7. Climate change assessments

7.1. Introduction

7.1.1. Elements of climate change that affect flooding behaviour

Climate change due to the enhanced greenhouse effect has the potential to result in the following changes to the flooding behaviour of the watercourses crossed by the project:

- Sea level rise
- Storm surge
- Increases to rainfall intensity.

Increased sea levels could result in higher ocean levels at the mouths of coastal rivers. The majority of the project would be located high enough to be unaffected, except for areas within the Clarence and Richmond river floodplains. Only these lower sections of the project boundary would be affected by sea level rise. Flood levels for these rivers would increase as a result of higher tailwater levels in the ocean.

Further, as these flood events are assumed to coincide as part of a cyclonic event or east coast tropical low, they are often accompanied by a storm surge. Flood modelling for the project has included combined flood and storm surge scenarios. Climate change may result in an increase in the frequency and intensity of east coast lows. This would lead to an increase in the magnitude of storm surges.

There is a possibility that the enhanced greenhouse effect would lead to an increase in the intensity of rainfall events. Essentially, this would imply that the rainfall expected to occur in a 100 year ARI flood event would occur more frequently. There is little literature to provide any solid conclusions on the expected increases in rainfall intensity. However, in terms of the impact on the project, it could mean that the design immunity of the highway would reduce.

7.1.2. Approach to climate change assessment

It is assumed that the design objective for flood immunity is that the average flood immunity of the project over the 100 year design life should be 20 years (Clarence/Richmond river floodplains) or 100 years (remainder of project).

The 20 year ARI flood immunity for the Clarence River and Richmond river floodplains implies an acceptance that the project can be overtopped for periods of time (a few days) about five times on average in a 100 year period. The project would be designed to withstand inundation by floodwaters so the impact would be loss of use of the highway rather than damage to infrastructure.

Given this, the consideration of the impacts of climate change on the project needs to assess the following two issues:

- What is the cost of constructing the project to achieve the design flood performance over the entire project life?
- What is the reduction in the design flood performance of the project if it is constructed to existing flood levels?

The first issue requires consideration of the project life. The main elements at risk from increased frequency of inundation are the road embankments and waterway crossings. These elements have a design life of 100 years. Assuming that the project is constructed by about 2020, this implies the design life of the project would be from 2020 to 2120.

Under climate change scenarios of increasing rainfall intensity and increasing sea levels, the flood immunity would change (decrease) over the project life. This is based on an assumption that the road embankments remain at a constant level without significant settlement on the floodplain soils.

Based on the above and a conservative assumption of a linear degradation of flood immunity, the average flood immunity over the 100 year design life would be met by constructing the project at embankment levels based on climate change predictions for 50 years into the project life, ie 2070. Therefore, 2070 has been used as the basis for these climate change assessments.

A third issue for consideration is the change in impacts of the project under predicted future climate change conditions. Due to overall increased rainfall intensities, any nominated ARI flood event would become notionally larger. This would result in changed flooding conditions and, therefore, changed project impacts. This issue was assessed by modelling the existing and project case under climate change conditions and comparing against the current climate conditions assessed in Chapters 4 to 6. The overall increase in absolute flood levels as a result of climate change was also considered with respect to the immunity of bridges along the project.

7.2. Sea level rise

7.2.1. Assumed sea level rise scenarios

The sea level rise estimates for this project were based on DECCW (2009). This policy states increases of 0.4 metres for 2050 and 0.9 metres for 2100.

Based on a linear interpolation of these values, a 2070 estimate of sea level rise would be 0.6 metres. A linear interpolation would result in conservative estimates, as the increase is likely to be lower in the first 50 years (2000 to 2050) compared to the last 50 years (from 2050 to 2100).

The research to date indicates that there is little potential for increases to the frequency and magnitude of storm surges in this part of the coast (CSIRO 2007b).

As well as a consideration of sea level rise scenarios to use in flood simulations, an assessment was made of the potential for the project to be inundated in non-flood events with a high tide. This required a consideration of the resulting sea level with the mean high water of the spring tides occurring at the end of the project life.

For this scenario, an assumed sea level rise of 1.1 metres for the year 2120 (the end of the project life) was assumed based on a linear interpolation of the 0.4 metres at 2050 and 0.9 metres at 2100. This value was added to the mean high water springs tide level of 0.66 metres AHD for the region. This would result in a mean high water springs tide level of 1.76 metres AHD in 2120.

7.2.2. Potential tidal inundation of project due to sea level rise

As discussed in Section 7.2.1 above, the predicted mean high water springs level at the end of the project life (the year 2120) would be about 1.76 metres AHD. The lowest road levels along the project would be at the Duck Creek area near Ballina.

At this location (station 164.0), the edge of the road would be constructed at 1.72 metres AHD. This would mean that the edge of one lane would have 0.04 metres (40 millimetres) of tidal inundation with the 1.76 metres AHD tide level listed above. Therefore, there are no parts of the project predicted to have significant tidal inundation of lanes during a mean high water springs tide event at the end of the project life.

7.2.3. Potential decrease in flood immunity of project due to sea level rise

For those parts of the project which would be affected by sea level rise (specifically the sections across the Clarence and Richmond River floodplains), the impacts to the project of these changes to sea level were assessed through flood modelling.

It was found that in order to maintain (for the 100 year project life) an average flood immunity of 20 year ARI, road embankment levels would need to be constructed to the following higher levels at various project locations on the major Clarence River and Richmond River floodplains:

- About 0.13 metres higher at Shark Creek
- About 0.09 metres higher at Chaselings and Gulmarrad basins
- About 0.16 metres higher at Harwood Island
- About 0.22 metres higher at Chatsworth Island
- About 0.08 metres higher at Tuckombil Canal.

However, when the assessed rainfall intensity increase and sea level rise scenario are considered together, these road embankments would need to be constructed even higher to meet the desired level of flood immunity (ie immunity up to and including the 20 year ARI event) on the Clarence and Richmond river floodplains. Specifically, the road embankments would need to be raised by:

- About 0.31 metres at Shark Creek

- About 0.17 metres at Chaselings and Gulmarrad basins
- About 0.25 metres at Harwood Island
- About 0.29 metres at Chatsworth Island
- About 0.27 metres at Tuckombil Canal and Woodburn area.

The required increases in embankment height were considered further in the context of an adaptive approach to climate change.

7.3. Increases to rainfall intensity

7.3.1. Assumed changes to rainfall intensity

In 2007, the then NSW Department of Environment and Climate Change released guidelines for consideration of climate change in floodplain management (DECC 2007). This guideline quoted other reports such as CSIRO (2007a) which indicated the extreme rainfall intensity (ie 40 year ARI one day rainfall total) may increase by five per cent to 10 per cent for the NSW Northern Rivers area by 2070. The guidelines suggest that the sensitivity of the project to increased rainfall should be calculated. Hence, a 10 per cent increase in rainfall intensities was used in the sensitivity test for this assessment.

7.3.2. Variability of predicted rainfall increase

The flooding behaviour for the majority of the project outside the Clarence and Richmond River floodplains is not influenced by sea levels or potential sea level rise. This is due to the elevation at these watercourse crossing locations being well above the areas where sea level rise has influence.

Therefore, based on an assumed 10 per cent increase in rainfall intensities, it is possible to quantify the possible reduction in the flood immunity of the project in these parts of the project.

The critical duration for most of the smaller watercourses crossed by the project (ie not the Clarence and Richmond River floodplains) is about two hours. If it is assumed that the 100 year ARI two hour rainfall total increased by 10 per cent, then this would result in the 55 year ARI flood resulting in similar flood levels to the 100 year ARI flood.

However, it needs to be noted that there are limits to the accuracy of current (non-climate change) design rainfall intensities. This is due to the relatively short periods of record and sparse rainfall gauge networks available in the catchments crossed by the project. To illustrate the limits of these accuracies, an assessment of the long-term rainfall gauges in a northern rivers catchment indicated the following:

- Rainfall gauges with about 50 years of record have a 90 percentile confidence range of 17 per cent for the 20 year ARI (24 hour) rainfall estimates and 27 per cent for the 100 year ARI (24 hour) rainfall estimates
- Rainfall gauges with about 100 years of record have a 90 percentile confidence range of nine per cent for the 20 year ARI (24 hour) rainfall estimates and 15 per cent for the 100 year ARI (24 hour) rainfall estimates.

The other point to note is the variations in the frequency of flood events. For the relatively long flow record of the Clarence River (171 years from 1839 to present), the four largest floods occurred in a single 17 year period (1876 to 1893). The next four largest flood events also occurred in a single 17 year period (1950 to 1967). These two periods account for the eight largest flood events on record.

There are two substantial periods without any floods larger than the 20 year ARI flood. One period is from 1893 to 1950 (56 years) and another is the current period, from 1967 to present (43 years).

The Clarence River period of recorded flows (171 years) can be used to represent 71 individual periods of 100 consecutive years of records (eg 1839 to 1938 is the first 100 year sequence and 1840 to 1939 is the second 100 year sequence). An assessment of these 71 sets of 100 year sequences indicates that in 13 per cent of the sequences, there were eight or more floods in 100 years greater than the 20 year ARI flood event. The average number of floods exceeding the 20 year ARI flood for the 71 sets of 100 year sequences is about 5.5 and the smallest value was four. Hence, based on the period of record, a road constructed at the 20 year ARI flood levels would have been overtopped between four and eight times in any 100 year sequence.

7.4. Impacts and immunity of project under climate change scenarios

7.4.1. Corindi River

Under existing conditions the predicted impact at the proposed bridge over Corindi River (on the upstream project boundary) is about 170 millimetres in the 100 year ARI flood. Under climate change conditions at the same location, the predicted impact is about 175 millimetres (Figure 7-1).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 30 millimetres higher under climate change conditions (Figure 7-1) at the bridge over Corindi River. The increase in flood levels would not decrease the flood immunity of the project at this location. The detailed design phase should consider the need for maintaining the 300 millimetre clearance under the bridge deck required for debris passage.

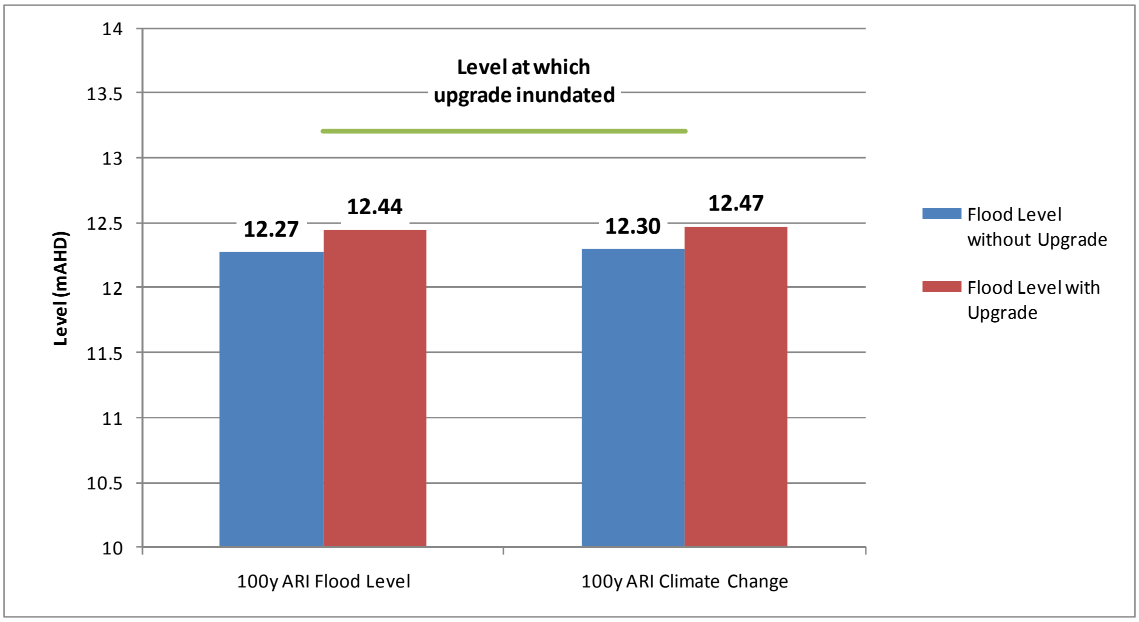


Figure 7-1 Flood impacts 100 year ARI event at bridge over Corindi River at station 3.55 under existing and climate change scenarios

At the proposed bridge crossing the Corindi floodplain (on the upstream project boundary), under existing conditions the predicted impact is about 250 millimetres in the 100 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about 255 millimetres (see Figure 7-2).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 50 millimetres higher under climate change conditions (see Figure 7-2) at the bridge crossing the Corindi floodplain. This increase in flood levels would not decrease the flood immunity of the project at this location. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

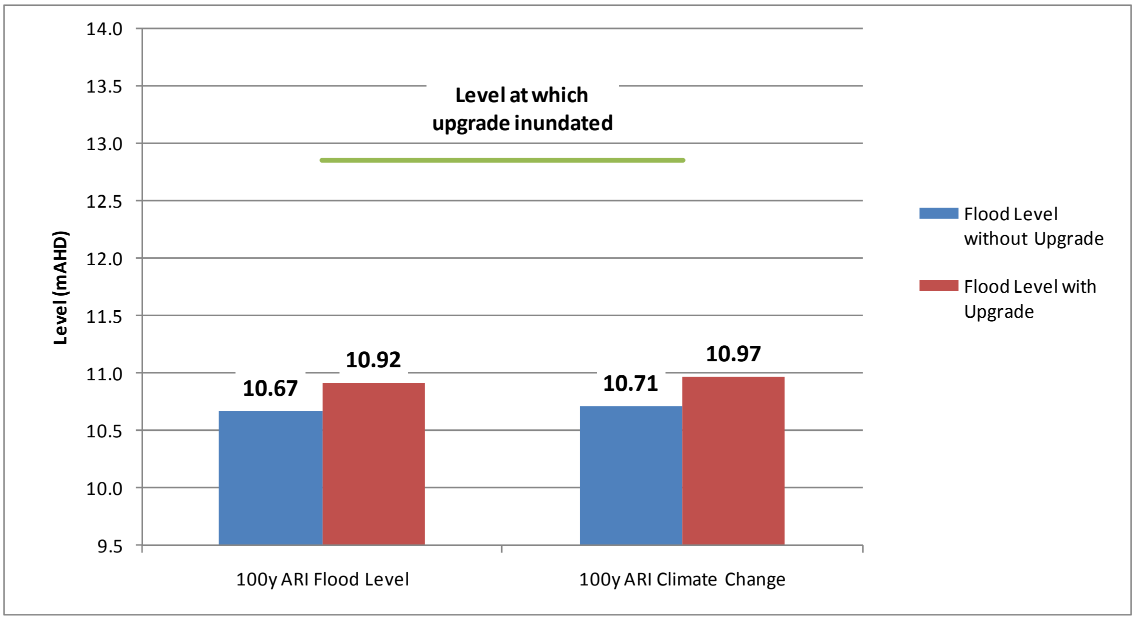


Figure 7-2 Flood impacts 100 year ARI event at bridge at station 4.01 under existing and climate change scenarios

At the proposed bridge over Cassons Creek (on the upstream project boundary) under both existing conditions and climate change conditions, the predicted impact is about 165 millimetres in the 100 year ARI flood (see Figure 7-3).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 50 millimetres higher under climate change conditions (see Figure 7-3) at the bridge crossing Cassons Creek.

As discussed in Section 6.2.3, this bridge does not meet flood immunity requirements for the 100 year ARI flood event under current climate conditions. As a result, it also does not meet flood immunity requirements for the 100 year ARI flood event under climate change conditions. This issue has been identified for mitigation through detailed design as discussed in Chapter 8.

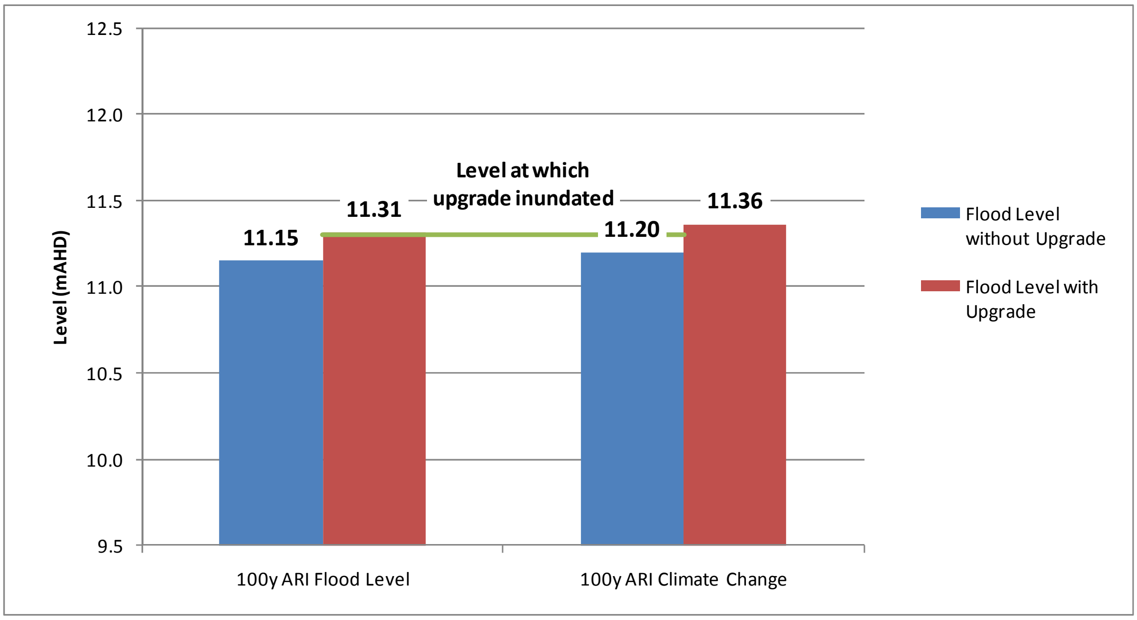


Figure 7-3 Flood impacts 100 year ARI event at bridge over Cassons Creek at station 4.69 under existing and climate change scenarios

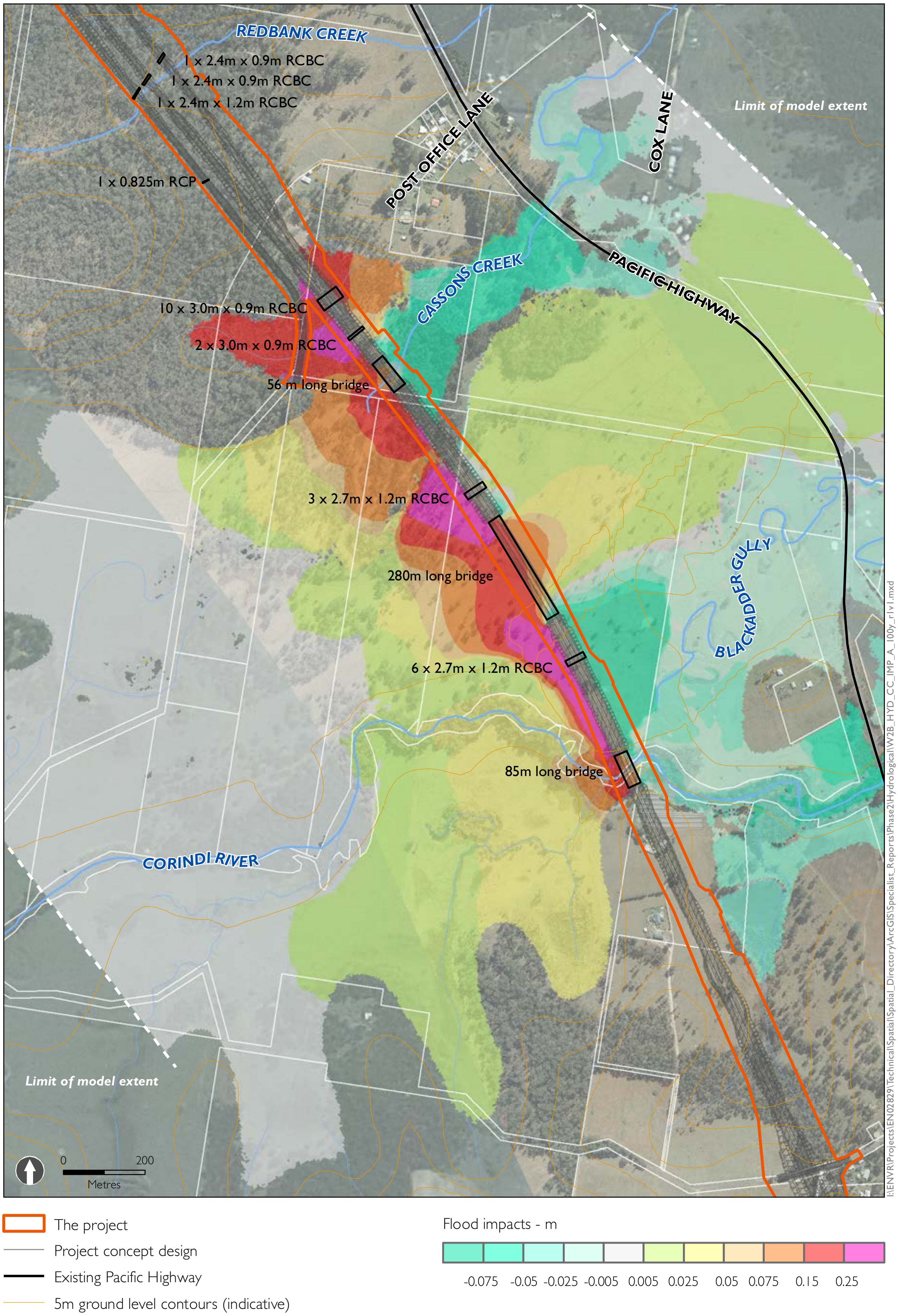
A map of the Corindi flood impacts under climate change conditions in the 100 year ARI event are presented in Figure 7-4.

A shed is located on the floodplain upstream of the project. Under current conditions, the predicted impact at the shed is about 20 millimetres. Under climate change conditions, the predicted impact is about 25 millimetres. No other buildings would be impacted by the project.

The maximum impact experienced upstream of the project boundary under climate change conditions is around 480 millimetres. This is higher than the 400 millimetre flood level impact objective. However, the area experiencing impacts greater than 400 millimetres is equal to 0.36 hectares, located upstream of the three 2.7 by 1.2 metre box culverts. The increased levels on agricultural and forested land described above are unlikely to affect farming operations.

In summary, aside from the Cassons Creek bridge and upstream of the three 2.7 by 1.2 metre box culverts, the flood assessment under climate change conditions indicates that the structure capacity of the project is sufficient to meet the flood design objectives for both flood immunity and flood level impacts under these conditions.

Figure 7-4 Flood impacts under 100 year ARI climate change scenario: Corindi River



7.4.2. Halfway Creek

Under existing conditions at the proposed bridge crossing Halfway Creek (on the upstream project boundary), the project reduces flood levels by about 730 millimetres in the 100 year ARI flood. At the same location under climate change conditions, the project also reduces flood levels by about 780 millimetres (see Figure 7-5).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 190 millimetres higher under climate change conditions (see Figure 7-5) at the bridge over Halfway Creek. This increase in flood levels would not decrease the flood immunity of the project at this location. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

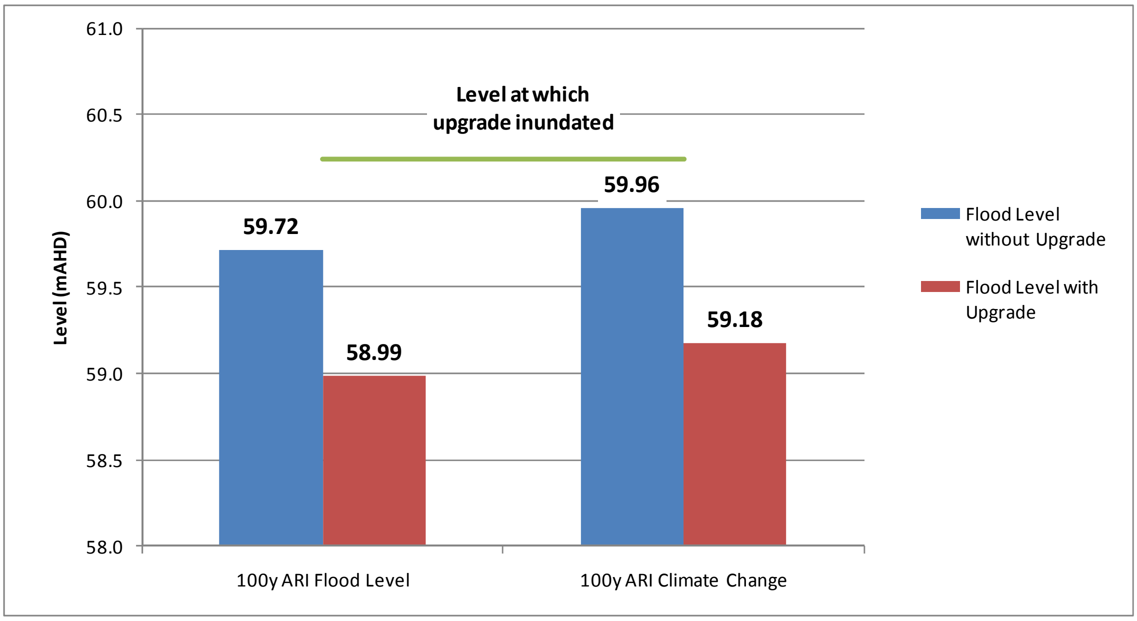


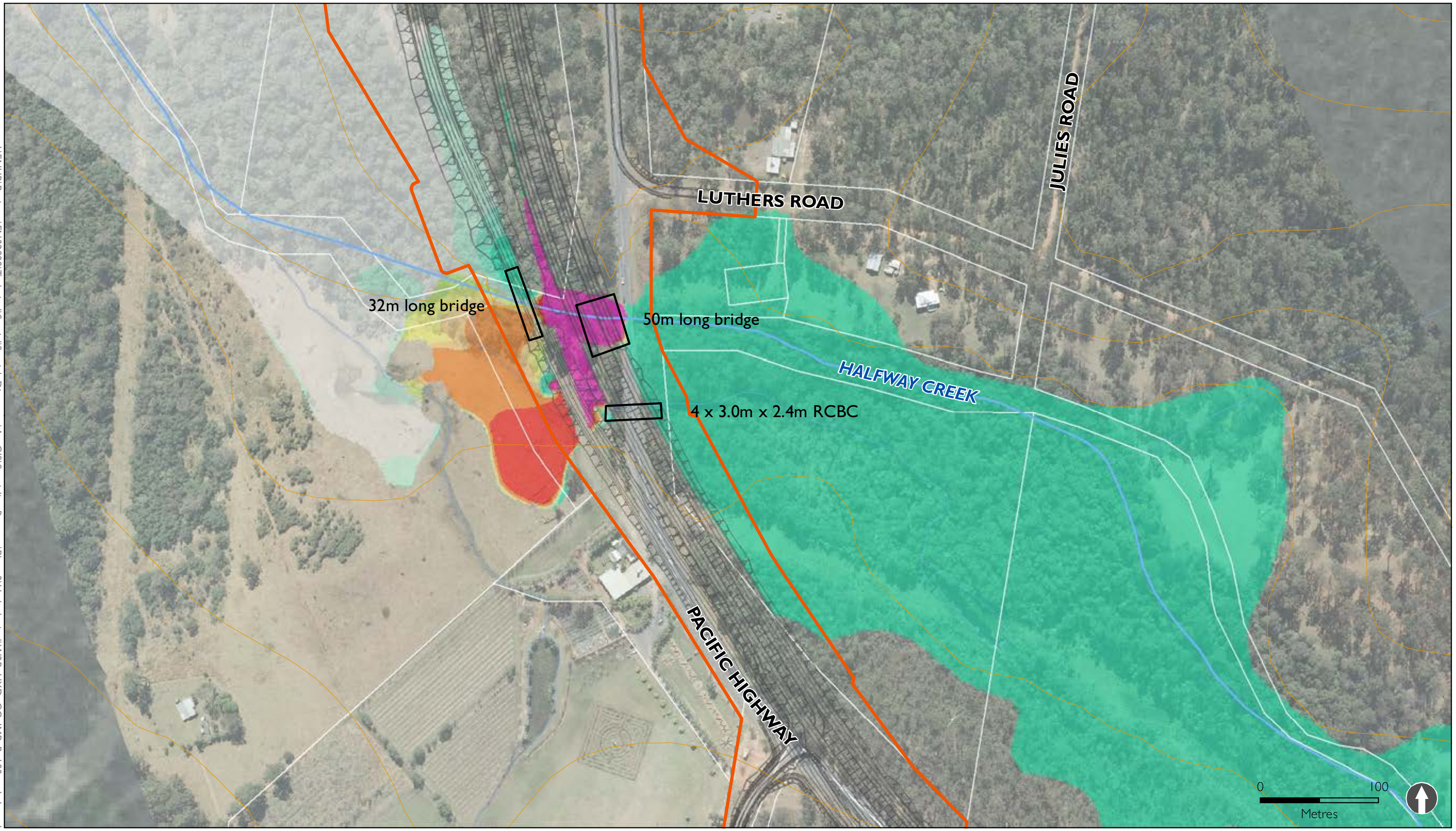
Figure 7-5 Flood impacts 100 year ARI event at bridge over Halfway Creek at station 20.72 under existing and climate change scenarios

A map of the Halfway Creek flood impacts under climate change conditions in the 100 year ARI event are presented in Figure 7-6.

A localised area downstream of the project boundary experiences impacts of up to 355 millimetres. This is within the flood level management objective.

In summary, the flood assessment under climate change conditions indicates that the structure capacity of the project is sufficient to meet the flood design objectives for both flood immunity and flood level impacts under these conditions.

Figure 7-6 Flood impacts under 100 year ARI climate change scenario: Halfway Creek



The project
Project concept design
Existing Pacific Highway
5m ground level contours (indicative)

Flood impacts - m

-0.075 -0.05 -0.025 -0.005 0.005 0.025 0.05 0.075 0.15 0.25

7.4.3. Pheasant Creek

Under existing conditions at the proposed bridge over Pheasant Creek (on the upstream project boundary), the predicted impact is about 25 millimetres in the 100 year ARI flood. At the same location, the project impact is also about 25 millimetres under climate change conditions (see Figure 7-7).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 30 millimetres higher under climate change conditions (see Figure 7-7) at the bridge over Pheasant Creek. This increase in flood levels would not decrease the flood immunity of the project at this location. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

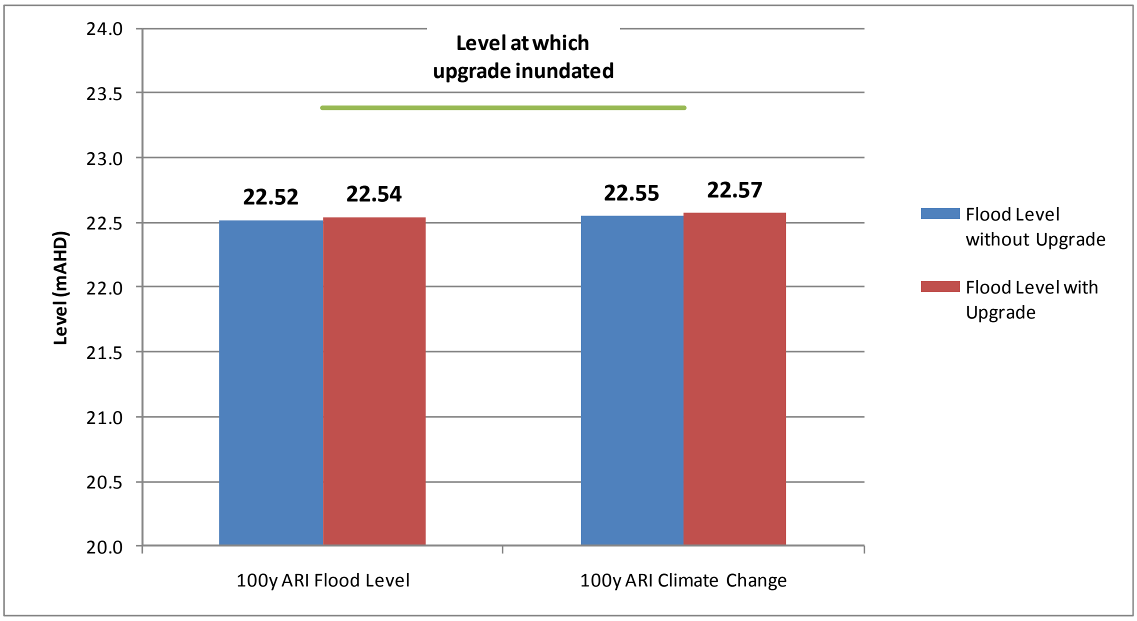
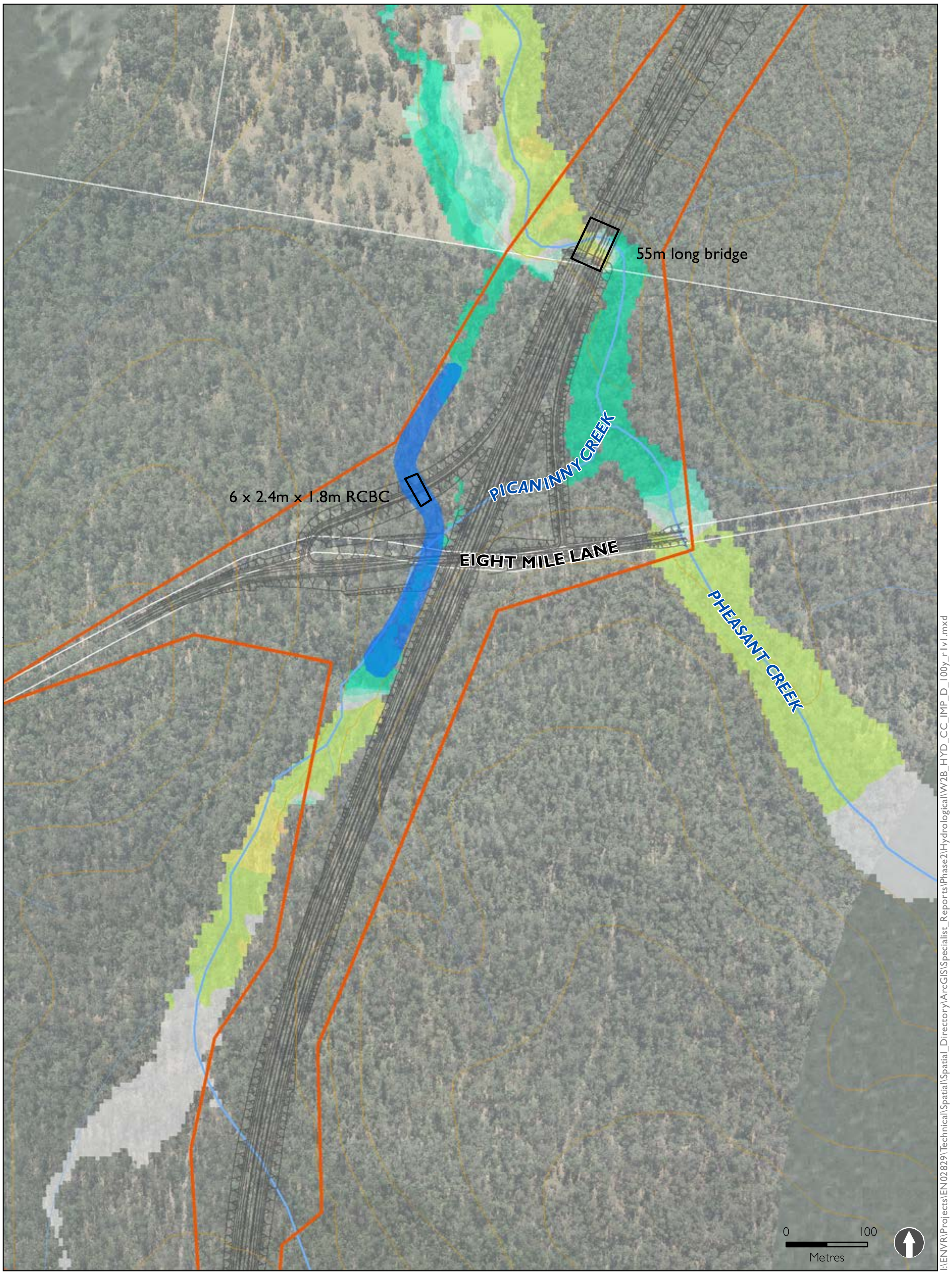


Figure 7-7 Flood impacts 100 year ARI event at bridge over Pheasant Creek at station 36.40 under existing and climate change scenarios

A map of the Pheasant Creek flood impacts under climate change conditions in the 100 year ARI event are presented in Figure 7-8.

In summary, the flood assessment under climate change conditions indicates that the structure capacity of the project is sufficient to meet the flood design objectives for both flood immunity and flood level impacts under these conditions

Figure 7-8 Flood impacts under 100 year ARI climate change scenario: Pheasant Creek



The project
Project concept design
Existing Pacific Highway
5m ground level contours (indicative)
Area inundated due to diversion

Flood impacts - m

-0.075 -0.05 -0.025 -0.005 0.005 0.025 0.05 0.075 0.15 0.25

7.4.4. Coldstream River

Under existing conditions at the proposed 120 metre span bridge over the Coldstream River western tributary (on the upstream project boundary) the predicted impact is about 190 millimetres in the 100 year ARI flood. Under climate change conditions at the same location, the predicted impact is about 210 millimetres (see Figure 7-9).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 75 millimetres higher under climate change conditions (see Figure 7-9) at the 120 metre span bridge. This increase in flood levels would not decrease the flood immunity of the project at this location. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

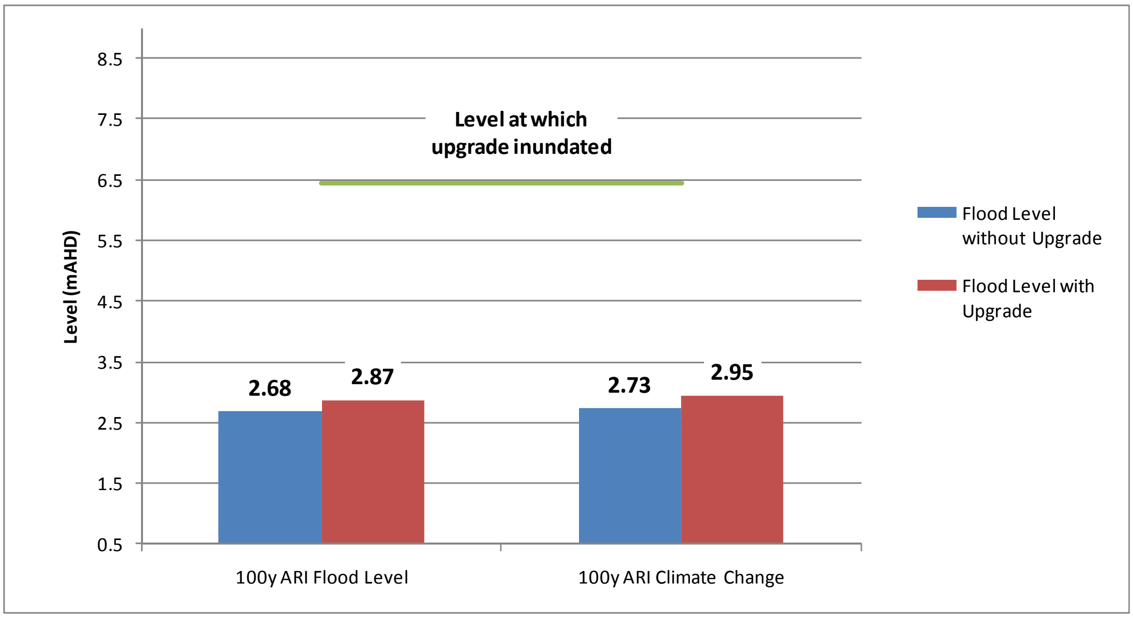


Figure 7-9 Flood impacts 100 year ARI event at bridge at station 42.54 under existing and climate change scenarios

Under existing conditions at the proposed 300 metre span bridge over Coldstream River (on the upstream project boundary) the predicted impact is about 190 millimetres in the 100 year ARI flood. Under climate change conditions at the same location, the predicted impact is about 110 millimetres (see Figure 7-10).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 60 millimetres higher under climate change conditions (see Figure 7-10) at the bridge over Coldstream River. This increase in flood levels would not decrease the flood immunity of the project at this location. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

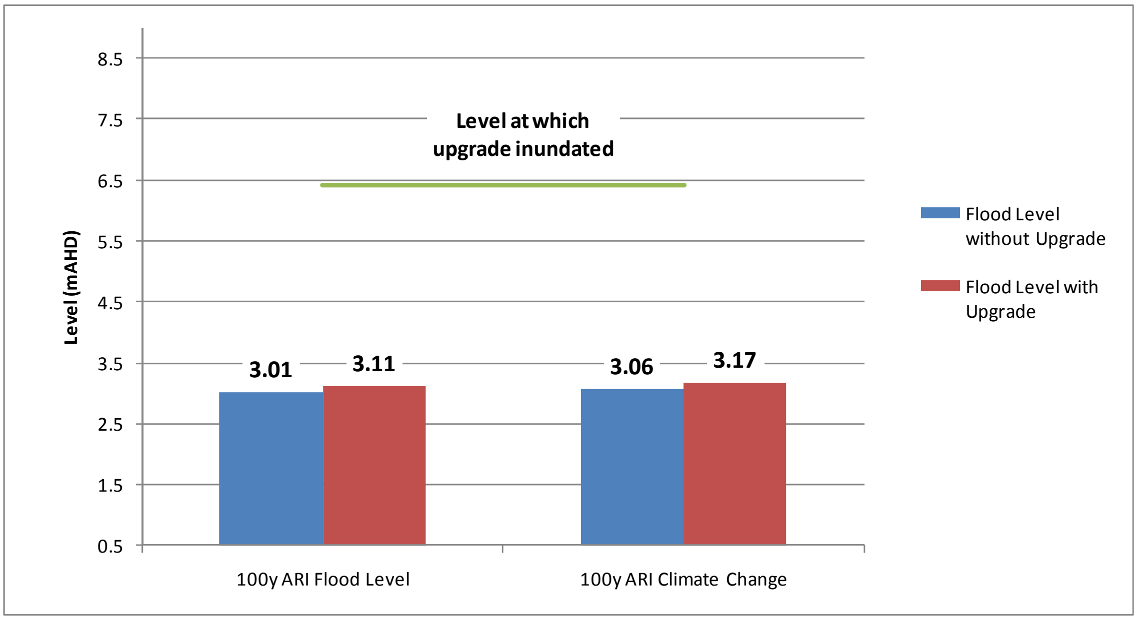


Figure 7-10 Flood impacts 100 year ARI event at bridge over Coldstream River at station 43.12 under existing and climate change scenarios

Under existing conditions at the proposed 160 metre span bridge over the unnamed creek to the east of the Coldstream River (on the upstream project boundary) the predicted impact is about 295 millimetres in the 100 year ARI flood. Under climate change conditions at the same location, the predicted impact is about 310 millimetres (see Figure 7-11).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 90 millimetres higher under climate change conditions (see Figure 7-11) at the 160 metre bridge. This increase in flood levels would not decrease the flood immunity of the project at this location. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

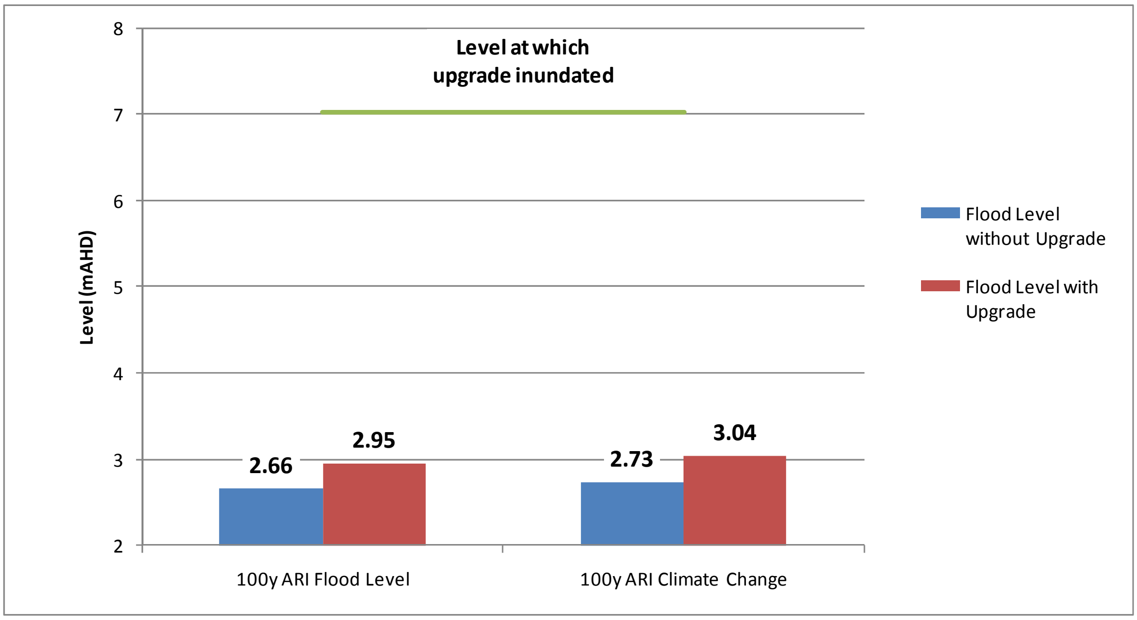


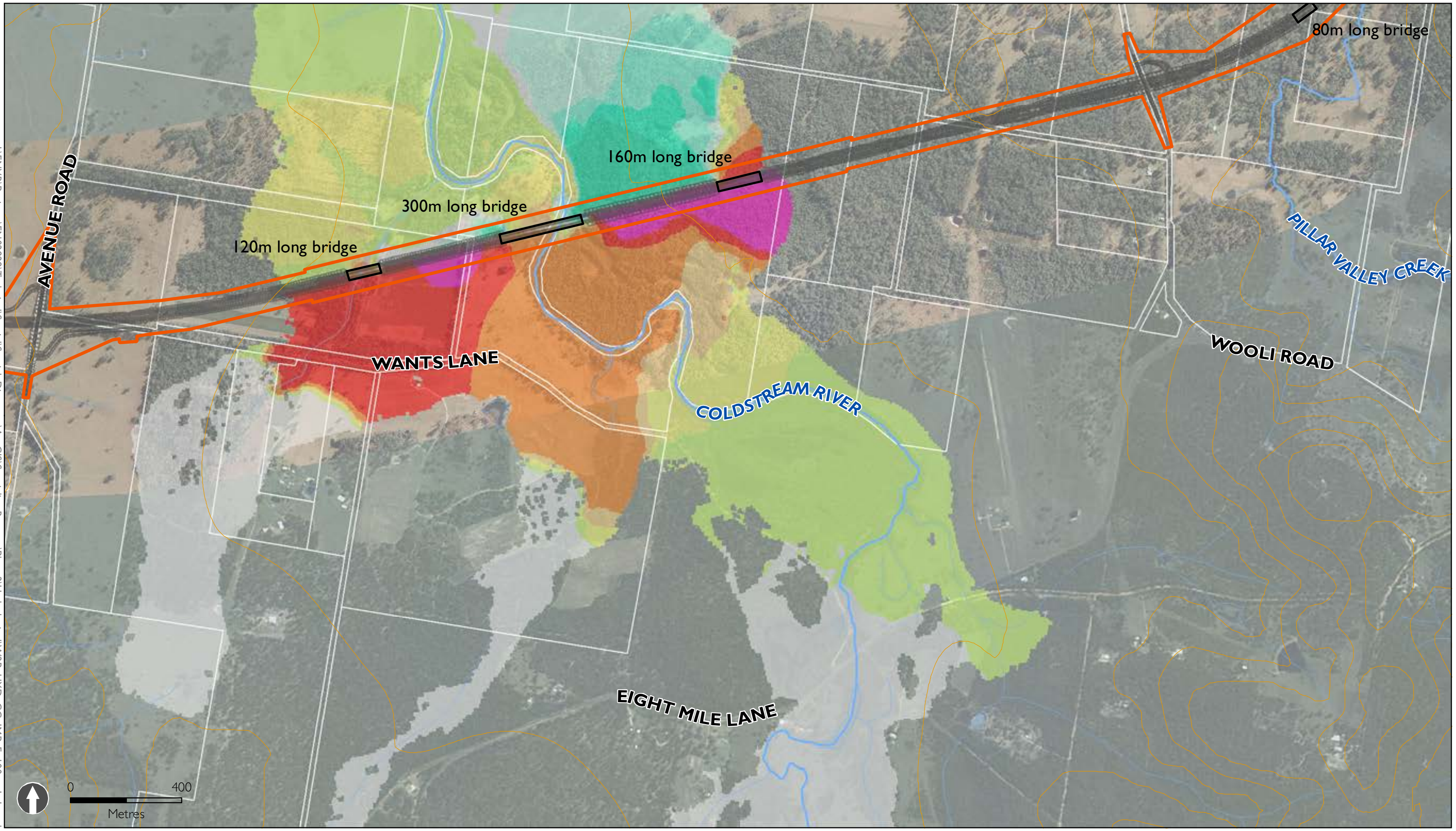
Figure 7-11 Flood impacts 100 year ARI event at bridge at station 43.91 under existing and climate change scenarios

A map of the Coldstream River flood impacts under climate change conditions in the 100 year ARI event are presented in Figure 7-12.

As under existing climate conditions, an area of 5.6 ha upstream of the Coldstream River western tributary experiences impacts greater than 250 millimetres and up to 325 millimetres. An additional area of one hectare located between the 120 and 300 metre long bridges experiences impacts between 250 and 260 millimetres. These are localised increases and are within the flood level impact objectives.

In summary, the flood assessment under climate change conditions indicates that the structure capacity of the project is sufficient to meet the flood design objectives for both flood immunity and flood level impacts under these conditions

Figure 7-12 Flood impacts under 100 year ARI climate change scenario: Coldstream River



The project
Project concept design
Existing Pacific Highway
5m ground level contours (indicative)

Flood impacts - m

-0.075 -0.05 -0.025 -0.005 0.005 0.025 0.05 0.075 0.15 0.25

7.4.5. Pillar Valley Creek

Under existing conditions at the proposed 80 metre bridge over Pillar Valley Creek anabranch (on the upstream project boundary), the predicted impact is about 110 millimetres in the 100 year ARI flood. Under climate change conditions at the same location, the predicted impact is about 125 millimetres (see Figure 7-13).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 95 millimetres higher under climate change conditions (see Figure 7-13) at the 80 metre bridge. This increase in flood levels would not decrease the flood immunity of the project at this location. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

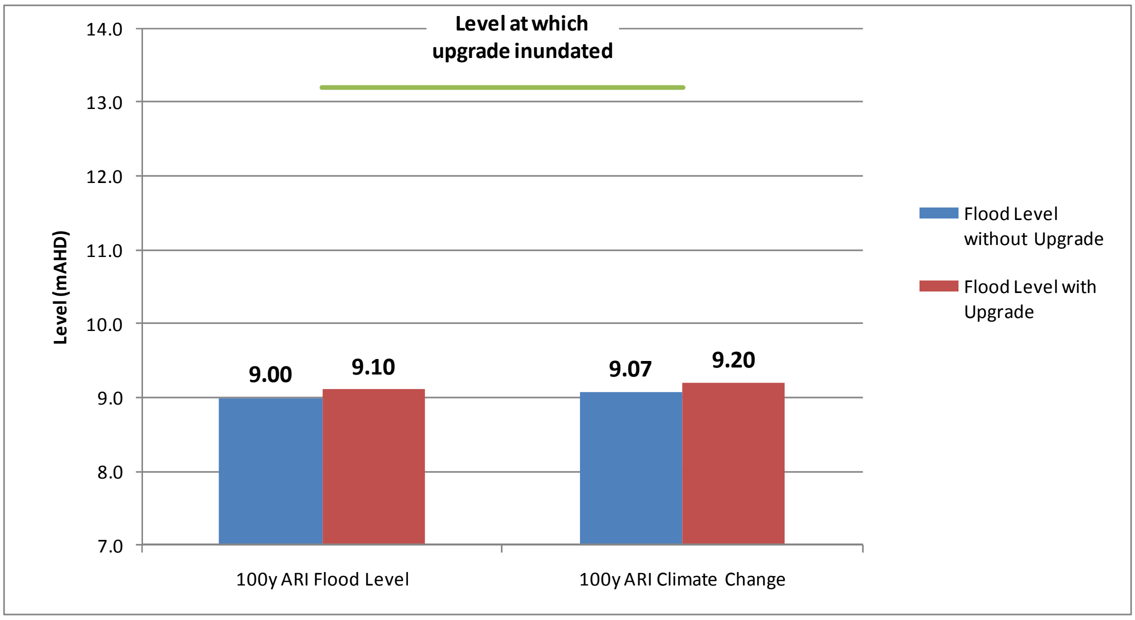


Figure 7-13 Flood impacts 100 year ARI event at bridge over Pillar Valley Creek anabranch at station 46.07 under existing and climate change scenarios

Under existing conditions at the proposed 90 m bridge over Pillar Valley Creek (on the upstream project boundary), the predicted impact is about 195 millimetres in the 100 year ARI flood. Under climate change conditions at the same location, the predicted impact is about 210 millimetres (see Figure 7-14).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 105 millimetres higher under climate change conditions (see Figure 7-14) at the bridge over Pillar Valley Creek. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

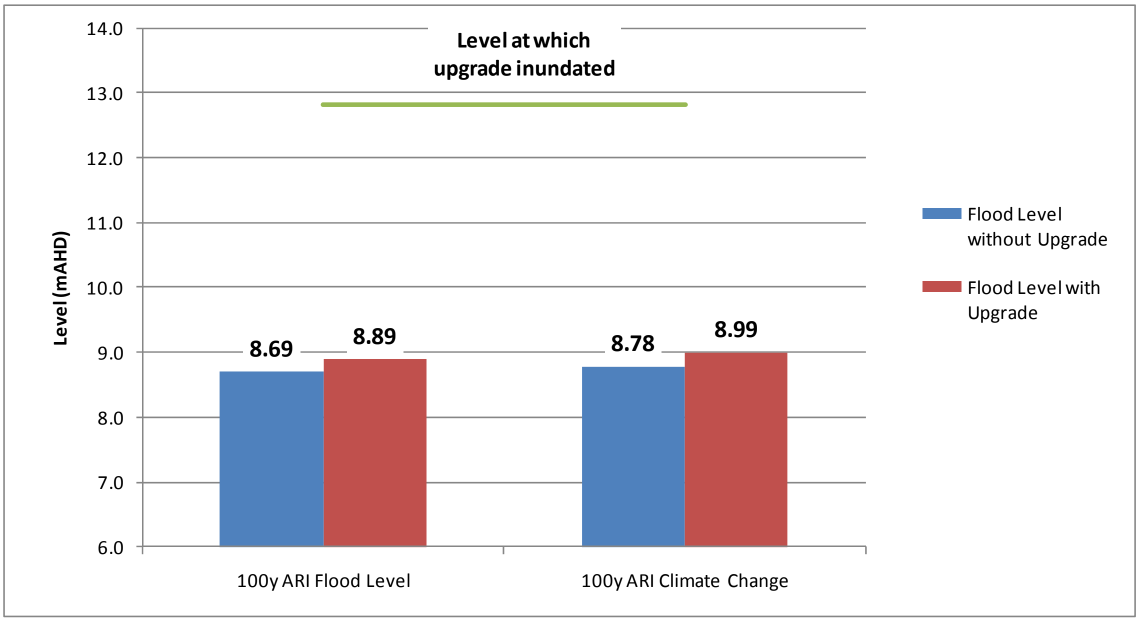


Figure 7-14 Flood impacts 100 year ARI event at bridge over Pillar Valley Creek at station 46.34 under existing and climate change scenarios

Under existing conditions at the proposed 50 metre bridge over Black Snake Creek (on the upstream project boundary), the predicted impact is about five millimetres in the 100 year ARI flood. Under climate change conditions at the same location, the predicted impact is also about five millimetres (see Figure 7-15).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 15 millimetres higher under climate change conditions (see Figure 7-15) at the bridge over Black Snake Creek. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

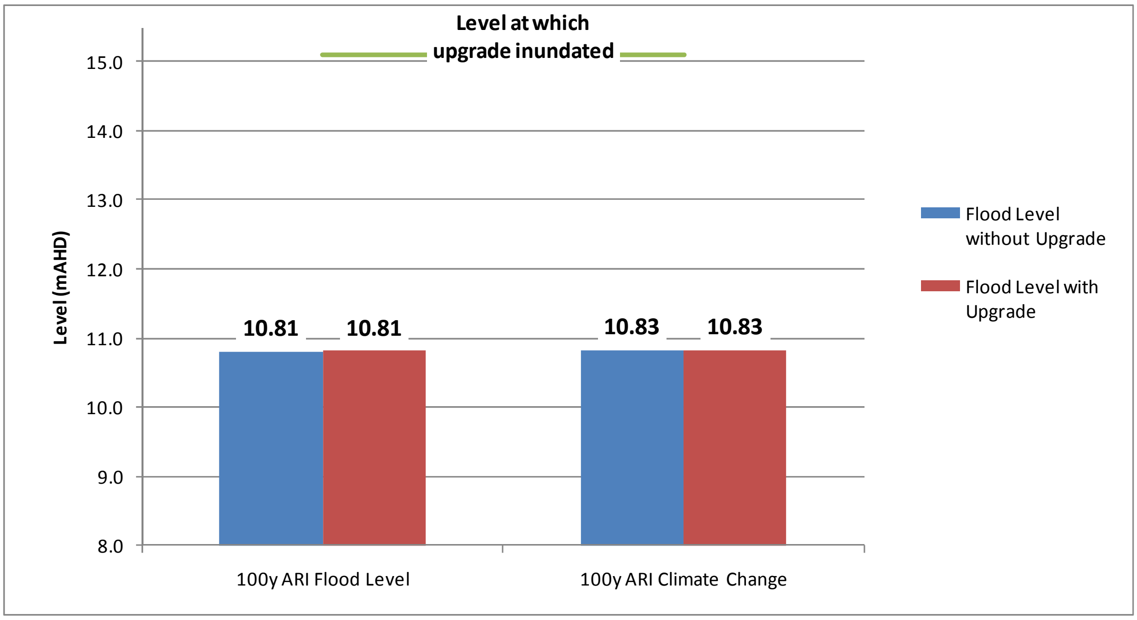


Figure 7-15 Flood impacts 100 year ARI event at bridge over Black Snake Creek at station 46.67 under existing and climate change scenarios

At the proposed 60 metre bridge over the first northern Pillar Valley Creek Tributary (on the upstream project boundary), under existing conditions the predicted impact is about 65 millimetres in the 100 year ARI flood. At the same location under climate change conditions, the predicted impact is about 75 millimetres (see Figure 7-16).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 40 millimetres higher under climate change conditions (see Figure 7-16) at the 60 metre bridge. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

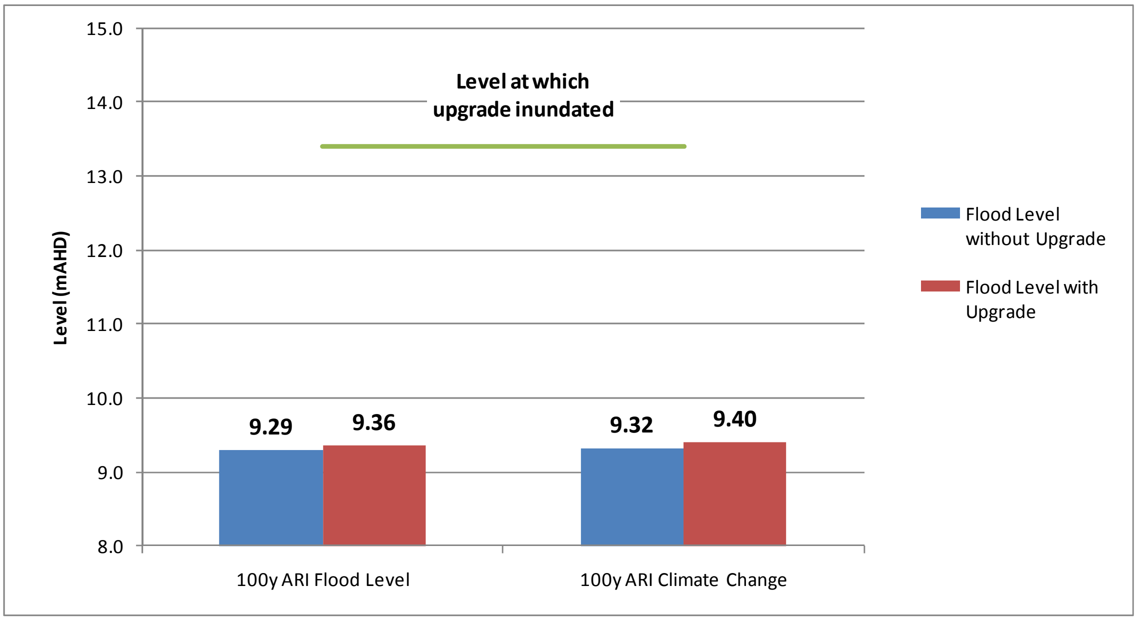


Figure 7-16 Flood impacts 100 year ARI event at bridge at station 47.66 under existing and climate change scenarios

Under existing conditions at the proposed 40 metre bridges for the northernmost Pillar Valley Creek Tributary (on the upstream project boundary), the predicted impact is about zero millimetres in the 100 year ARI flood. At the same location under climate change conditions, the predicted impact is also about zero millimetres (see Figure 7-17).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 10 millimetres higher under climate change conditions (see Figure 7-17) at the 40 metre bridge. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

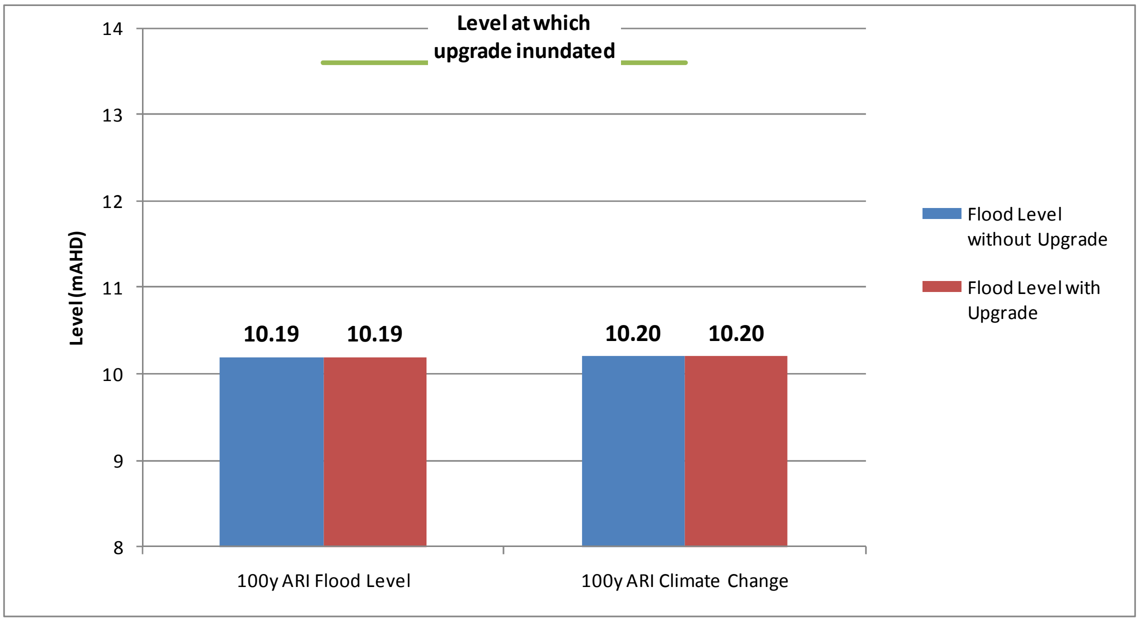


Figure 7-17 Flood impacts 100 year ARI event at bridge at station 47.81 under existing and climate change scenarios

At the proposed 80 metre span bridge over the first unnamed creek near Mitchell Road (on the upstream project boundary) under existing conditions the predicted impact is about zero millimetres in the 100 year ARI flood. Under climate change conditions, at the same location, the predicted impact is also about zero millimetres (see Figure 7-18).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 5 millimetres higher under climate change conditions (see Figure 7-18) at the 80 metre bridge. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

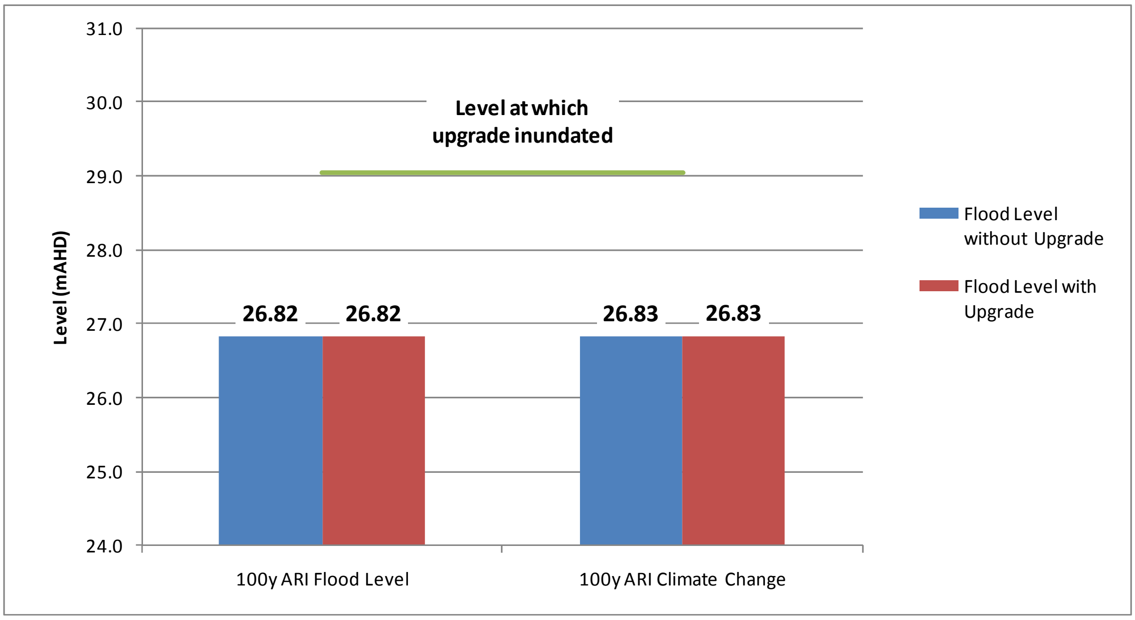


Figure 7-18 Flood impacts 100 year ARI event at bridge at station 49.27 under existing and climate change scenarios

At the proposed 25 metre span bridge over the second unnamed creek near Mitchell Road (on the upstream project boundary) under existing conditions the predicted impact is about 200 millimetres in the 100 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about 230 millimetres (see Figure 7-19).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 70 millimetres higher under climate change conditions (see Figure 7-19) at the 25 metre bridge. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

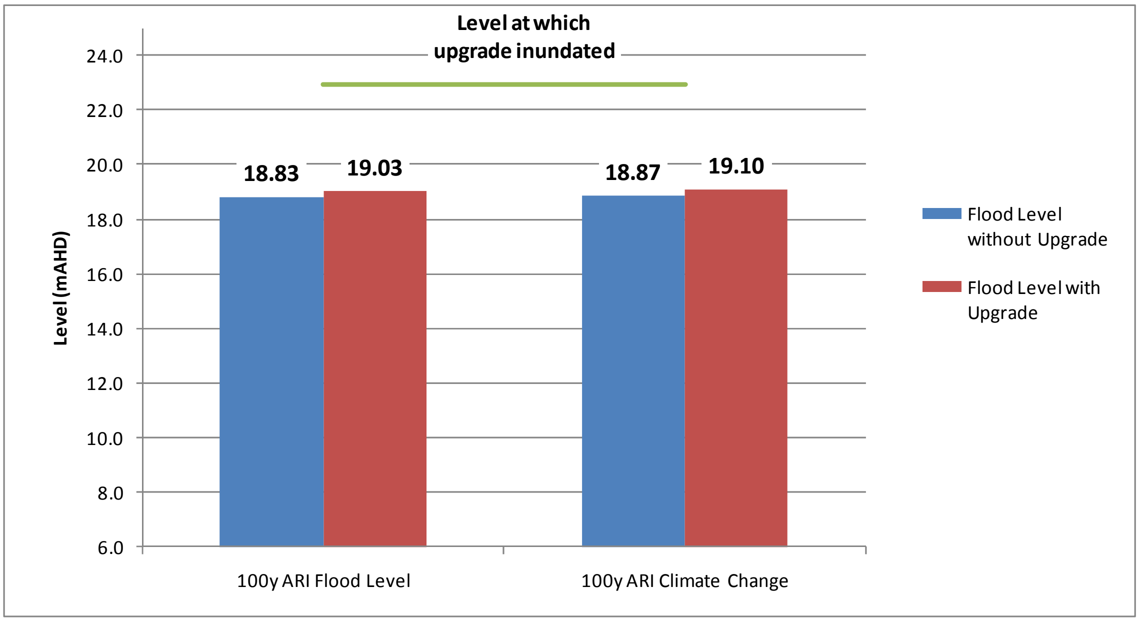


Figure 7-19 Flood impacts 100 year ARI event at bridge at station 50.30 under existing and climate change scenarios

A map of the Pillar Valley Creek flood impacts under climate change conditions in the 100 year ARI event are presented in Figure 7-20. A map of the flood impacts under climate change conditions at the unnamed creeks near Mitchell Road in the 100 year ARI event are presented in Figure 7-21.

In summary, the flood assessment under climate change conditions indicates that the structure capacity of the project is sufficient to meet the flood design objectives for both flood immunity and flood level impacts under these conditions.

Figure 7-20 Flood impacts under 100 year ARI climate change scenario: Pillar Valley Creek

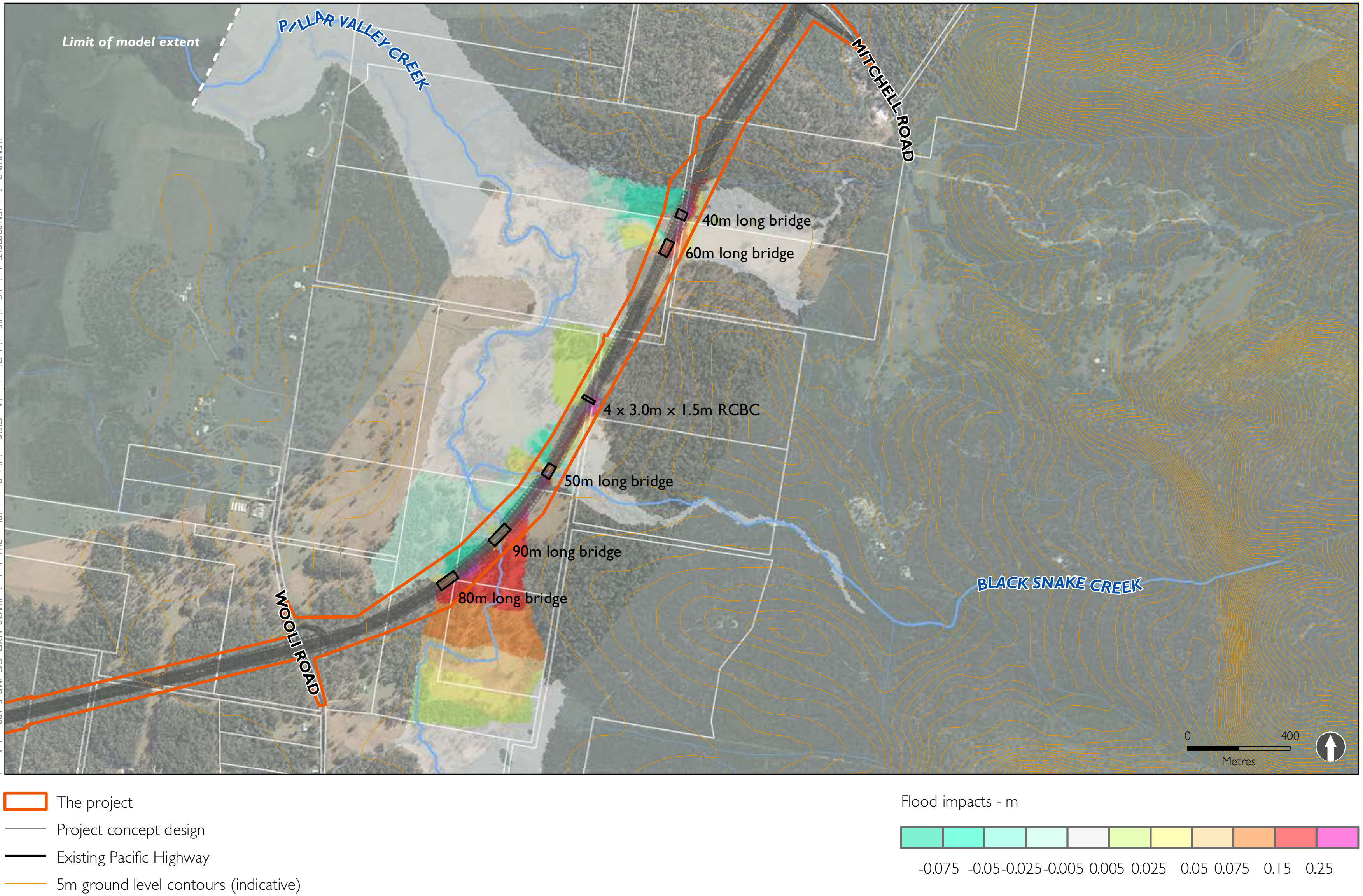
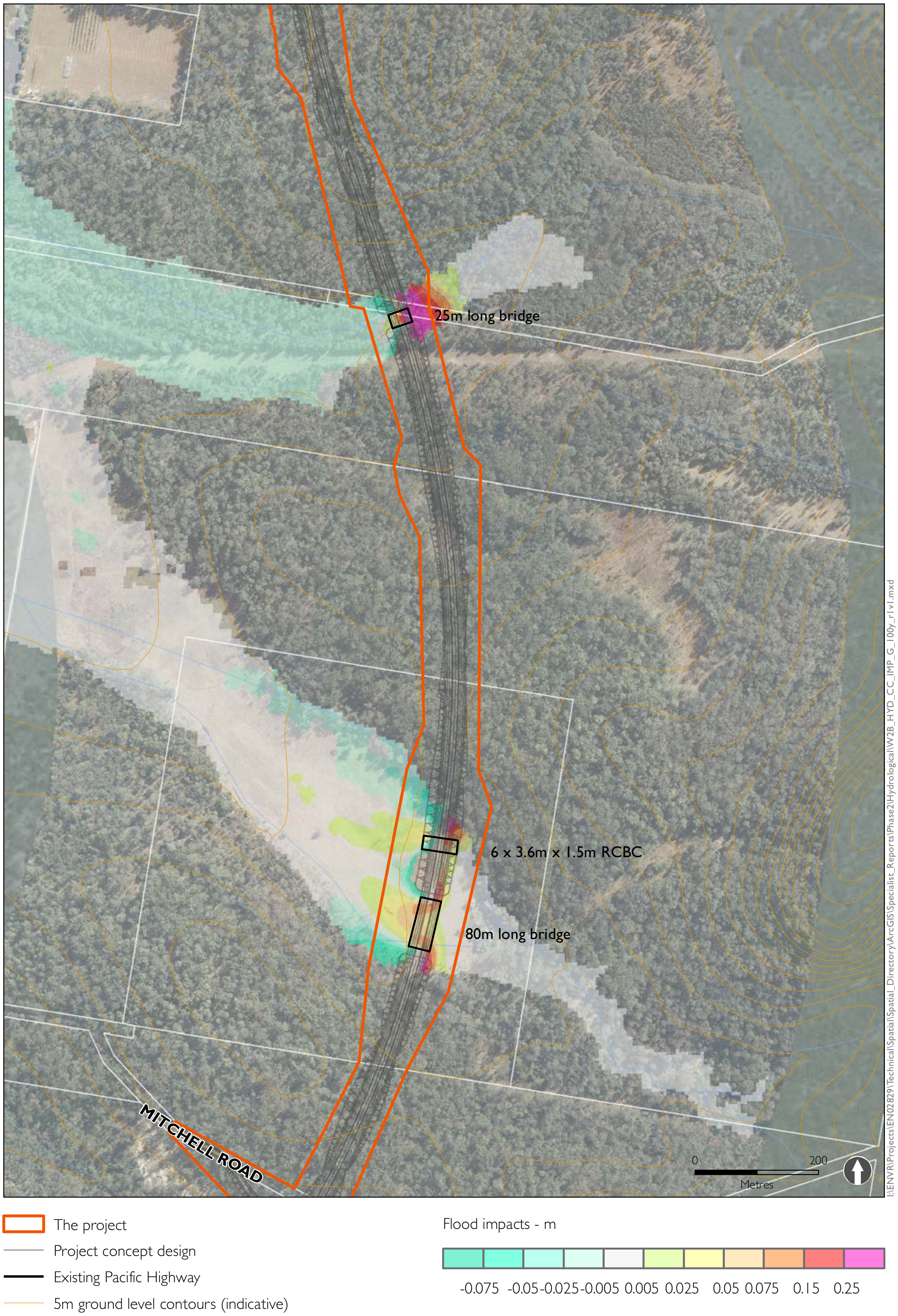


Figure 7-21 Flood impacts under 100 year ARI climate change scenario: unnamed creek near Mitchell Road



7.4.6. Chaffin Creek and nearby creeks

At the proposed 60 metre span bridge over Chaffin Creek (on the upstream project boundary), under existing conditions the predicted impact is about 230 millimetres in the 100 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about 250 millimetres (see Figure 7-22).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 130 millimetres higher under climate change conditions (see Figure 7-22) at the bridge over Chaffin Creek. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

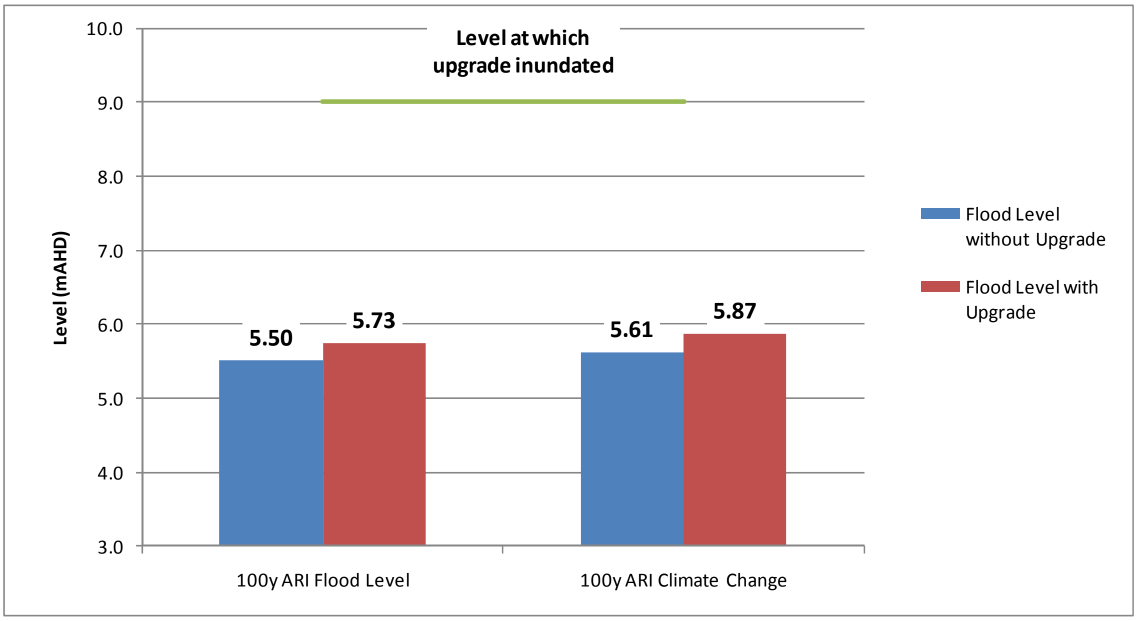


Figure 7-22 Flood impacts 100 year ARI event at bridge over Chaffin Creek at station 52.44 under existing and climate change scenarios

At the proposed 60 metre span bridge over the first unnamed creek near Bostock Road (on the upstream project boundary), under existing conditions the predicted impact is about 10 millimetres in the 100 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about 15 millimetres (see Figure 7-23).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 30 millimetres higher under climate change conditions (see Figure 7-23) at the 60 metre bridge. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

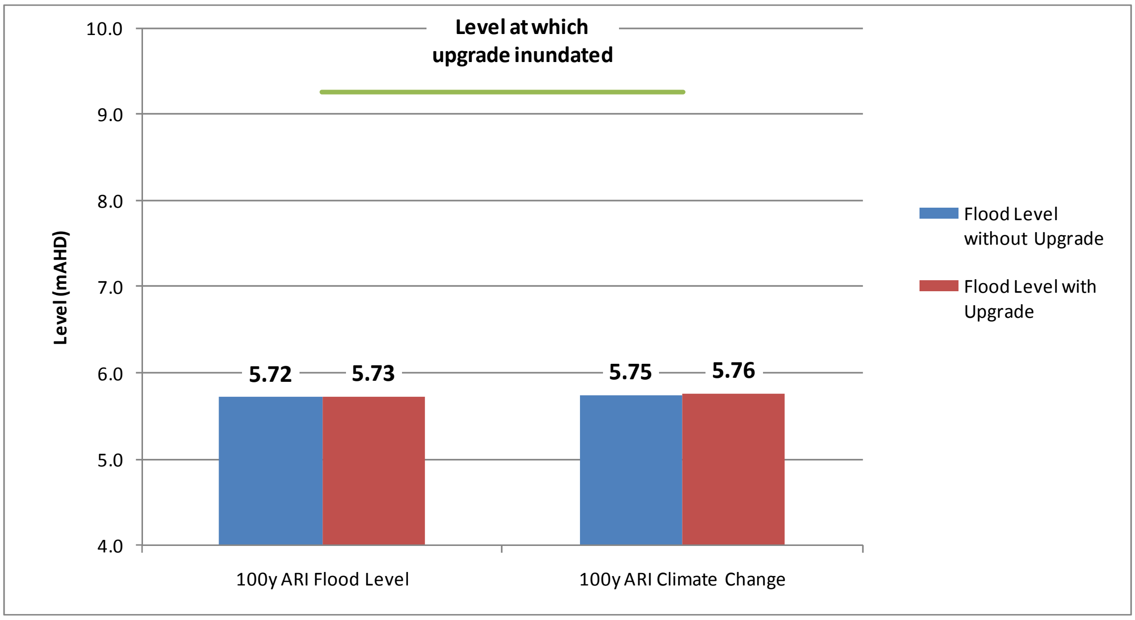


Figure 7-23 Flood impacts 100 year ARI event at bridge at station 54.71 under existing and climate change scenarios

A map of the Chaffin Creek flood impacts under climate change conditions in the 100 year ARI event are presented in Figure 7-24. A map of the flood impacts under climate change conditions in the 100 year ARI event for the unnamed creek near Bostock Road are presented in Figure 7-25.

At a property about 500 metres upstream of the project boundary, two sheds are inundated. Under climate change conditions, impacts experienced at these sheds are approximately 60 millimetres (approximately 50 millimetres under existing climate conditions). Under climate change conditions, the house is inundated and impacts experienced at the house are approximately 50 to 60 millimetres (partial inundation with 50 millimetres of impact under existing climate conditions). This is greater than the flood level impact design objectives.

In summary, apart from this house, the flood assessment under climate change conditions indicates that the structure capacity of the project is sufficient to meet the flood design objectives for both flood immunity and flood level impacts under these conditions

Figure 7-24 Flood impacts under 100 year ARI climate change scenario: Chaffin Creek

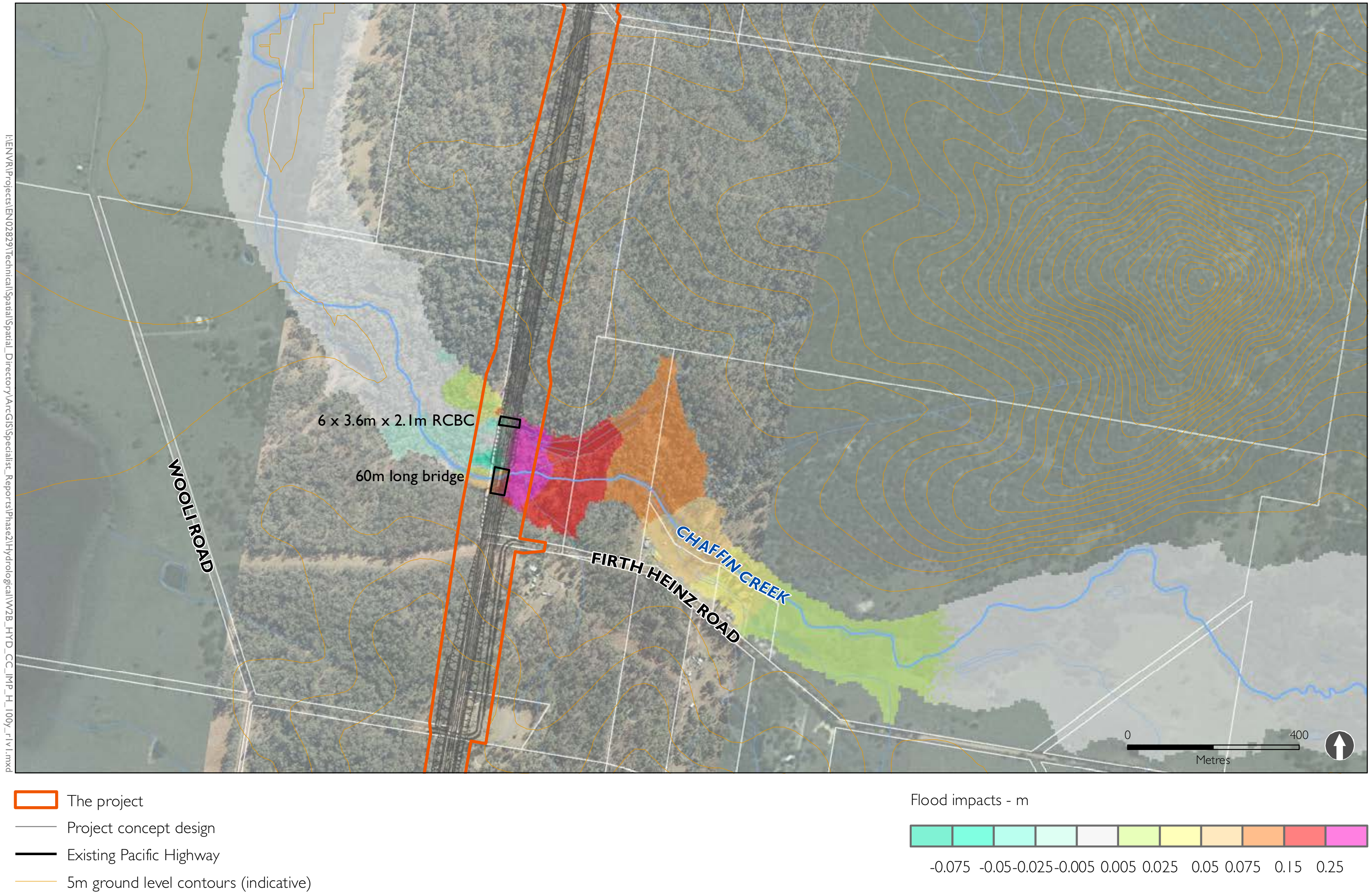
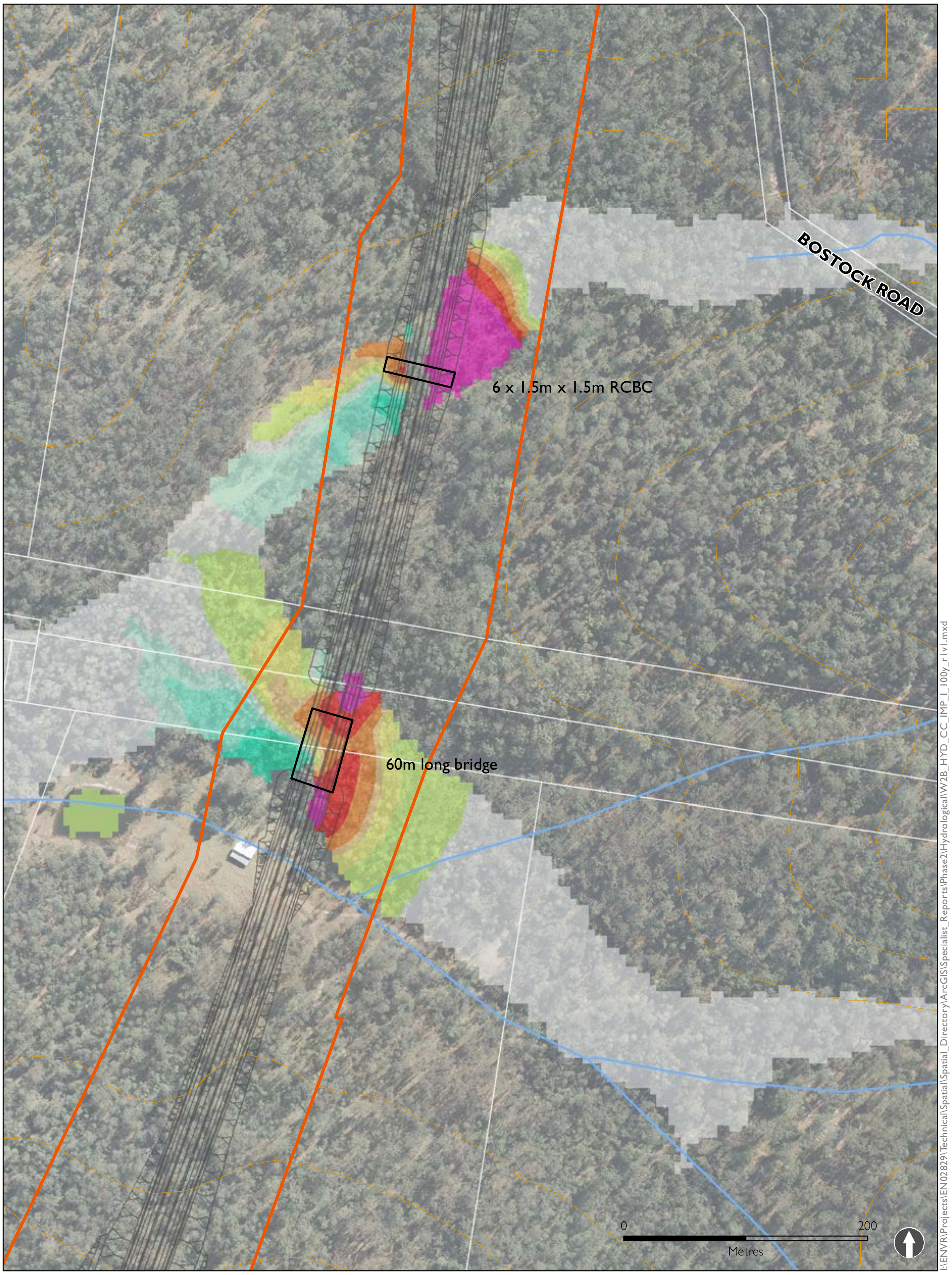


Figure 7-25 Flood impacts under 100 year ARI climate change scenario: unnamed creek near Bostock Road



The project
Project concept design
Existing Pacific Highway
5m ground level contours (indicative)

Flood impacts - m

-0.075 -0.05 -0.025 -0.005 0.005 0.025 0.05 0.075 0.15 0.25

7.4.7. Champions Creek and nearby creeks

At the proposed bridge crossing Champions Creek (on the upstream project boundary), under existing conditions the predicted impact is about 350 millimetres in the 100 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about 380 millimetres (see Figure 7-26).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 100 millimetres higher under climate change conditions (see Figure 7-26) at the bridge over Champions Creek. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

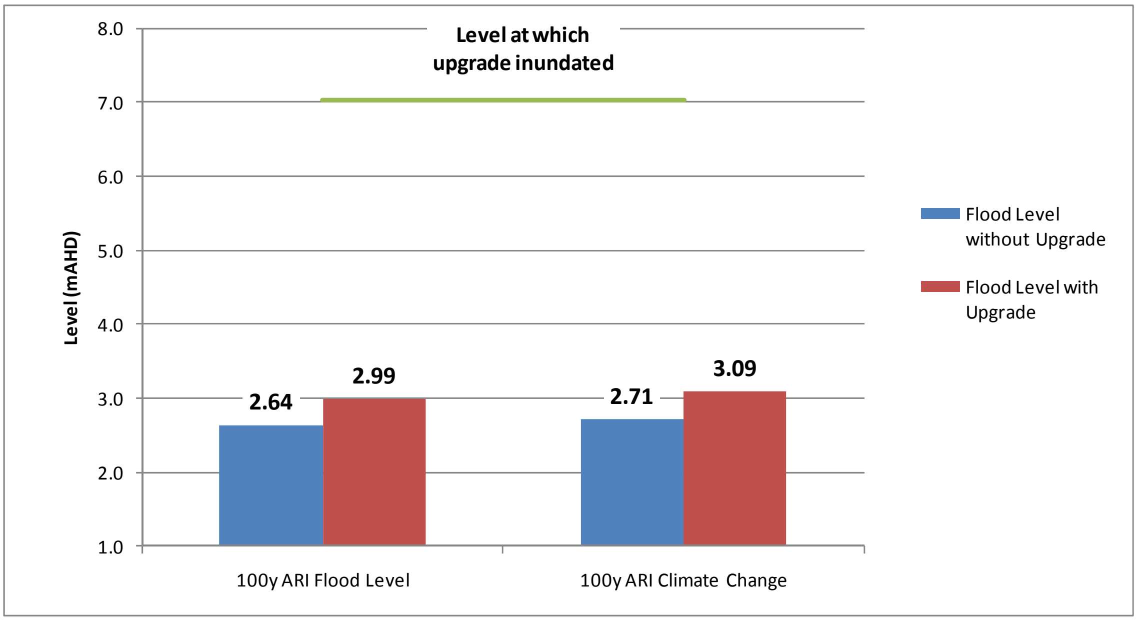


Figure 7-26 Flood impacts 100 year ARI event at bridge over Champions Creek at station 57.03 under existing and climate change scenarios

At the proposed 50 metre bridge over the unnamed creek north of Champions Creek (on the upstream project boundary), under existing conditions the predicted impact is about five millimetres in the 100 year ARI flood. The predicted impact is also about five millimetres under climate change conditions at the same location (see Figure 7-27).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 100 year ARI flood levels with the upgrade would be around 40 millimetres higher under climate change conditions (see Figure 7-27) at the 50 metre bridge. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetres clearance under the bridge deck required for debris passage.

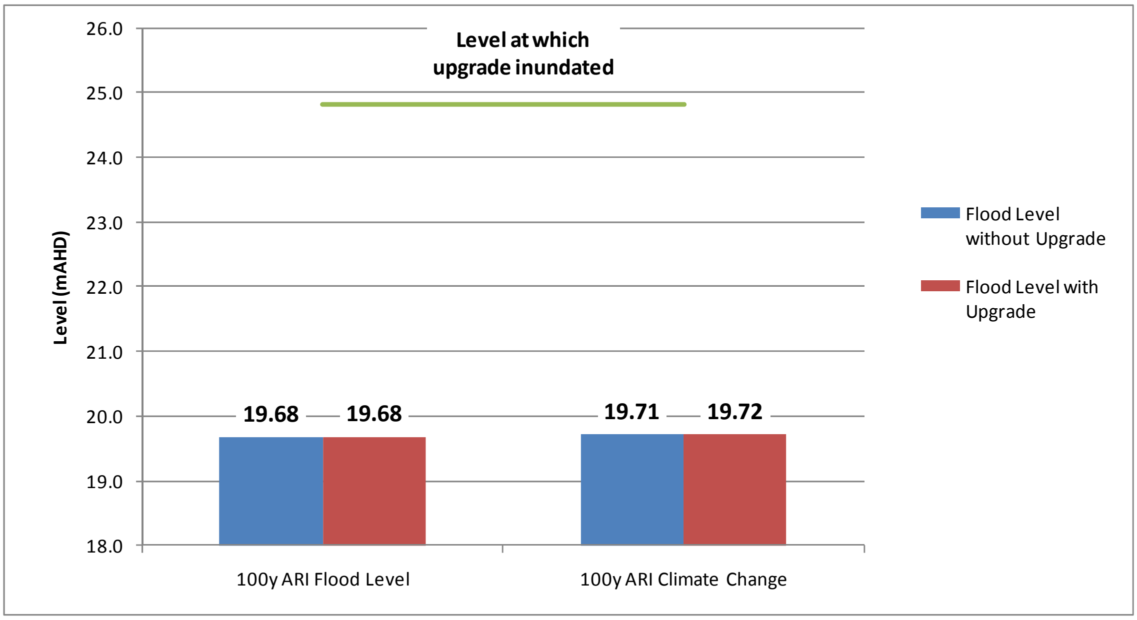


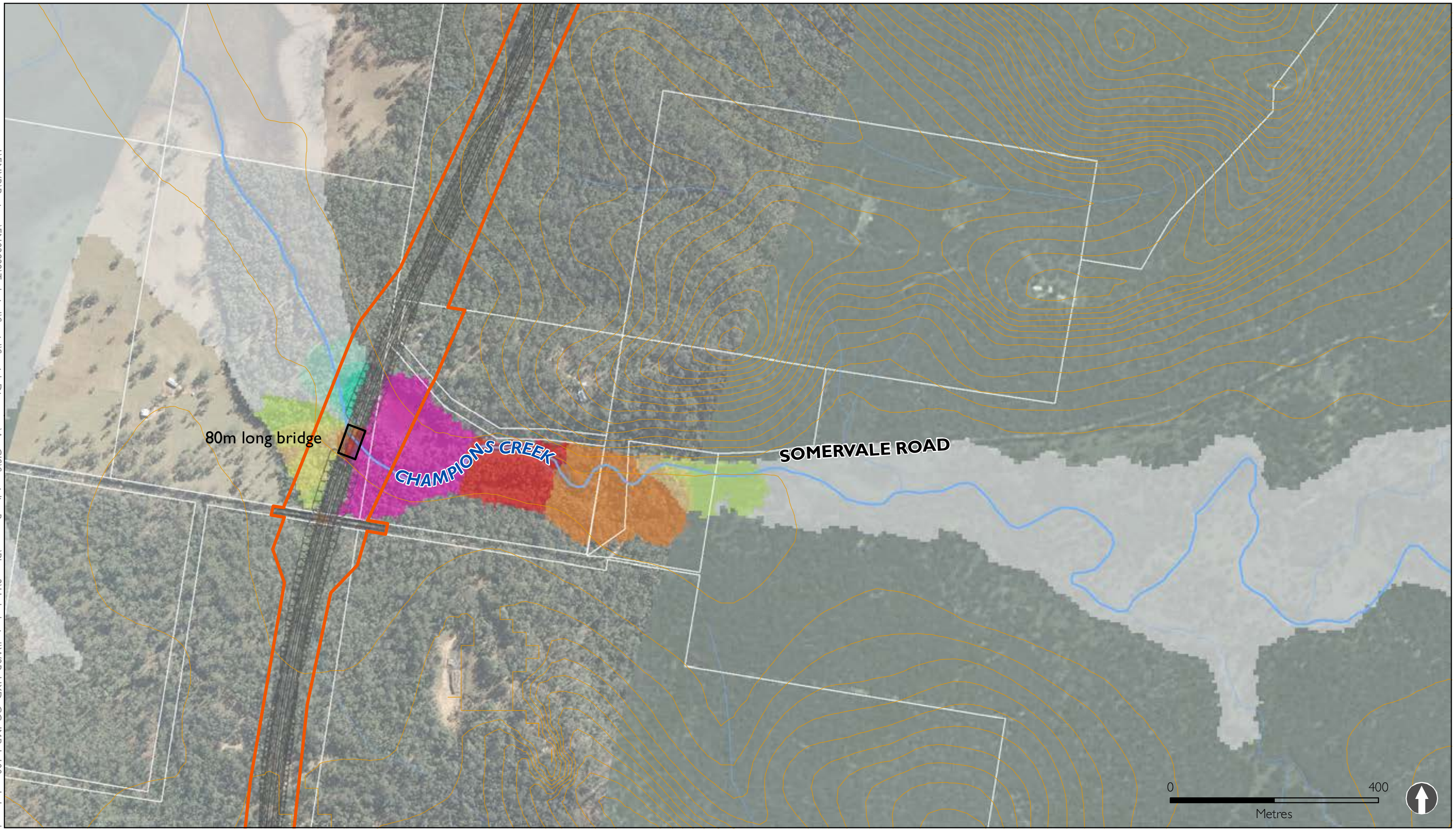
Figure 7-27 Flood impacts 100 year ARI event at bridge at station 58.64 under existing and climate change scenarios

A map of the Champions Creek flood impacts under climate change conditions in the 100 year ARI event is presented in Figure 7-28.

As under current climate conditions, an area of around 2.3 hectares upstream of the Champions Creek bridge experiences flood impacts greater than 250 millimetres, but less than 400 millimetres. This is a localised increase and is within the flood level impact objectives.

In summary, the flood assessment under climate change conditions indicates that the structure capacity of the project is sufficient to meet the flood design objectives for both flood immunity and flood level impacts under these conditions.

Figure 7-28 Flood impacts under 100 year ARI climate change scenario: Champions Creek



The project
Project concept design
Existing Pacific Highway
5m ground level contours (indicative)

Flood impacts - m

-0.075 -0.05 -0.025 -0.005 0.005 0.025 0.05 0.075 0.15 0.25

7.4.8. Clarence River floodplain (Glenugie to Tyndale)

This section of the Clarence River catchment encompasses the subcatchments of Pheasant Creek, the Coldstream River, Pillar Valley Creek, Chaffin Creek, and Champions Creek and nearby creeks. In addition to local subcatchment flooding, Clarence River flooding affects the project along some of these tributaries by backing up into the tributary floodplains that act as storage areas. Clarence River floods are of long duration (several days for the 100 year ARI event), compared to the shorter duration tributary events. The impacts of the project under climate change conditions for project areas affected by the Clarence River flooding were assessed.

At the proposed 120 metre span bridge over the Coldstream river western tributary (on the upstream project boundary), under existing conditions the predicted impact is about zero millimetres in the 20 year ARI flood. The predicted impact is about five millimetres under climate change conditions at the same location (see Figure 7-29).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 20 year ARI flood levels with the upgrade would be around 285 millimetres higher under climate change conditions (see Figure 7-29) at the 120 metre bridge. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetre clearance under the bridge deck required for debris passage.

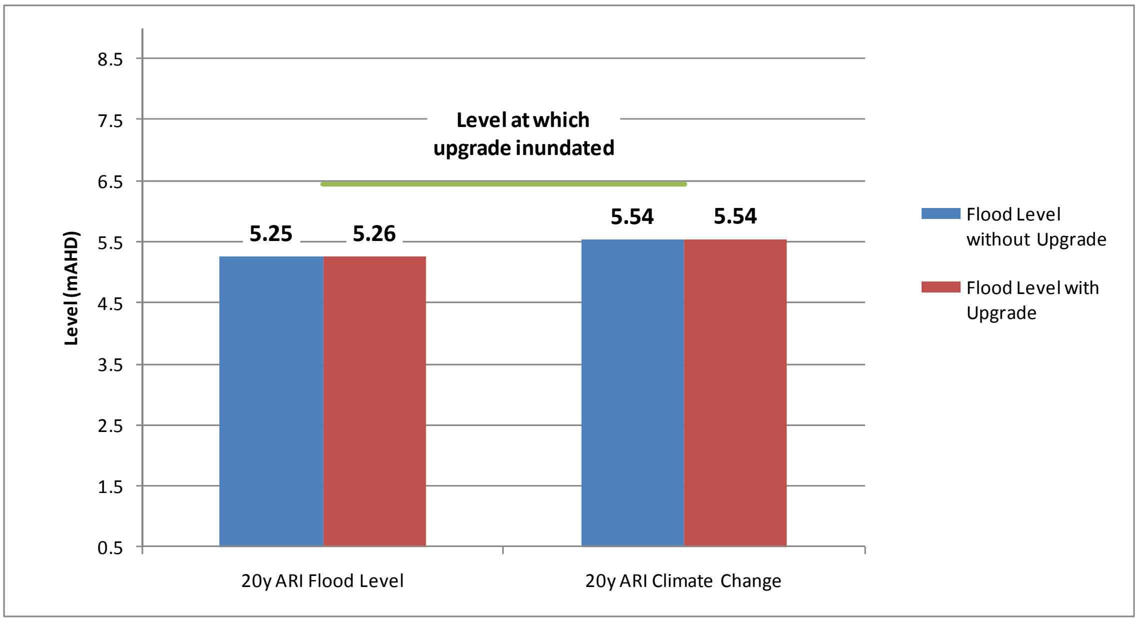


Figure 7-29 Flood impacts 20 year ARI event at bridge at station 42.54 under existing and climate change scenarios

At the proposed bridge crossing Coldstream River (on the upstream project boundary), under existing conditions the predicted impact is about zero millimetres in the 20 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about five millimetres (see Figure 7-30).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 20 year ARI flood levels with the upgrade would be around 285 millimetres higher under climate change conditions (see Figure 7-30) at the bridge over Coldstream River. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetre clearance under the bridge deck required for debris passage.

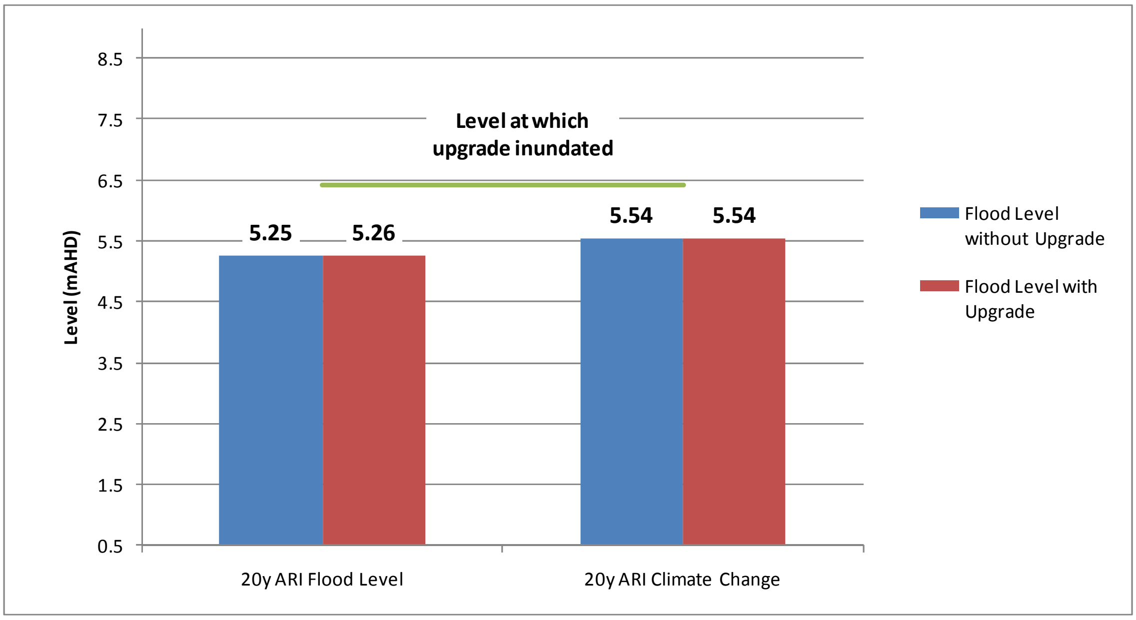


Figure 7-30 Flood impacts 20 year ARI event at bridge over Coldstream River at station 43.12 under existing and climate change scenarios

At the proposed 160 metre bridge over the unnamed creek to the east of the Coldstream River (on the upstream project boundary), under existing conditions the predicted impact is about zero millimetres in the 20 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about five millimetres (see Figure 7-31).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 20 year ARI flood levels with the upgrade would be around 285 millimetres higher under climate change conditions (see Figure 7-31) at the 160 metre bridge. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetre clearance under the bridge deck required for debris passage.

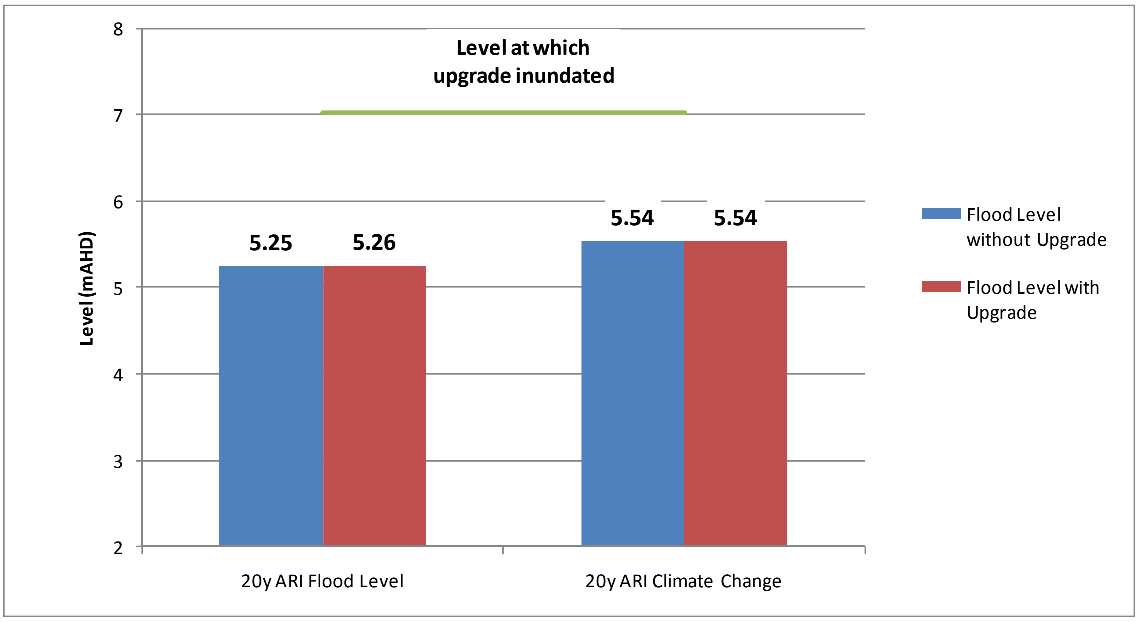


Figure 7-31 Flood impacts 20 year ARI event at bridge at station 43.91 under existing and climate change scenarios

At the proposed 60 metre bridge over Chaffin Creek (on the upstream project boundary), under existing conditions the predicted impact is about zero millimetres in the 20 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about five millimetres (see Figure 7-32).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 20 year ARI flood levels with the upgrade would be around 285 millimetres higher under climate change conditions (see Figure 7-32) at the bridge over Chaffin Creek. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300 millimetre clearance under the bridge deck required for debris passage.

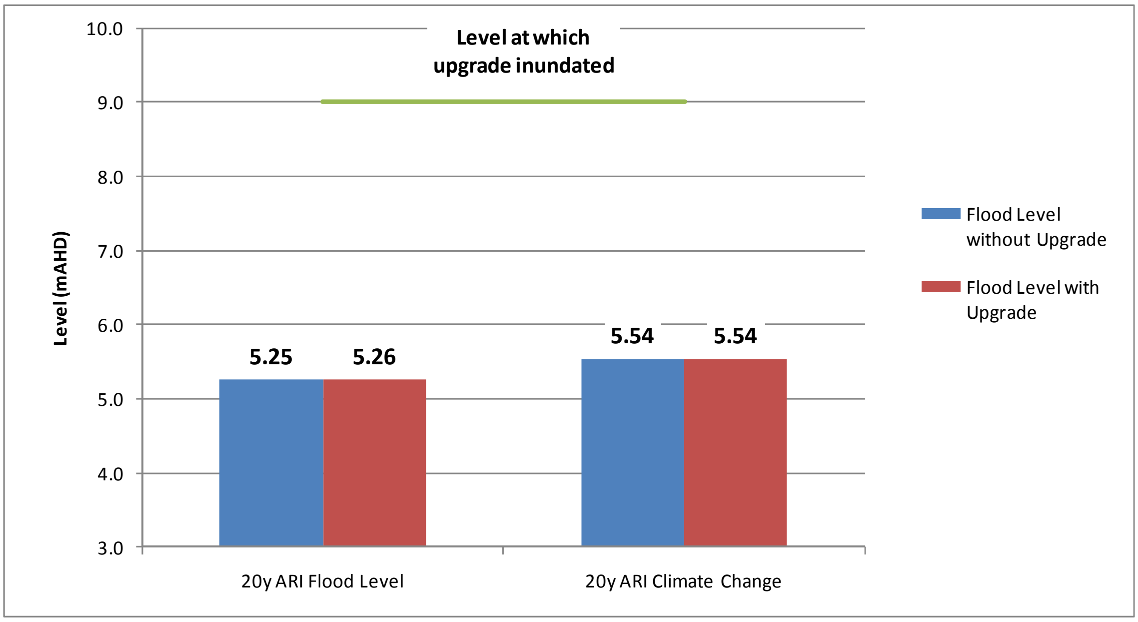


Figure 7-32 Flood impacts 20 year ARI event at bridge over Chaffin Creek at station 52.44 under existing and climate change scenarios

At the proposed 60 metre span bridge over the unnamed creek near Bostock Road (on the upstream project boundary), under existing conditions the predicted impact is about zero millimetres in the 20 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about five millimetres (see Figure 7-33).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 20 year ARI flood levels with the upgrade would be around 290 millimetres higher under climate change conditions (see Figure 7-33) at the 60 metre bridge. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300mm clearance under the bridge deck required for debris passage.

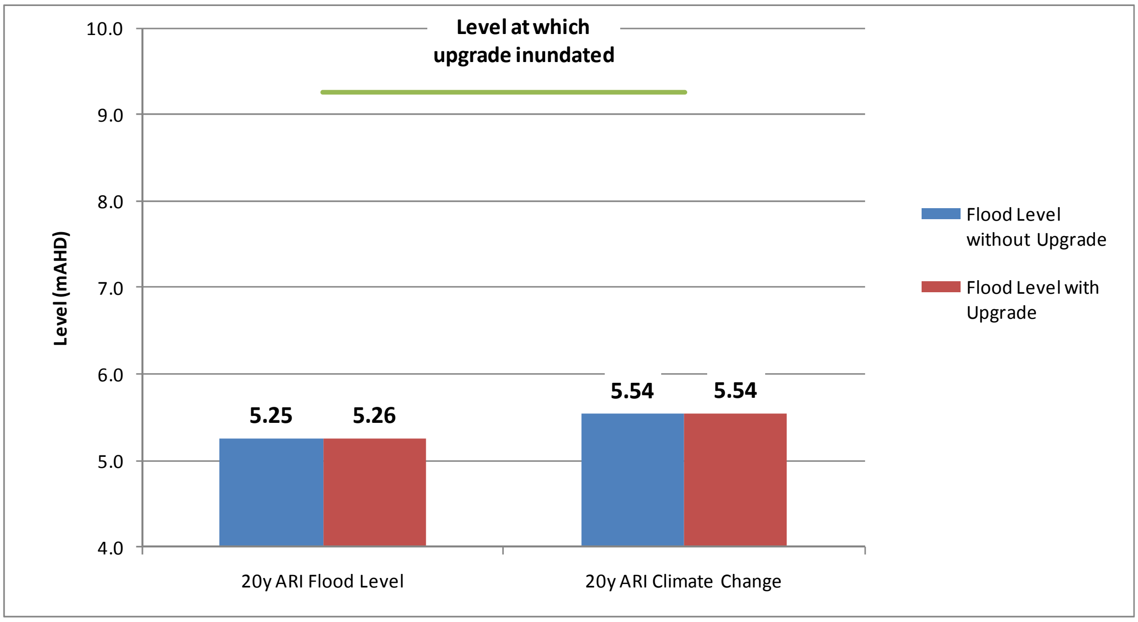


Figure 7-33 Flood impacts 20 year ARI event at bridge at station 54.71 under existing and climate change scenarios

At the proposed bridge crossing Champions Creek (on the upstream project boundary), under existing conditions the predicted impact is about zero millimetres in the 20 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about five millimetres (see Figure 7-34).

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling carried out under climate change conditions indicates that the predicted peak 20 year ARI flood levels with the upgrade would be around 280 millimetres higher under climate change conditions (see Figure 7-34) at the bridge over Champions Creek. However, the project would still meet the design flood immunity objectives at this location under climate change conditions. The detailed design phase should consider the need for maintaining the 300mm clearance under the bridge deck required for debris passage.

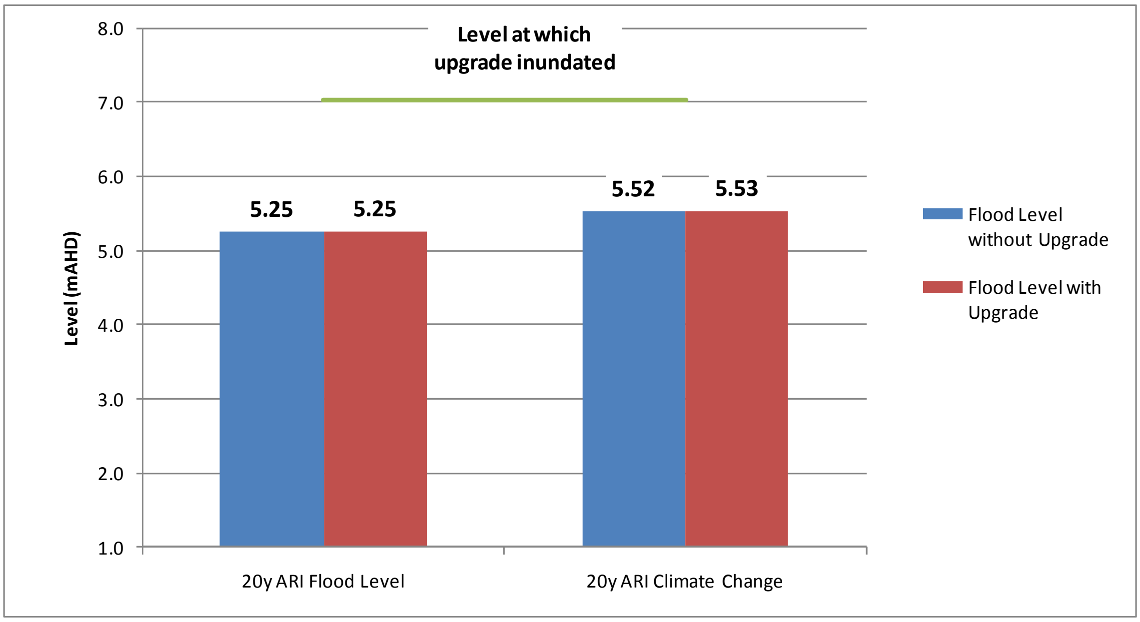


Figure 7-34 Flood impacts 20 year ARI event at bridge over Champions Creek at station 57.03 under existing and climate change scenarios

In summary, the regional flood assessment under climate change conditions indicates that the structure capacity of the project is sufficient to meet the flood design objectives for both flood immunity and flood level impacts under these conditions.

7.4.9. Clarence River (Tyndale to Maclean)

At the proposed nine metre wide bridge crossing (on the upstream project boundary), under existing conditions the predicted impact is about 10 millimetres in the 20 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about five millimetres (see Figure 7-35).

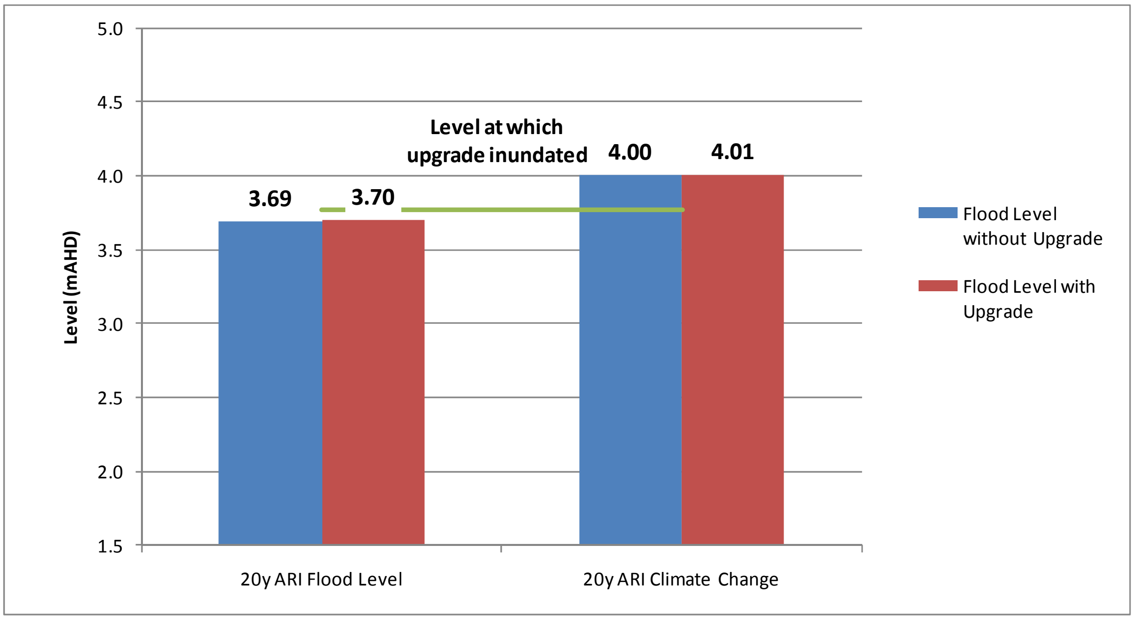


Figure 7-35 Flood impacts 20 year ARI event at bridge at station 70.46 under existing and climate change scenarios

At the proposed six metre wide bridge crossing (on the upstream project boundary), under existing conditions the predicted impact is about 15 millimetres in the 20 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about five millimetres (see Figure 7-36).

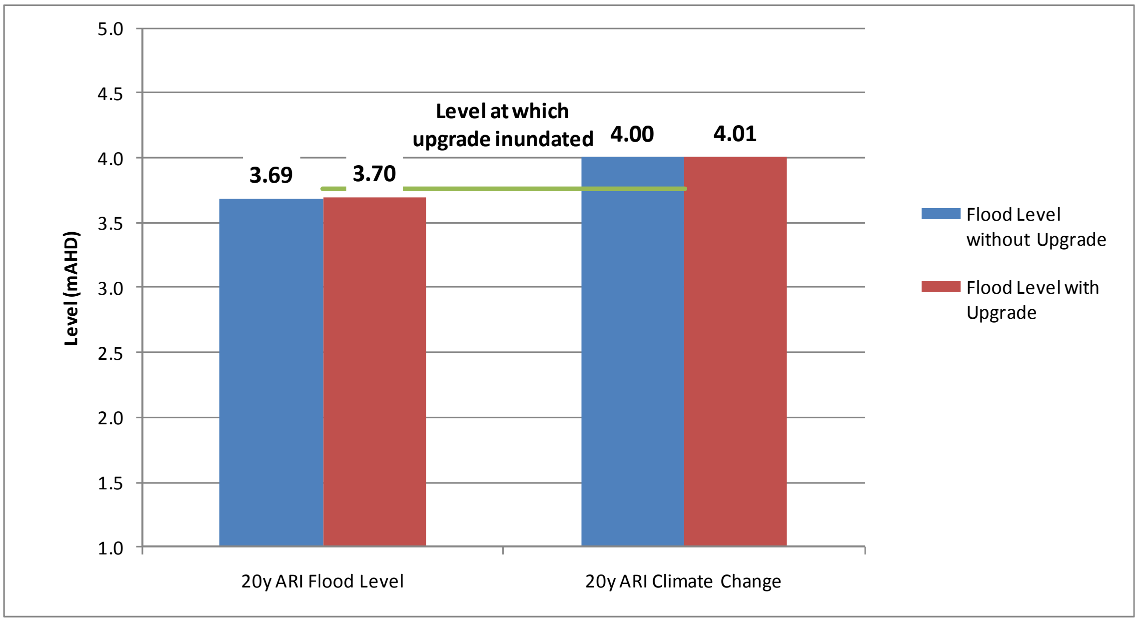


Figure 7-36 Flood impacts 20 year ARI event at bridge at station 73.50 under existing and climate change scenarios

At the proposed 400 metre long bridge across Shark Creek and the adjacent floodplain (on the upstream project boundary), under existing conditions the predicted impact is about 10 millimetres in the 20 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about zero millimetres (see Figure 7-37).

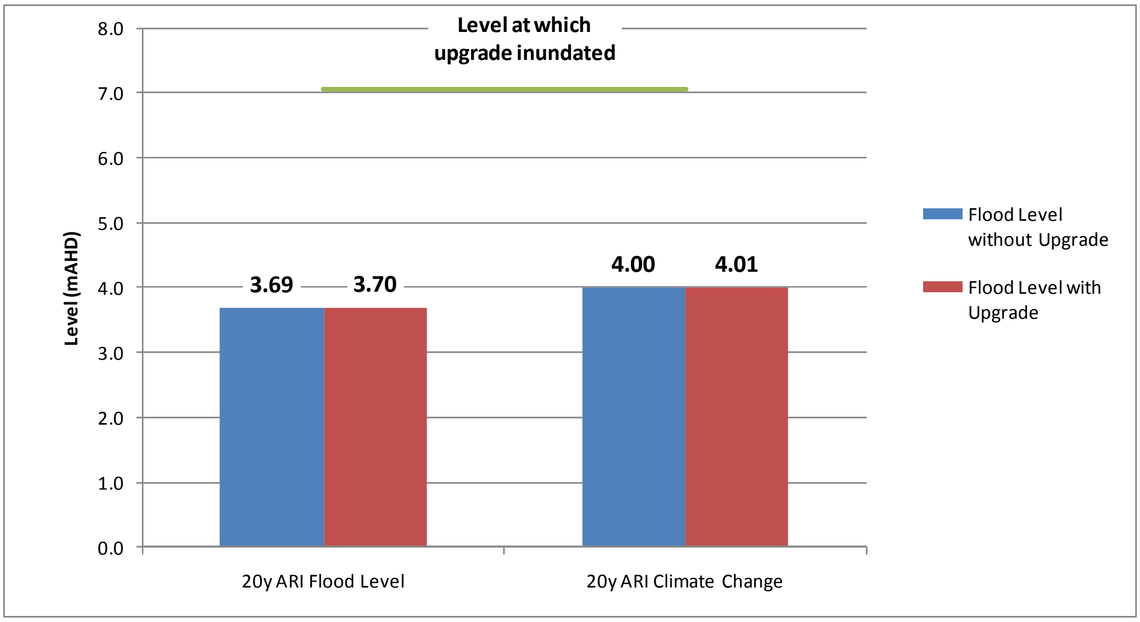


Figure 7-37 Flood impacts 20 year ARI event at bridge over Shark Creek at station 74.76 under existing and climate change scenarios

At the proposed bridge over Edwards Creek (on the upstream project boundary), under existing conditions the predicted impact is about five millimetres in the 20 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about 10 millimetres (see Figure 7-38).

As discussed in Section 6.10.3, this bridge does not meet flood immunity requirements for the 20 year ARI flood event under current climate conditions. As a result, it also does not meet flood immunity requirements for the 20 year ARI flood event under climate change conditions. This issue has been identified for mitigation through detailed design as discussed in Chapter 8.

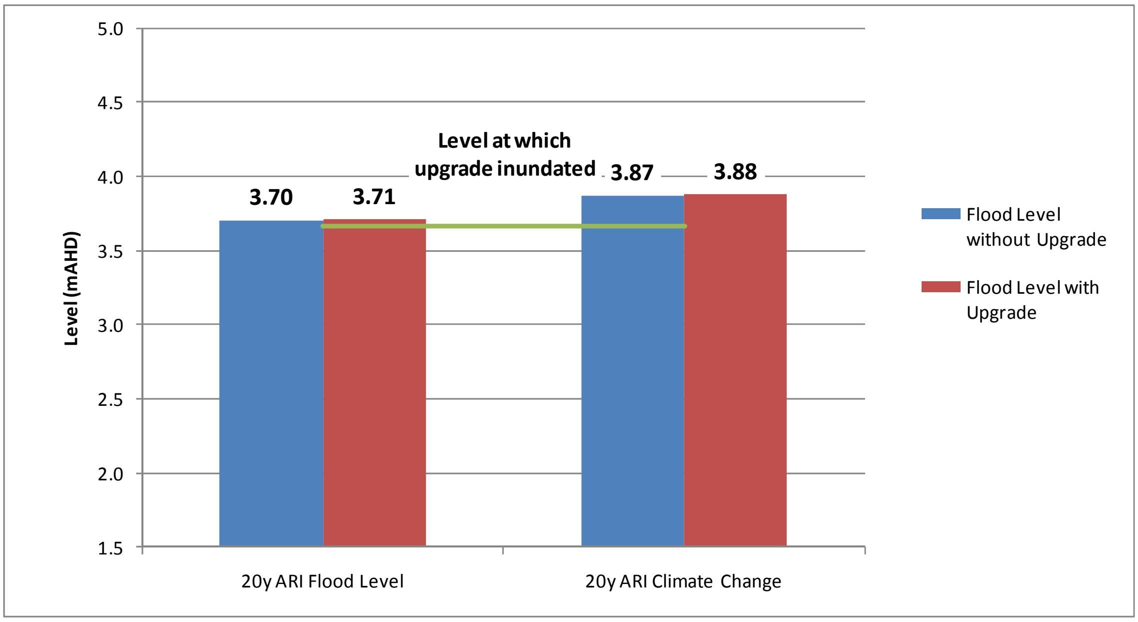


Figure 7-38 Flood impacts 20 year ARI event at bridge over Edwards Creek at station 80.15 under existing and climate change scenarios

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling indicates that the predicted peak 20 year ARI flood levels with the project under climate change conditions would increase by the following heights:

- 310 millimetres at Shark Creek
- 170 millimetres at Chaselings and Gulmarrad basins.

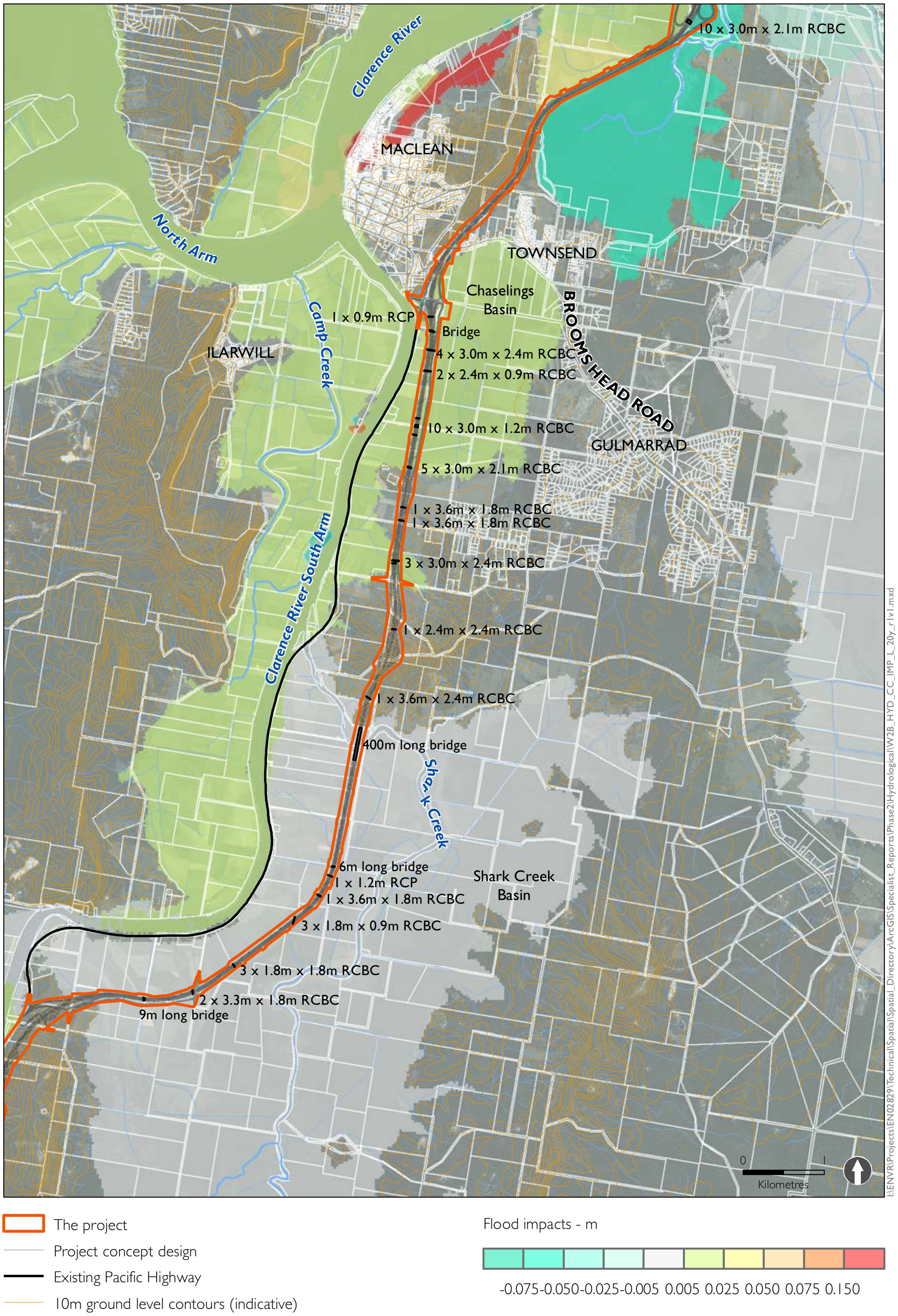
These required increases in embankment height would be considered further as part of the adaptive approach to climate change that is proposed for the project.

This estimated increase in embankment height has not been incorporated into the road design. However, the project boundaries have been designed so as to provide adequate space should road embankment heights be increased in the future.

A map of the Clarence River flood impacts under climate change conditions in the 20 year ARI event around Shark Creek/Maclean are presented in Figure 7-39.

The majority of the floodplain experiences flood impacts of around 5 millimetres. Between Shark Creek and Maclean, the floodplain experiences impacts up to 10 millimetres. This is within flood level impact objectives.

Figure 7-39 Flood impacts under 20 year ARI climate change scenario: Clarence River at Shark Creek / Maclean



7.4.10. Clarence River (Maclean to Iluka Road)

At the proposed 1323 metre Harwood Bridge (on the upstream project boundary), under existing conditions the predicted impact is about 10 millimetres in the 20 year ARI flood. Under climate change conditions, at the same location, the predicted impact is also about 10 millimetres (see Figure 7-40).

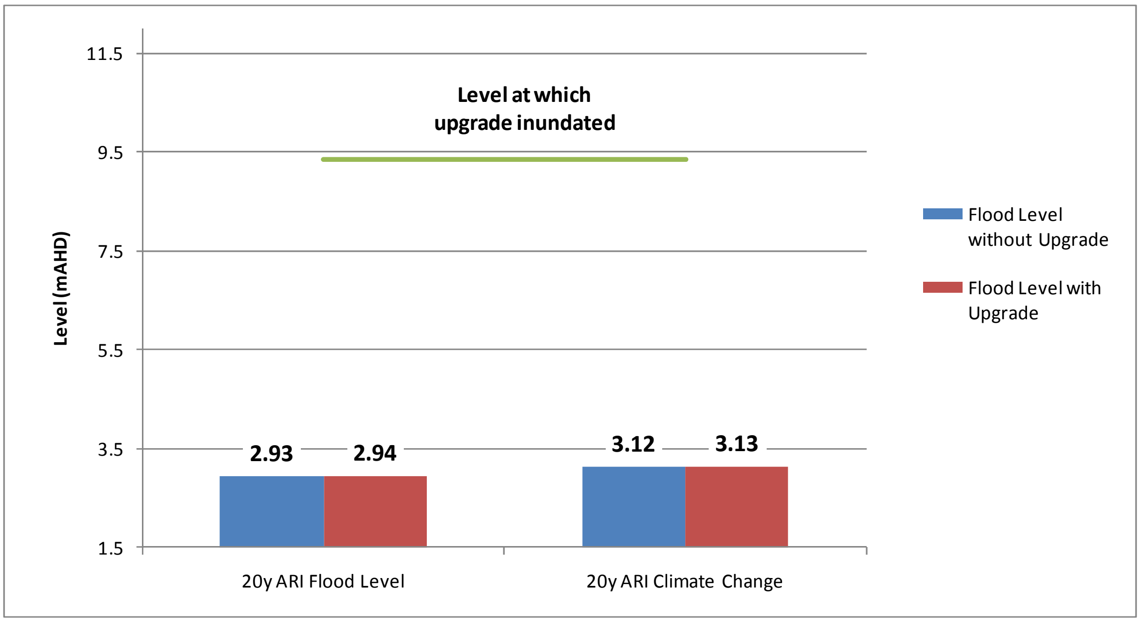


Figure 7-40 Flood impacts 20 year ARI event at Harwood Bridge at station 85.60 under existing and climate change scenarios

At the proposed 60 metre span bridge over Serpentine Channel (on the upstream project boundary), under existing conditions the predicted impact is about 25 millimetres in the 20 year ARI flood. Under climate change conditions, at the same location, the predicted impact is about 30 millimetres (see Figure 7-41).

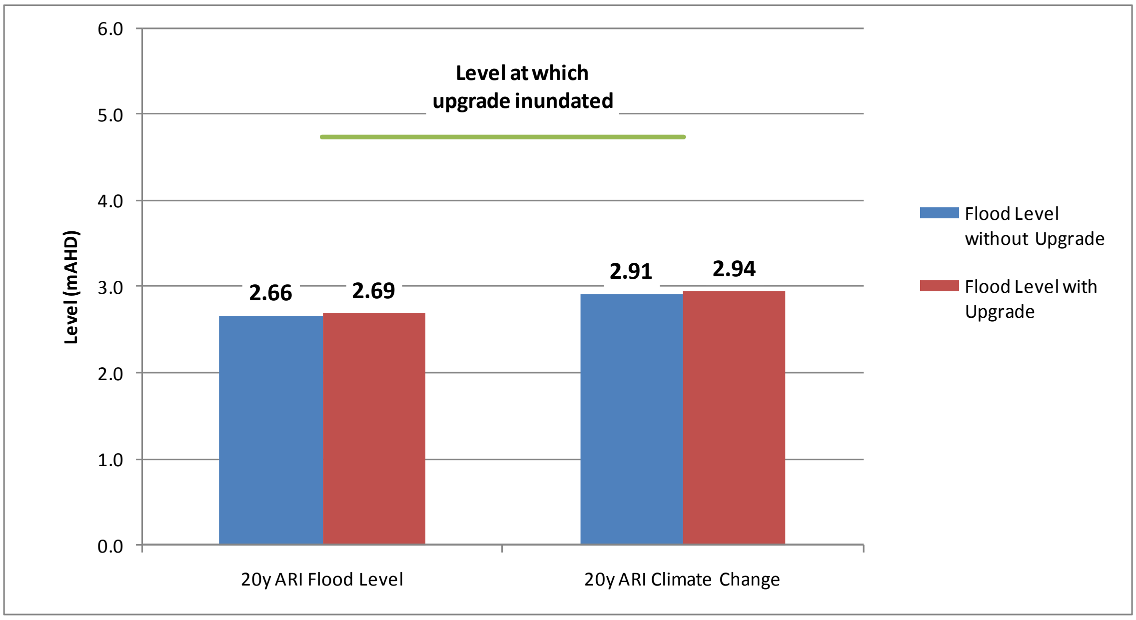


Figure 7-41 Flood impacts 20 year ARI event at bridge over Serpentine Channel at station 89.34 under existing and climate change scenarios

At the proposed 220 metre span bridge over the Clarence River North Arm (on the upstream project boundary) under existing conditions the predicted impact is about 15 millimetres in the 20 year ARI flood. The predicted impact is also about 15 millimetres at the same location under climate change conditions (see Figure 7-42).

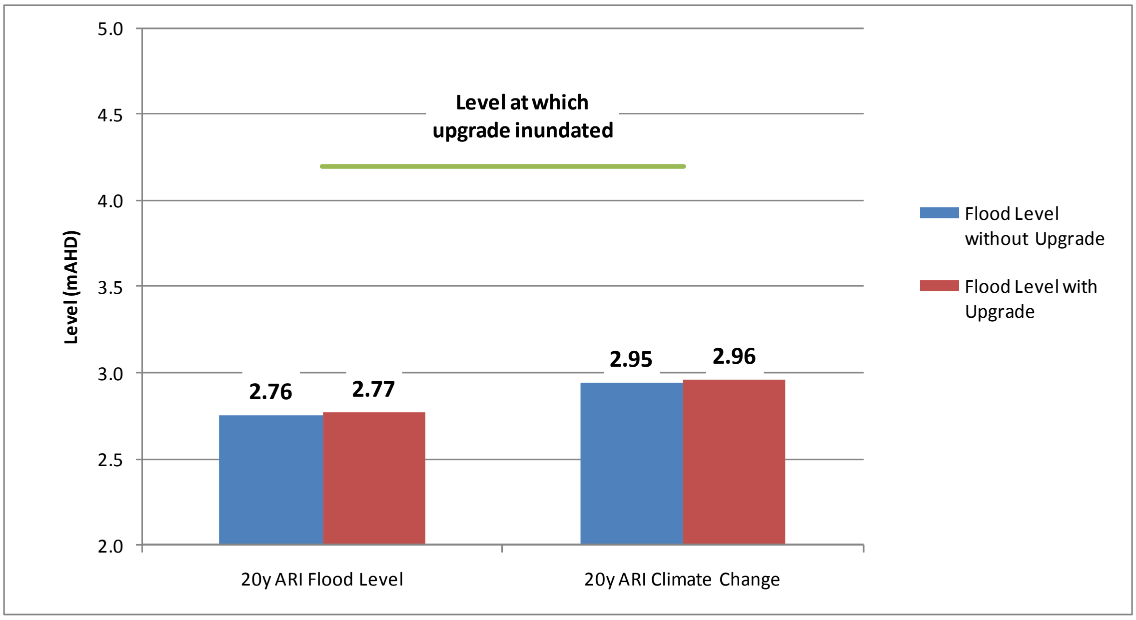


Figure 7-42 Flood impacts 20 year ARI event at Mororo Bridge at station 93.99 under existing and climate change scenarios

There is a potential for climate change to reduce the design flood immunity of the project through increasing flood levels. The flood modelling indicates that the predicted peak 20 year ARI flood levels with the project under climate change conditions would increase by the following heights:

- 250 millimetres at Harwood Island
- 290 millimetres at Chatsworth Island
- These required increases in embankment height would be considered further as part of the adaptive approach to climate change that is proposed for the project.
- This estimated increase in embankment height has not been incorporated into the road design. However, the project boundaries have been designed so as to provide adequate space should road embankment heights be increased in the future.

A map of the Clarence River flood impacts under climate change conditions in the 100 year ARI event are presented in Figure 7-44.

Impacts on flood immunity of Maclean levee

As discussed in Section 6.11.3, impacts are amplified inside the Maclean levee for flood events of frequency between 35 year ARI and 50 year ARI. For the assessment of climate change, the 20 year ARI flood event under climate change conditions results in similar behaviour. These amplified impacts can be seen in Figure 7-44 inside the levee system. Figure 7-43 below shows that the 20 year ARI flood under climate change conditions results in a flood that peaks close to the crest of the Maclean levee.

While the impacts inside the levee exceed the flood level impact objectives of 50 millimetres, there are few, if any houses where these increases result in increased over-floor flooding.

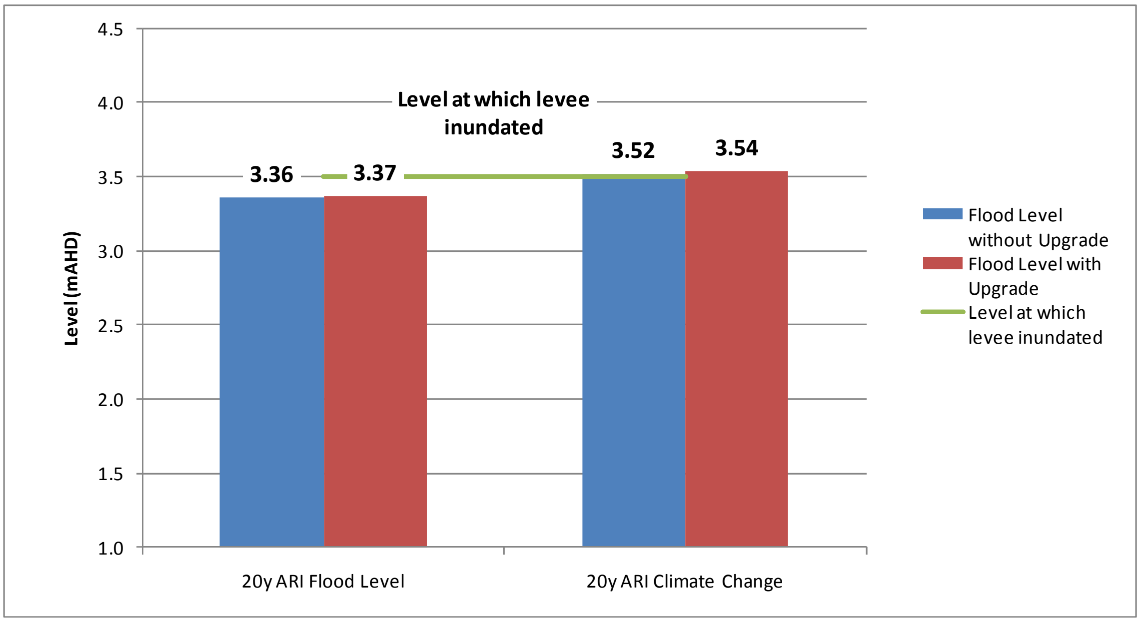
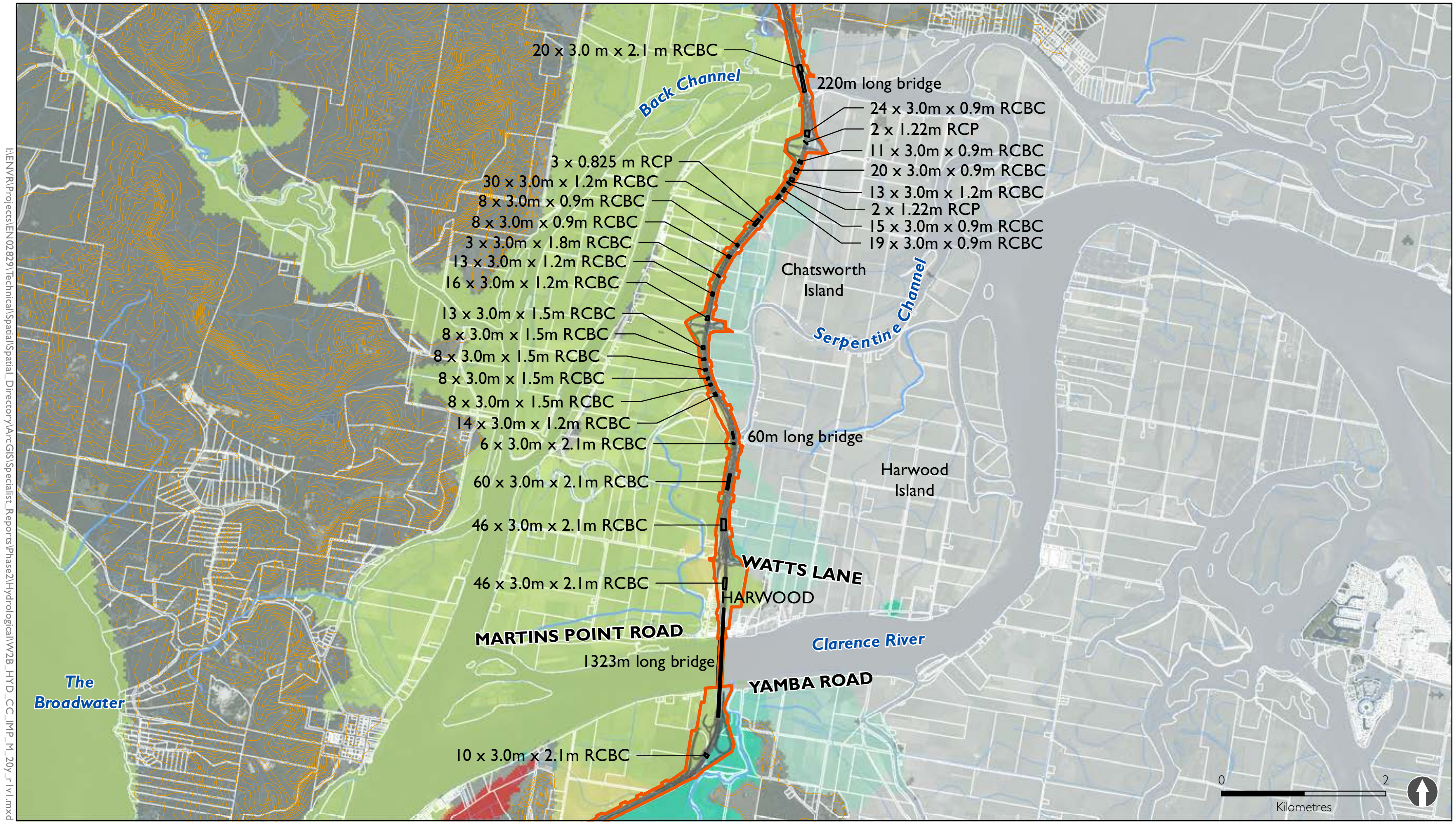


Figure 7-43 Flood impacts 20 year ARI event at Maclean Levee under existing and climate change scenarios

Figure 7-44 Flood impacts under 20 year ARI climate change scenario: Clarence River at Chatsworth and Harwood islands



The project
Project concept design
Existing Pacific Highway
10m ground level contours (indicative)

Flood impacts - m

-0.075 -0.050 -0.025 -0.005 0.005 0.025 0.050 0.075 0.150