mangaone Stream – west side of the Expressway, Mangaone Overflow approach flow path and the Lucinsky Overflow. Other residential access bridges on the main Mangaone Stream channel were ignored as they were relatively thin structures and easily overtopped.

Appendix B summarises the changes made to the previous MIKE11 model to transform it into the new MIKEFLOOD model over the area described. Two versions of the new MIKEFLOOD model were developed: version one represented the existing situation with the NIMT railway and SH1 in place while version two represented the proposed situation with the Expressway, the NIMT railway, SH1 and the local east / west local link road in place.

The original MIKE11 model developed for GWRC was not calibrated in the normal sense of a computational hydraulic model so that it was not possible to calibrate the new MIKEFLOOD model either. However the new MIKEFLOOD model was validated in a qualitative sense by simulating the 28 October 1998 flood event and ensuring that predicted flood inundation patterns matched anecdotal observations. Appendix C summarises the comparison between the predicted flood inundation patterns and anecdotal evidence.

[3] MIKEFLOOD is an overarching software shell which incorporates both the MIKE11 one-dimensional and MIKE21 two-dimensional computational hydraulic modelling packages. It enables the hydraulic interaction of linear watercourses linked to two-dimensional water bodies or surfaces to be more accurately simulated where overland flow paths are uncertain. 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.

Figure 1-2 Aerial photograph of alluvial fan and floodplain system for Mangaone Stream alluvial fan and floodplain from foothills to sea showing area of MIKEFLOOD model

The further detailed investigations undertaken using the two-dimensional computational hydraulic modelling approach were focussed on confirming the effects of the proposed expressway on existing flood inundation patterns, levels and flow velocities and on confirming the appropriateness or otherwise of the culvert sizes determined from the preliminary investigations. In addition consideration was given to other possible effects identified by GWRC:

- potential sediment deposition in low velocity ponding areas;
- potential erosion of the floodplain surface due to excessively high flow velocities; and
- any change 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.

1.4 Proposed Expressway Crossing of Mangaone Stream and Overflow

The Expressway runs roughly parallel with but further to the east of SH1and the NIMT railway line (Figure 1-1). The Expressway therefore crosses the Mangaone Stream and its left bank overflow path on the upstream side of these transport links. The Expressway will be slightly elevated above the existing ground surface but will need to be protected by an elevated upstream bund where it crosses the Mangaone Stream and overflow path in order to achieve the required level of service and remain flood free up to that level. The ponding that currently occurs upstream of the NIMT railway line will be transferred to upstream of the Expressway embankment. Construction of the Expressway therefore represents an opportunity to rectify some of the existing localised flooding issues although the real issues remain the volume of storm runoff (for which there is no control over) that must be safely passed through all three parallel transport links, the historic development of the fan surface and the historic modification and channelization of the natural drainage system.

The east / west local link road (Figure 1-1) also crosses the Mangaone Stream twice (on the east side of the Expressway and on the west side) and also intercepts an existing overland flow path leading to the Mangaone Overflow culvert system and the existing Lucinsky Overflow. The latter provides flood relief for the fairly narrow main stream channel downstream of the SH1 culvert which runs alongside Te Horo Beach Road.

It is critical that the Expressway culverts on the main Mangaone Stream and the Mangaone Overflow are aligned with the existing NIMT railway and SH1 culverts.

1.5 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.

1.6 Flood Magnitudes and Climate Change Effects

In this report, flood magnitudes are identified by reference to their annual exceedance probability (AEP). This is a statistical measure of how large a flood is and is generally based on a flood frequency analysis of the annual flood maxima series for a continuous measured flow record from a hydrological gauging station such as exists on the Mangaone Stream before it breaks out onto the lower coastal plain.

For example a 1% (1 in 100) AEP flood is one that would be exceeded on average once every 100 years over a very long period of time (much longer than 100 years).

The floods of interest for the Mangaone Stream were primarily the 1% and 0.5% AEP floods. However other smaller floods were also considered (5% and 2% AEP) because of the lower level of service requirement for the local link road providing east / west connectivity across the Expressway between .School Road and Te Horo Beach Road.

The flood estimates for the 1%, 0.5% and 0.2% AEP floods for each of the watercourses considered were adjusted for the effects of possible future climate change to 2090 based on a mid-range estimate for increased average temperature and hence rainfall for the Wellington and Manawatu regions from the MfE (2010) Guidelines. The timeframe for consideration of climate change effects reflects the projected design life of the required bridge and culvert structures over the watercourses.

1.7 Topographic Data

Topographic data for the general area of these investigations was obtained from LiDAR data provided by KCDC. The LiDAR data was collected in July and August 2010 over a 255km2 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.

This LiDAR-sourced topographic data was used to define the terrain in the MIKE21 component of the MIKEFLOOD model.

Cross-section data for the MIKE11 component of the MIKEFLOOD model of the Mangapouri Stream were sourced from the original MIKE11 model developed for the previous flood hazard assessment for the stream (MWH, 2002a and b).

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 Description of Mangaone Stream Catchment

The Mangaone Stream drains a 38.6km^2 catchment extending from the foothills of the Tararua Ranges to the sea at Te Horo Beach. After exiting from the foothills, the stream crosses the coastal plain over a distance of about 7km, cutting through lines of inland and coastal dune barriers to its beach exit (Figure 1-2). SH1 and the NIMT railway line cross the stream at Te Horo, about 3.5km to the south of the Ōtaki River.

In a geomorphologic sense the coastal plain area between the foothills and the sea is a steeply sloping (> 1%) alluvial fan. In an unconstrained and undeveloped situation, the drainage system across the fan surface would be in a continual dynamic state, changing course over time and potentially splitting into a number of smaller distributor channels. However, the alluvial fan in this context has historically been modified to facilitate development of the fan surface for agricultural, horticultural and residential purposes. This modification has interfered drastically with existing drainage paths such that many of the historical distributor channels across the fan surface have been rerouted or severed from the main stream. The presence of a couple of major transport links crossing transversely across the alluvial fan surface compound the historical interference in the natural drainage patterns.

The Mangaone Stream is gauged at Ratanui within the foothills of the Tararua Range. Between the foothills and the existing SH1 and NIMT railway crossings, the stream traverses a steeply sloping plain. The topography of this plain means that the catchment area at the SH1 crossing (measured as 24.95km^2 from LiDAR-sourced ground level data) is much larger than the catchment area at the gauging station site (measured as 9.2km^2 from 20m contour data). Expressed another way, the gauging station catchment area is only 37% of the catchment area at the SH1 stream crossing.

This is problematical for the estimation of flood frequencies and magnitudes at the SH1 crossing of the stream and therefore the proposed expressway crossing. The rainfall / runoff relationship of the catchment at the Ratanui gauging station site is different to that of the lower part of the catchment across the coastal plain. The lower part of the catchment across the plain is likely to receive less rainfall because of less orographic enhancement. The flatter ground slopes on the alluvial gravels of the plain also mean that there is likely to be significantly less runoff from this part of the catchment. It is a common occurrence with the Mangaone Stream that significant floods break out of the main channel near the head of the plain and flow overland via several paths before being intercepted by the railway line embankment and then channelled through a culvert system to the seaward side of SH1. The alluvial gravel deposits forming the coastal plain create an unconfined groundwater aquifer system which has the potential to receive water from stream flow, overland flow and floodplain detention storage infiltrating through these deposits. The process of overland flow across the plain gives rise to the attenuation of the peak discharges of flood events due to the effects of surface (bed) friction.

This means that flood frequency estimates obtained from a frequency analysis of the annual flood maxima series for the Ratanui gauging station site cannot simply be extrapolated to determine flood estimates for the existing SH1 stream crossing using the catchment area scaling approach of McKerchar and Pearson's (1989) regional flood frequency method.

2.2 Previous Flood Estimates for Mangaone Stream at SH1 Crossing

There have been several previous flood estimates for the Mangaone Stream at the existing SH1 crossing.

McKerchar (1991) utilised the regional flood frequency method of McKerchar and Pearson's (1989) to establish flood frequencies and magnitudes at the existing SH1 crossing from other nearby gauging station flow records. These flood estimates are summarised in Table 2-1. In addition to the problems hinted at before, there are two other problems with this approach. Firstly, the catchment area of 16.6km^2 is significantly underestimated as the catchment boundaries would have been determined from 20m topographic contour data which is ill-defined across the plain area. Secondly, the flood estimates are likely to be biased by the different rainfall / runoff characteristics and hence higher flow regime of the Ōtaki River Catchment used in McKerchar and Pearson's (1989) regional flood frequency method.

Table 2-1 Comparison of flood frequency estimates for Mangaone Stream at SH1 crossing

AEP (%)	**Flood Estimate (m^3/s)**			
	McKerchar (1991)	**MWH (2002b)**	**REC**	**Current Study – GEV**
	Catchment Area 16.6km^2	Catchment Area ~ 27 km^2	Catchment Area 19.01km^2 (24.95km^2)	Catchment Area 24.95 km^2
42.9	25	19.7	26.8 (33.3)	33.7
20	35	25.4		45.5
10	42	29.7		55.3
5	48	33.8		64.4
2	56	38.8		76.6
1	63	43.6	57.3 (71.2)	85.7
0.5	68	47.5		94.8
0.2	-	-		106.8

MWH (2002a, 2002b) used a hybrid approach to obtain flood estimates at the existing SH1 stream crossing. They first carried out a frequency analysis on the 1993-2000 annual flood maxima series for the Mangaone Stream at Ratanui gauging station flow record. Flood hydrographs scaled to fit these estimated flood discharge peaks were then used as an upstream boundary condition for a one-dimensional MIKE11 computational hydraulic model of the stream channel and overland flow path system across the coastal plain to the sea. The runoff contribution from the lower coastal plain part of the catchment was estimated with a rainfall / runoff model using rainfall data as an input and the predicted runoff hydrographs were applied as an internal boundary condition to the hydraulic model of the stream channel and overland flow path system. The flood estimates obtained by MWH (2002b) are also summarised in Table 2-1.

There are a number of problems with the MWH (2002b) flood estimates. Firstly, the hybrid approach mixing flood hydrographs scaled from gauged stream flow records for one part of the catchment and rainfall / runoff model predictions for another part of the catchment is unusual. Secondly, the catchment area at the SH1 stream crossing assumed by MWH to be ~ 27km^2 (this excludes those sub-catchment areas to the south of the stream crossing from which surface runoff flows directly across the road) is slightly overestimated compared to the catchment area of 24.95km^2 estimated from the LiDAR-sourced topographic data in these investigations. Thirdly, the rainfall data used as the primary input to the rainfall / runoff model over the lower coastal plain part of the catchment was sourced from HIRDS (a tool produced by NIWA that can estimate rainfall frequency at any point in the country) but the predictive accuracy of actual rainfall over the coastal plain by this tool is unknown. Fourthly and most importantly, the annual flood maxima series used by MWH to obtain the flood frequency estimates for the Ratanui gauging station site was only 8 years long (1993-2000). Consequently the frequency distributions fitted to the data have an extremely poor fit (as seen in Figure 2-1 below) which makes the flood frequency estimates obtained for the gauging station site unreliable. It is reasonable therefore to conclude that the flood estimates obtained by MWH (2002b) for the SH1 crossing of the Mangaone Stream contain a high level of uncertainty.

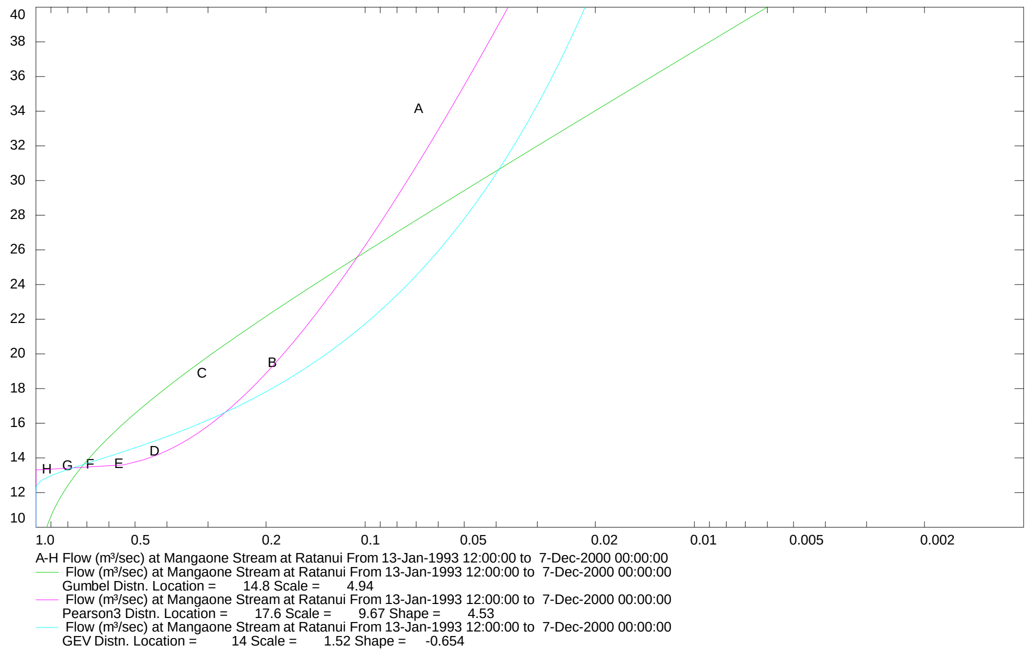

Figure 2-1 Flood frequency distributions for Mangaone Stream at Ratanui (1993-2000) (horizontal axis – AEP, vertical axis – discharge (m^3/s))

The latest iteration of McKerchar and Pearson's (1989) regional flood frequency method incorporated in NIWA's GIS-based River Environment Classification (REC) System predicts a mean annual (42.9% AEP) flood estimate of 26.8m^3/s and a 1% AEP flood estimate of 57.3m^3/s based on a catchment area of 19.01km^2. As noted before this is a significant underestimate of the actual catchment area which is probably based on 20m topographic contour data. If the flood estimates are corrected for the 24.95km^2 catchment area measured from LiDAR-sourced topographic data in these investigations, the corrected mean annual and 1% AEP flood values are 33.3 and 71.2m^3/s respectively. The original and corrected REC flood estimates are summarised in Table 2-1 above.

2.3 Flood Frequency Estimates for Mangaone Stream at Ratanui Gauging Station

Table 2-2 summarises flood frequency estimates obtained for the Mangaone Stream at Ratanui gauging station site using the Gumbel, GEV and Log Pearson 3 frequency distributions based on a January 1993 to December

2010 flow record (18 years). For comparison, Table 2-2 also contains similar flood estimates using the stream flow record that was available in 2000 and therefore likely used in previous reports. In fact, none of the common statistical distributions appear to fit the shorter annual maxima series (Figure 2-1). It is perhaps fortuitous that the Gumbel-derived estimates using the 1993-2000 record are not too dissimilar to those obtained using the longer 1993-2010 flow record (Table 2-2).

It is reasonable to conclude that the design flow estimates produced up until 2000 also contain a high level of uncertainty.

Table 2-2 Flood estimates for Mangaone Stream at Ratanui Gauging Station

AEP (%)	**Flood Estimate (m^3/s)**					
	1993-2000 Gumbel	***1993-2000 PE3***	***1993-2000 GEV***	**1993-2010 Gumbel**	**1993-2010 PE3**	**1993-2010 GEV**
42.9	*17.6*	*14.2*	*15.0*	15.2	15.2	15.2
20	*22.2*	*18.9*	*17.8*	20.5	20.7	20.5
10	*25.9*	*26.2*	*21.7*	24.9	25.0	24.9
5	*29.4*	*35.5*	*27.8*	29.0	29.0	29.0
2	*34.0*	*49.5*	*41.4*	34.4	34.0	34.5
1	*37.5*	*61.0*	*58.6*	38.4	37.6	38.6
0.5	*40.9*	*73.1*	*85.6*	42.5	41.1	42.7
0.2	*45.4*	*89.7*	*146.4*	47.8	45.7	48.1

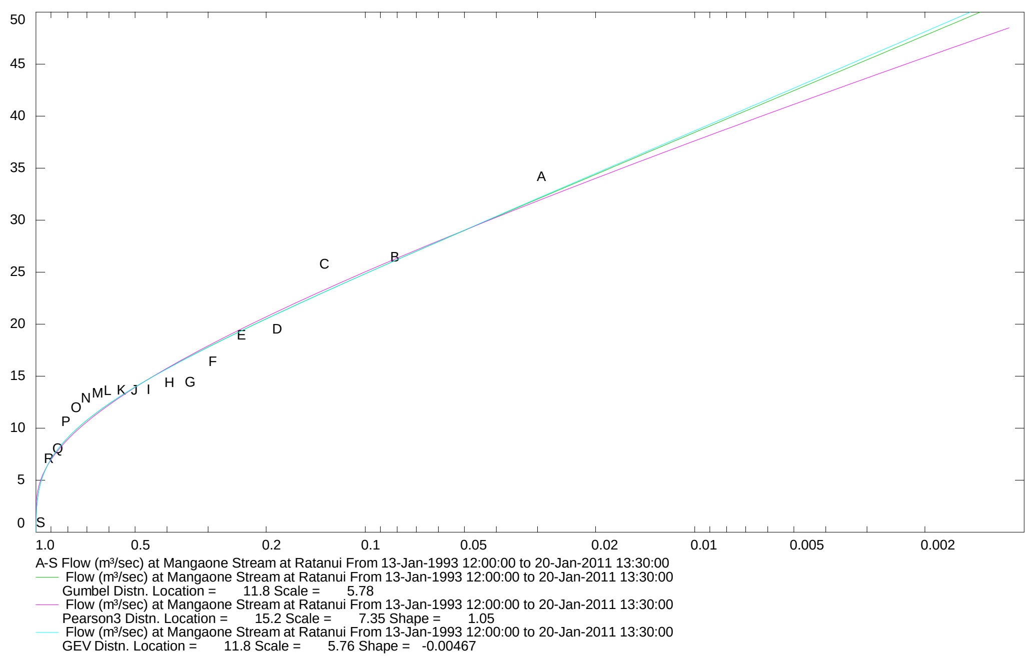

Figure 2-2 Flood frequency distributions for Mangaone Stream at Ratanui (1993-2010) (horizontal axis – AEP, vertical axis – discharge (m^3/s))

Figure 2-2 above shows the flood frequency distribution plots for the 1993-2010 flow record (Figure 2-1 shows the comparable frequency distribution plots for the much shorter 1993-2000 flow record which imply a very poor fit). Using the longer flow record now available, all the three distributions closely approximate the annual maxima flood series; although the PE3 estimates are slightly lower than the Gumbel and GEV estimates, especially for the more extreme events.

The Environmental Protection Agency's Technical Reviewer has queried whether there is any influence on the stream flow record of the Inter-decadal Pacific Oscillation (IPO). This is discussed in detail in Appendix E. The basic conclusion from the analysis of the stream flow record is that the 18 year long record is not long enough to determine with any certainty whether there is an effect on the record of the IPO or the related Southern Oscillation Index (SOI). While variations in the IPO and SOI indices appear to be associated with changes in the average stream flow, they do not appear to affect the maximum and minimum flows experienced.

As the series of annual maximum flows has been used above to derive flood frequency estimates for the stream (Table 2-2), it can be concluded then that the IPO is unlikely to have had any influence on the value of the flood estimates obtained.

2.4 Flood Frequency Estimates for Mangaone Stream at SH1 Crossing

The ratio of the difference in catchment areas $A^{0.8}$ (as per McKerchar and Pearson's (1989) regional flood frequency method) between Ratanui and the SH1 stream crossing implies a scaling factor of 2.22 (i.e. flows estimated using the Ratanui flow record should be increased 2.22 times to provide the equivalent design storm at SH1). Application of this scaling factor to the GEV flood frequency estimates obtained for the gauging station site gives the following flood estimates at the SH1 crossing.

Table 2-3 Flood frequency estimates for Mangaone Stream at SH1 crossing scaled as per McKerchar and Pearson's (1989) regional flood frequency method

AEP (%)	Flood Estimate (m^3/s)	
	Mangaone at Ratanui (GEV)	**Mangaone at SH1 Culvert (GEV)**
Scale Factor	1.00	2.22
42.9	15.2	33.7
20	20.5	45.5
10	24.9	55.3
5	29.0	64.4
2	34.5	76.6
1	38.6	85.7
0.5	42.7	94.8
0.2	48.1	106.8

However, as noted previously, a simple scaling of a flood estimates derived from an analysis of the Ratanui flow record as in Table 2-3 is likely to over-estimate corresponding flood magnitudes at the SH1 culvert (although scaling of flood volumes from recorded flood hydrographs may produce more reliable estimates). This is due to a range of factors including:

- differing rainfall / runoff relationships between the upper foothills part of the catchment and the lower coastal plain part of the catchment;
- the lower coastal plain part of the catchment receiving less rainfall because of less orographic enhancement;
- the flatter ground slopes on the lower coastal plain part of the catchment producing less runoff;
- infiltration through the alluvial gravels of the coastal plain into the groundwater system of overland flow and surface water in detention storage; and
- attenuation of overland flow peaks across the coastal plain by surface friction.

The flood routing predictions of the MIKE11 model used by MWH (2002b) in their floodplain hazard study for the Mangaone Stream provide an approximate indication of the attenuating effect on flood peaks of at least some of these factors, primarily the attenuation of overland flow peaks by surface friction. By comparing the summation of flood discharge predictions by the MIKE11 model at the SH1 main and overflow culverts with the peak total inflow to the model (represented by the summation of the Mangaone Stream at Ratanui flood inflow hydrograph and the rainfall / runoff model predicted runoff hydrographs for the lower part of the catchment), it is possible to estimate the attenuation of the flood flows across the coastal plain from the foothills to SH1. These estimated attenuation factors are given in Table 2-4.

Table 2-4 Estimated attenuation factors for Mangaone Stream flows across coastal plain from foothills to SH1 as predicted by MWH (2002b) MIKE11 model

AEP (%)	Attenuation Factor
10	0.835
2	0.833
1	0.796

From Table 2-4 it can be concluded that, for larger floods, an attenuation factor of 0.8 is probably a reasonable estimate of the degree of attenuation of peak discharges across the coastal plain to SH1. However an attenuation factor of 0.85 would provide an upper bound estimate which would be appropriate to use for sensitivity tests.

Table 2-5 summarises adjusted flood frequency estimates for the Mangaone Stream at the SH1 culverts based on assumed attenuation factors of 0.8 and 0.85 (flood estimates for the latter upper bound attenuation factor are given in brackets in the table). As noted for both the Ōtaki River and Waitohu Stream Catchments, the MfE (2010) Guidelines for estimating the effects of possible future climate change on flood flows suggest a mid-range estimate for increased average rainfall of +17% to 2090 for the Wellington and Manawatu regions. Table 2-5 therefore also summarises estimated values of the selected floods adjusted for the effects of climate change assuming the same forecast increase in average rainfall to 2090 applies to peak flood discharges.

Table 2-5 Adjusted flood frequency estimates for Mangaone Stream at SH1 crossing

AEP (%)	**Flood Estimate (m^3/s)**		
	Scaled from Ratanui flood estimate	**Adjusted for Attenuation Effects**	**Adjusted for Climate Change Effects to 2090**
Scaling Factor	1.00	0.80 (0.85)	1.17
5	64.4	(54.7)	(64.1)
2	76.6	(65.1)	(76.2)
1	85.7	68.6 (72.9)	80.2 (85.2)
0.5	94.8	75.8 (80.6)	88.7 (94.3)

2.5 Magnitude of 28 October 1998 Flood Event

The 28 October 1998 flood is an example of a recent historical flood event which is known to have inundated SH1 at Te Horo (see photograph on front cover of report). The peak flood discharge was measured as 22.0m^3/s at the Ratanui gauging station. This equates to about a 15% AEP flood based on the flood frequency data for the 1993-2010 annual flood maxima series in Table 2-2. The peak flood discharge at the Ratanui gauging station scales to a value of about 41.5m^3/s at the SH1 crossing when adjusted for the effects of attenuation by surface friction across the alluvial fan (Table 2-6).

Table 2-6 Estimated magnitude of 28 October 1998 flood event for Mangaone Stream at SH1 crossing

AEP (%)	**Flood Discharge (m^3/s)**		
	Mangaone at Ratanui	**Scaled from Ratanui to SH1 Crossing**	**Adjusted for Attenuation Effects to SH1 Crossing**
15	22.0	48.8	41.5

2.6 Distribution of Peak Flood Discharge at SH1Crossing

Figure 2-3 shows part of the Kāpiti Coast District Plan flood hazard map in the vicinity of the SH1 and NIMT railway crossings of the Mangaone Stream and Overflow. This shows a number of overland flow paths across the surface of the alluvial fan. Based on the results of the hydraulic model simulations carried out for the 2002 flood hazard assessment for the Mangaone Stream carried out for GWRC (MWH, 2002a, 2002b), the distribution of the peak flood discharge approaching the SH1 crossing of the Mangaone Stream and Overflow is estimated to be approximately as shown in Table 2-7 for the historic 28 October 1998 flood and the estimated 1% and 0.5% AEP floods adjusted for the effects of possible future climate change to 2090.

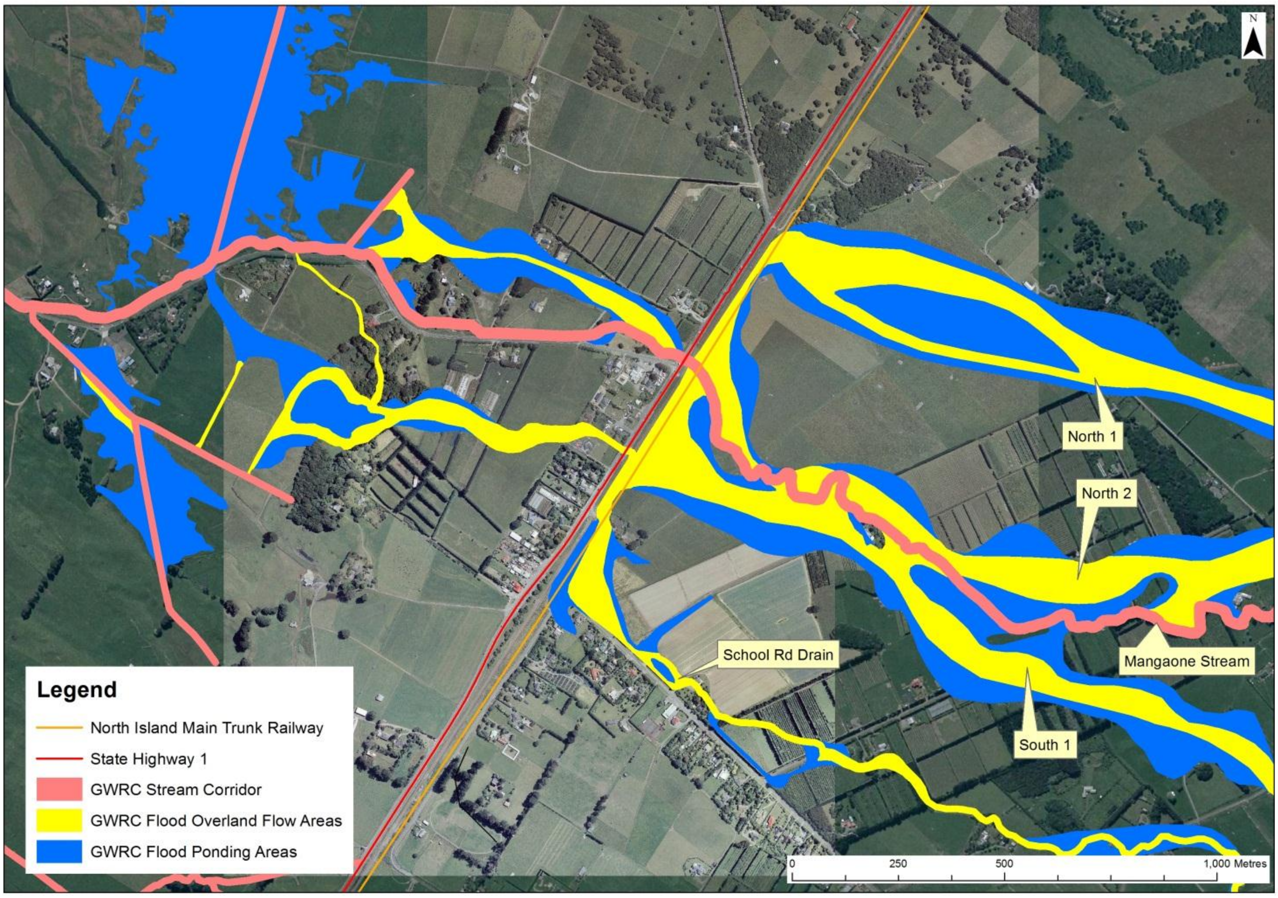

Figure 2-3 Flow paths for Mangaone Stream across surface of alluvial fan approaching SH1 crossing

Table 2-7 Estimated distribution of peak flood discharge across alluvial fan approaching SH1 crossing of Mangaone Stream and Overflow (for flow path locations, refer to Figure 2-3)

Flow Path	Proportion of Peak Flood Discharge for 28 October 1998 flood	Proportion of Peak Flood Discharge for 5% to 0.5% AEP floods adjusted for possible future climate change effects
North-2	0.075	0.075
North-1	0.280	0.370
River	0.470	0.325
South -1	0.100	0.155
School Rd	0.075	0.075
TOTAL	1.000	1.000

The assumed distribution of flow between the various flow paths given in Table 2-7 may not be entirely accurate over the whole range of flows considered but this is of no great consequence as the flows are redistributed by overland flow across the floodplain and by the culvert system under the NIMT railway line and SH1 in the existing situation and, in addition, the local link road and the Expressway in the proposed situation.

2.7 Flood Discharge Hydrographs for 5%, 1% and 0.5% AEP Floods

The measured flood discharge hydrograph at the Ratanui gauging station for the historic 28 October 1998 flood was used as a basis for obtaining flood discharge hydrographs for the 5%, 1% and 0.5% AEP floods adjusted for the effects of possible future climate change to 2090 for the Mangaone Stream and Overflow approaching the SH1 crossing. These hydrographs were distributed amongst the various overland and main stream channel flow paths according the proportions outlined in Table 2-7. Figure 2-4 shows the assumed flood discharge hydrographs for the various flow paths and as a whole for the 1% AEP flood adjusted for possible future climate change effects.

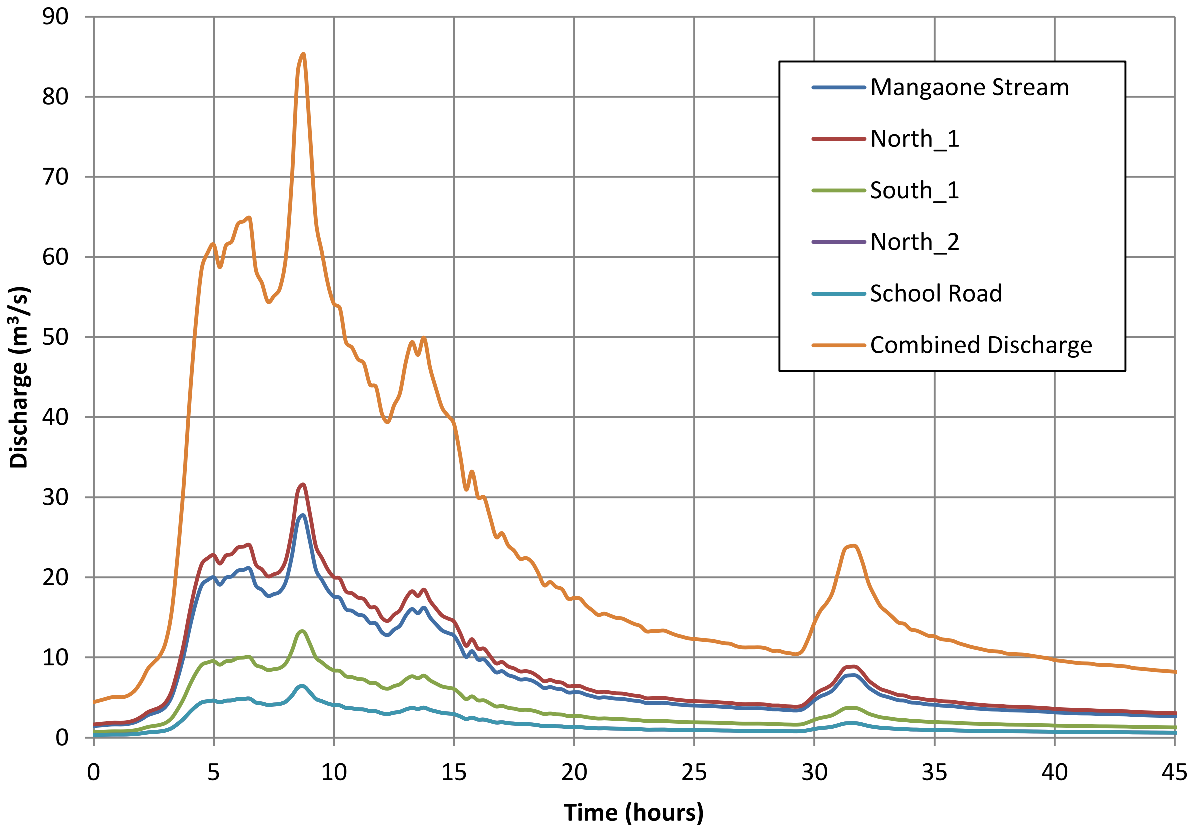

Figure 2-4 Assumed flood discharge hydrographs for main stream channel and overland flow paths approaching SH1 crossing of Mangaone Stream and Overflow for 1% AEP flood adjusted for possible future climate change effects to 2090

The EPA's Technical Reviewer has queried the choice of the flood hydrograph on which to base the design inflow hydrographs for the Mangaone Stream. The 28 October 1998 flood hydrograph from the upstream Ratanui gauging station with a peak discharge of 22m3/s (a 15% AEP flood approximately) was selected as the base hydrograph for these investigations. While this particular flood event is not the largest on record (a flood 7 days previously on 21 October 1998 with a peak of 34m3/s is the largest), relative to its peak it did have the largest volume. Consequently when scaled to produce hydrographs for the 5%, 1% and 0.5% AEP floods at the SH1 crossing of the Mangaone Stream, the resulting hydrographs had a slightly larger volume than would have been the case if they had been scaled from the measured 21 October 1998 flood hydrograph.

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

The 28 October 1998 flood hydrograph for the Mangaone Stream exhibited three distinct peaks over a period of about 6 hours. The choice of the hydrograph for this particular flood event as a base hydrograph for scaling flood hydrographs for the Mangaone Stream at the SH1 culvert was therefore rational and reasonable.

3. Treatment Philosophy for Expressway Crossing of Floodplain

SH1 has a history of being overtopped by floodwaters every few years in the immediate vicinity of the culvert system for the Mangaone Stream because the vertical alignment of the road is essentially at-grade through Te Horo. The stream channel downstream of the existing SH1 culvert also has limited channel capacity which results in extensive overland flow and floodplain inundation.

Construction of the Expressway past this location therefore represents an opportunity to improve the level of flood security to downstream properties. The Expressway will be constructed slightly above the ground surface but, in order to achieve the required level service at the Mangaone Stream and Overflow crossings, a bund will need to be constructed on the upstream side of the road. This bund will function as a flood detention barrier. Under significant flood conditions, floodwaters will pond upstream of the expressway embankment as they currently do upstream of the NIMT railway embankment.

The 1% AEP flood adjusted for possible future climate change effects to 2090 was adopted as the Serviceability Limit State flood for the Expressway crossing of the Mangaone Stream alluvial fan and floodplain system in accordance with the guidelines of the NZ Transport Agency's *Bridge Manual* (Transit NZ, 2003). The same document indicates that culverts under the Expressway on the main stream channel and providing continuity for existing overland flow paths across the alluvial fan would require a minimum design freeboard allowance of 500mm. Structural considerations would also require a minimum depth of fill over any culvert.

The local link road providing east / west connectivity across the Expressway between School Road and Te Horo Beach Road will also cross the main channel of the Mangaone Stream twice, the overland flow path leading to the Mangaone Overflow culvert system (within the flood ponding area upstream of the bund protecting the Expressway) and the Lucinsky Overflow. Based on the importance level of the local link road, the Serviceability Limit State flood according to the guidelines of the NZ Transport Agency's *Bridge Manual* (Transit NZ, 2003) for these stream and overland flow path crossings would be either the 4% or 2% AEP flood adjusted for possible future climate change effects to 2090. The minimum design freeboard allowance of 500mm would also apply to the culvert structures forming these crossings.

The existing Mangaone and Lucinsky Overflows form an integral part of the alluvial fan drainage system to ease floods past the residential areas of Te Horo. It is a critical design requirement that this drainage system continues to function as intended after the Expressway is constructed with these overland flow paths not impeded adversely.

4. Hydraulic Performance in Current Situation

4.1 Outline of Existing Situation

Figure 4-1 shows an aerial photograph of the SH1 and NIMT railway crossings of the Mangaone Stream in its present form. Both transport links run essentially parallel with each other across the alluvial fan surface with the NIMT railway line on the "uphill" side. The railway line sits slightly elevated above the fan surface on a ballasted embankment which acts as a flood detention barrier for floodwaters flowing across the fan surface as seen in Figure 4-2. There are two culverts under the embankment to provide passage for flood flows – one on the main stream and another to the south known as the Mangaone Overflow (seen in the distance in Figure 4-3). SH1 runs at grade across the alluvial fan surface and also incorporates two culverts, one in series with the NIMT railway culvert on the main stream channel and the other in series with the NIMT railway culvert on the Mangaone Overflow (Figure 4-1). Appendix D contains photos of the existing culverts and flow channels.

The SH1 crossing of the Mangaone Stream and Overflow is a known flooding hotspot with the road having been overtopped by floodwaters on a number of occasions in recent years. Figures 4-2 shows a photograph of the aftermath of one such event on 28 October 1998[4], although by the time the photograph was taken, any floodwaters inundating SH1 had receded. In addition to ponding of floodwaters upstream of the NIMT railway embankment, Figure 4-2 also shows evidence of overland flow in a secondary distributor channel cross the alluvial fan upstream of SH1 and breakout of floodwaters along the true right downstream of the main SH1 culvert through a dedicated secondary flow path known as the Lucinsky overflow channel (Figure 4-1).

Figure 4-3 shows another photograph of the same 28 October 1998 flood event looking in a south-easterly direction across Te Horo Village and the two existing primary transport links towards School Road. This provides evidence of the downstream overland flow path followed by flood flows conveyed by the overflow culvert system under the NIMT railway line and SH1. This follows a course across the alluvial fan surface between some of the houses in Te Horo Village on the western side of SH1 before crossing Te Horo Beach Road to re-join the main stream channel (refer to the Kāpiti Coast District Plan flood hazard in Appendix A).

The indication in Figure 4-2 of flood breakout from the main stream channel downstream of the SH1 culvert on the main channel of the Mangaone Stream highlights anecdotal evidence provided by local residents of existing flooding problems along Te Horo Breach Road.

Figure C-7 in Appendix C shows the flood inundation patterns predicted for the 28 October 1998 flood. This suggests that floodwaters probably overflowed SH1 at several locations through Te Horo Village (including at the Mangaone Overflow) as well as to the north of the village around the intersection of Te Waka Road with SH1. It is not known how accurate these predictions are including whether the overflow locations are correct and whether the extent of inundation is quite as widespread as that shown. The road overflow locations and most of the inundated areas are predicted to have very shallow peak flow depths (less than 0.2m).

[4] This flood event is estimated to have had an annual exceedance probability of about 15%.

The photographs shown in Figures 4-2 and 4-3 of the aftermath of the 28 October 1998 flood are the best information available with which to validate the MIKEFLOOD model predictions. Some photographic evidence is available for other earlier flood events (MWH, 2002b) but there is no flow record for these events and they were estimated to be smaller than the 28 October 1998 flood.

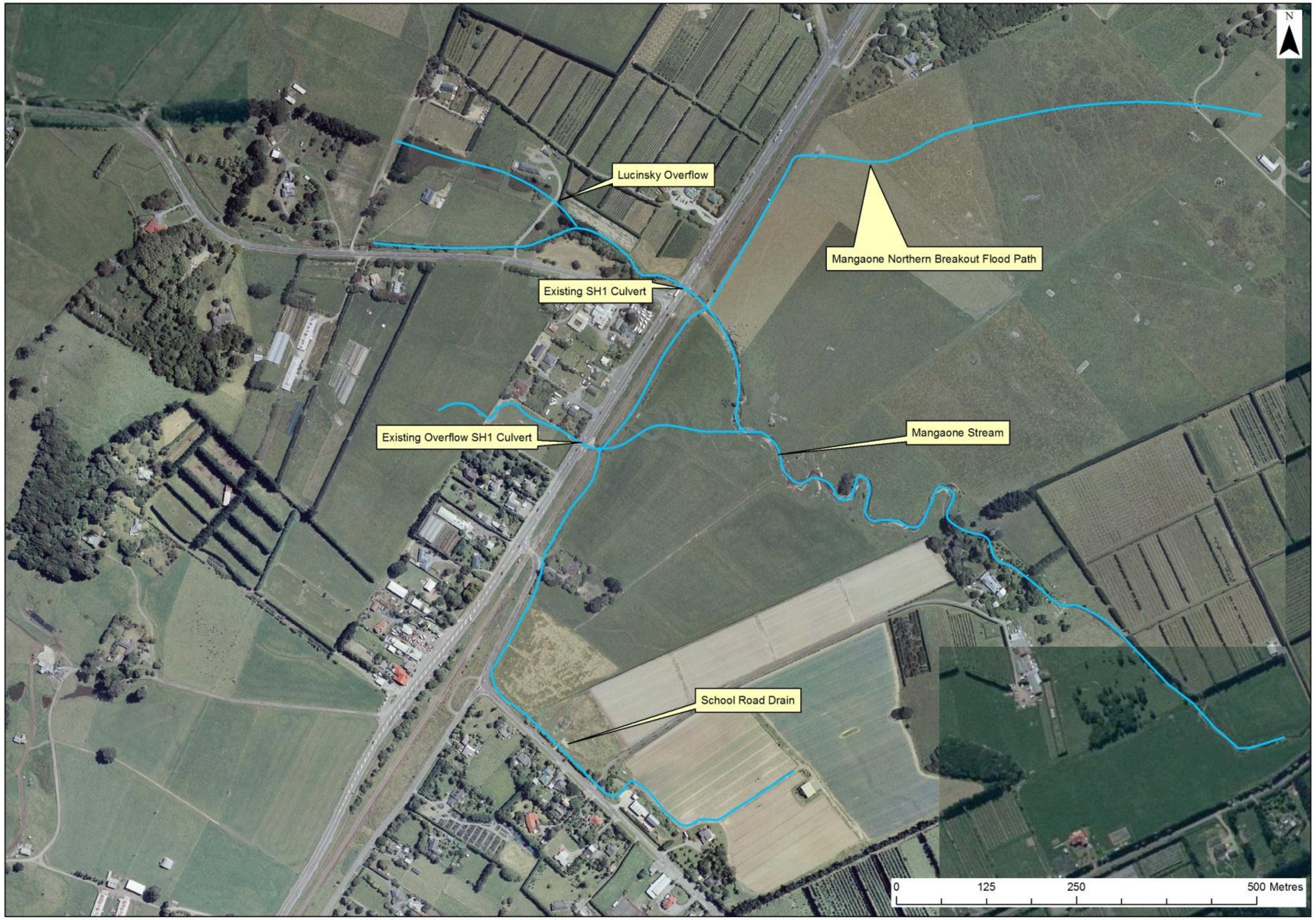

Figure 4-1 Aerial photograph showing existing SH1 and NIMT railway crossings of Mangaone Stream with main drainage paths marked

Figure 4-2 28 October 1998 flood in Mangaone Stream - view looking east across SH1 and NIMT railway line crossings of stream (photograph courtesy of GWRC)

Figure 4-3 28 October flood in Mangaone Stream - view looking south-east across Te Horo Village, SH1 and NIMT railway line with School Road in distance stream (photograph courtesy of GWRC)

Other anecdotal evidence provided by local residents has highlighted further flooding issues in the vicinity of School Road arising from historical interference with natural drainage paths across the alluvial fan surface associated with the Mangaone Stream. The School Road drain (Figure 4-1) conveys floodwaters from a historically modified distributor channel to the overflow system under the NIMT railway line and SH1. However, from on-site observation, the size and flow capacity of the upstream channel, which skirts around the boundary of a horticultural property opposite the Te Horo Community Hall, is significantly greater than the size and capacity of the drain running alongside School Road. Whenever the upstream channel flows full, floodwaters will inevitably break out of the School Road drain and cause an inundation nuisance across the road and on neighbouring residential properties.

Table 4-1 summarises culvert types, dimensions and levels for the NIMT railway and SH1 main stream and overland flow path crossings on the Mangaone Stream alluvial fan and floodplain system

Table 4-1 Culvert types, dimensions and levels for NIMT railway and SH1 crossings on Mangaone Stream and Overflow

Location	**Type**	**Size (m)**	**Invert Level (m MSL Wellington (1953))**		**Length (m)**	**Slope (%)**	**Road Level (m MSL Wellington)**
			u/s	d/s			
Mangaone Stream							
NIMT railway - existing	box	3.00 x 2.38	16.34	16.34	4.4	0.0	19.34
SH1 - existing	box	4.00 x 1.76	16.64	16.30	15	2.3	18.65
Mangaone Overflow							
NIMT railway - existing	box (2 cells)	3.00 x 2.05 (1 cell)	15.53	15.48	5.0	1.0	19.24
SH1 - existing	box	3.70 x 1.95	15.08	15.08	13.6	0.0	17.74

The two culvert systems on the main stream channel and on the overflow will operate under outlet controlled conditions due to the backwater effect of the downstream channel in each case. However it is worth noting that the discharge capacity of the SH1 culvert on the main stream channel slightly exceeds the discharge capacity of the upstream NIMT railway culvert. In contrast, due to the large disparity is size between the NIMT railway and SH1 culverts on the overflow, the discharge capacity of the fairly new railway culvert (again based on inlet control conditions) significantly exceeds the discharge capacity of the downstream SH1 culvert. This situation will inevitably lead to overtopping of the existing SH1 in a large enough flood.

4.2 Flood Inundation Predictions for Existing Situation for 1% AEP Flood

Figures 4-4a and b shows the extent of flood inundation and the ranges of peak flood depths across the alluvial fan and floodplain predicted by the MIKEFLOOD model for the 1% AEP flood adjusted for the effects of possible .future climate change to 2090. Figure 4.4a focuses on the immediate area of the SH1 and NIMT railway crossings of the Mangaone Stream and overflow while Figure 4.4b covers the wider area represented by the MIKEFLOOD model. Figure 4-5 shows the predicted flood extent (indicated by the pink hatching) overlaid on the flood hazard map from the Kāpiti Coast District Plan.

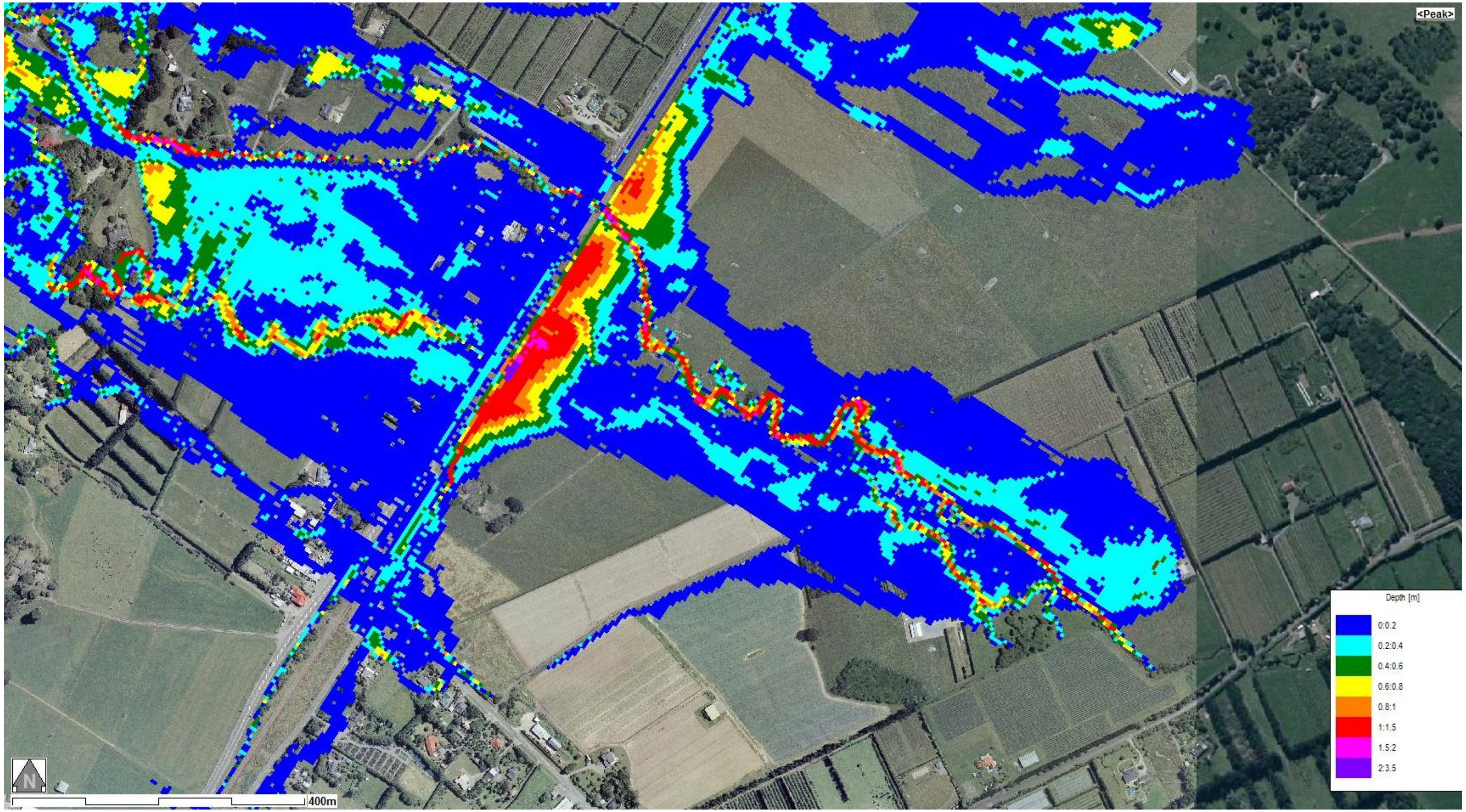

Figure 4-4a Predicted flood depths across Mangaone Stream alluvial fan and floodplain system in existing situation for 1% AEP flood adjusted for possible future climate change effects to 2090

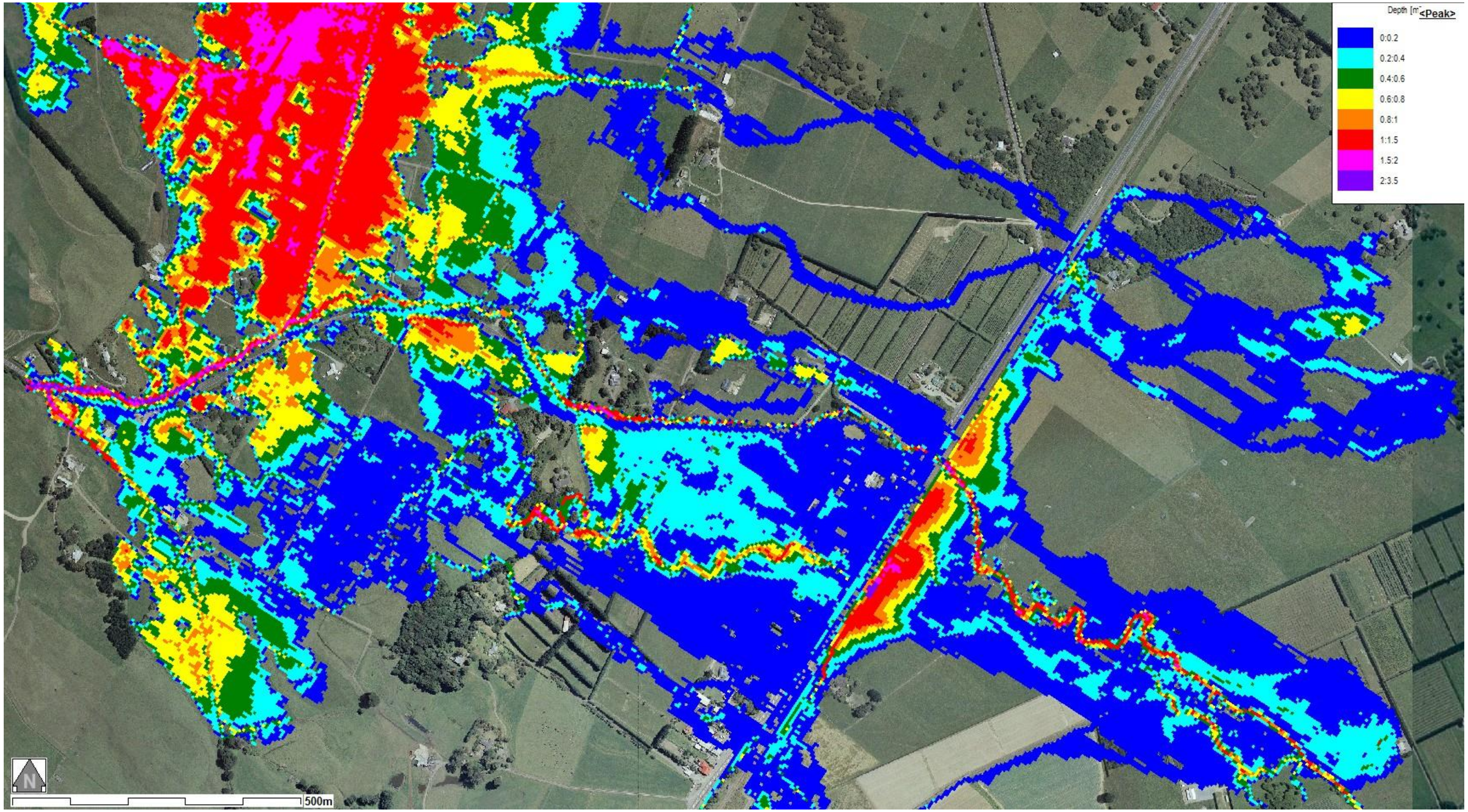

Figure 4-4b Smaller scale view of flood inundation pattern across Mangaone Stream alluvial fan and floodplain system in existing situation for 1% AEP flood adjusted for possible future climate change effects to 2090

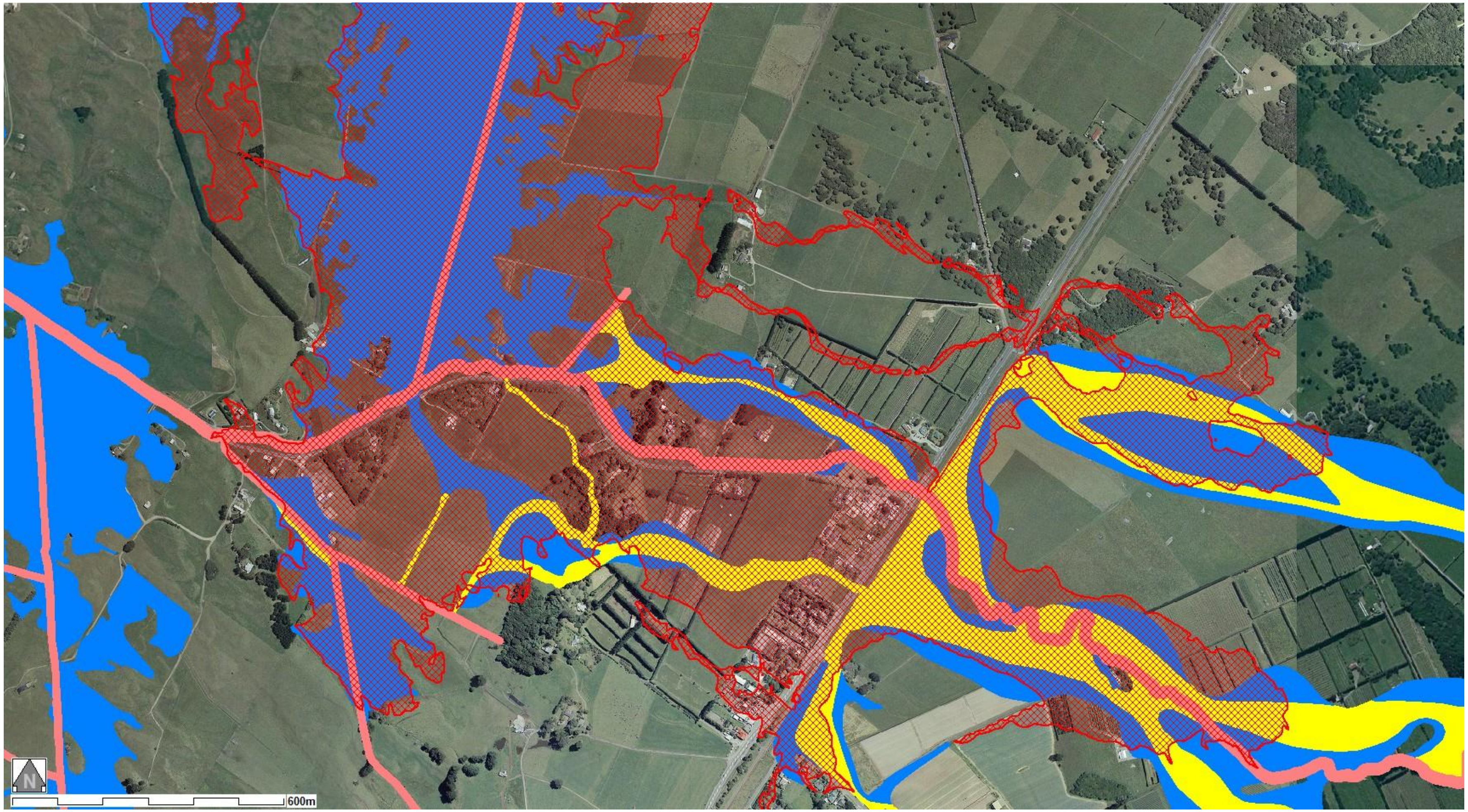

Figure 4-5 Predicted flood extent across Mangaone Stream alluvial fan and floodplain system in existing situation for 1% AEP flood adjusted for possible future climate change effects compared to flood extent on Kāpiti Coast District Plan flood hazard map

Figure 4-5 indicates that, although the MIKEFLOOD model satisfactorily reproduces the predominant overland flow paths shown on the District Plan flood hazard map, the extent of flood inundation is predicted to be much more widespread, particularly to the west of SH1. The main reason for this is the difference in peak flood estimates for the 1% AEP flood adjusted for possible future climate change effects from the flood hazard assessment on which the District Plan flood hazard map is based (MWH, 2002a and b) and from this investigation (43.6m^3/s, Table 2-1, and 85.2m^3/s, Table 2-6, respectively). However a secondary reason is that the one-dimensional computational hydraulic modelling used to predict the flood hazard extent for the District Plan map required overland flow paths to be predetermined (probably from previously observed flow paths) so that all flow paths for the simulated extreme flood are not necessarily correctly identified.

Key observations from the predicted flood inundation pattern shown in Figures 4-4a and b for the 1% AEP flood adjusted for possible future climate change effects are:

- The predominant overland flow paths follow the course of natural dry channels across the alluvial fan and floodplain.
- Significant ponding to depths of 1.5-2m occurs upstream of the NIMT railway line over a distance of nearly 900m. However the extent of ponding in the upstream direction is limited to less than 100m due to the steepness of the slope of the alluvial fan.
- Overland flow on the upstream (eastern) side of the NIMT railway line is generally very shallow mostly less than 0.2m but up to a maximum of 0.4m in places away from the main stream channel.
- The northern overland flow path breaks out into several old dry channels across the alluvial fan surface upstream of the NIMT railway line. These channels intercept the railway embankment and result in floodwaters ponding upstream and then spreading southwards towards the main channel of the Mangaone Stream.
- Overtopping of the NIMT railway line and SH1 occurs:
    - opposite the intersection of School Road and Gear Road on the east side of the NIMT railway line (from the School Road drain);
    - intermittently between the School Road / Gear Road intersection and the Mangaone Overflow;
    - intermittently between the Mangaone Overflow and the main stream channel; and
    - opposite the SH1 / Te Waka Road intersection on the west side of SH1 (from the northern overland flow path).
- In addition overtopping of SH1 occurs at the Mangaone Overflow and the main stream channel.
- Extensive inundation occurs through Te Horo Village on the western side of the SH1 although the peak flow depths are very shallow (mostly less than 0.2m),
- The Lucinsky Overflow (Figure 4-1) forms a shallow 70-90m wide overland flow path breaking out along the north (right) bank of the main stream channel downstream of the SH1 culvert. Floodwaters overtopping SH1 and spreading northwards along SH1are the source of flow along the Overflow as a low bank along the right bank of the stream channel prevents floodwaters form breaking out of the channel.

- The NIMT railway / SH1 overflow originating from opposite the School Road / Gear Road intersection continues to follow old dry channels westwards across the alluvial fan surface on the south side of Te Horo Village with peak flow depths less than 0.2m.
- The NIMT railway / SH1 overflow at the SH1 / Te Waka Road intersection also continues to follow old dry channels westwards across the alluvial fan surface.
- All overflow paths west of SH1 are directed towards a floodplain storage area on the eastern side of a line of inland sand hills. The peak flow depths in this long linear storage area are much deeper (1.5-2m) to the north of Te Horo Beach Road.
- Floodwaters drain away from this ponding area via a narrow drain through the sand hills about 600m north of Te Horo Beach Road. Other floodwaters flowing along the main stream channel and overland across the alluvial fan surface to the south of Te Horo Beach Road drain through the narrow gap in the sand hills occupied by the road and the main stream channel.

Figures 4-6 and 4-7 show stage and discharge hydrographs respectively around the NIMT railway and SH1 crossings of the main stream channel. The stage hydrographs in Figure 4-6 confirm that the culvert system is outlet controlled (i.e. the discharge through the SH1 culvert is controlled by tailwater level conditions in the downstream channel while the discharge through the NIMT railway culvert is controlled by the headwater level upstream of the SH1 culvert). The stage hydrographs in Figure 4-6 indicate that SH1 overflows to a peak flow depth of about 0.25m (refer Table 4-1 for road level). The discharge through the SH1 culvert is reduced compared to that through the upstream rail culvert due to the lateral spread of floodwaters along the roadside drain between the railway line and the road (see Figure 4-4).

Similarly Figures 4-8 and 4-9 show stage and discharge hydrographs respectively around the NIMT railway and SH1 crossings of the Mangaone Overflow. As with the culverts on the main stream channel, the stage hydrographs in Figure 4-8 indicate that the culvert system on the overflow is also outlet controlled (i.e. the discharge through the SH1 culvert is controlled by tailwater level conditions in the downstream overflow channel while the discharge through the NIMT railway culvert is controlled by the headwater level upstream of the SH1 overflow culvert). Floodwaters up to about 0.45m deep (refer Table 4-1 for road level) are predicted to overtop SH1 at the overflow crossing due to the significant mismatch in discharge capacities of the SH1 culvert and the upstream NIMT railway culvert. These road overtopping floodwaters spread north and south along SH1. The NIMT railway culvert conveys up to 40m^3/s peak discharge while the SH1 culvert only conveys 25m^3/s, a 37.5% reduction.

The road overflow hydrographs in Figures 4-7 and 4-9 only accounts for the volume of overflow within the width of the main stream and overflow channels respectively so that they underestimate the total volume of road overflow from floodwaters spreading north and south of these culvert locations.

Comparison of Figures 4-7 and 4-9 demonstrates that the overflow culvert system conveys the majority of the total flow compared to the main stream channel culvert system for the 1% AEP flood adjusted for possible future climate change effects. This equates to nearly 50% more peak flow volume.

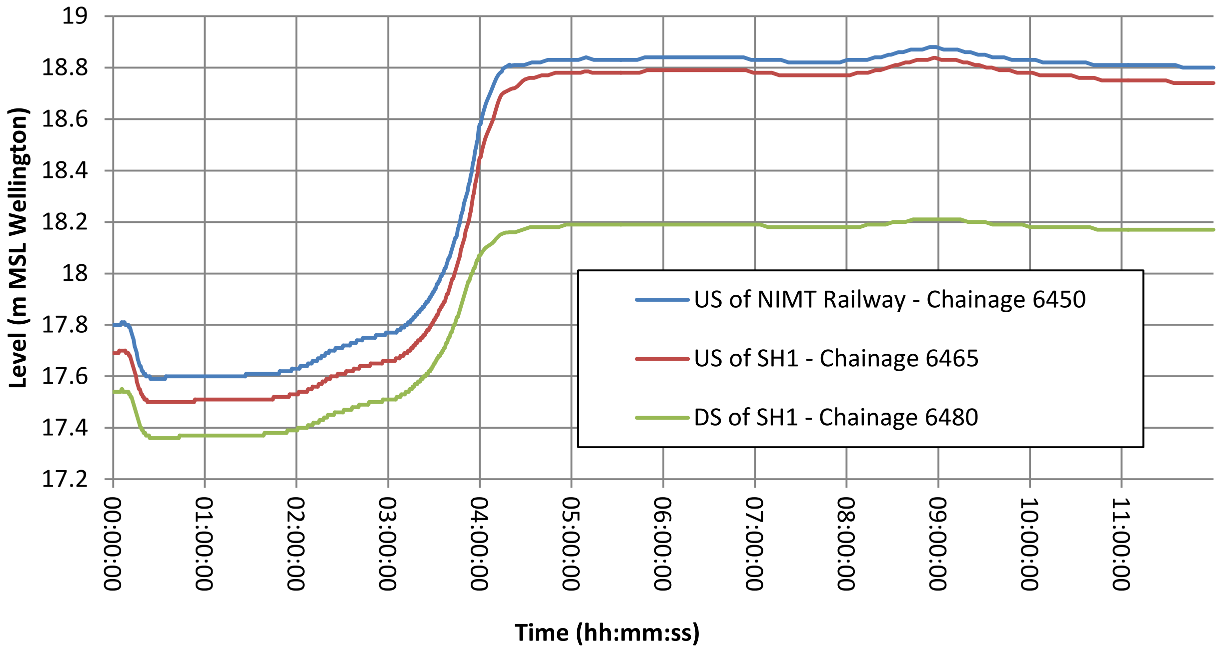

Figure 4-6 Predicted stage hydrographs upstream of NIMT railway crossing and upstream and downstream of SH1 crossing of main stream channel for 1% AEP flood adjusted for possible climate change effects to 2090

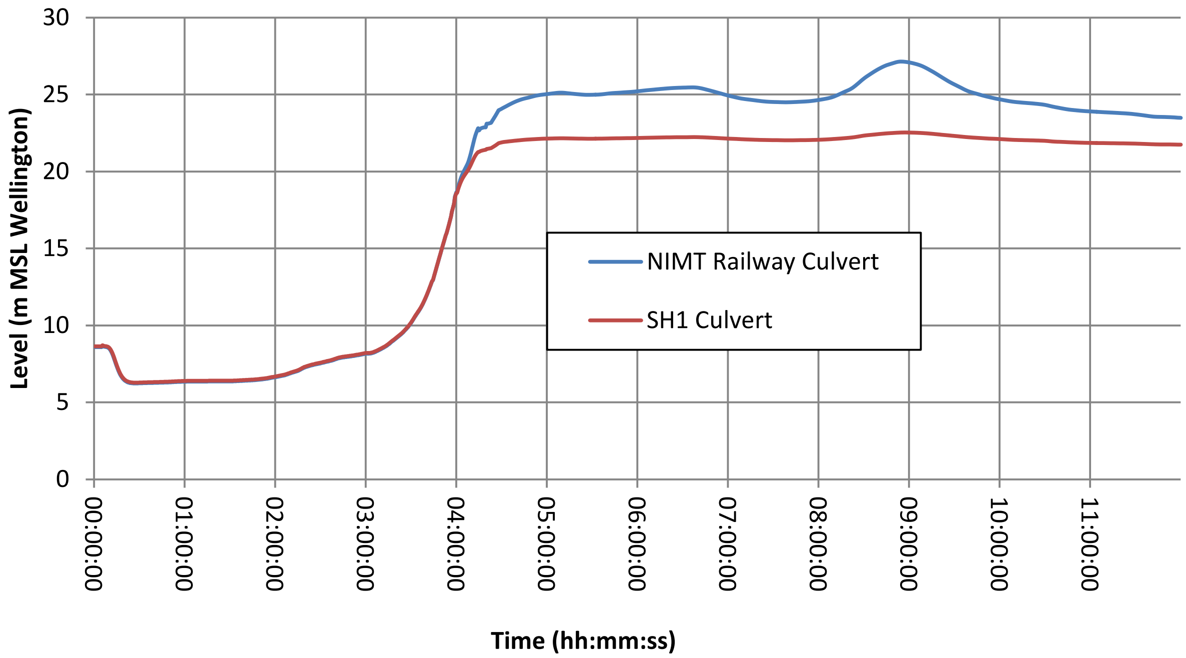

Figure 4-7 Predicted discharge hydrographs at NIMT railway and SH1 crossings of main stream channel for 1% AEP flood adjusted for possible climate change effects to 2090

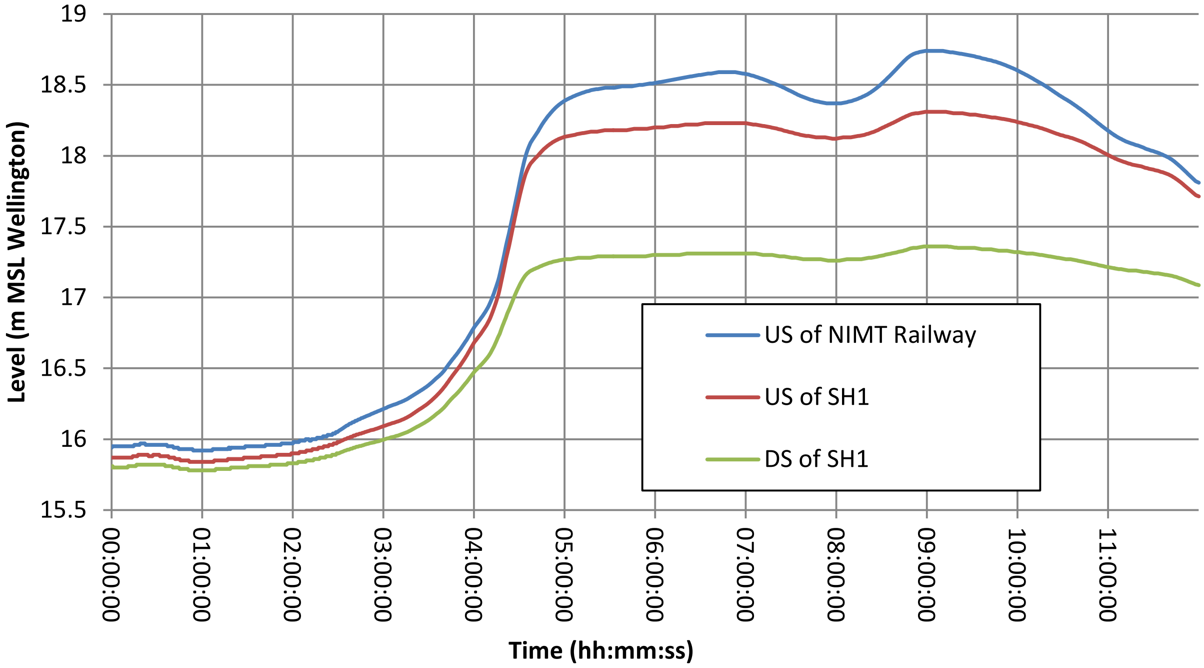

Figure 4-8 Predicted stage hydrographs upstream of NIMT railway crossing and upstream and downstream of SH1 crossing of Mangaone Overflow for 1% AEP flood adjusted for possible climate change effects to 2090

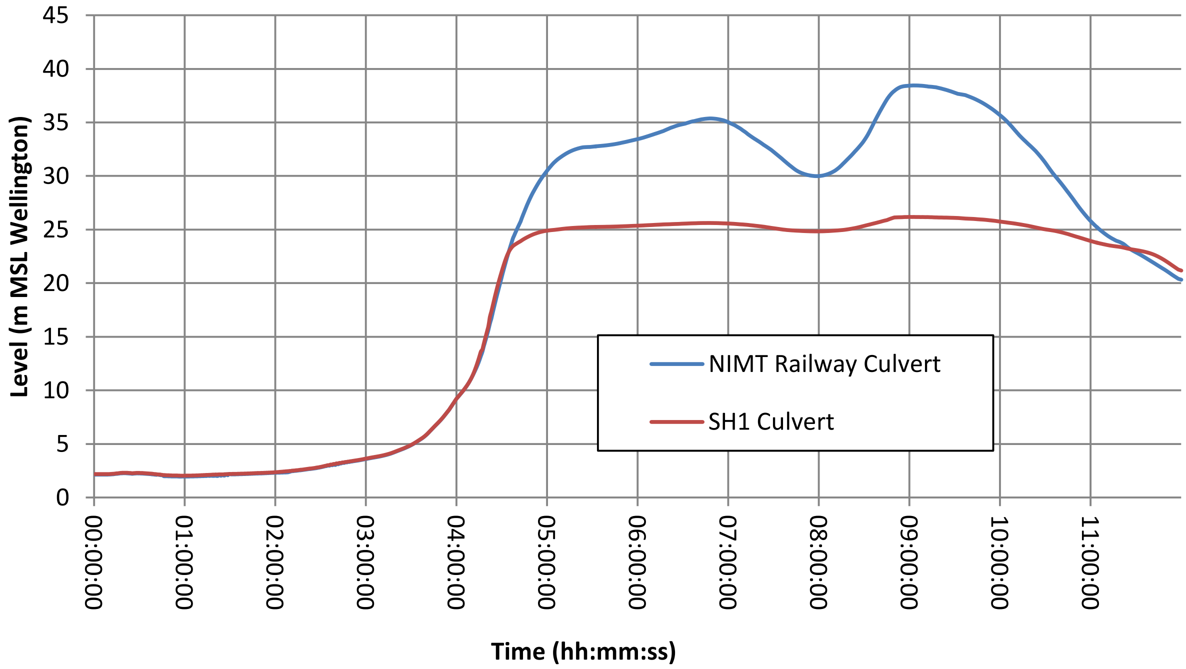

Figure 4-9 Predicted discharge hydrographs at NIMT railway and SH1 crossings of Mangaone Overflow for 1% AEP flood adjusted for possible climate change effects to 2090

Table 4-2 summarises the predicted peak flood levels and discharges upstream of the existing NIMT railway and SH1 crossings of the Mangaone Stream and Overflow for the 1% AEP flood adjusted for possible future climate change effects.

Table 4-2 Predicted peak flood levels and discharges for existing NIMT railway and SH1 crossings of Mangaone Stream and Overflow for 1% AEP and 0,5% AEP floods adjusted for effects of possible future climate change to 2090

Location	Peak Flood Level (m MSL Wellington datum) *		Peak Flood Discharge (m^3/s)	
	1% AEP Flood	0.5% AEP Flood	1% AEP Flood	0.5% AEP Flood
Mangaone Stream				
NIMT railway – existing culvert	18.89 US 18.88 DS	18.91 US 18.78 DS	27.1	28.1
SH1 – existing culvert	18.88 US 18.23 DS	18.78 US 18.25 DS	22.9 culvert 1.8 road overflow	23.0 culvert 2.0 road overflow
Mangaone Overflow				
NIMT railway – existing culvert	18.68 US 18.20 DS	18.71 US 18.58 DS	40.1	40.4
SH1 – existing culvert	18.20 US 17.31 DS	18.22 US 17.32 DS	25.2 culvert 1.2 road overflow	25.3 culvert 1.4 road overflow

* Note that flood levels in this table are given to two decimal places because large increases in flood discharge result in only small increases in flood level.

Complementing Figure 4-4, Figure 4-10a shows peak flow velocities across the floodplain predicted by the MIKEFLOOD model for the 1% AEP flood adjusted for the effects of possible future climate change to 2090. This figure highlights quite graphically the original course of the Mangaone Stream now followed by the Mangaone Overflow. Peak flow velocities along this overland flow path are predicted to be considerably higher than elsewhere across the alluvial fan surface (except in the main stream channel) with values typically in the range 1-1.5m/s and pockets as high as 1.5-2m/s. Elsewhere across the alluvial fan surface flow velocities are much lower (0.2-0.4m/s).

Figure 4-10b shows an alternative version of Figure 4-10a around the existing SH1 and NIMT railway crossings of the Mangaone Stream and Overflow with velocity vectors superimposed to indicate the directions of overland flow paths. This figure reinforces the understanding obtained from Figure 4-10a that the majority of the total flood flow follows the course of the Mangaone Overflow under and over the NIMT railway line and SH1 and through the middle of the part of Te Horo Village to the west of SH1. Figure 4-10b also indicates that the NIMT railway line acts as a partial barrier to flood flows by:

- directing School Road drain flows northwards towards the Mangaone overflow (excluding any flow which overtops the railway line and continues in a north-westerly direction); and also by
- directing flows in the northern overland path southwards towards the main channel of the Mangaone Stream (again excluding any flow which overtops the railway line and continues in a north-westerly direction).

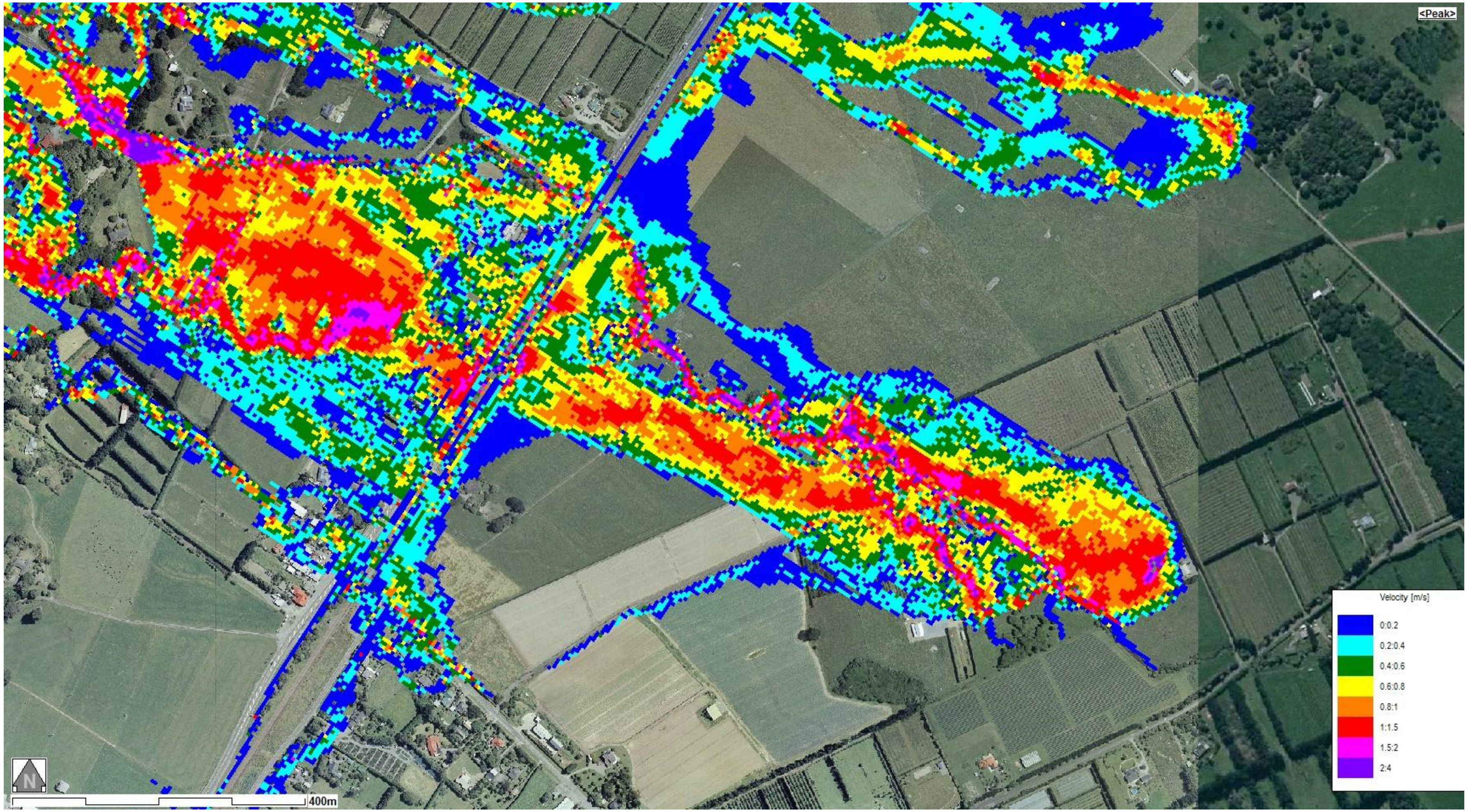

Figure 4-10a Predicted flow velocities across Mangaone Stream alluvial fan and floodplain system in existing situation for 1% AEP flood adjusted for possible future climate change effects to 2090

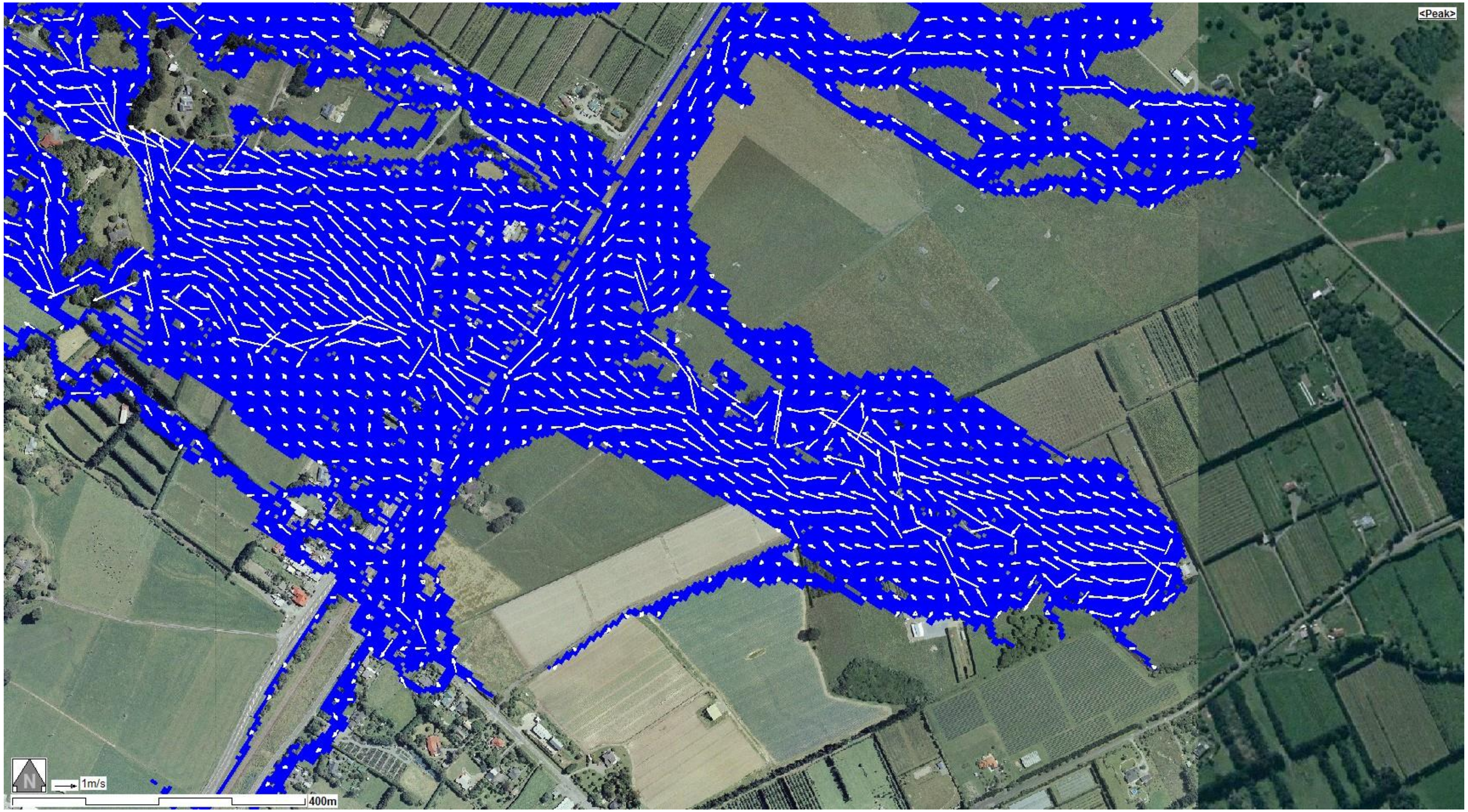

Figure 4-10b Blown-up section of Figure 4-6b showing velocity vectors for overland flow past the existing SH1 and NIMT railway crossings of the Mangaone Stream and Overflow

4.3 Sensitivity Tests for Existing Situation

As a sensitivity test, the MIKEFLOOD model was also used to simulate the flood pattern across the alluvial fan and floodplain resulting from the 0.5% AEP flood adjusted for the effects of possible future climate change to 2090. This represents an increase in flood magnitude of about 10 per cent relative to the 1% AEP flood adjusted for possible future climate change effects (88.7m^3/s for the 0.5% AEP flood compared to 80.2m^3/s for the 1% AEP flood – see Table 2-5). Figure 4-11 shows the resulting flood pattern and the range of peak flood depths. Similarly Figure 4-12 shows the distribution and range of peak flow velocities.

The flood inundation pattern for the 0.5% AEP flood adjusted for possible future climate change effects is very similar to that for the 1% AEP flood (also adjusted for possible future climate change effects) in Figure 4-4a with only a marginally greater extent. Peak overland flow depths are still fairly shallow (mostly less than 0.2m with some slightly deeper areas up to 0.4m. Some additional old distributor channels across the alluvial fan surface are also evident.

Figure 4-12 highlights even more emphatically than Figure 4-10a for the 1% AEP flood adjusted for possible future climate change effects that the primary flow path follows the course of the Mangaone Overflow upstream of the NIMT railway line and then through the middle of Te Horo Village to the west of SH1. The extent of flow velocities in the range 1.5-2m/s is more extensive than in Figure 4-10a.

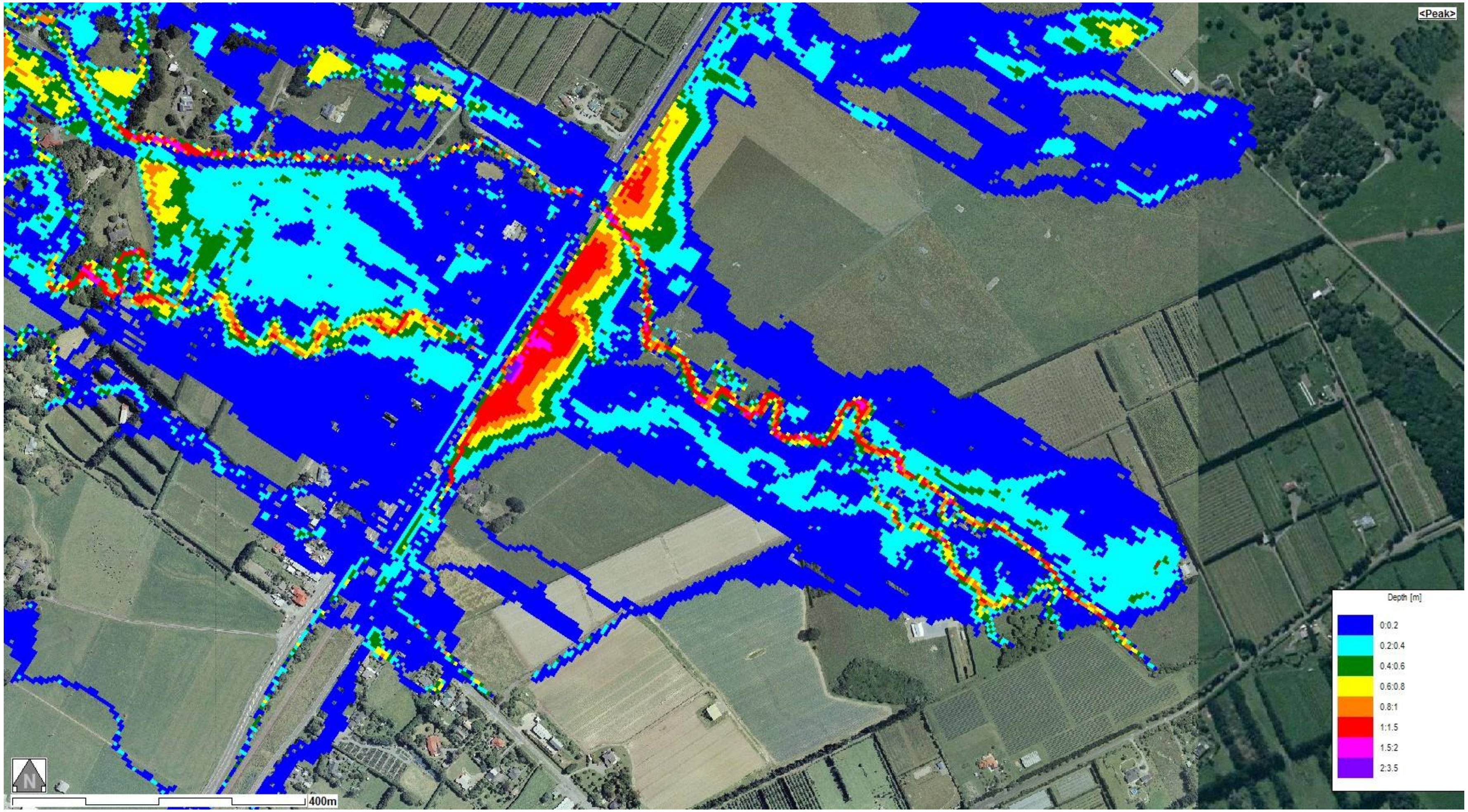

Figure 4-11 Predicted flood depths across Mangaone Stream alluvial fan and floodplain in existing situation for 0.5% AEP flood adjusted for possible future climate change effects to 2090

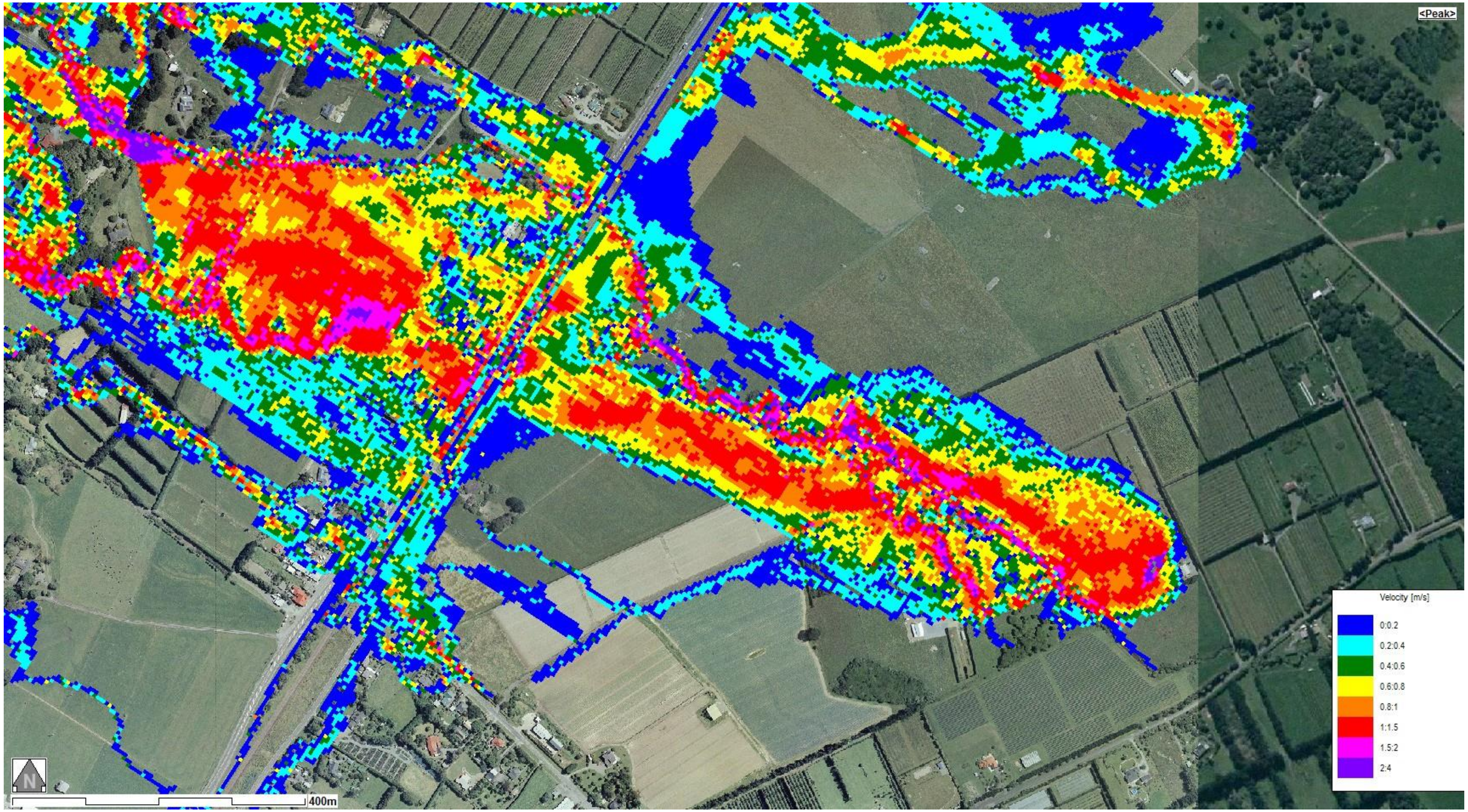

Figure 4-12 Predicted flow velocities across Mangaone Stream alluvial fan and floodplain system in existing situation for 0.5% AEP flood adjusted for possible future climate change effects to 2090

5. Hydraulic Performance in Proposed Expressway Situation

5.1 Outline of Proposed Situation

Figure 5-1a shows an aerial photograph of the existing SH1 and NIMT railway crossings of the Mangaone Stream and Overflow with the layout of the Expressway and the local link road superimposed. The Expressway requires very long culverts on both the main stream channel and the overflow to provide continuity with the existing SH1 and NIMT railway culvert systems immediately downstream on each watercourse. The local link road similarly requires culverts of both watercourses. In addition the local link road also requires:

- a culvert on the School Road drain where this has been relocated to run parallel with the realigned Gear Road;
- either a wide (~ 10m) gap between the flood detention barrier upstream of the Expressway and the eastern abutment to the local link road overbridge or a dry culvert through the eastern approach embankment) in order to provide continuity for the overland flow path between the northern overland flow system and the main stream channel (the wide gap option would require the overbridge to have an additional span);
- a dry culvert through the western approach embankment to the overbridge to provide continuity for the existing Lucinsky Overflow: and
- a single span bridge crossing on the main stream channel on the western side of SH1where it approaches the tee interception with Te Horo Beach Road.

Table 5-1 gives the dimensions and levels of these culverts (in addition to those of the existing SH1 and NIMT railway culverts) and Table 5-2 gives the dimensions of the single span bridge on the local link road along with those of other existing bridges on the Mangaone Stream downstream of the SH1 crossing. The dimensions and levels of the latter bridges were obtained mostly from the 2002 flood hazard assessment carried out for GWRC by MWH (2002a and b). The new culverts on the main stream channel will need to be formed from over-deep box culvert units so that a gravel streambed material layer can be used to form the channel invert through each culvert in order to facilitate fish passage and allow normal sediment transport processes to continue.

Figure 5-1a also shows the layout of the main drainage paths linking these culverts and bridge which are represented mostly by the one-dimensional MIKE11 component of the MIKEFLOOD model that was developed to evaluate flood inundation patterns and extents across the alluvial fan and floodplain.

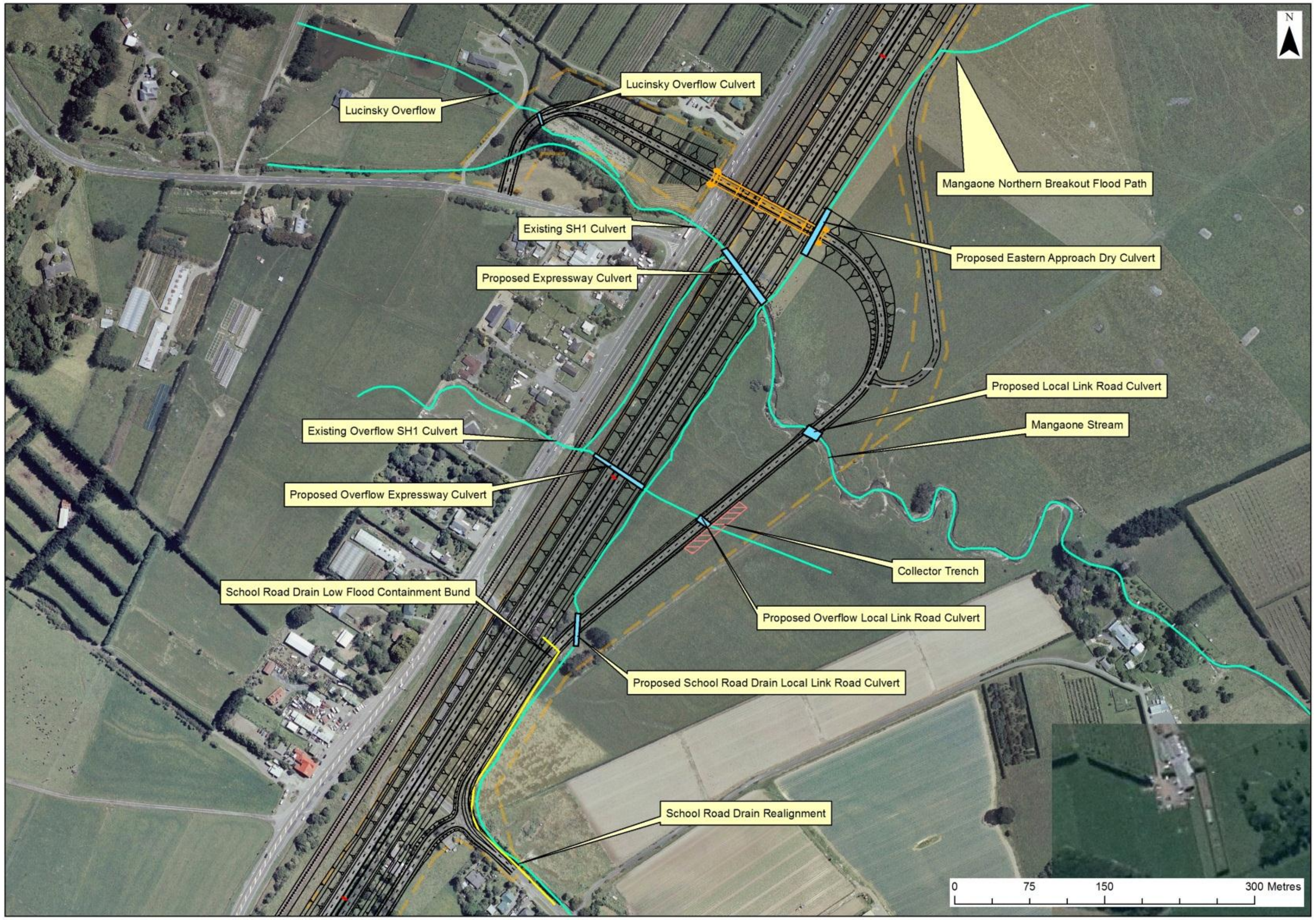

Figure 5-1a Proposed treatment measures to mitigate effects of Expressway on flows across Mangaone Stream alluvial fan and floodplain system resulting from an extreme flood

Table 5-1 Culvert types, dimensions and levels for proposed and other existing transport links

Location	Type	Size (m)	Invert Level (m MSL Wellington (1953))		Length (m)	Slope (%)	Road Level (m MSL Wellington)
			u/s	d/s			
Mangaone Stream							
Local link road (eastern side) proposed	box	5.0 x 2.5 [2]	19.27	19.10	16	1.06	22.30 (minimum)
Expressway – proposed	box	5.0 x 2.0 [2]	17.17	16.70	50	0.94	19.77 (at road chge 7250m)
NIMT railway - existing	box	3.00 x 2.38	16.34	16.34	4.4	0.0	19.34
SH1 - existing	box	4.00 x 1.76	16.64	16.30	15	2.3	18.65
Mangaone Overflow							
Local link road – proposed	box	5.0 x 1.5	18.95	18.65	20	1.50	20.95
Expressway - proposed	box	8.0 x 1.5	17.51	16.97	50	1.08	19.52 (at road chge 7500m)
NIMT railway - existing	box (2 cells)	3.00 x 2.05 (1 cell)	15.53	15.48	5.0	1.0	19.24
SH1 - existing	box	3.70 x 1.95	15.08	15.08	13.6	0.0	17.74
School Rd Drain							
Local link road – proposed	box [1]	2.5 x 1.0	17.90	17.78	16	0.75	19.40 (minimum)
Lucinsky Overflow							
Local link road (western side)– proposed	box	5.0 x 1.0	15.5	15.4	16	0.63	17.20
Northern Overland Flow Path							
Local link road (eastern approach to over-bridge)– proposed	box	10.0 x 1.5	18.9	18.9	50	0.0	>28m

Note
1. School Road Drain assumed to be diverted to run parallel with new local link road from Gear Road / School Road intersection to a low point in the ground topography opposite existing Gear Road / SH1 intersection. A box culvert under local link road conveys drain flows to an extension of drain to connect with Mangaone Overflow. Drain extension to run alongside flood detention bund upstream of Expressway.
2. Culverts on main stream channel to be constructed from oversize box culvert sections to allow normal sediment transport processes to continue and to facilitate fish passage with a gravel invert (depth dimension given from soffit to bed)

Table 5-2 Dimensions and levels for bridges along Mangaone Stream downstream of SH1 culvert

Location	Type	Span (m)	Soffit Level (m MSL Wellington (1953))	Deck Level (m MSL Wellington (1953))
Local link road (western side) – proposed	single span bridge	8m	16.05	16.75 (minimum)
Access bridge to Lucinsky property	single span bridge	4.37	14.35	14.94 (left bank US) 14.75 (right bank US)
Bridge 7 [1]	single span bridge	2.5	15.0	15.1
Bridge 9 [1]	single span bridge	4.0	6.4	6.9
Bridge 11 [1]	single span bridge	4.25	5.7	6.2

Notes
1. Dimensions and levels for this bridge obtained from field survey
2. Dimensions and levels for these bridges sourced from MWH (2002b)

The local link road will be slightly elevated above the alluvial fan surface but, in order to keep elevations as low as possible, the Mangaone Overflow channel upstream of the Expressway culvert will need to be partially excavated into the ground. A trapezoidal-shaped and grassed channel with an 8m base width and 2: 1 (h: v) side slopes is envisaged between the local link road and Expressway culverts with the invert levels matching the downstream invert level of the local link road culvert at the upstream end and the upstream invert level of the Expressway culvert at the downstream end. To ease the entry of overland flows into the upstream end of the depressed local link road culvert on the Mangaone Overflow, a shallow vee-shaped collector trench will need to be excavated into the ground. This trench will be 10m wide with an invert level of 20.85m in front of the local link road culvert and be 160m long parallel with the local link road (80m in either direction away from the culvert and sloping up to natural ground level over this distance).

It is recognised that these lowered channels on the Mangaone Overflow may act as sediment traps for fine silt material and will need to be monitored over time.

After passing under the local link road, the School Road Drain will need to be extended parallel with the flood detention bund upstream of the Expressway to link with the Mangaone Overflow channel. It is envisaged that this drain extension would be formed by a trapezoidal-shaped and grass-lined channel with a 2.5m base width and 2: 1 (h: v) side slopes. These drain dimensions are designed to match the width of the proposed culvert under the local link road (refer Table 5-1).

Upstream of the local link road culvert, the School Road drain would run parallel with the realigned Gear Road. The drain would be formed by a trapezoidal-shaped and grass-lined channel with a base width of 1.5m at the School Road and Gear Road intersection increasing to 2.5m at the local link road culvert. The side slopes would be steeper at 1.5: 1 (h: v).

Further upstream along School Road, the drain would need to be relocated in order to allow the construction of a low bund (Figure 5-1b) to prevent floodwaters from spilling out of the drain and flowing down the road and causing inundation of the road intersection and neighbouring residential properties as occurs at present. The drain would also need to be enlarged to approximately 1.2m wide at the base to approximately match the capacity of the drain around the perimeter of the horticultural enterprise opposite the Te Horo Village Hall. These local drainage improvements to solve an existing flooding nuisance are strictly outside the scope of the Expressway Project and would need to be carried out in cooperation with KCDC.

The flood containment bund along School Road would also need to extend around the corner along the realigned Gear Road to the local link road culvert (Figure 5-1b). This would allow Gear Road to slope down to grade to the south of the culvert.

As noted in Section 4.2, floodwaters along the Lucinsky Overflow in the existing situation originate from the floodwaters overtopping SH1 to the north of the SH1 culvert on the main stream channel and flowing along the right bank parallel with the mains stream channel downstream of the SH1 culvert. Floodwaters in the main stream channel are prevented from breaking out along the right bank by a low stopbank which also prevents Lucinsky Overflow flows spilling back into the mains stream channel.

In the proposed situation, the footprint of the western approach embankment to the local link road overbridge blocks out a substantial proportion of the 70-90m wide overland flow path along the Lucinsky Overflow which significantly reduces the conveyance capacity of the Overflow. In order to provide continuity for the Overflow through the overbridge approach embankment, it is necessary to provide a dry culvert through the embankment. This discussed further in Section 5.5 with respect to the preservation of hydraulic neutrality.

5.2 Effects of 1% Annual Exceedance Probability Flood

Figures 5-2a and b show the predicted extent of flood inundation across the Mangaone Stream alluvial fan and floodplain system in the proposed situation for the 1% AEP flood adjusted for possible future climate change effects to 2090. These figures are comparable to Figures 4-4a and b for the existing situation with Figure 5-2a focusing on the flood extent around the three key transport links crossing the Mangaone Stream and Overflow and Figure 5-2b providing a wider perspective of the flood extent across the alluvial fan and floodplain. As with Figures 4-4a and b, Figures 5-2a and b show ranges of peak flood depths shaded in different colours.

Figure 5-3 shows a difference map of peak flood depths between Figures 5-2a and 4-4a.

The following observations can be made from Figures 5-2a and b and 5-3:

- The Expressway and the local link road are not inundated.
- There is more extensive inundation between the Expressway and the local link road in the proposed situation compared to upstream of the NIMT railway line in the existing situation. However the extent of inundation in the proposed situation is again limited by the steepness of the slope of the alluvial fan. The maximum depths of inundation in the enclosed area between the Expressway and the local link road are in the range of 1.0-1.5m.
- The combination of the elevated local link road and the flood containment bund for the School Road drain cause ponding to occur upstream but the extent of ponding extends no more than about 100m upstream due to the steepness of the alluvial fan slope. As with the enclosed area between the Expressway and the local link road, the maximum depths of inundation across the alluvial fan upstream of the local link road and the School Road flood containment bund are in the range of 1.0-1.5m.
- The flood nuisance around the School Road / Gear Road intersection in the existing situation has been eliminated in the proposed situation.
- The overtopping of SH1 by the northern overland flow path in the existing situation has also been eliminated in the proposed situation by the slightly elevated expressway.
- Downstream of SH1, the flood inundation pattern in the proposed situation is broadly similar to that in the existing situation. However there are a couple of noteworthy differences. The local link road and western approach embankment to the overbridge in the proposed situation confine the initial width of the Lucinsky Overflow over the approximately 170m distance downstream of SH1 but the dry culvert through the approach embankment provides continuity for the overland flow path. The overland flow path observed at the south end of Te Horo Village in the existing situation has been eliminated in the proposed situation.
- Within the primary area of inundation downstream of SH1 in the proposed situation, peak flood depths are much the same as in the existing situation (see Figure 5-3).

Figure 5-4 compares the predicted backwater profiles past the system of culverts on the main channel of the Mangaone Stream for the existing and proposed situations for the 1% AEP flood adjusted for possible future climate change effects. Similarly Figure 5-5 compares the predicted backwater profiles past the system of culverts on the Mangaone Overflow for the existing and proposed situations for the same flood.

Table 5-3 compares predicted peak flood levels and discharges at key locations across the alluvial and floodplain system between the existing and proposed situations for the 1% AEP flood adjusted for possible climate change effects. This includes locations upstream of each culvert on the main watercourses or on a normally dry overland flow path.

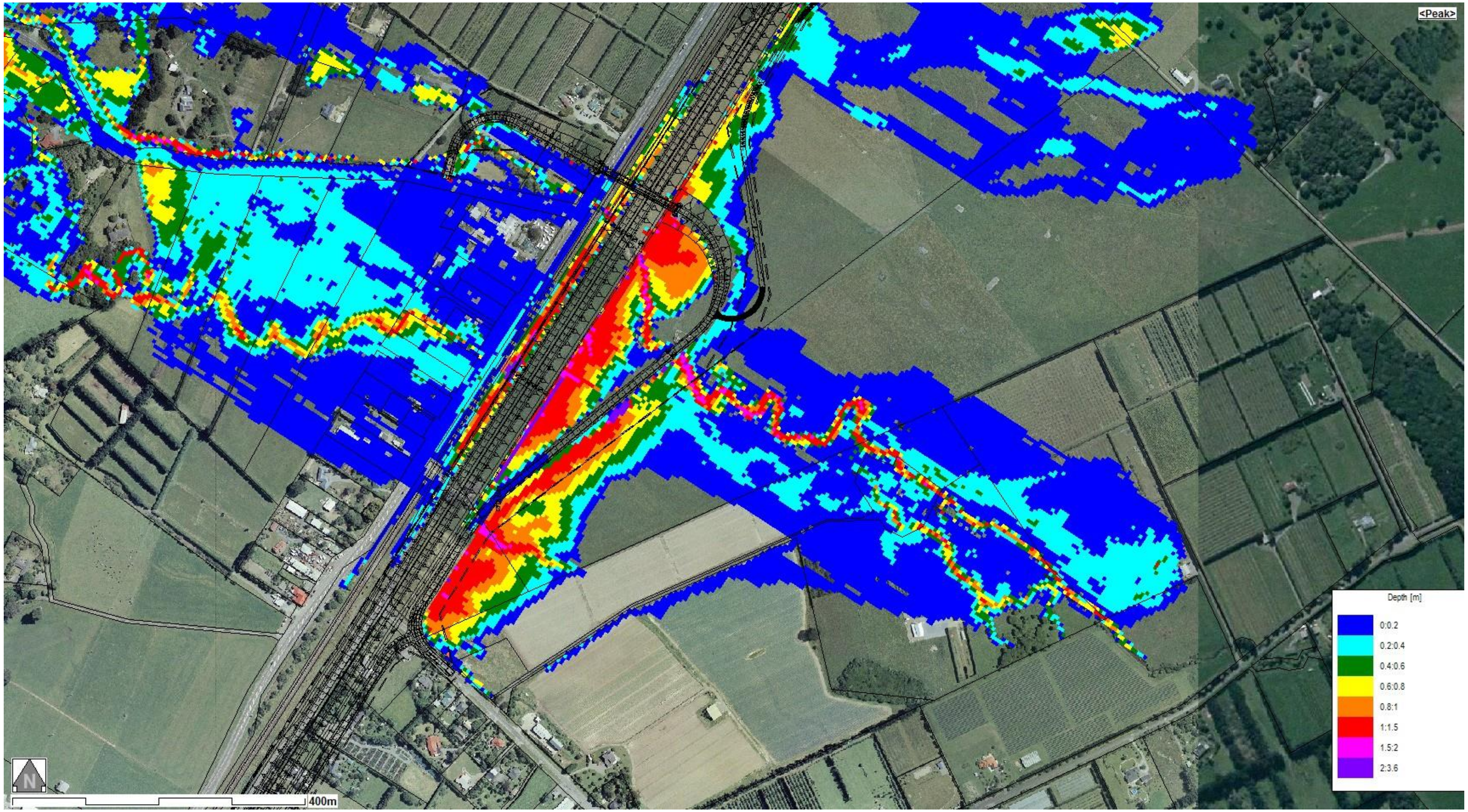

Figure 5-2a Predicted peak flood depths across the Mangaone Stream alluvial fan and floodplain system in proposed situation for 1% AEP flood adjusted for possible future climate change effects to 2090

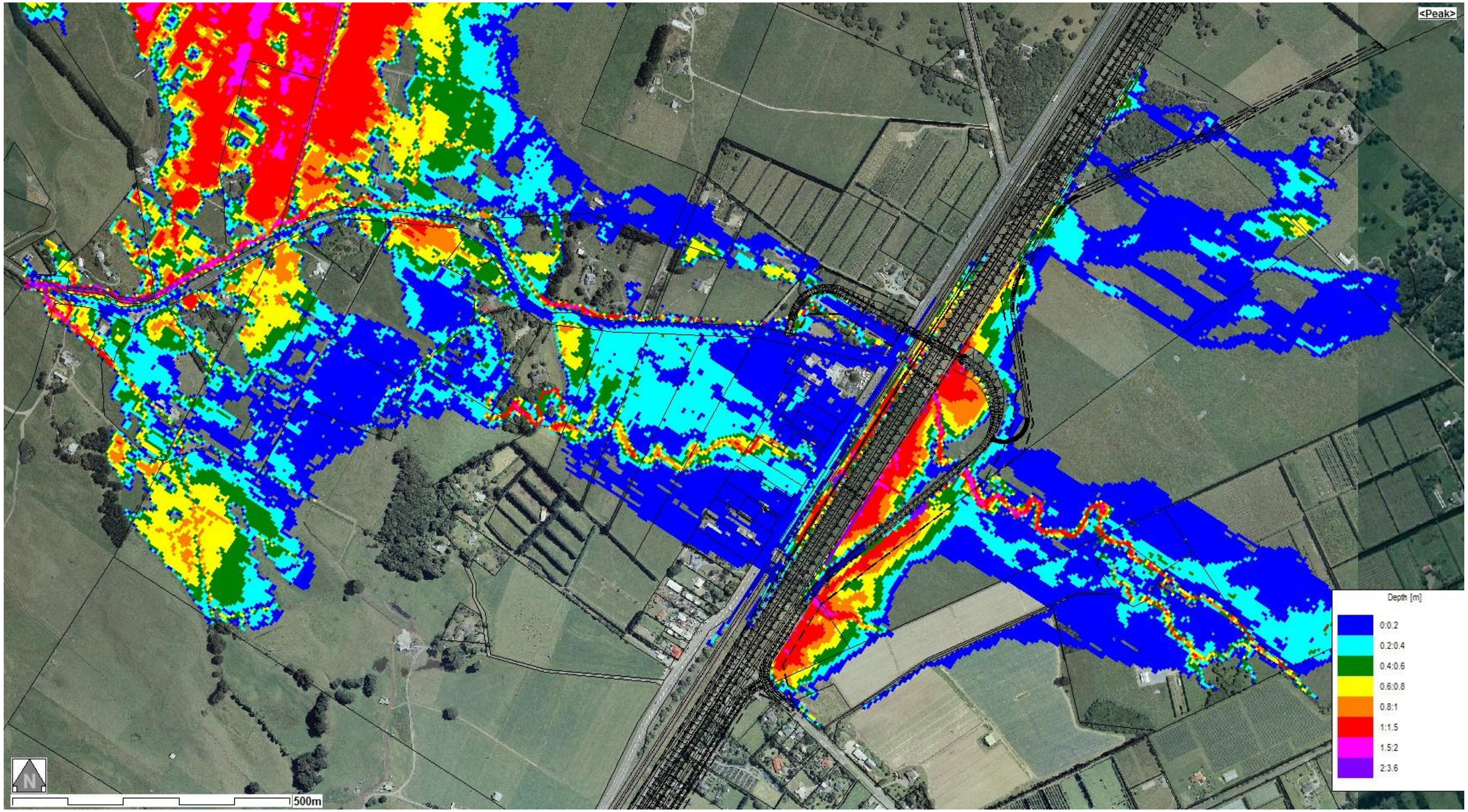

Figure 5-2b Smaller scale view of flood inundation pattern across Mangaone Stream alluvial fan and floodplain system in proposed situation for 1% AEP flood adjusted for possible future climate change effects to 2090

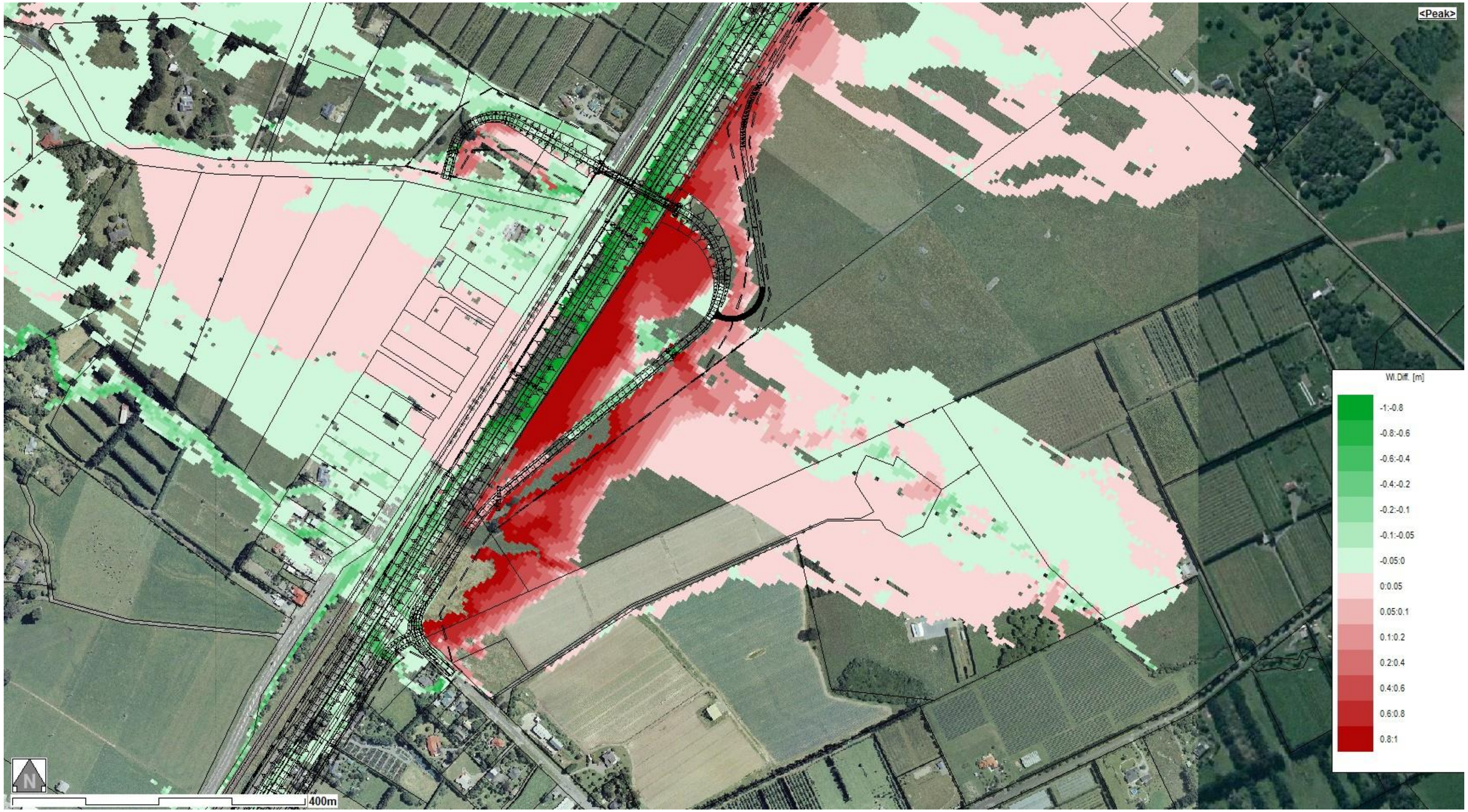

Figure 5-3 Changes in predicted peak flood depths across the Mangaone Stream alluvial fan and floodplain system between existing and proposed situations for 1% AEP flood adjusted for possible future climate change effects to 2090 (pink shading indicates areas of increased flow depths, green shading indicates areas of decreased flow depths)

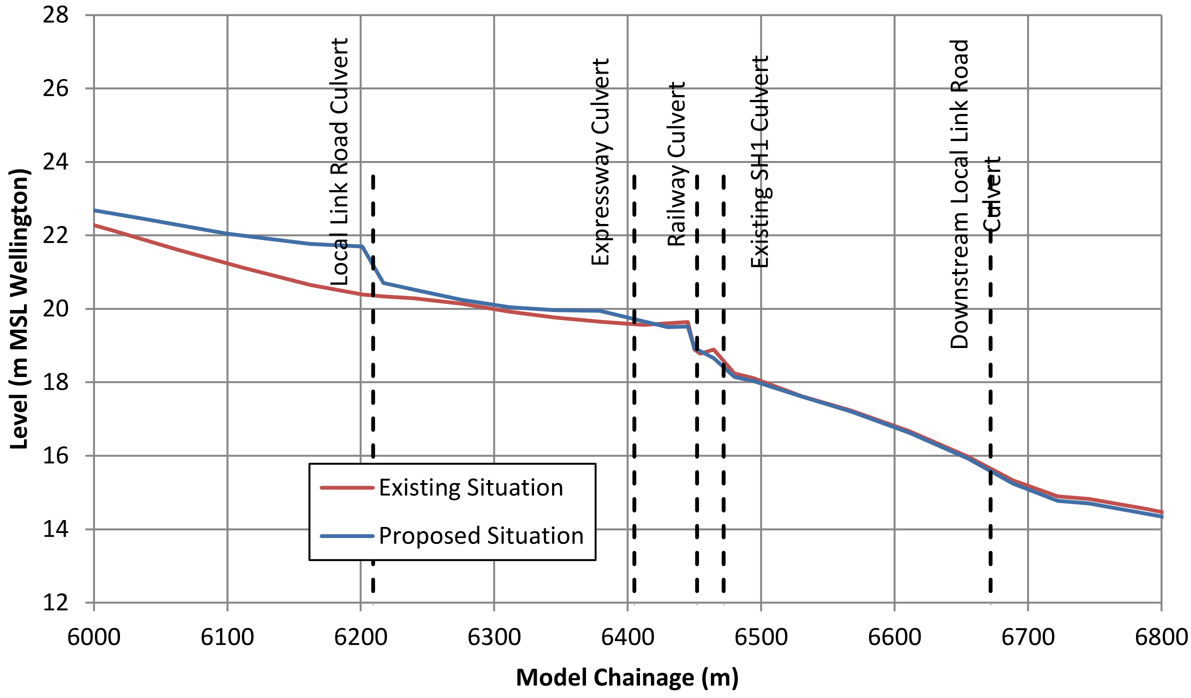

Figure 5-4 Comparison of predicted backwater profiles for existing and proposed situations along main channel of Mangaone Stream past local link road, Expressway, NIMT railway and SH1 culverts

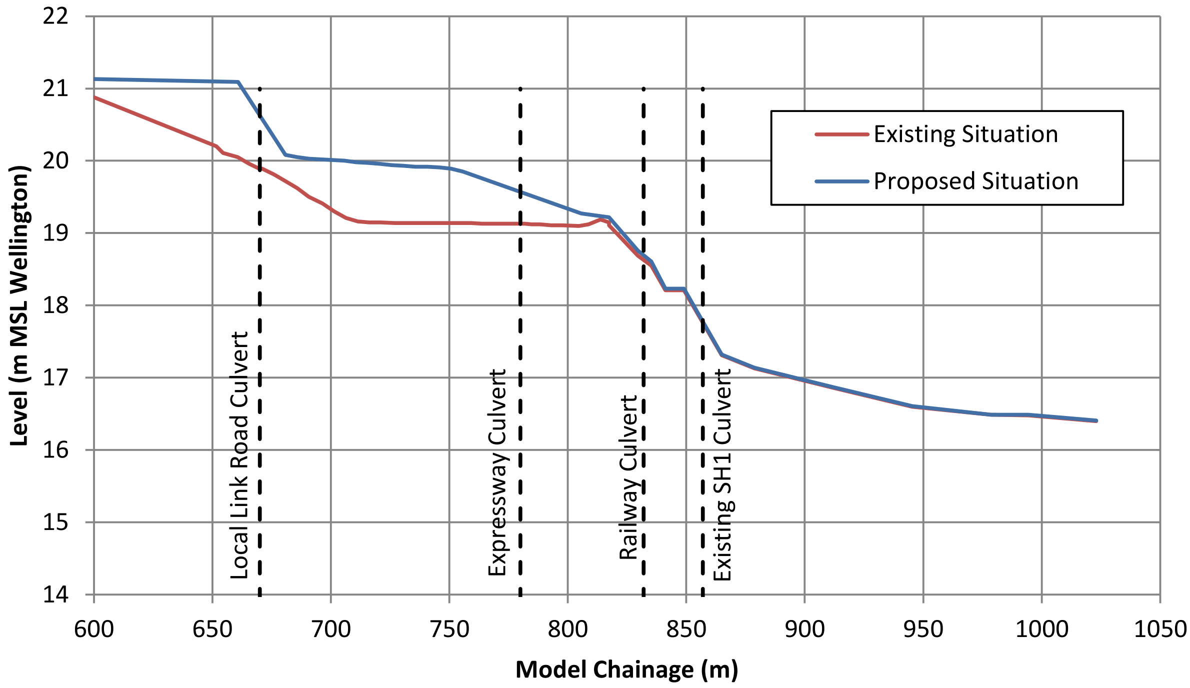

Figure 5-5 Comparison of predicted backwater profiles for existing and proposed situations along Mangaone Overflow past local link road, Expressway, NIMT railway and SH1 culverts

Table 5-3 Predicted peak flood levels and discharges for proposed situation with Expressway and local link road for 1% AEP flood adjusted for possible climate change effects to 2090

Location	Peak Flood Level (m MSL Wellington datum)		Peak Flood Discharge (m^3/s)	
	Existing	Proposed	Existing	Proposed
Mangaone Stream				
Local link road (eastern side) - proposed	20.38	21.70 US	39.6	31.4
Expressway – proposed	19.65 US 19.56 DS	19.94 US * 19.50 DS	39.6	27.9
NIMT railway - existing	18.89 US 18.88 DS	18.93 US 18.85 DS	27.1	21.7
SH1 - existing	18.88 US 18.23 DS	18.67 US 18.15 DS	22.9 culvert 1.8 road overflow	20.8 culvert 0.0 road overflow
Local link road (western side)– proposed	15.97	15.90	18.8	17.4
Mangaone Overflow				
Local link road – proposed	20.26	21.07 US *	25.1	24.0
Expressway - proposed	19.14	19.85 US 19.28 DS	49.2	46.1
NIMT railway - existing	18.68 US 18.20 DS	18.75 US 18.62 DS	40.1	42.5
SH1 - existing	18.20 US 17.31 DS	18.22 US 17.32 DS	25.2 culvert 1.2 road overflow	26.8 culvert 1.6 road overflow
School Rd Drain				
School Rd / Gear Rd intersection		21.15		4.8
Local link road culvert – proposed		21.06		5.8
Lucinsky Overflow				
Local link road (western side)– proposed	15.71	15.83	3.5	0.71

* These flood levels are below the road level given for the Expressway at each culvert location. However a low bund will be constructed upstream of the Expressway to provide the necessary freeboard for the design 1% AEP flood adjusted for possible future climate change effects in order to prevent the Expressway from being overtopped.

The predicted peak flood level profiles along the main stream channel in Figure 5-4 are broadly similar for both situations downstream of the local link road culvert. Upstream of the local link road culvert in the proposed situation, the 5m wide by 2.5m high box culvert structure causes the peak flood level profile to be elevated by about 1.5m relative the existing situation profile. This backwater effect of the local link road culvert rapidly reduces with distance upstream – by 200m upstream of the culvert, it is fairly small. The backwater effect contributes to floodwaters spreading in both directions away from the main stream channel along the upstream side of the elevated local link road.

Between the local link road culvert and the Expressway culvert on the main stream channel, the proposed situation peak flood level profile in Figure 5-4 is slightly elevated above the existing situation peak flood level profile, probably due to a slightly larger main channel flow. The Expressway culvert also has the effect of causing a slight backwater effect upstream in the proposed situation but to a much lesser effect than the upstream local link road culvert. This and the naturally low bank levels cause floodwaters to break out of the main channel in a south-westerly direction along the front of the flood detention bund upstream of the Expressway towards the Mangaone Overflow.

Downstream of the SH1 culvert, the proposed situation peak flood level profile in Figure 5-4 is marginally lower than the existing situation one. This is due to the slightly lower flow conveyed by the main stream channel in the proposed situation.

The predicted peak flood level upstream of the local link road culvert is 21.70m (Table 5-3). This gives 0.07m clearance to the soffit of the 5m wide by 2.5m high structure. The minimum road level of 22.3m is 0.6m above the predicted peak flood level which easily satisfies the required freeboard standard of the NZ Transport Agency's *Bridge Manual* (Transit NZ, 2003)[5].

In the case of the long Expressway culvert, the predicted peak flood level of 18.93m is 0.64m below the soffit level so that the design 1% AEP flood adjusted for possible future climate change effects to 2090 would operate under a free surface flow regime over its entire length.

In practice both the local link road and Expressway box culvert structures would need to be constructed using over deep box sections buried below the specified invert levels so that a natural gravel bed could be formed along the base of each structure to promote fish passage.

In Figure 5-5, the existing situation peak flood level profile along the Mangaone Overflow for the 1% AEP flood adjusted for possible climate change effects is elevated upstream of the NIMT railway culvert due the flood ponding effect of the culvert. This behaviour is replicated by the Expressway culvert and the local link road culvert in the proposed situation. Again this is due to the flood ponding effects of these culverts and is reflected in the peak flood depth patterns seen in Figure 5-2a.

Downstream of the SH1 culvert on the Mangaone Overflow, the existing and proposed situation peak flood level profiles match each other very closely. Table 5-3 indicates the total peak flood discharge downstream of the SH1 culvert is marginally increased above that for the existing situation but the downstream peak flood levels are within 0.01m which would be imperceptible.

The peak flood discharge data in Table 5-3 indicate that, while there is a slight reduction in the main stream channel flow and a slight increase in the Mangaone Overflow flow in the proposed situation, overall there is a slight reduction in the total flow downstream of SH1 along the two primary watercourses compared to the total flow in the existing situation.

Figure 5-6a shows predicted peak flow velocities across the Mangaone Stream alluvial fan and floodplain system in the proposed situation for the 1% AEP flood adjusted for possible future climate change effects to 2090 in a similar fashion to Figure 4-10a for the existing situation. Figure 5-6b shows the flow vectors superimposed on the pattern of peak flow velocities.

Figure 5-7 shows changes in peak flow velocity between the proposed and existing situations. The areas in Figure 5-7 with the lightest pink and green shading indicate areas where the predicted change is peak flow velocity is within ±0.05m/s which is within the predictive accuracy of the MIKEFLOOD model. Therefore there is effectively no change in peak flow velocity in these areas between the existing and proposed situations.

[5] As noted in Section 3, the design flood standard for the local link road is either a 4% or 2% AEP flood adjusted for possible climate change effects to 2090 so that the 0.6m freeboard in the 1% AEP flood adjusted for possible climate change effects means that this design standard is easily satisfied.

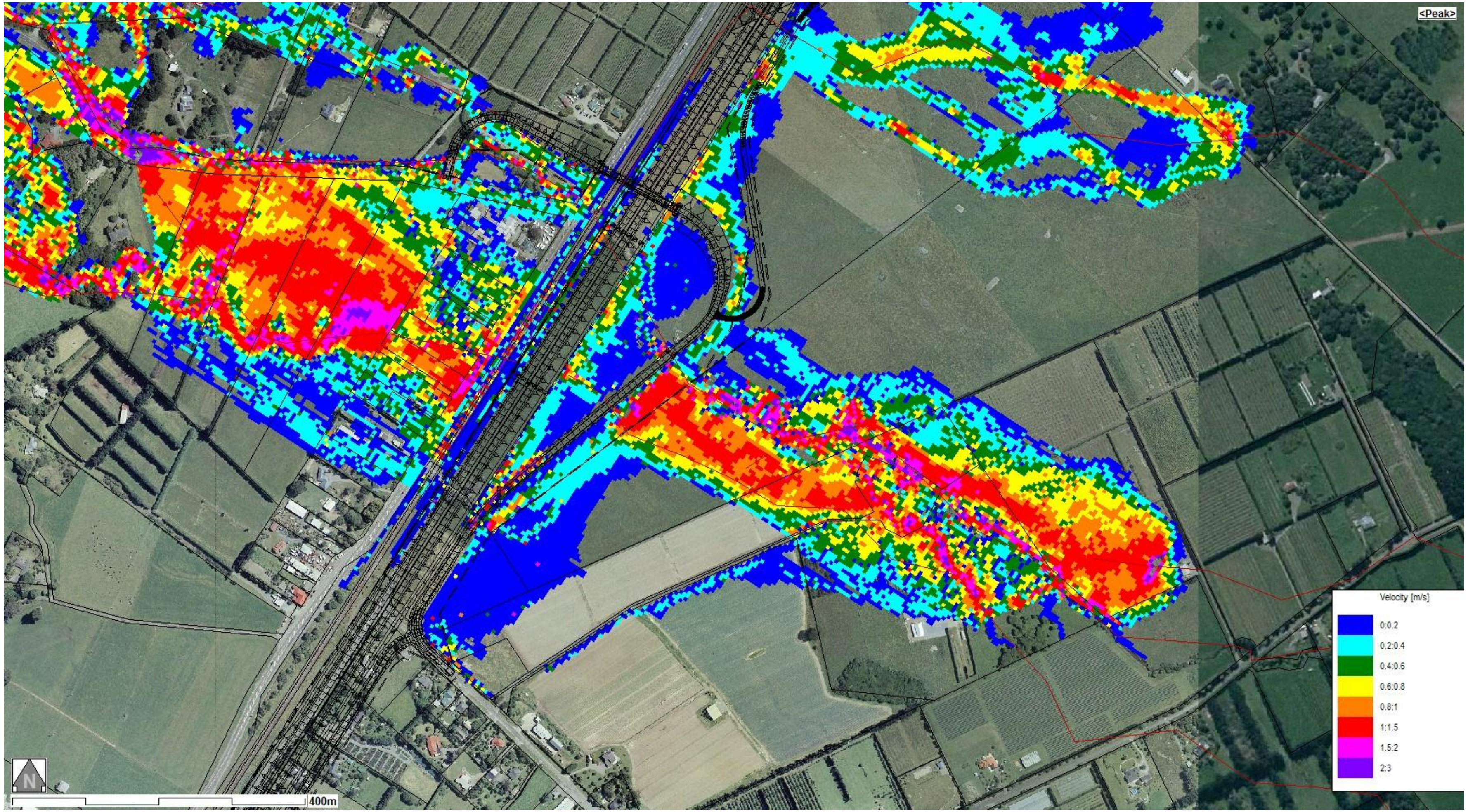

Figure 5-6a Predicted peak flow velocities across the Mangaone Stream alluvial fan and floodplain system in proposed situation for 1% AEP flood adjusted for possible future climate change effects to 2090

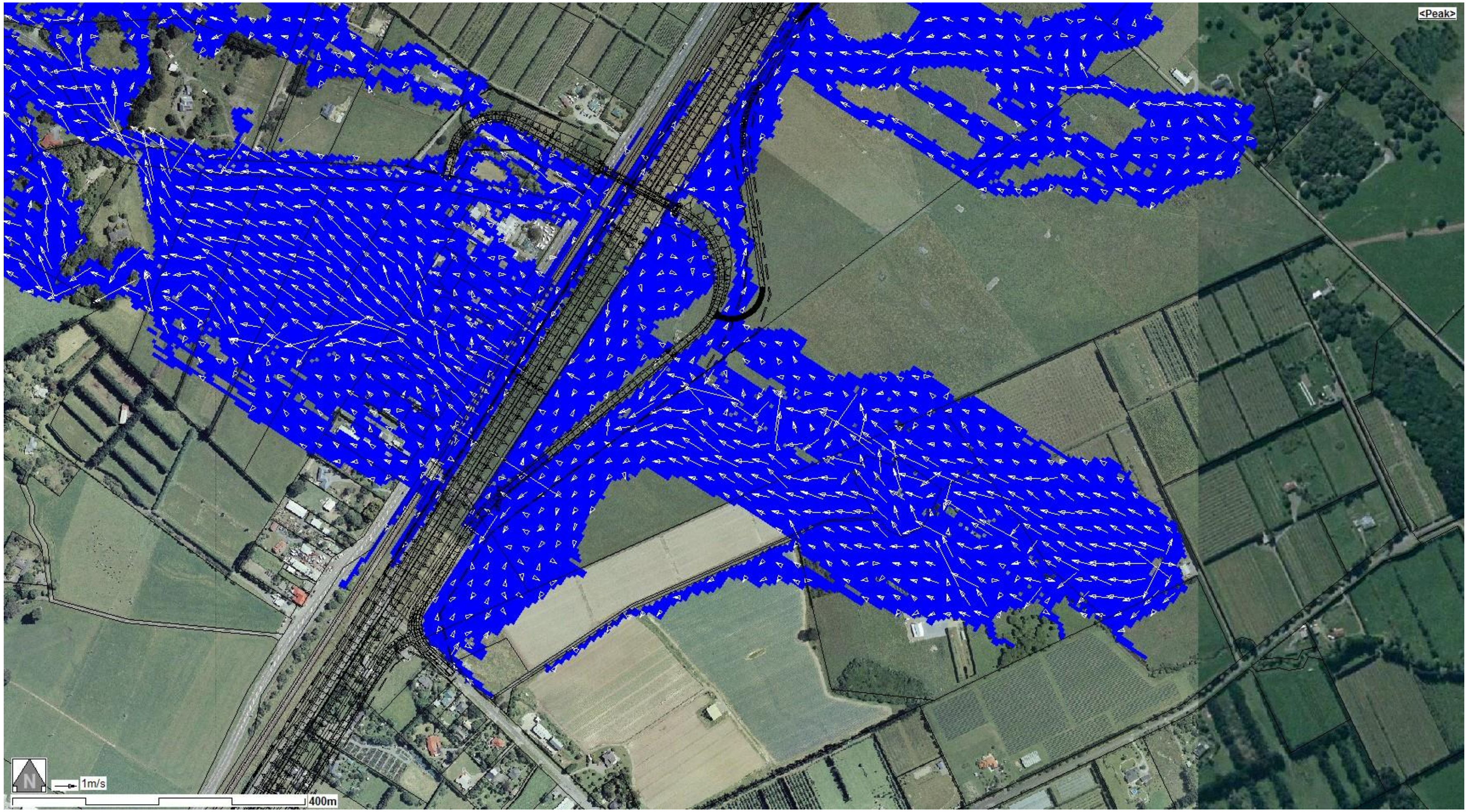

Figure 5-6b Blown-up section of Figure 5-6b showing velocity vectors for overland flow past the local link road, Expressway, NIMT railway and SH1 and crossings of the Mangaone Stream and Overflow

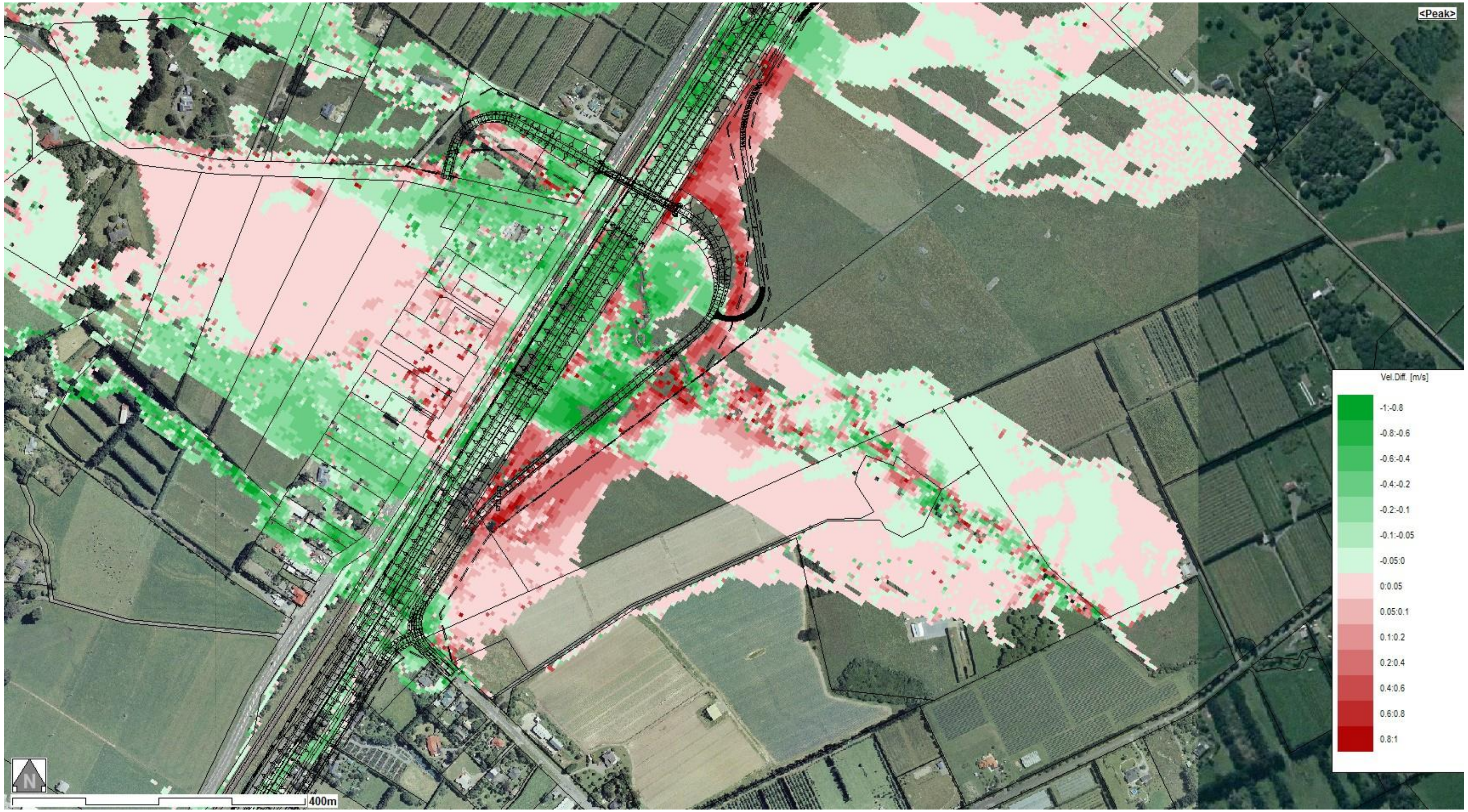

Figure 5-7 Changes in predicted peak flow velocities across the Mangaone Stream alluvial fan and floodplain system between proposed and existing situations for 1% AEP flood adjusted for possible future climate change effects to 2090 (pink shading indicates areas of increased flow depths, green shading indicates areas of decreased flow depths)

Figures 5-6a again highlights that the peak overland flow velocities for the 1% AEP flood adjusted for possible future climate change effects to 2090 are confined primarily to the Mangaone Overflow overland flow path. However the occurrence of flood ponding upstream of the Expressway culvert is to cause flow velocities along the Overflow between the local link road culvert and Expressway culvert to be significantly reduced. This is indicated by the darker green shading in the area between the local link road and the Expressway in Figure 5-7.

Elsewhere across the alluvial fan and floodplain system, peak flow velocities are reduced in the proposed situation over a 170m wide strip through the residential area of Te Horo Village to the south of Te Horo Beach Road and to the west of SH1 and also along the Lucinsky Overflow.

Conversely, peak flow velocities are increased upstream of the local link road (indicated by the darker red areas in Figure 5-7) although the magnitude of the increased flow velocities seen in Figure 5-6a in this area is generally very low (< 0.4m/s) except in the immediate vicinity of the Mangaone Overflow and School Road drain culverts under the local link road. The primary reason for the apparent increase in peak flow velocities upstream of the local link road is that this area is not inundated in the existing situation (see Figure 4-10a) for the 1% AEP flood adjusted for possible climate change effects to 2090.

Figure 5-6b showing the predicted directions of flow across the alluvial fan and floodplain is very illuminating. The length of the velocity vectors is proportional to the magnitude of the flow velocities so that the course of the Mangaone Overflow where the higher flow velocities are concentrated is readily apparent. The magnitude of the 1% AEP flood adjusted for possible climate change effects to 2090 is such that the floodwaters approaching the local link road are spread across the alluvial fan either side of the main stream channel. The effect of the elevated local link road is to deflect the overland flow sideways to follow the line of the road embankment away from the main stream channel culvert. The elevated flood detention bund upstream of the Expressway has a similar deflection effect except in this case the eastern approach embankment to the local link road overbridge contains the spread of floodwaters northwards and floodwaters are primarily directed southwards along the line of the Expressway to the Mangaone Overflow culvert under the Expressway. The Expressway also acts to deflect overland flows in the northern overland flow path in a southerly direction along the upstream side to the gap between the Expressway and the eastern abutment of the local link road overbridge to re-enter the main stream channel.

Downstream of SH1, Te Horo Beach Road appears to act as a natural flow path for overland flows. However this is not an effect of the Expressway as the flow path is the same in both the existing and proposed situations (see Figure 4-10b and Figure 5-6b).

Figures 5-8 shows stage hydrographs at key culvert locations along the main channel of the Mangaone Stream for the 1% AEP flood adjusted for the effects of possible future climate change to 2090 while Figure 5-9 shows predicted discharge hydrographs at the same locations. Similarly Figure 5-10 shows stage hydrographs at key culvert locations along Mangaone Overflow for the 1% AEP flood adjusted for possible future climate change effects to 2090 while Figure 5-11 shows predicted discharge hydrographs at the same locations. Figure 5-12 compares discharge hydrographs at the Lucinsky Overflow between the existing and proposed situations for the 1% AEP flood adjusted for possible future climate change effects to 2090.

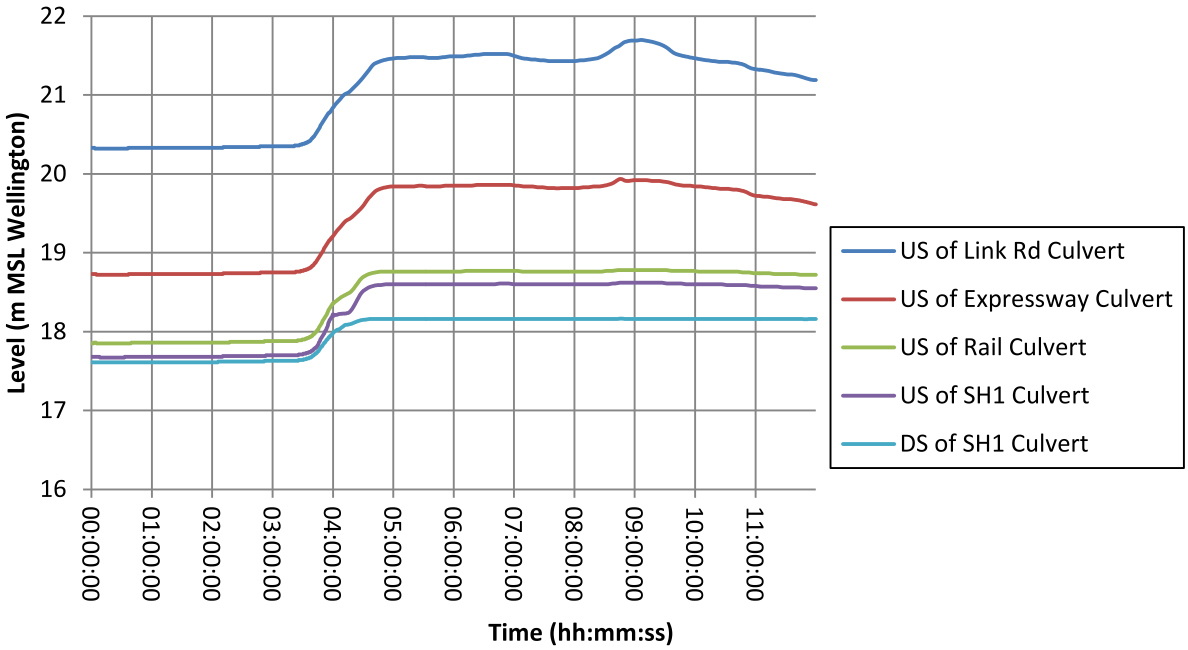

Figure 5-8 Predicted stage hydrographs upstream of local link road, Expressway, NIMT railway culverts and upstream and downstream of SH1 culvert on main channel of Mangaone Stream for 1% AEP flood adjusted for effects of possible future climate change to 2090

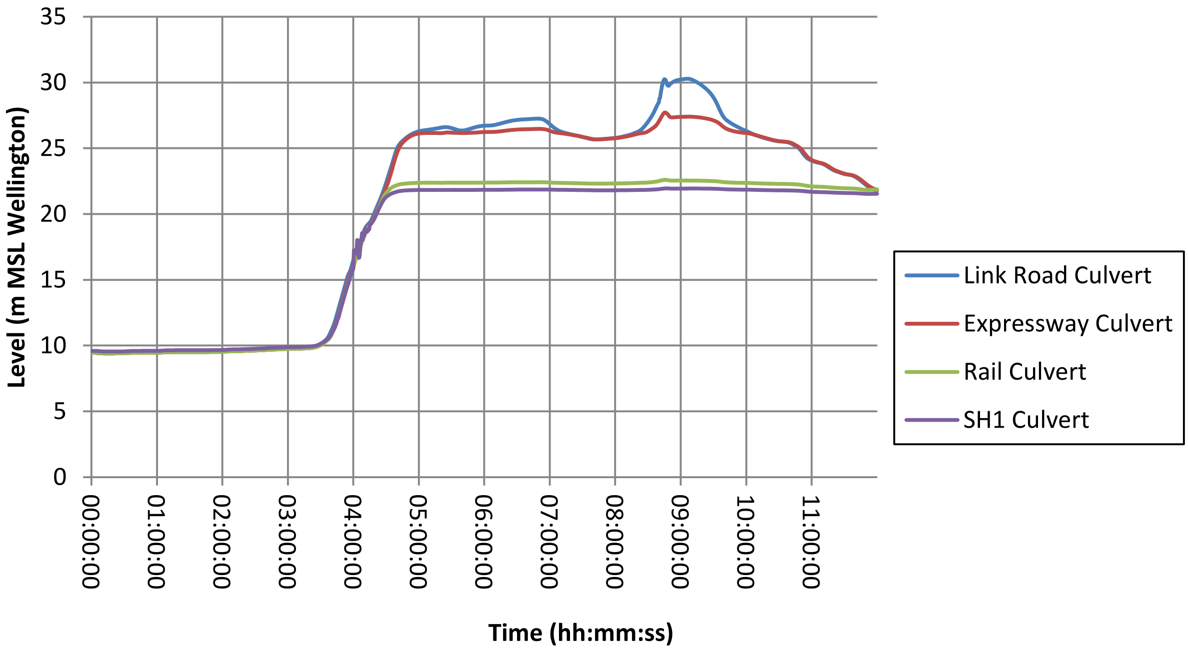

Figure 5-9 Predicted discharge hydrographs at local link road, Expressway, NIMT railway and SH1 culverts and SH1 overtopping flow on the main channel of Mangaone Stream for 1% AEP flood adjusted for effects of possible future climate change to 2090

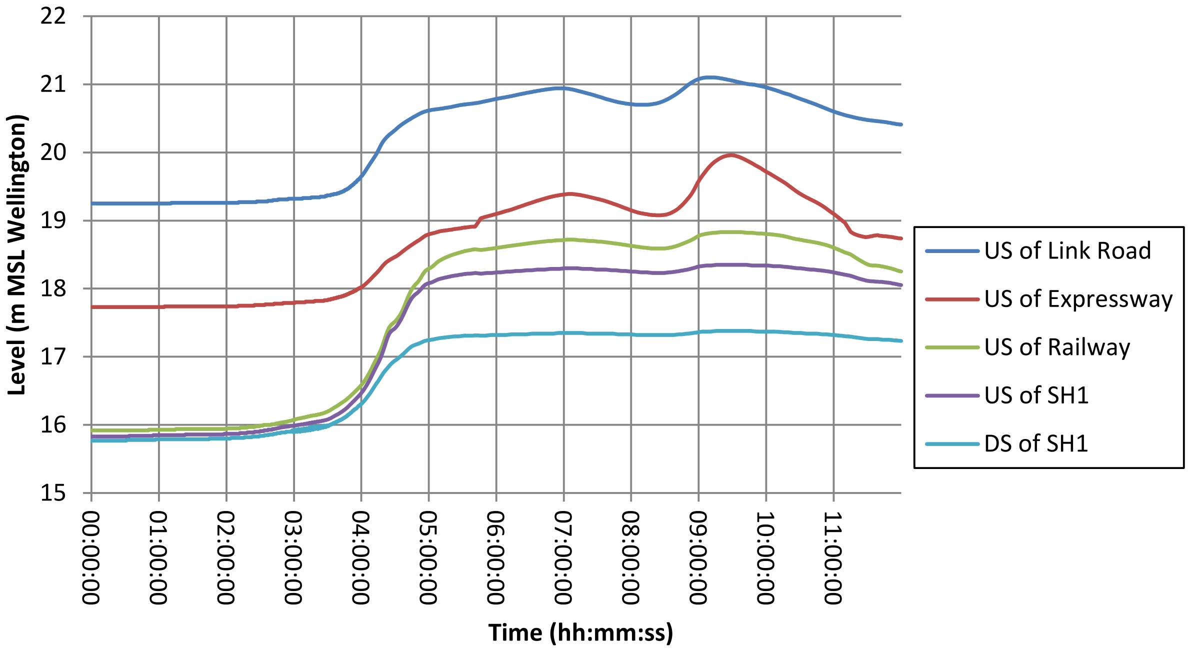

Figure 5-10 Predicted stage hydrographs upstream of local link road, Expressway, NIMT railway culverts and upstream and downstream of SH1 culvert on Mangaone Overflow for 1% AEP flood adjusted for effects of possible future climate change to 2090

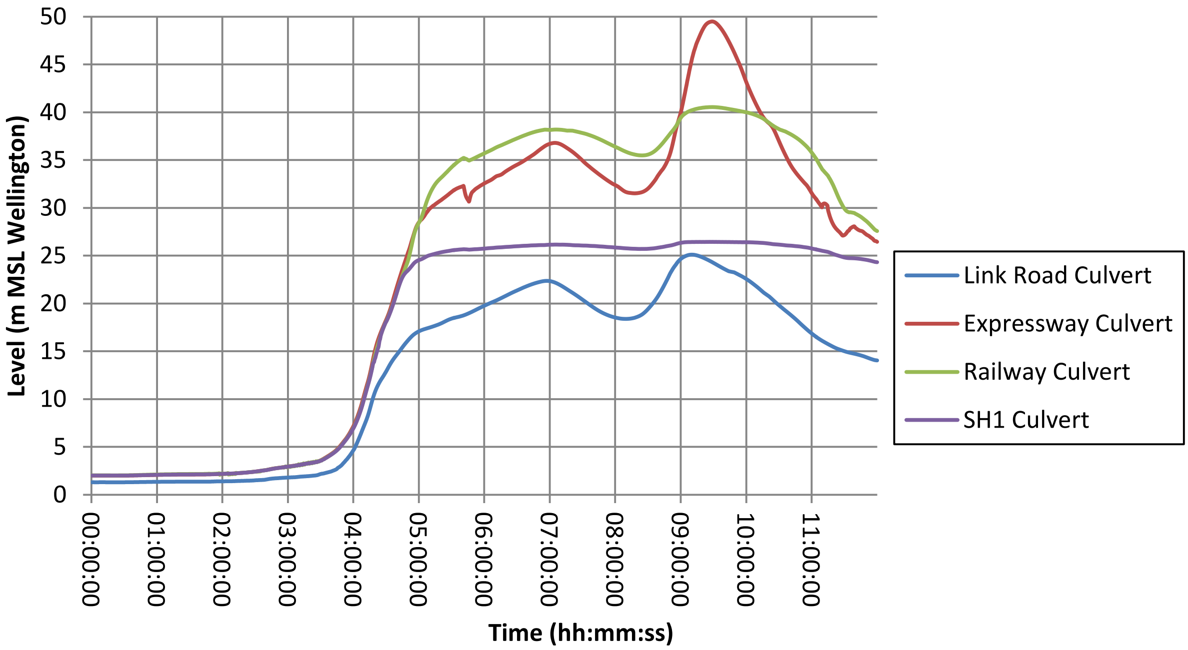

Figure 5-11 Predicted discharge hydrographs at local link road, Expressway, NIMT railway and SH1 culverts and SH1 overtopping flow on the Mangaone Overflow for 1% AEP flood adjusted for effects of possible future climate change to 2090

The stage and discharge hydrographs in Figures 5-8 to 5-11 only cover 12 hours of the input total flood discharge hydrograph seen in Figure 2-4. As noted previously the flood hydrograph is multi-peaked reflecting several discrete bursts of heavy rainfall within the overall rainstorm event. The first 12 hours of the total discharge hydrograph covers the worst of the flood event such that flood levels and discharges are falling after 12 hours.

The elevated local link road and the flood detention bund upstream of the Expressway in causing flood ponding to occur upstream and the systems of existing and new culverts on the main stream channel on the overflow act in combination to have a number of effects:

- flood discharge peaks are smoothed out;
- maximum flood discharges are progressively reduced through successive culverts on each culvert system; and
- maximum flood levels become relatively constant over a period of time before gradually falling.

Figure 5-12 compares the predicted flood discharge hydrographs for the existing and proposed situations along the Lucinsky Overflow. In the latter situation, continuity for the Overflow has been provided for by means of 5m wide by 1m high dry culvert through the western approach embankment to the local link road overbridge. As noted previously for the existing situation, the origin of the flood flows passed by the Overflow is floodwaters overtopping SH1 to the north of the SH1 culvert of the main stream channel. Flood flows in the mainstream channel downstream of the SH1 culvert are prevented from breaking out along the right and joining the overland flow along the Lucinsky Overflow in both the existing and proposed situations.

The footprint of the western approach embankment blocks off a substantial part of the 70-90m width of the Lucinsky Overflow in the proposed situation. This is the reason why the peak discharge of 3.5m^3/s passed by the overflow in the existing situation is reduced to 0.7m^3/s in the proposed situation.

The other flood discharge hydrograph shown in Figure 5-12 (red coloured hydrograph) represents the result of a sensitivity test involving a modification to the right bank stopbank between the Overflow and the main stream channel. This is discussed further in Section 5.5.

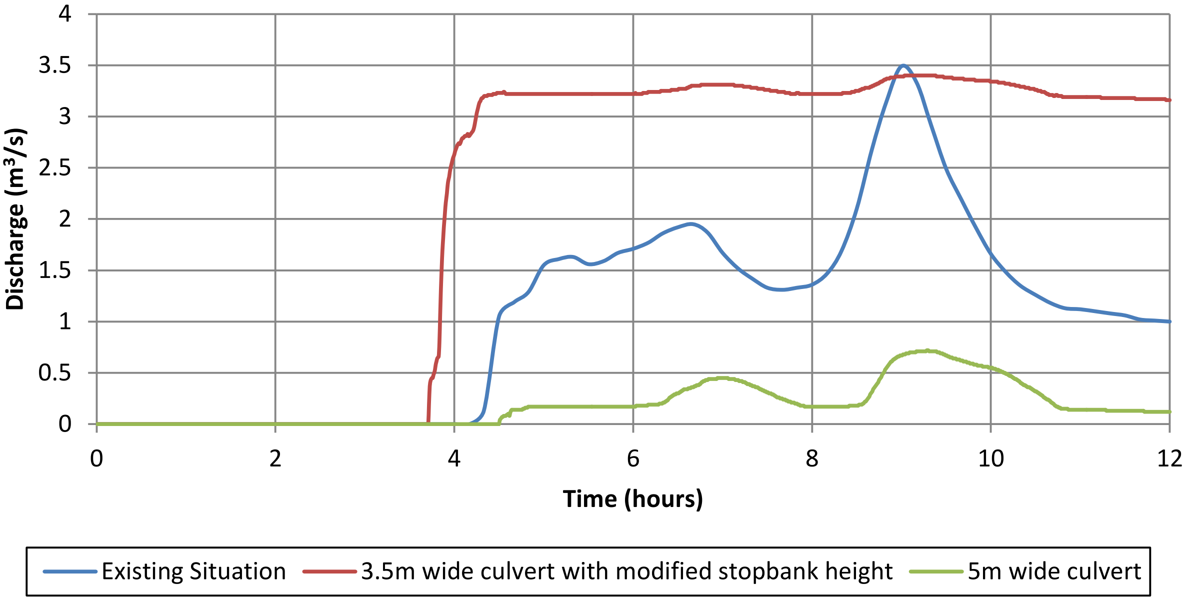

Figure 5-12 Comparison of predicted discharge hydrographs on Lucinsky Overflow between proposed and existing situations for 1% AEP flood adjusted for effects of possible future climate change to 2090

5.3 Sensitivity of Predicted Peak Flood Levels to Flood Magnitude

In Section 3, the Serviceability Limit State flood for the local link road was determined to be either the 4% or 2% AEP flood adjusted for possible climate change effects. However we note from Table 2-5 that there is not a large difference between the 5%, 2% and 1% AEP floods adjusted for possible climate change effects. For this reason the MIKEFLOOD model was used to simulate the effects of the 5% AEP flood across the alluvial fan and floodplain system for the Mangaone Stream.

At the other end of the scale, the MIKEFLOOD model was also used to simulate the effects of the 0.5% AEP flood across the alluvial fan and floodplain system for the Mangaone Stream.

From the results of these two additional flood simulations, the sensitivity of predicted peak flood levels and discharges along the Mangaone Stream and Overflow to flood magnitude was able to be assessed.

Figure 5-13 shows the predicted flood extent across the alluvial fan and floodplain system for the Mangaone Stream for the 5% AEP flood adjusted for possible climate change effects to 2090 while Figure 5-14 shows the predicted flood extent for the 0.5% AEP flood adjusted for possible climate change effects to 2090.

Figure 5-15 shows predicted peak flow velocities across the alluvial fan and floodplain system for the Mangaone Stream for the 5% AEP flood adjusted for possible climate change effects to 2090 while Figure 5-16 shows the predicted peak flow velocities for the 0.5% AEP flood adjusted for possible climate change effects to 2090.

Comparison of Figure 5-13 for the 5% AEP flood adjusted for possible climate change effects with Figure 5-2a for the 1% AEP flood also adjusted for possible climate change effects indicates that the extent of flood inundation upstream of both the local link road and the Expressway for the former flood (with a peak discharge about 16m^3/s lower than that of the latter flood - 64.1m^3/s compared to 80.2m^3/s, Table 2-5) is significantly reduced. Flood storage ponding in the former case is marginally greater upstream of the local link road between the School Road drain culvert and the School Road / Gear Road intersection and upstream of the Expressway on the right bank between the main stream channel and the eastern approach embankment to the local link road overbridge.

Comparison of Figure 5-14 for the 0.5% AEP flood adjusted for possible climate change effects with Figure 5-2a for the 1% AEP flood also adjusted for possible climate change effects indicates that the extent of flood inundation upstream of both the local link road and the Expressway for the former flood (with a peak discharge about 8.5m^3/s higher than that of the latter flood – 88.7m^3/s compared to 80.2m^3/s, Table 2-5) is slightly increased. The increased extent of flood inundation is primarily due to the increased volume of the flood rather than the increased peak discharge.

Figures 5-15 and 5-16 reinforce further the fact that the Mangaone Overflow is the primary flow path for floodwaters across the Mangaone Stream alluvial fan and floodplain system. The peak flow velocity map in Figure 5-15 for the 5% AEP flood adjusted for possible future climate change effects with its slightly lower peak discharge enables the primary flow paths upstream of the local link road and Expressway to be distinguished a bit more clearly than in the peak flow velocity maps in Figures 5-6a and 5-16 for the 1% and 0.5% AEP floods adjusted for possible climate change effects.

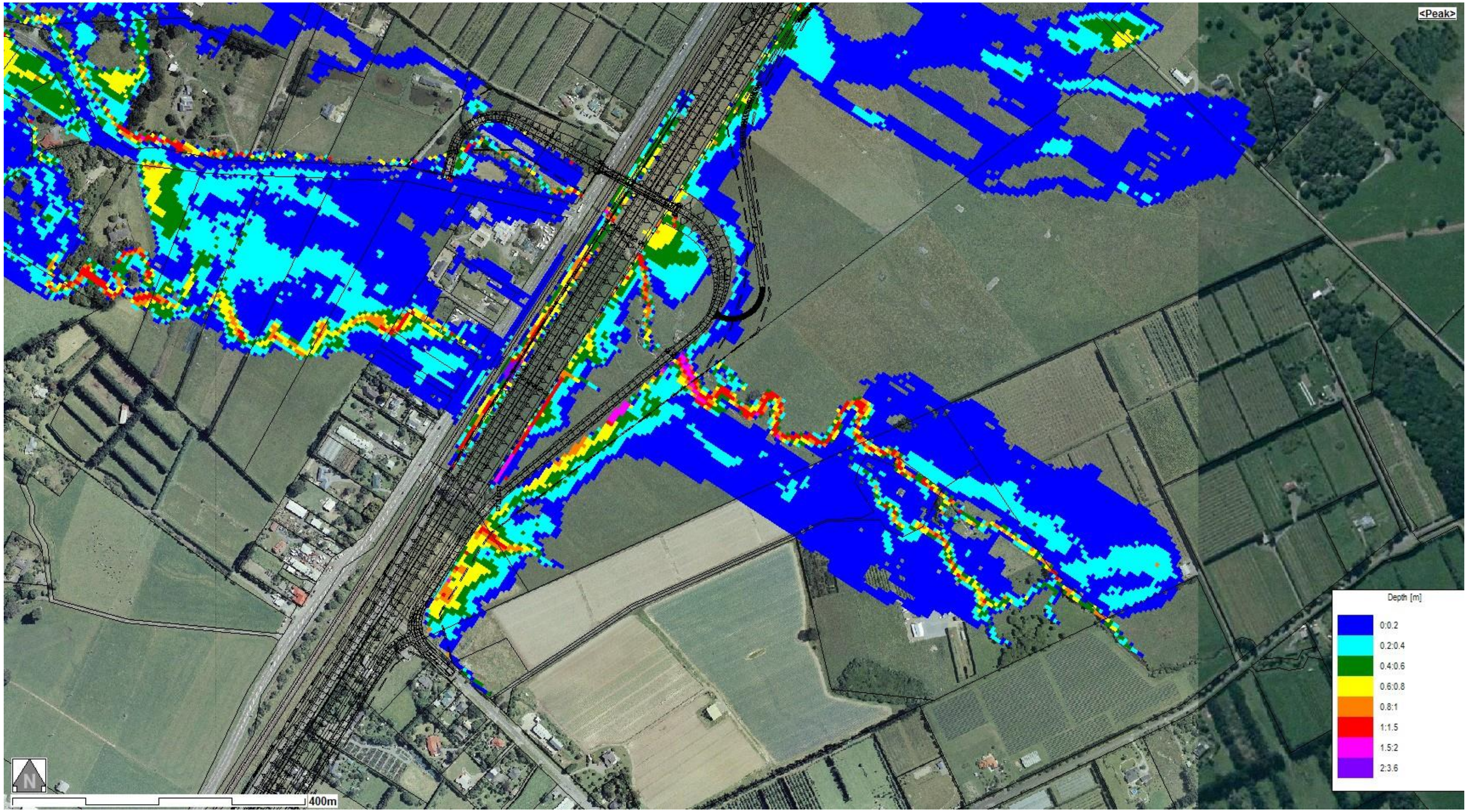

Figure 5-13 Predicted peak flood depths across the Mangaone Stream alluvial fan and floodplain system for 5% AEP flood adjusted for possible future climate change effects to 2090

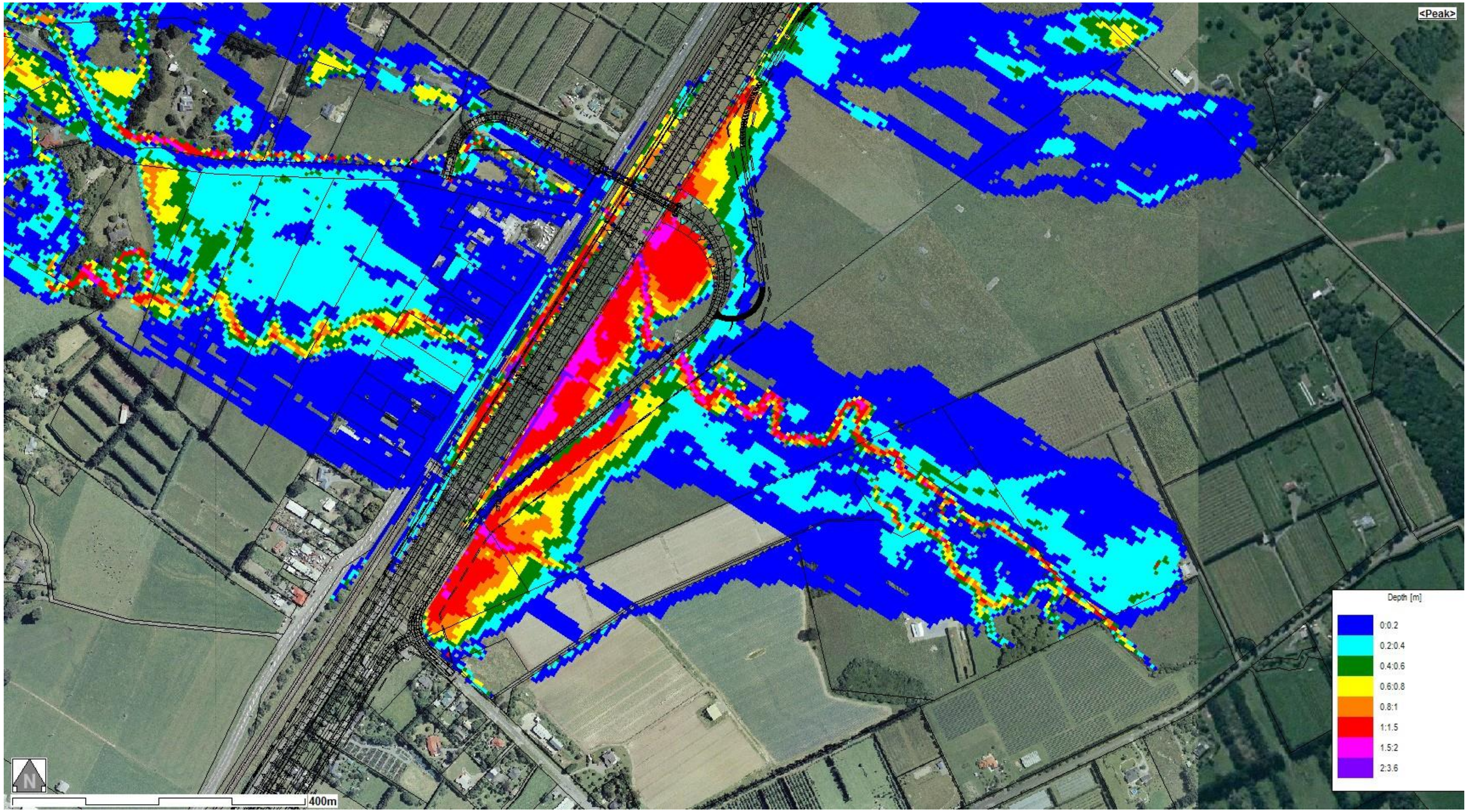

Figure 5-14 Predicted peak flood depths across the Mangaone Stream alluvial fan and floodplain system for 0.5% AEP flood adjusted for possible future climate change effects to 2090

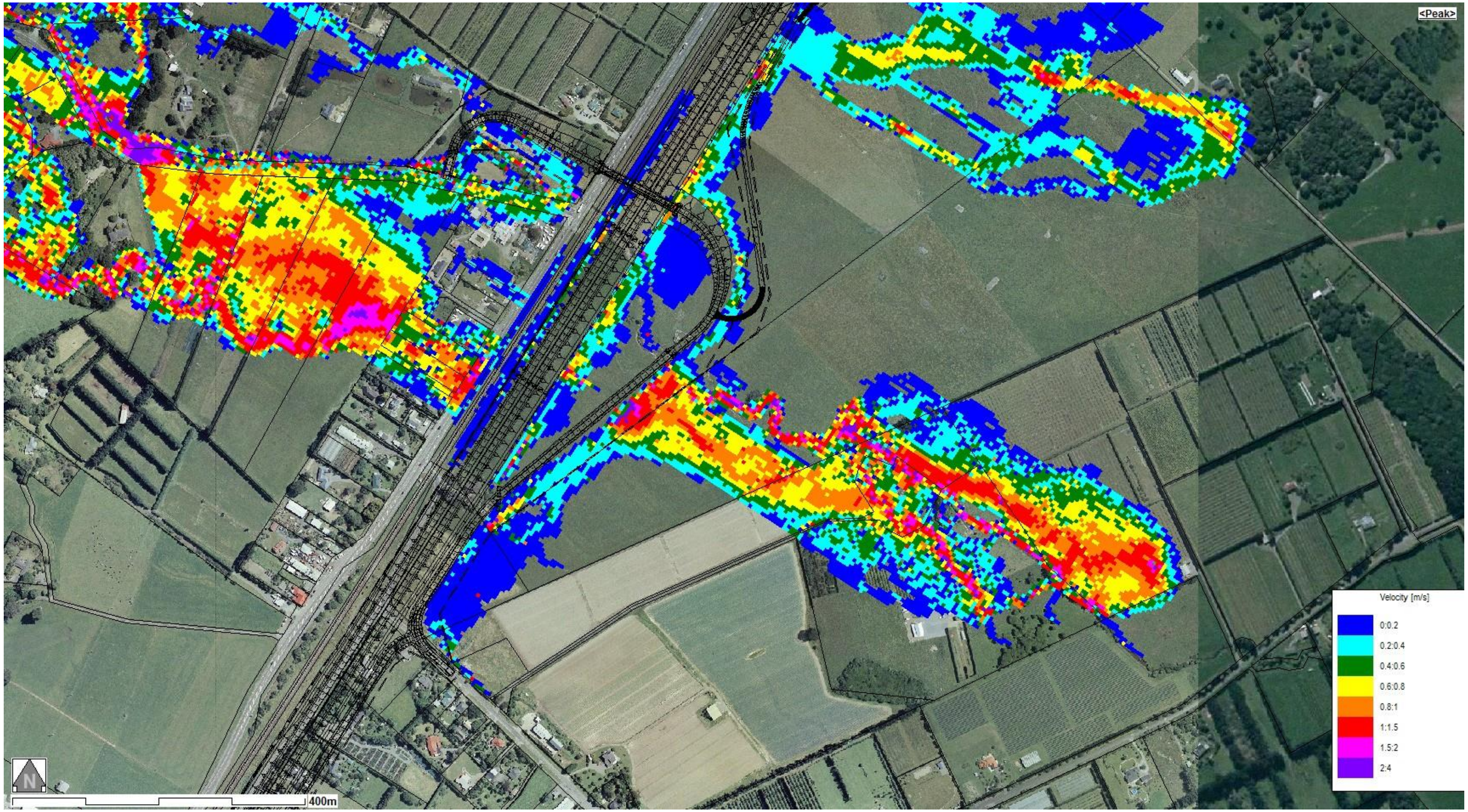

Figure 5-15 Predicted peak flow velocities across the Mangaone Stream alluvial fan and floodplain system for 5% AEP flood adjusted for possible future climate change effects to 2090

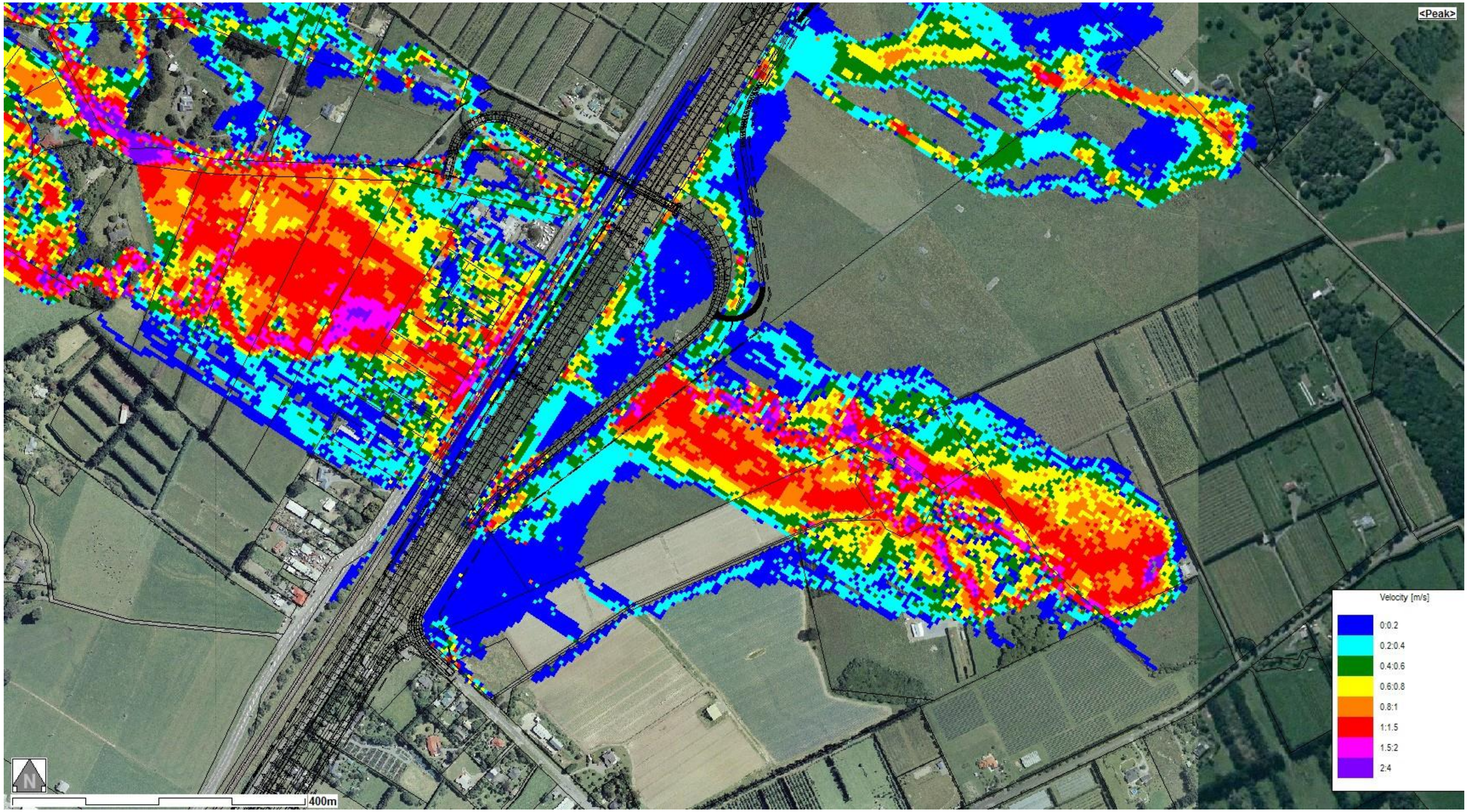

Figure 5-16 Predicted peak flow velocities across the Mangaone Stream alluvial fan and floodplain system for 0.5% AEP flood adjusted for possible future climate change effects to 2090

Table 5-4 compares peak flood levels and discharges for the proposed expressway situation for the 5% and 0.5% AEP floods adjusted for the effects of possible future climate change to 2090.

Table 5-4 Predicted peak flood levels and discharges at ley locations for proposed situation with Expressway and local link road for different flood magnitudes adjusted for effects of possible future climate change to 2090

Location	Peak Flood Level (m MSL)			Peak Flood Discharge (m^3/s)		
	5% AEP Flood	1% AEP Flood	0.5% AEP Flood	5% AEP Flood	1% AEP Flood	0.5% AEP Flood
Mangaone Stream						
Local link road (eastern side) proposed	21.47	21.70 US	21.73	26.4	31.4	31.0
Expressway – proposed	19.84 US * 19.47 DS	19.94 US * 19.50 DS	19.95 US * 19.50 DS	26.2	27.9	27.9
NIMT railway - existing	18.91 US 18.83 DS	18.93 US 18.85 DS	18.93 US 18.85 DS	21.5	21.7	21.7
SH1 - existing	18.64 US 18.14 DS	18.67 US 18.15 DS	18.67 US 18.15 DS	20.6	20.8	20.8
Local link road (western side)– proposed	15.91	15.92	15.93	17.9	18.1	18.1
Mangaone Overflow						
Local link road – proposed	20.64	21.07 US	21.16	17.4	24.0	26.0
Expressway - proposed	18.86 US 18.80 DS	19.85 US * 19.28 DS	20.21 US * 19.32 DS	30.7	46.1	57.6
NIMT railway - existing	18.47 US 18.37 DS	18.75 US 18.62 DS	18.80 US 18.65 DS	34.8	42.5	43.2
SH1 - existing	18.12 US 17.26 DS	18.22 US 17.32 DS	18.25 US 17.33 DS	24.7	26.9	27.1
School Rd Drain						
School Rd / Gear Rd intersection	20.67	21.15	21.2	4.6	4.8	4.8
Local link road culvert – proposed	20.49	21.00	21.01	5.1	5.7	5.7
Lucinsky Overflow						
Local link road (western side)– proposed	15.56	15.64	15.66	0.17	0.71	0.82

* These flood levels are below the road level given for the Expressway at each culvert location. However a low bund will be constructed upstream of the Expressway to provide the necessary freeboard for the design 1% AEP flood adjusted for possible future climate change effects in order to prevent the Expressway from being overtopped.

To put these predicted peak levels and discharges into perspective, they reflect peak flood discharge values of 64.1m^3/s, 80.2m^3/s and 88.7m^3/s for the 5%, 1% and 0.5% AEP floods adjusted for possible climate change effects.

The peak flood discharge data summarised in Table 5-4 demonstrate that the system of culverts on the main stream channel provides a very effective throttle for downstream flood flows with these limited to a range of 20.6-20.8m^3/s past the SH1 culvert. The system of culverts on the Mangaone Overflow also throttles flood flows along that watercourse although the existing SH1 culvert at the downstream end is the primary control. There is slightly more variation in the downstream discharges (24.7-27.1m^3/s) across the range of floods than in the case of the main stream channel.

The peak flood levels upstream of both the local link road and Expressway culverts on the main stream channel do not increase very much as the flood magnitude increases, particularly for the two larger floods. The same is true of peak flood levels upstream of the local link road culvert on the Mangaone Overflow and the School Road drain, again for the two larger floods in particular. The limited increase in peak flood levels upstream of the local link road culverts on both the main stream channel and the Overflow is reflected in the relatively small increase in the extent of flood ponding seen between Figure 5-2a for the 1% AEP flood and Figure 5-14 for the 0.5% AEP flood (both floods adjusted for the effects of possible future climate change effects).

The variation in peak flood levels in the School Road drain at the new School Road / Gear Road intersection for the range of floods is more a reflection of the degree of flood ponding upstream of the flood containment bund than the peak flood discharge in the drain.

Figure 5-17 shows backwater profiles along the School Road drain and its extension downstream to the Mangaone Overflow for the 5%, 1% and 0.5% AEP floods adjusted for possible future climate change effects. These profiles are superimposed on an existing ground level profile along the line of the drain. The information in Figure 5-17 indicates that the flood containment bund for the School Road drain would need to be at least 1.7m high locally and at least 1.5m high on average (with freeboard added) between the School Road / Gear Road intersection and the local link road culvert in order to contain floodwaters up to the 0.5% AEP flood. A higher design standard is appropriate for this flood containment bund than the design standard for the local link road as this bund forms part of the primary flood defence system for the Expressway.

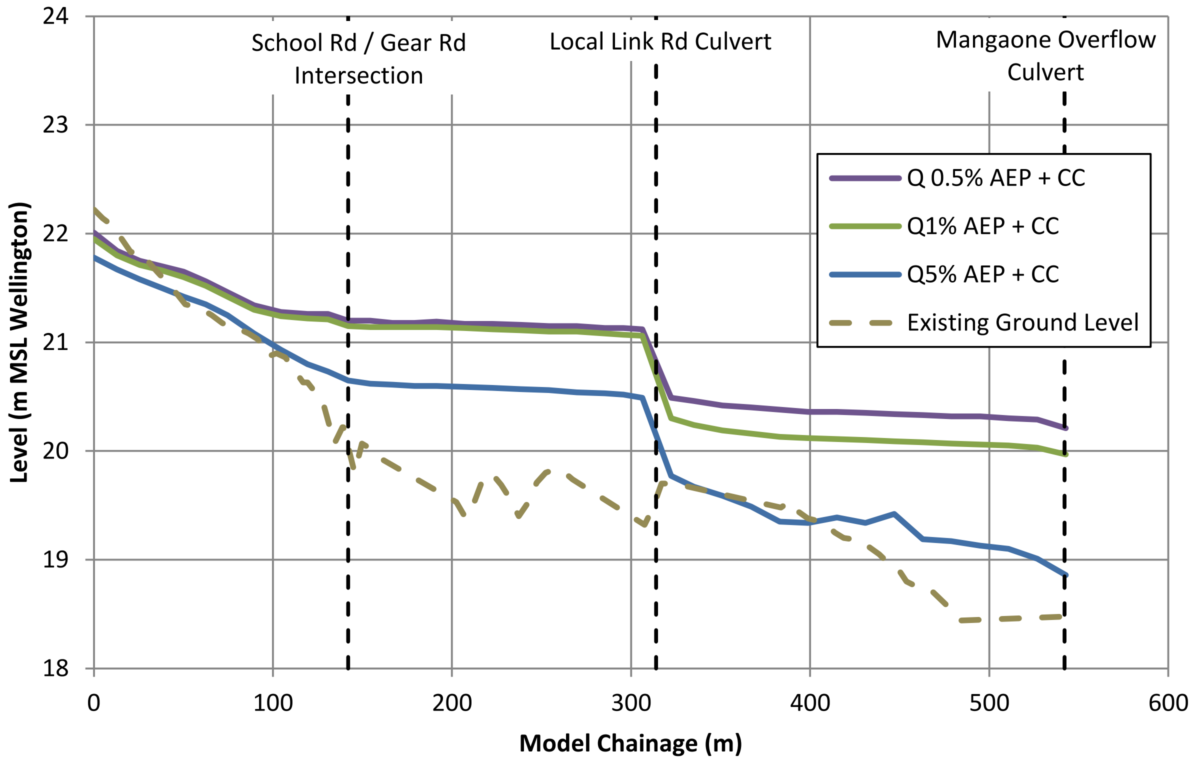

Figure 5-17 Peak flood level profiles along School Road drain for 5%, 1% and 0.5% AEP floods adjusted for possible climate change effects to 2090

5.4 Consideration of Other Effects

5.4.1 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 or vegetative 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, most of the culverts proposed to be constructed as part of the Expressway Project will be multi-cell box culvert structures so that the third criterion is easily satisfied. The second criterion is also satisfied for the main stream channel and may also be partly satisfied for the Mangaone Overflow. The upper catchment is fairly heavily forested and there are a reasonable number of large trees adjacent to the mains stream channel down the alluvial fan so that the first criterion is also satisfied.

The culverts most at risk of a partial blockage are the two main link road culverts – the one on the main stream channel and to a lesser degree the one on the Mangaone Overflow. The local link road culvert on the School Road drain is a much smaller culvert and could still be at risk of a blockage from smaller woody and vegetative debris. The main stream channel between the existing SH1 culvert and the Lucinsky Overflow is lined with willow trees so that the Lucinsky Overflow culvert is also at risk of being partially blocked.

The following partial culvert blockage scenarios were therefore considered:

- partial blockage of local link road culvert on main channel of Mangaone Stream (5m wide x 2.5m high culvert reduced in size to 5m wide x 1.5m high – 40% blockage over 1m depth across full width of structure);
- partial blockage of local link road culvert on Mangaone Overflow (5m wide by 1.5m high culvert reduced in size to 2.5m wide x 1.5m high – 50% blockage over the full depth of the structure)[6];
- partial blockage of local link road on School Road drain (2.5m wide x 1.0m high culvert reduced in size to 1.25m wide x 1.0m high - 50% blockage over the full depth of the structure); and
- partial blockage of Lucinsky Overflow culvert (10m wide x 1m high culvert reduced in size to 5m wide x 1.0m high – 50% blockage over the full depth of the structure).

Figures 5-18 to 5-21 show the predicted flood inundation maps for the 1% AEP flood adjusted for possible future climate change effects to 2090 resulting from these partial culvert blockage scenarios assuming them to occur independently of each other.

[6] These culverts operate under a submerged inlet condition for the design 1% AEP flood adjusted for possible future climate change effects to 2090 so that the effects of a partial blockage over the full depth under such conditions are the same as the effects of a partial blockage over the full width.

Compared to the flood inundation map in Figure 5-2a, the flood inundation maps in Figures 5-18 to 5-21 show very little change. The effect of one of the local link road culverts becoming partially blocked is simply for the blocked culvert flow to be transferred to adjacent culverts.

It is considered that it would a very extreme event for more than one of these culverts to suffer concurrent partial blockages by woody debris material. For the Mangaone Overflow and School Road drain culverts on the local link road and the Lucinsky Overflow culvert to experience a partial blockage, the woody debris material would first have to be conveyed by very shallow and slow flowing overland flow so that there is a high chance of such material becoming grounded before it reached the inlets of these culverts to cause a blockage.

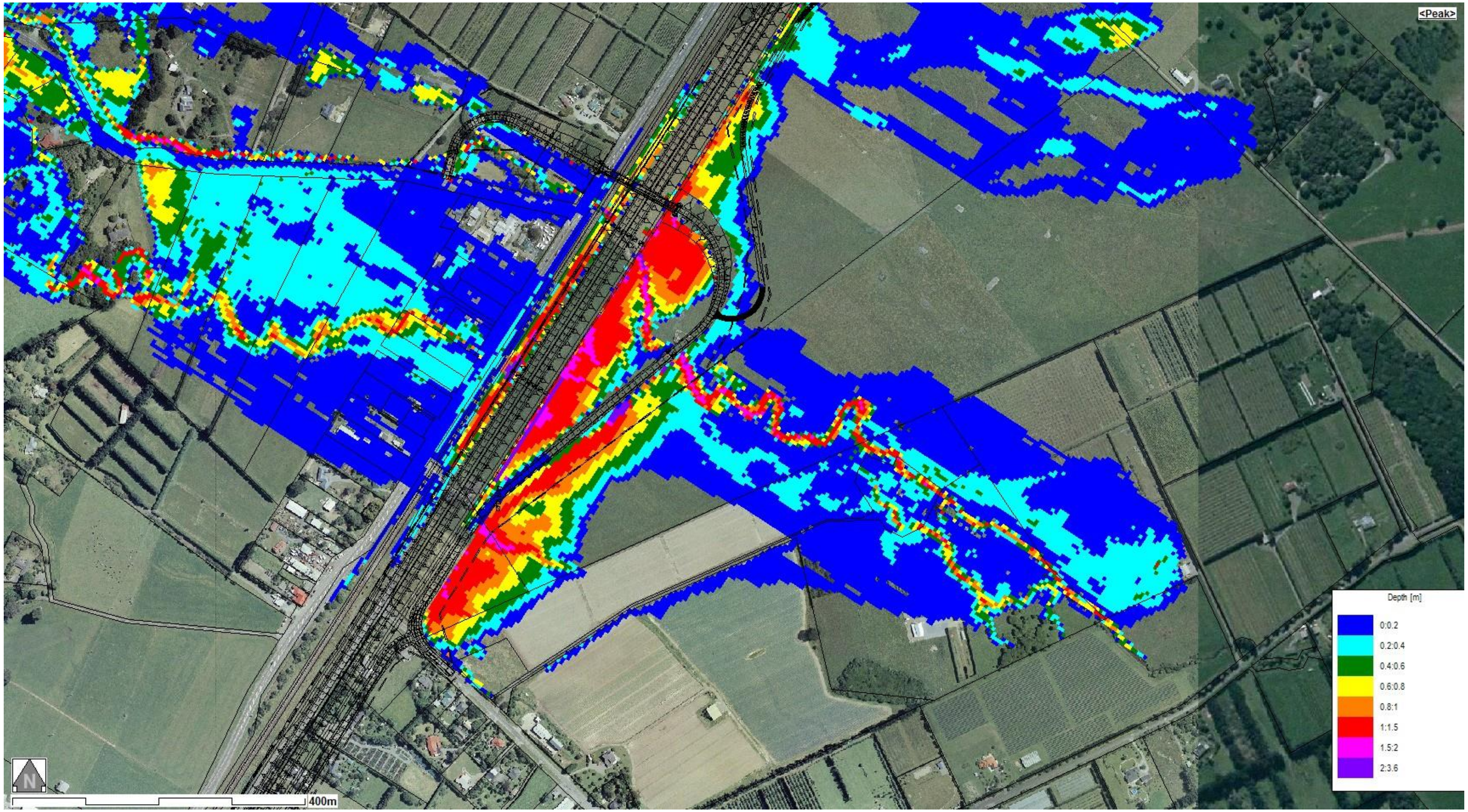

Figure 5-18 Flood inundation map for Mangaone Stream alluvial fan and floodplain system for 1% AEP flood adjusted for possible future climate change effects to 2090 with partial blockage of local link road culvert on main channel of Mangaone Stream

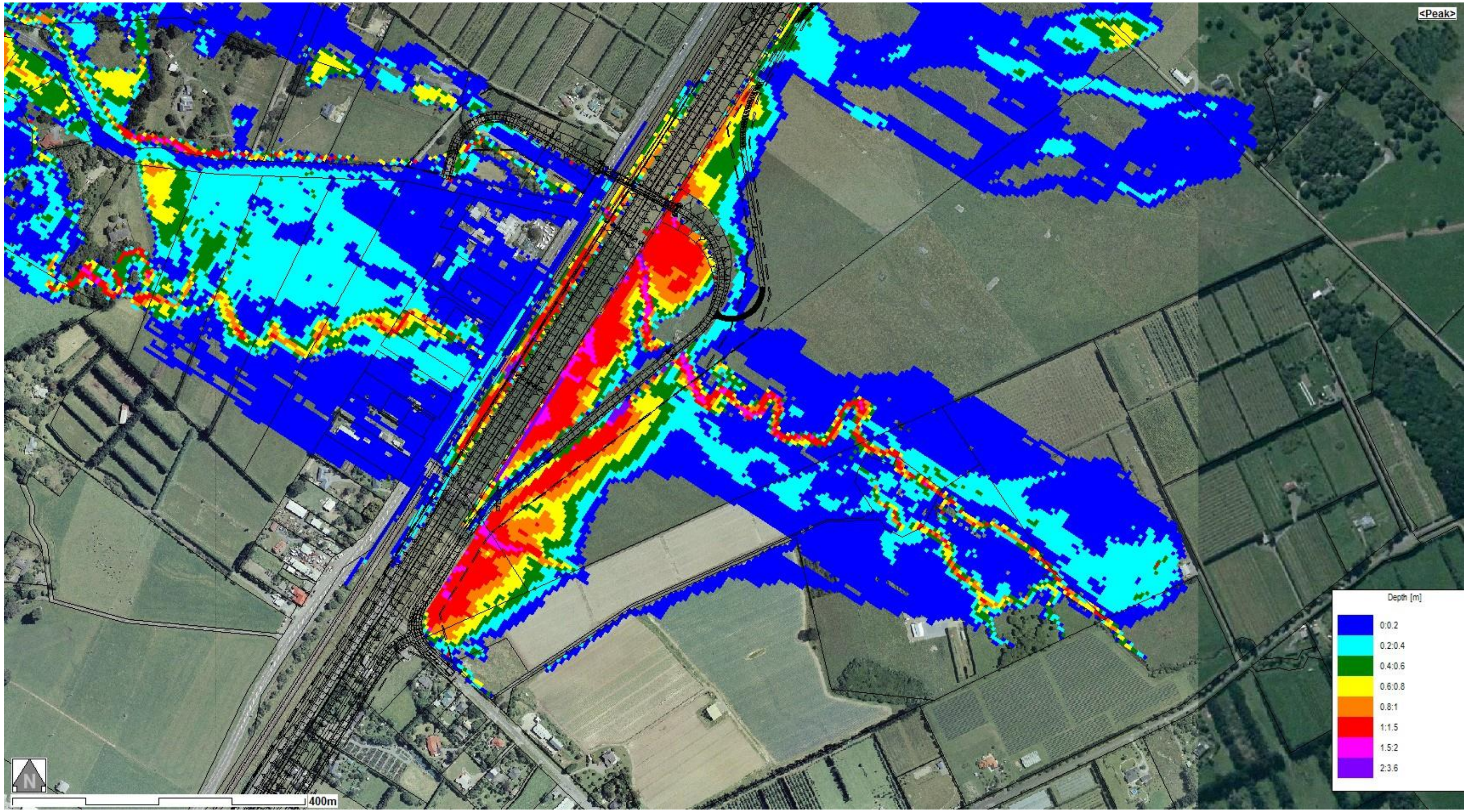

Figure 5-19 Flood inundation map for Mangaone Stream alluvial fan and floodplain system for 1% AEP flood adjusted for possible future climate change effects to 2090 with partial blockage of local link road culvert on Mangaone Overflow

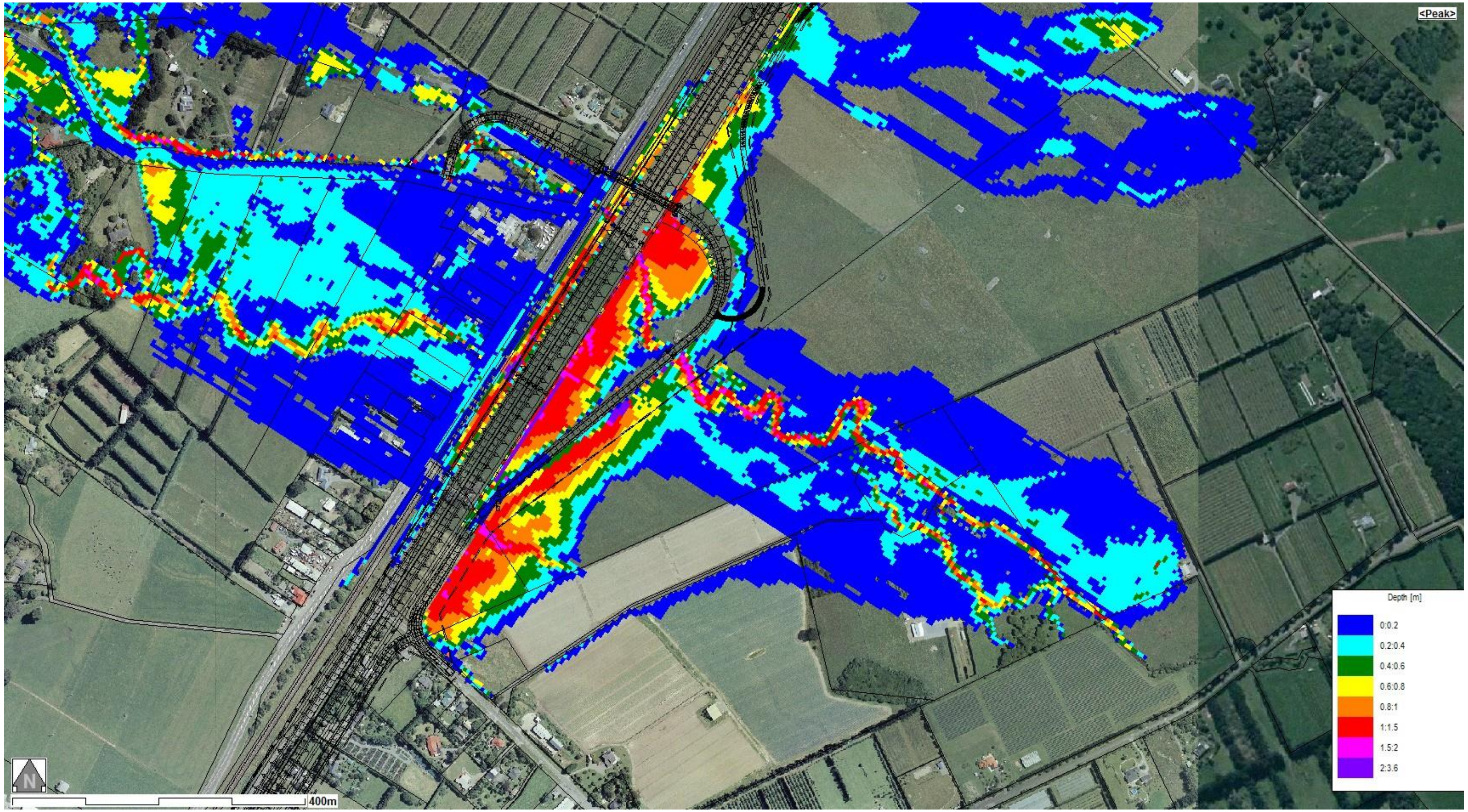

Figure 5-20 Flood inundation map for Mangaone Stream alluvial fan and floodplain system for 1% AEP flood adjusted for possible future climate change effects to 2090 with partial blockage of local link road culvert on School Road drain

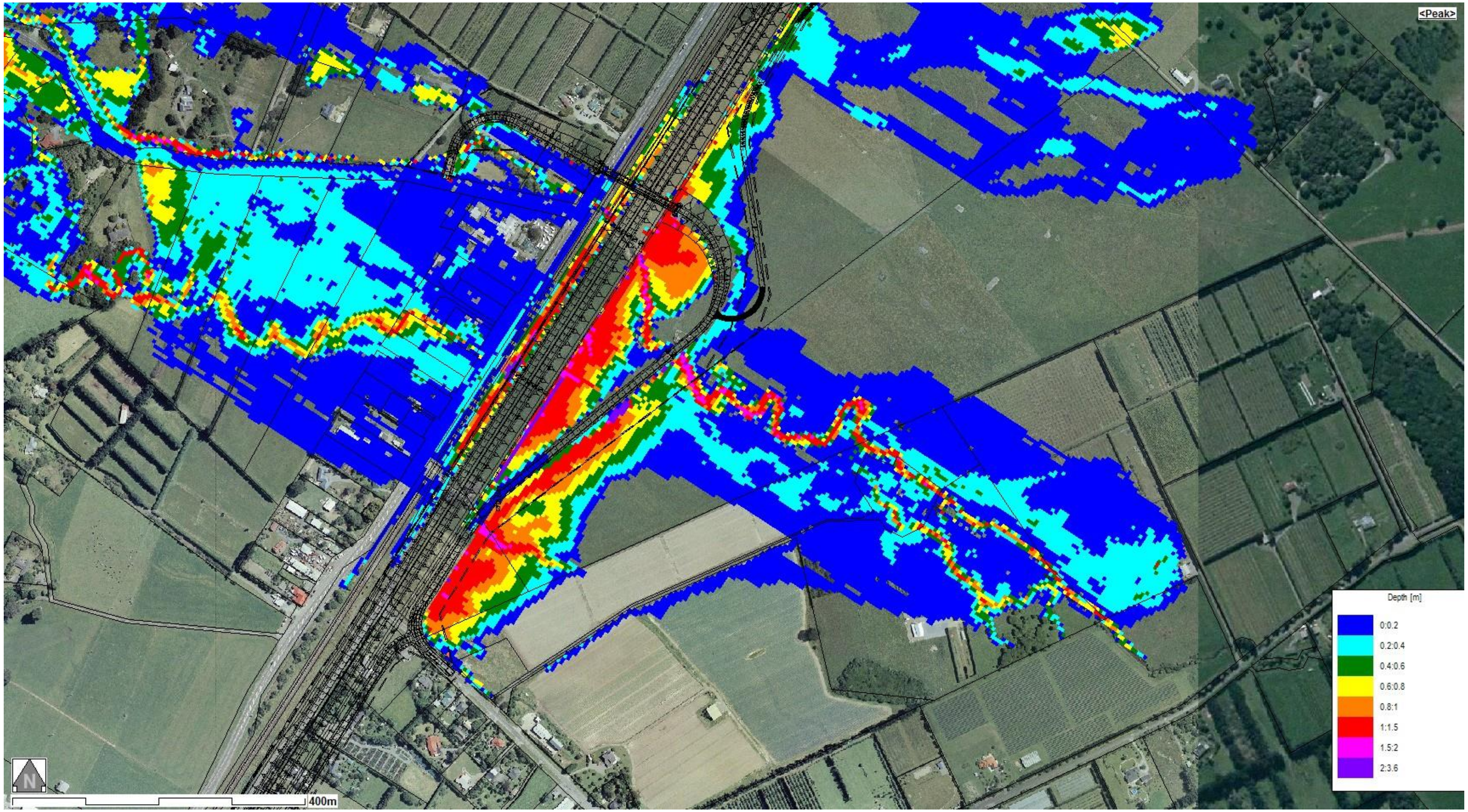

Figure 5-21 Flood inundation map for Mangaone Stream alluvial fan and floodplain system for 1% AEP flood adjusted for possible future climate change effects to 2090 with partial blockage of local link road culvert on Lucinsky Overflow

Table 5-5a summarises peak flood levels in front of each of the local link road culverts for the various culvert blockage scenarios compared to the proposed situation without any culvert blockages. Similarly Table 5-5b shows a summary of peak flood discharges at the same culvert locations for the various blockage scenarios compared to the proposed situation without any culvert blockages.

Table 5-5a Predicted peak flood levels at local link road culverts in proposed situation for 1% AEP flood adjusted for effects of possible future climate change to 2090 with partial blockage of selected culverts

Blockage Case	Peak Flood Level (m MSL Wellington datum)			
	Mangaone Stream culvert	Mangaone Overflow culvert	School Road Drain culvert	Lucinsky Overflow Culvert
No blockage	21.70	21.07	21.06	15.65
40% blockage of Mangaone Stream culvert	21.77	21.14	21.10	15.62
50% blockage of Mangaone Overflow	21.70	21.23	21.15	15.64
50% blockage of School Road drain culvert	21.70	21.12	21.10	15.65
50% blockage of Lucinsky Overflow Culvert	21.7	21.07	21.06	15.71

Table 5-5b Predicted peak discharges at local link road culverts in proposed situation for 1% AEP flood adjusted for effects of possible future climate change to 2090 with partial blockage of selected culverts

Blockage Case	Peak Discharge (m^3/s)			
	Mangaone Stream culvert	Mangaone Overflow culvert	School Road Drain culvert	Lucinsky Overflow Culvert
No blockage	31.4	24.0	5.8	0.72
40% blockage of Mangaone Stream culvert	24.7	25.8	5.8	0.48
50% blockage of Mangaone Overflow	30.4	12.3	5.9	0.69
50% blockage of School Road drain culvert	30.4	25.3	5.0	0.71
50% blockage of Lucinsky Overflow Culvert	31.4	24	5.8	0.71

The peak flood level and discharge data summarised in Tables 5-5a and 5-5b indicates that partial blockage of one or other of the different culverts along the local link road simply results in a redistribution of flood flows laterally to the other two culverts. The increase in peak flood level at each of those other two culverts is relatively small.

5.4.2 Sediment Deposition in Ponding Areas

Sediment deposition across the Mangaone Stream alluvial fan and floodplain would occur in the existing situation primarily upstream of the NIMT railway line where ponding of floodwaters occurs and along overland flow paths where sediment laden floodwaters would be relatively slow moving. The aerial photographs in Figures 4-2 and 4-3 showing the aftermath of the 28 October 1998 flood illustrate this. Fortunately this would only occur in the order of once every 5-10 years on average (the 28 October 1998 flood had an estimated annual exceedance probability of 15% - Table 2-6).

In the proposed situation, the primary location for deposition of suspended sediment would be transferred to the ponding areas upstream of the Expressway and upstream of the local link road (Figure 5-2a). The first ponding area between the Expressway and the local link road falls entirely within the area of the Project and is proposed to be used as an area for offset mitigation for ecological purposes. The second ponding area upstream of the local link road and between the Mangaone Overflow culvert and School Road is presently used for pastoral purposes and it is envisaged that this land use will continue in the future. Any sediment deposition in either of these areas during a flood will be an infrequent occurrence as in the existing situation.

Despite this redistribution of the areas of potential sedimentation, the overall amount of sediment deposition is likely to be similar to that which would occur in the existing situation. However the lowered channel areas on the Mangaone Overflow will need to be monitored in particular following the occurrence of significant flood events. Any accumulation of fine sediment material in these channels over time will need to be removed to maintain the design invert levels.

5.4.3 Erosion of Floodplain Surfaces Due to High Flow Velocities

Figure 5-6a illustrates the estimated peak flow velocities across the alluvial fan and floodplain surface in the proposed situation for the 1% AEP flood adjusted for possible climate change effects to 2090 (Figure 4-10a shows a comparable peak flow velocity map for the existing situation). As noted previously, the maximum overland flow velocities are predicted to follow the course of the Mangaone Overflow with peak flow velocities as high as 1.5-2.0m/s in both the existing and proposed situations. The areas affected by high flow velocities are primarily grass-covered and used for pastoral purposes.

The 28 October 1998 flood event on which the hydrographs for 1% AEP and other floods adjusted for possible change effects are based was a comparatively long period event with several distinct rainfall bursts apparent within the rainstorm that gave rise to it. These floods therefore provides a reasonable indication of an upper limit on the likely duration of the peak flow velocities which is estimated to be less than 10 hours (Figure 2-4). Well grassed surfaces can sustain peak flow velocities as high as 3m/s for up to 12 hours (Hewlett *et al*, 1985) so that the pasture along the course of the Mangaone Overflow should be able to sustain the expected peak flow velocities in a 1% AEP flood adjusted for possible change effects, possibly with some minor damage. This applies to both the existing and proposed situations.

Figure 5-7 shows a map of peak flow velocities differences between the existing and proposed situations. As noted before, the areas of darker red indicate increased peak flow velocities. These areas are predominantly upstream of the local link road where the peak flow velocities shown in Figure 5-6a are mostly in the range of 0.2-0.4m/s except in the immediate vicinity of the local link road culvert on the Mangaone Overflow.

Conversely peak flow velocities in the ponding area between the Expressway and the local link road and along an approximately 130m wide strip west of SH1 and to the south of Te Horo Beach Road are decreased in the proposed situation, as indicated by the darker green shading. Elsewhere across the alluvial fan and floodplain surface, flow differences are generally in the order of ±0.05m/s which is within the accuracy of the MIKEFLLOD model predictions so that there is no real change between the existing and proposed situations.

Flow velocities approaching and exiting form culverts across the floodplain would be increased relative to flow velocities across the wider floodplain. Any floodplain surface erosion that did occur in a major flood event due to such increased flow velocities, particularly around culvert entrances and exits, would be localised and easily repairable.

On the whole then it can be argued that the Expressway has no effect on the maximum peak flow velocities across the alluvial fan and floodplain surface which follow the course of the Mangaone Overflow and has a very slight positive effect of reducing peak flow velocities in some areas. The Expressway does not increase the erosion potential of high flood flow velocities across the alluvial fan and floodplain surface.

5.4.4 Drainage Times for Ponding Areas

Figures 4-6 and 4-8 show stage hydrographs in the ponding area upstream of the NIMT railway line along the main stream channel and along the Mangaone Overflow in the existing situation while Figures 5-8 and 5-10 show similar stage hydrographs in the ponding areas upstream of the Expressway and upstream of the local link road in the proposed situation. Visual comparison of equivalent pairs of these stage hydrographs indicates no real change in their pattern and duration between the existing and proposed situations. This is not surprising given the limited storage volume of the ponding areas in both situations. The Expressway will therefore have no real effect on the drainage times of the ponding areas in the proposed situation.

Maximum durations of flood ponding of up to 8-10 hours are expected for the 1% AEP flood adjusted for possible future climate change effects.

5.5 Sensitivity Test for Lucinsky Overflow

In Section 5.2, the effect of the local link road and western approach embankment to the local link road overbridge on flow behaviour along the Lucinsky Overflow was discussed. As noted in that Section, the origin of the flood flows passing along this Overflow is from flood flows overtopping SH1 to the north of the SH1 culvert on the main stream channel. As the footprint of the local link road and approach embankment significantly constrains the width of the overland flow path in the proposed situation, the peak flow volume passed by the Overflow is reduced from the 3.5m^3/s of the existing situation to 0.7m^3/s. The situation is compounded by a low stopbank along the right bank which contains floodwaters along the main stream channel and prevents them from breaking out into the course of the Lucinsky Overflow.

Another sensitivity test was therefore carried out in which a 30m long section of the low stopbank along the right bank of the main stream channel was lowered about 0.6m to a level of 16.7m (MSL Wellington datum). This lowering of a short section of the stopbank allowed floodwaters to break out of the main stream channel and bolster the flood flows originating from overtopping of SH1 and passing along the Lucinsky Overflow. The volume of flow passing through the dry culvert under the western approach embankment to the local link road culvert was constrained by limiting the culvert width to 3.5m.

The red coloured hydrograph shown in Figure 5-12 is the result of this additional sensitivity test. Although the peak flow is limited to no more than what it would be in the existing situation for the 1% AEP flood adjusted for possible climate change effects (3.5m^3/s), the overall flood volume passed through the Overflow is significantly larger as the gap in the low stopbank where flood levels in the main stream channel remain largely constant for a period of time becomes the primary contributor to flood flows along the Lucinsky Overflow.

Although this modification offsets the effects of the local link road and overbridge approach embankment on the Lucinsky Overflow, the increased flood volume that it passes would probably be acceptable to other parties. The length of stopbank along the right bank of the main stream channel that was lowered could be significantly reduced to achieve a better match between total flood volume passed through the Lucinsky Overflow in the proposed situation and that passed in the existing situation.

5.6 Other Potential Modifications to School Road Drain

As noted previously there is a local flood nuisance which occurs in the existing situation along School Road which impacts on local properties and also results in the occurrence of flood ponding at the intersection of School Road and Gear Road. This arise because the discharge capacity of the drain around the perimeter of a horticultural property (this drain may in fact be modified and realigned local distributor channel across the alluvial fan surface) which feeds into the School Road drain significantly exceeds the discharge capacity of the School Road drain itself.

The solution to this local flood nuisance problem would be to increase the size of the School Road drain and thereby increase its discharge capacity. This is strictly outside the scope of the PP2O Project. However, as part of the existing School Road drain needs to be relocated to facilitate construction of the proposed flood containment bund, it would seem appropriate to undertake this enlargement of the drain in conjunction with the Project works. This improvement in the local drainage system would need to be agreed and undertaken in consultation with KCDC.

6. Response to Comments by GWRC

Table 6-1 summarises the key comments made by GWRC in their review of the preliminary investigations for the initial scheme design of 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
Minimal information provided on development and calibration of model.	Appendix B provides details of the development of the MIKEFLOOD model of the Mangaone Stream alluvial fan and floodplain system using elements of a MIKE11 model previously developed for GWRC for a 2002 flood hazard assessment. It was not possible to calibrate the MIKEFLOOD model in a conventional sense due to a lack of measured peak flood level data along the main channel of the Mangaone Stream and the Overflow from historic flood events. There is also considerable uncertainty over the magnitude of previous flood estimates for historic events. The flow resistance description for the main stream channel downstream of the existing SH1 culvert from the 2002 MIKE11 model was retained although this watercourse does not convey the majority of the flow volume in significant flood events. The majority of the flow volume in such events is conveyed as overland flow. Appendix C describes a qualitative calibration check on the predictions of the MIKEFLOOD model for the 28 October 1998 flood for which there are a few post-peak aerial photographs of flood inundation patterns available.
Descriptions of model do not provide sufficient information to determine where ponding areas are located.	Detailed flood inundation maps for the existing and proposed situations now clearly show where ponding areas are located relative to the various transport links crossing the Mangaone Stream alluvial fan and floodplain system. These flood inundation maps also show ranges of peak flood depths. The flood inundation maps are complemented by peak flow velocity maps.

Comment	Our Response
No information provided on how flood inundation maps produced. Uncertainty about accuracy of flood inundation maps.	The method of derivation of the flood inundation maps is now clearly outlined in this report. They have been produced using a MIKEFLOOD model incorporating a one-dimensional MIKE11 component to simulate flow behaviour in stream channels, drains and culverts and a two-dimensional MIKE21 component to simulate overland flow behaviour across a near flat surface. This approach should dispel any uncertainties about accuracy of the flood inundation maps.
Sensitivity tests should be undertaken with regard to the model inflows given uncertainty in flood estimates.	Model simulations have been undertaken to predict the extent of flood inundation for the 5%, 1% and 0.5% AEP floods adjusted for the effects of possible future climate change to 2090. This represents a range of flood magnitudes and enables the sensitivity of flood inundation extent and peak flood levels to flood size to be assessed.
Flood inundation maps should show ranges of peak flood depths in addition to areal extent of inundation.	All flood inundation maps now show ranges of peak flood depths.
A flood level difference map between proposed and existing situations should be produced.	A peak flood level (depth) difference map has been produced to indicate where major changes in flood inundation have occurred in the proposed situation compared to the existing situation.
Maps showing peak flow velocities across alluvial fan and floodplain system should be produced for existing and proposed situations.	Peak flow velocity maps have now been produced.

Comment	Our Response
Peak flow velocity difference map between proposed and existing situations should be produced.	A peak flow velocity difference map has now been produced comparing the proposed and existing situations
Consideration should be given to the potential effects of partial blockage of culverts by flood-transported woody debris.	This matter is addressed in Section 5-4 of this report. Consideration has been given to partial blockages of the local link road culvert on the main channel of the Mangaone Stream, the local link road culvert on the Mangaone Overflow, the local link road culvert on the School Road drain and the dry culvert through the western approach embankment to the local link road overbridge on the Lucinsky Overflow.
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 also addressed in Section 5-4 of this report.

7. Conclusions

7.1 Existing Flood Patterns and Effects of Transport Links

The Mangaone Stream flows across an alluvial fan between the foothills of the Tararua Ranges and the sea. Under flood conditions, floodwaters break out of the main channel near the head of the fan into other overland flow paths which follow the course of old distributor channels over the fan surface. The main drainage paths down the fan surface appear to have been heavily modified in historical times to facilitate development of the fan surface for pastoral, horticultural and residential purposes. For example the Mangaone Overflow through the middle of Te Horo Village follows the original course of the main channel of the Mangaone Stream. The present main channel is located about 250m further north and generally follows the route of Te Horo Beach Road to the west of SH1.

The existing SH1 and NIMT railway links cut transversely across the Mangaone Stream alluvial fan and intercept all of the overland flow paths conveying floodwaters down the alluvial fan. Some of the floodwaters in the outlying overland flow paths overtop the NIMT railway line and SH1 and continue flowing down the alluvial fan surface but the majority of floodwaters are conveyed under the railway line and SH1 via two culvert systems, one on the main stream channel and the other on the Mangaone Overflow.

The railway line, which lies upstream of SH1 and is slightly elevated above the alluvial fan surface, intercepts several of the central overland flow paths down the fan. This flood detention barrier action of the elevated railway line in combination with the limited discharge capacity of the two culvert systems (the one on the main stream channel and the other on the Overflow) causes flood ponding to occur upstream which attenuates peak flood discharges downstream on each of the main watercourses. The extent of flood ponding upstream is limited due to the steepness of the slope of the alluvial fan.

SH1 is constructed at grade across the fan surface and, despite the occurrence of flood peak attenuation by flood ponding upstream of the NIMT railway line, is known to be overtopped by floodwaters every few years in only moderately sized flood events at the main stream channel and overflow culvert locations.

The predicted flood extent across the alluvial fan surface for the 1% AEP flood adjusted for possible climate change effects to 2090 (Figure 4-4a) indicates that most of Te Horo Village to the west of SH1 would be inundated although the peak flow depths would be shallow (< 0.4m) and fairly slow moving (< 0.6m/s) except along the course of the Mangaone Overflow (Figure 4-10a).

7.2 Proposed Mitigation Measures for Expressway Crossing

The Expressway will run parallel with the existing NIMT railway and SH1 transport links and will be located upstream of the former. It will therefore also cut transversely across the Mangaone Stream alluvial fan. To be able to satisfy the required serviceability design flood standard (the 1% AEP flood adjusted for possible climate change effects to 2090), the Expressway will need to emulate the present flood detention function of the elevated NIMT railway line. This will be achieved by means of an elevated bund upstream of the Expressway functioning as a flood detention barrier. To provide continuity for the existing main watercourses, the Expressway will also need to incorporate the following culverts aligned with the downstream NIMT railway and SH1 culverts on each primary watercourse:

- a 5.0m wide by 2.0m high box culvert structure on the main stream channel; and
- an 8.0m wide by 1.5m high box culvert structure on the Mangaone Overflow.

The proposed situation is further complicated by the presence of an east / west link road connecting School Road and Gear Road on the east side with Te Horo Beach Road on the west side via an overbridge across the Expressway. The route of this local link road also intercepts existing overland flow paths across the Mangaone Stream alluvial fan. The serviceability design flood standard for this local link road is lower than that for the Expressway (between the 4% and 2% AEP flood adjusted for possible climate change effects to 2090) so that the road will need to be slightly elevated above the alluvial fan surface to meet the design flood standard. The route of the local link road crosses the main channel of the Mangaone Stream and the Mangaone Overflow upstream of the Expressway on the east side and the Lucinsky Overflow and main stream channel on the west side. The local link road will therefore also require the following culverts and bridge:

- a 5.0m wide by 2.5m high culvert on the main stream channel upstream of the Expressway (east side);
- a 5.0m wide by 1.5m high culvert on the Mangaone Overflow upstream of the Expressway (east side);
- a 5.0m wide by 1.0m high dry culvert on the Lucinsky Overflow (west side); and
- an 8m span single span bridge across the main stream channel downstream of SH1 (west side).

The invert levels of the local link road and Expressway culverts on the Mangaone Overflow have been set fairly low in order to keep road levels as low as possible. A shallow 8m wide excavated channel will need to be formed to provide hydraulic connectivity between the two culverts. A shallow 10m wide, 160m wide trench running parallel with the local link road will also need to be formed upstream of the local link road culvert on the Mangaone Overflow to act as a collector basin for overland flows approaching the Overflow.

In order to provide hydraulic connectivity with the main stream channel upstream of the Expressway culvert for overland flows in the northern breakout flow path deflected southwards by the Expressway, either a 10m wide gap between the Expressway and the eastern abutment of the local link road overbridge or a 10m wide by 1.5m high dry culvert incorporated within the overbridge approach embankment needs to be provided.

The School Road drain will need to be relocated as part of the relocation of Gear Road to form the new local link road. However, to provide containment of floodwaters along the drain and the flood ponding induced by the elevated local link road across the Mangaone Overflow and main channel of the Mangaone Stream, a flood containment bund will need to be constructed between the local link road and the relocated School Road drain. The bund will need to extend upstream along School Road to cover the extent of flood ponding on the alluvial fan surface. It will also need to incorporate a ninety degree dogleg extension to connect with the flood detention barrier upstream of the Expressway, located to the south of a 2.5m wide by 1.0m high culvert on the School Road drain under the local link road. The School Road drain flood containment bund therefore forms part of the primary flood defence for the Expressway rather than the local link road.

A 5m wide by 1.0m high dry culvert will need to be provided through the western approach embankment to the local link road overbridge to provide hydraulic continuity for the Lucinsky Overflow.

In a flood large enough to cause inundation upstream of the Expressway and the local link road, the increased flood levels upstream of the local link road relative to the existing situation would potentially impact on farming operations utilising the inundated land. One possible additional mitigation measure to address this impact could be to use the water level recorder at the existing Ratanui flow gauging station upstream to provide automated flood warnings to affected land owners (this would need to be implemented by GWRC as the operator of the gauging station). A facility of this type would also be of benefit to other floodplain residents although anecdotal evidence indicates that they are already aware of the flood hazard potential of the stream from past experience and that they are on a heightened alert whenever there is a heavy rain forecast for the Tararua Ranges.

7.3 Effects of Expressway on Flood Patterns

Whereas flood ponding occurs upstream of the slightly elevated NIMT railway line in the existing situation, flood ponding will be transferred to upstream of the Expressway and the local link road in the proposed situation. However, this flood ponding will rare and only temporary, lasting no more than a few hours. It will also not impact of people or property directly as the inundated land is used for farming purposes and is not inhabited.

Overland flow paths along the northern edge of the alluvial fan and along School Road which result in overtopping of SH1 in significant flood events will be eliminated. The downstream extensions of these flow paths to the west of SH1 beyond the intersection of Te Waka Road with SH1 (northern breakout flow path) and through the south end of Te Horo Village will also be eliminated.

The culvert systems on the main stream channel and on the Mangaone Overflow in the proposed situation will cause a slight redistribution of the peak flow volumes between the main stream channel and the Mangaone Overflow in the case of the design 1% AEP flood adjusted for possible climate change effects to 2090. However the total peak flow volume between the two primary watercourses will be slightly reduced.

Downstream (to the west) of SH1, much of To Horo Village and beyond will be inundated by the design 1% AEP flood adjusted for possible climate change effects to 2090. However the predicted peak flood depth and flow velocity differences between the existing and proposed situations across much the inundated area are within the level of accuracy of the MIKEFLOOD model. In other words no effective change in peak flood depths and velocities is predicted over most of the inundated area west of SH1.

Peak flood depths and flow velocities over a nominal 100m wide strip to the south of Te Horo Beach Road and west of SH1 (which passes through a mixed residential and retail part of Te Horo Village) will be slightly reduced in the proposed situation compared to the corresponding values in the existing situation (see Figures 5-3 and 5-7).

The footprint of the western approach embankment to the local link road overbridges will block out part of the effective width of the Lucinsky Overflow in the proposed situation. As a result the peak flood discharge along the Lucinsky Overflow will be reduced from 3.5m^3/s in the existing situation to 0.7m^3/s in the proposed situation. The original peak flood discharge can be restored in the proposed situation by lowering to a level of 16.7m (mean sea level Wellington datum) a 30m section of the low stopbank along the right bank of the main stream channel over a distance 70-100m downstream of the existing SH1 culvert.

In summary then, with the proposed mitigation measures outlined in Section 7.2 in place, the effects of the Expressway crossing of the Mangaone Stream and alluvial fan would be no more than minor.

8. References

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