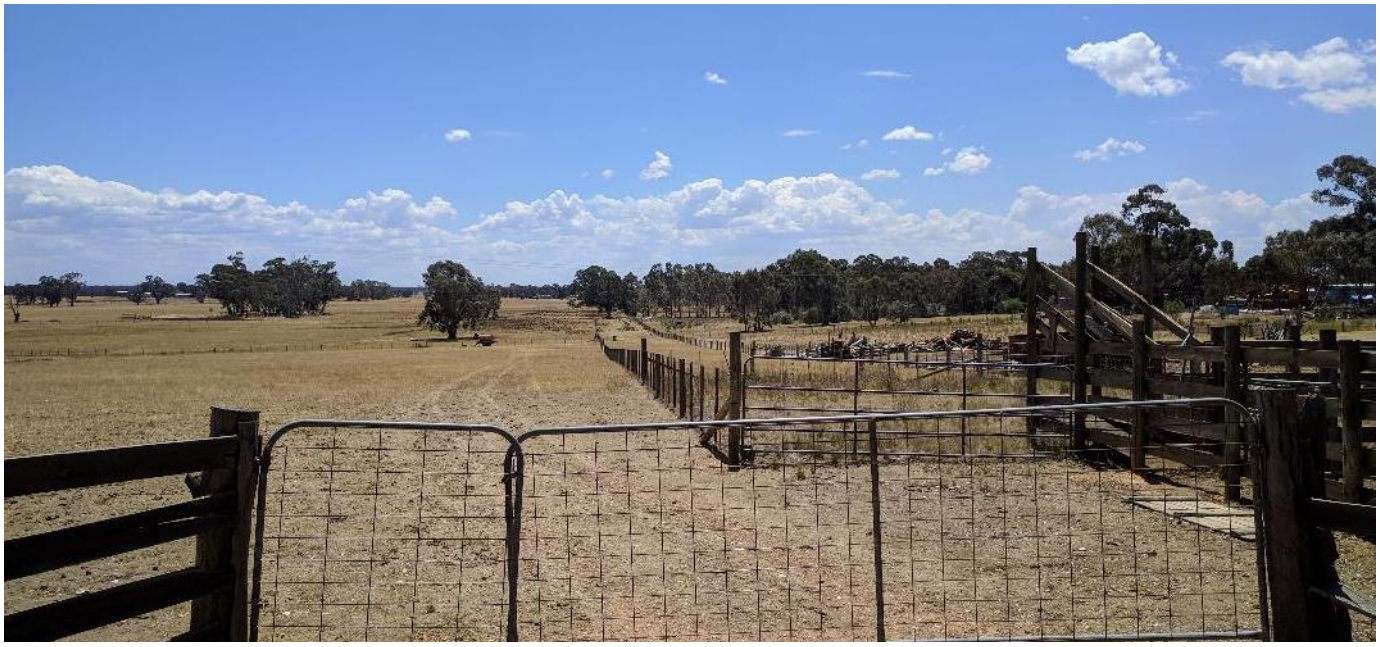
Carisbrook Flood Study Review

Department of Environment, Land, Water and Planning

Carisbrook Flood Study Review

V2 | Final

February 27, 2018



Carisbrook Flood Study Review

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Document history and status

Revision	Date	Description	By	Review	Approved
Draft Final	22/12/2017	Draft final report for submission to DELWP	P Pedruco	R Barling	R Barling
Draft Final V1	17/01/2018	Draft final responding to DELWP comments	P Pedruco	R Barling	R Barling
Final V2	27/02/2018	Final report addressing minor comments from DELWP	P. Pedruco	P. Pedruco	P. Pedruco

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1. Introduction

The Carisbrook Flood and Drainage Management Plan (the Plan) (Water Technology, 2013a) was completed in 2013 with the aim of developing a plan to manage flooding in Carisbrook. The recommendations of the study were endorsed by the North Central Catchment Management Authority (NCCMA) and a funding application was submitted to the Natural Disaster Resilience Grants Scheme by Central Goldfields Shire. The application was successful and the Investigation and Design of the Carisbrook Flood and Drainage Mitigation Treatments (Detailed design) (Entura, 2016) was commissioned. The design of the flood and drainage mitigation treatments also involved the delivery of the on ground engineering works. The purpose of this report is to review the Flood Management Plan and the flood mitigation works completed to November 2017.

1.1 Carisbrook Flood and Drainage Management Plan

The purpose of the Plan was to develop a community supported plan to manage and reduce flooding. This involved:

- Community consultation and engagement to collect local knowledge and ideas for flood management;
- Development of flood models (both hydrologic and hydraulic) to define existing case conditions and test mitigation measures;
- Landuse planning;
- Flood warning;
- Develop and prioritise flood mitigation options;
- Assessment of the flood mitigation options using the flood models;
- Preliminary costing;
- Economic assessment; and
- Deliver a preferred community supported plan.

1.2 Design of Carisbrook Flood and Drainage Mitigation Treatments

The purpose of the Detailed Design was to undertake detailed design of the community supported flood management plan. This involved:

- Confirming the plan and making adjustments based on information such as detailed topographic, service locations, property boundaries and geotechnical information;
- Undertaking the required detailed assessment including cultural heritage and environmental assessments plus geotechnical investigations;
- Undertaking the detailed design and costing; and
- Development of detailed drawings for the tendering and delivery of the required engineering works.

1.3 Purpose of review

The purpose of this review was to:

1. Undertake a review of the technical basis for deciding on the preferred works.
2. Undertake a review of the mitigation options assessment.

3. Confirm that works either completed to date or planned for completion align with the scheme endorsed by the community as documented in the management plan.
4. Confirm that the mitigation scheme adopted as the preferred scheme and documented in the plan represents the best outcome for Carisbrook. That is, the outcome was based on a rigorous process with the community that considered all options available at the time.
5. Advise if there are any additional checks that could be made to increase community confidence in the mitigation works.

1.4 Summary of findings

The review of the Carisbrook Flood and Drainage Management Plan and the Design of Carisbrook Flood and Drainage Mitigation Treatments found:

- The technical basis, or flood modeling, for deciding the preferred works was reviewed and found to be an appropriate basis for this decision. The flood model was calibrated to two flood events which means it is suitable for determining the flooding characteristics in and around Carisbrook as well as assessing the effectiveness of different mitigation options.
- There were 19 mitigation options assessed in the Plan, which were suggested from a variety of sources including the Carisbrook Community and the Plan's Steering Committee including all options articulated at the time. These were combined into different mitigation schemes (a combination of options) and at least five of these schemes investigated in the flood model. The development of the final adopted scheme was undertaken iteratively, with the feedback from the Community being provided at each iteration. The mitigation options assessment is considered to be a robust assessment done to industry best practice that was supported by the Community at the time.
- The Detailed Design, represents the adopted scheme from the Plan with some minor alterations as more detailed and site specific information came to light. The main changes have been using existing roads as levees rather than private property and the introduction of drainage to take advantage of the natural contours of the land to the west of the western levee.
- At this point in time not all of the scheme has been delivered due to land acquisition issues and the western levee is currently incomplete although this is still planned to be completed. In a small number of areas, the performance levels agreed to by the community has not been achieved. It is considered that these areas are either not fundamental to the integrity of the levee or can be managed through additional minor works.
- The preferred flood mitigation scheme adopted for Carisbrook and outlined in the detailed design report represents the preferred option outlined in the Plan. The flood modelling in the Plan and the Detailed Design have demonstrated the effectiveness of the adopted scheme to protect Carisbrook against flood events up to the 1% AEP event, but there remains a residual flood risk.
- This review has a number of actions that would increase community confidence in the mitigation works and enhance the outcomes of the Plan. The majority of these actions are standard actions that would be expected to completed following the delivery of such a study or actions that address newly available information. It is also of note that as new information becomes available it is best practice to incorporate this where possible. In summary these are:
    - Examining the short duration storms in the Western catchment
    - Reviewing the assessment of probability of peak flow events using recently developed techniques and additional data
    - Testing the final Detailed Design in the flood model
    - Presenting updates and findings to the community

1.5 Structure of report

The report has been structured to address each requirement listed in Section 1.3. This structure is as follows:

- A technical review of the flood modelling developed as part of the Plan. This involved reviewing the hydrologic and hydraulic modelling. This addressed purpose 1 listed above.
- A review of the flood mitigation options. This includes a review of the options assessment process, review of works delivered to date and confirmation of the flood mitigations effectiveness in protecting Carisbrook. This addressed purposes 2, 3 and 4 listed above.
- A set of recommendations to increase community confidence in the mitigation works and address any gaps in the process.

2. Background

Following two separate flood events which affected the Carisbrook community during 2010-11 funding for the Carisbrook Flood and Drainage Management Plan was made available. The purpose of the Plan was to develop a set of measures to manage, and where possible to reduce flooding to the Carisbrook Community. A key outcome was to develop a Plan that had strong community support. Water Technology were commissioned to assist the NCCMA and Central Goldfields Shire Council (Council) to develop the Plan.

The Plan was based on flood modelling developed as part of the process and this modelling was calibrated to the two most recent flood events, being September 2010 and January 2011, which were the largest on record. These events were respectively assigned the following return periods: 1 in 75 and 1 in 135 Annual Exceedance Probability (AEP) events.

The modelling found that the flood risk to Carisbrook emanated from three distinct sources:

- Tullaroop Creek or Deep Creek
- McCallum Creek
- Local catchment to the west and south-west

The largest flows and volumes emanate from McCallum Creek, whilst Tullaroop Creek is a similar size to McCallum, however, flows are attenuated by the Tullaroop Reservoir. The local catchments to the west are also a significant source of flows contributing to flooding in the recent events.

Once the flood model was calibrated it was used to develop mitigation works to manage flooding in Carisbrook. The tested mitigation measures were developed in conjunction with the community lead Steering Committee and the preferred option determined. This option included:

- A Western Floodway and Levee to divert overland flows to the west of the township
- Vegetation works on Tullaroop and McCallums Creek extending from Camp Street to a point 500 m downstream of the railway bridge
- A smaller levee near Williams Road to divert additional overland flow into McCallums Creek through the existing bluestone drain
- A non-return valve on culverts under Landrigan Road near Camp Street
- A long-term recommendation that the highway bridge be replaced with a clear-span structure when the bridge is due for replacement (or when funding becomes available).

The purpose of the Western levee and Williams Road levee is to protect flows from Carisbrook from overland flow from the local catchments and these have been designed to the 1% (1 in 100) Annual Exceedance Probability (AEP) event level plus a 300mm allowance for freeboard. The non-return valve prevents water surcharging under Landrigan Road and protects flooding of a number of properties to the south of the highway.

This package of works protects Carisbrook from the local catchments up to and exceeding the 1% AEP event due to the 300mm freeboard. The vegetation works protect the town from flooding from the main creek system up to the 1% AEP event, but not for rarer events such as the January 2011.

2.1 Documents reviewed

In undertaken the review the following reports were considered:

- Carisbrook Flood and Drainage Management Plan (Water Technology, 2013a)

- Carisbrook Flood and Drainage Plan: Flood Mitigation Options Costing Memo (Water Technology, 2013b)
- Carisbrook Flood and Drainage Plan: Flood Mitigation – Package 3 results (Water Technology, 2012)
- Technical advice regarding impact of vegetation removal on the hydraulic roughness of waterways at Carisbrook (Water Technology, 2016)
- Carisbrook Flood and Drainage Management Plan: NCCMA Board Meeting No. 175 (North Central Catchment Management Authority, 2013)
- Investigation and Design of Carisbrook Flood and Drainage Mitigation Treatments: Preliminary Design Report ENTURA-95365 (Entura, 2015)
- Investigation and Design of Carisbrook Flood and Drainage Mitigation Treatments: Detailed Design Report ENTURA-A31FA (Entura, 2016)

The technical review involved a review of the reported hydrologic and hydraulic modelling only as a review of the models and modelling files was beyond the scope of this report. In undertaking this work, none of the following were reviewed: the input data, model files or outputs (except for the information documented in the reports), the landuse planning outcomes, the flood warning assessment or the Municipal Flood Emergency Management Plan.

3. Technical review

The first task reviewed the technical basis for mitigation works, that is the completed flood modelling. The flood modelling completed was based on an industry standard approach of coupling a rainfall-runoff model to a hydraulic model to produce flood mapping products across a variety of probabilities. The rainfall-runoff modelling was completed using the RORB software package and the hydraulic modelling using the Mike FLOOD software package. The technical review involved a review of the reported hydrologic and hydraulic modelling only, as a review of the models and modelling files was beyond the scope of this report.

Overall, the flood model (the combined hydrology and hydraulic models) were adequately calibrated to the two separate flood events; being the September 2010 and January 2011 flood events. This demonstrated that the computer modelling was able to satisfactorily replicate flood data such as gauged flow records and survey flood marks as well as the flooding behavior during these events. This means that the flood model was a suitable tool to develop the Plan. There were, however, a number of technical issues that could enhance confidence in the outcomes, although these are not considered to fundamentally change the outcomes of the Plan or Detailed Design. These technical issues are described below together with the likely impacts.

3.1 General

This section considers some of the general elements of the flood modelling that are not specifically related to the hydrologic or hydraulic modelling. Whilst the overall approach is considered acceptable, addressing the issues outlined below would improve the outcomes of the Plan and provide valuable information to the Carisbrook community.

- The study did not document the flood history of Carisbrook. This is an important piece of information in any flood study as it contextualises the frequency of occurrence of flood events and can be used to validate the probability of large events, documents historic floods and can be used in flood awareness campaigns. The report notes that large flood events have occurred in the past; however, no further information has been provided.
- Flows at a number of gauges were reported to have been reviewed by Thiess (now Ventia) but it is unclear if these flows were used in the final analysis. It is understood from the Plan's report that large flows were underestimated at key gauges and some missing flood peaks had been infilled. This information is vital in assigning probabilities to peak flood flows and further it is possible that historic peaks could also have been underestimated. This information could have a significant impact on the flood quantiles (peak flows for a given probability).

3.2 Hydrology

This section addresses the completed hydrologic modelling which included at-site flood frequency analysis and rainfall-runoff modelling.

- The rainfall-runoff modelling (RORB) included some unusual parameters and input variables, in particular the size of the sub-catchments was considered to be small for the catchment area. The resulting number of sub-catchments was 421 whereas typically 20-50 sub-catchments would be recommended for a RORB model. This was acknowledged in the report and to compensate the RORB's k_c parameter was unusually small and does not fit within typical ranges. Whilst this is non-standard practice, the RORB model was able to satisfactorily reproduce flows at key gauges, although there were some artefacts in the modelled hydrographs such as multiple peaks in September 2010 at Creswick Creek at Clunes but these did not affect flow rates at Carisbrook. The extents of the RORB model are shown in Figure 4-2 of the Plan.
- The issue of joint probability was identified in the report; however, this has not been addressed in the report and perfect correlation has been assumed, which can significantly over-estimate flood risk if there is not a strong correlation between rainfall in the catchments. Preliminary analysis of daily rainfall from the Talbot

(Post Office) and Campbelltown rain gauges suggests that there is a positive correlation of around 0.5 for annual maxima rainfall totals for Pearson, Kendall and Spearman's methods. While these are significant they are not perfect and it can be concluded that this assumption has led to conservative flood flows and levels.

- The local catchments were assessed together with the main creek systems and the shortest duration storm assessed was the 2-hour storm. For small catchments the critical duration storm is likely to be less than 2-hours and this would mean that the peak flood levels from these catchments may not have been calculated. Further the use of Areal Reduction factors for these local catchments will have also reduced peak flows from these sources and hence peak flood levels. This means that flood levels from the local catchments may be underestimated. The location of the inflows, from the local catchments and the main creeks, are shown in Figure 4-3 of the Plan.
- The sensitivity testing of the RORB model found that results were sensitive to the assumed rainfall losses. This means that choice of loss values is influential in determining the resulting flood quantiles (peak flows verse probability or return periods).
- The flood frequency analysis (FFA) completed was not relied upon in the Plan and the location of the gauges analysed is shown on Figure 3-9 of the Plan. This analysis would benefit from revision utilising the recently published advice in Australian Rainfall and Runoff (2016), the additional streamflow data at gauges since 2012 (including revisions to the rating curve and the 2016 event) and a flood history of Carisbrook. This analysis would provide a useful verification of the flood quantiles produced from the RORB model. This is considered to be important as flood quantiles determine the probability of a given peak and thus are an important component in determining the level of flood risk (risk = probability x consequence) and standard of protection. The importance of this can be highlighted by the quoted return period of the January 2011 event as being the 1 in 135 AEP event.
    - The use of new techniques for FFA would address the over fitting of frequent flood events which can affect the estimate of rarer flood events. This can be readily remedied by censoring these frequent flows (called Probable Influential Low Flows) producing more reliable results from the FFA.
    - These new techniques would also allow for the incorporation of non-precise peak flows (through a Bayesian Framework) and this would be preferred over the "minimum flow approach".

Overall, the hydrologic analysis has reproduced flows for two events being the September 2010 and January 2011, through the event based rainfall runoff modelling (RORB), albeit with some unusual and non-standard parameters. The design event modelling in the rainfall-runoff model was the primary tool used to determine the flood quantiles (peak flows for a given probability or return period). Sensitivity analysis of input into the RORB model has demonstrated that the flood quantiles are sensitive to the selected rainfall loss values. It is desirable where stream flow gauge data exists that flood quantiles are verified against at-site flood frequency analysis (FFA); however, there was considerable uncertainty in this analysis and there would be considerable benefits in reviewing the at-site FFA using newer techniques and additional data. Given this, there is some uncertainty in the flood quantiles and hence the probabilities of a given peak flow. This ultimately means that the flood risk, which is the product of probability and consequences, determined by the flood model contains a degree of uncertainty. This uncertainty will not affect the effectiveness of any flood mitigation scheme only the level of service it provides.

3.3 Hydraulic analysis

This section addresses the hydraulic modelling completed.

- The model was set up as a 1D-2D linked hydraulic model with a grid size of 5m which is considered appropriate for the purposes of the study.
- The inflows to the model were based on RORB modelling and applied as flow timeseries, which is considered appropriate for the purposes of the study.

- The downstream boundary was applied as a discharge-level relationship which is considered appropriate for the purposes of the study; however, no details, including the location of the boundary, were reported. Further sensitivity testing of this boundary was not undertaken, which would have provided confidence that the setup of the boundary is not unduly affecting results.
- The description that all structures were modelled as culvert and weir structures, if applied to the large bridges which is considered to be an unusual approach. Typically, bridges are modelled using the bridge routines within the software and the resulting hydraulic losses compared to the results of other software packages and/or standard calculations. This can have a significant local impact on flood levels for structures such as the Pyrenees Highway Bridge and the Rail Bridge. However, calibration of the flood model for the September 2010 event to the flood marks around the Pyrenees Highway Bridge (excluding one clearly erroneous data point) is considered acceptable.
- Channel and floodplain roughness (Manning's n values) are considered appropriate and fall within the expected values (although generally towards the higher end) for the various different landuses, with the exception of those for "Backyards' which are unusually high. However, the model has calibrated, so these values are considered appropriate.
- The calibration for the September 2010 event is considered reasonable, although the modelled flood levels are generally high. This could be due to the high Manning's n values. The hydraulic model results for the September 2010 event are shown in Figure 5-4 and Figure 5-5 of the Plan.
- The calibration for the January 2011 event is considered reasonable and a better result than the September 2010 event. Given that this was the larger event this is considered an appropriate approach. The hydraulic model results for the January 2011 event are shown in Figure 5-6 and Figure 5-6 of the Plan.
- Comparison of the September 2010 and January 2011 Flood Extents (Figure 5-8 of the Pan) shows that the contribution of local flows in the two events was similar, with the 2010 event having the greater extent. This is despite the large difference in the estimated return periods which suggests that the joint probability between the main creek flood and the local catchment flood is weaker than assumed.

Overall the hydraulic modelling results have been demonstrated to reproduce the flood levels from the September 2010 and January 2011 flood events, that is, the model has been calibrated to two food events. While there are a number of minor technical issues, such as the bridge losses and high Manning's values, the results suggest that these balance out. For these reasons, the hydraulic model is considered appropriate for its intended purposes.

3.4 Economics

An economic cost benefit assessment was undertaken to evaluate the financial viability of the flood mitigation schemes. A discount rate of 6% over a 30 project life was used for the assessment and these are considered to be appropriate values. However, the flood damages appear to be based on old data and more recent data suggests that this has underestimated flood damages by a factor of 2. Regardless, of this significant increase in flood damages none of the schemes would be considered cost effective with the exception of the vegetation clearing option.

4. Mitigation scheme

As well as reviewing the technical basis for the Carisbrook Flood Management a review of the mitigation scheme was undertaken. This involved:

- Reviewing the mitigation options assessment presented in the Plan.
- Confirm that works either completed to date or planned for completion align with the scheme endorsed by the community as documented in the management plan.
- Confirm whether the mitigation scheme adopted as the preferred scheme and documented in the plan represents the best outcome for Carisbrook.

4.1 Mitigation options assessment

Mitigation options were collated from the community via a questionnaire, the Steering Committee and the consultant which resulted in a long list of 19 options. These 19 options were then assessed using a multi-criteria analysis based on the Reduction of Flood Damages, Indicative cost, Feasibility and Environmental Impact and assigned a weighted score. These rankings were used to develop four mitigation package (a combination of mitigation options), effectively a short listing process, in conjunction with the Steering Committee. This is considered to be a thorough and appropriate process for developing mitigation options.

Once the mitigation packages were defined they were tested in the flood model to determine their effectiveness, costed and presented to the Steering Committee. This resulted in the development/refinement of a further four mitigation packages and the results of these packages were presented to the community with the identified preferred package. This represents a high degree of input from the Steering Committee and should be considered to be best practice.

The findings of the Plan were presented to the community on the 15th February 2013 and then followed by a period during which feedback was sought from the community. Of the 115 submissions 101 were supportive of the preferred option and 14 not supportive. This is considered to be a high rate of support.

Overall, the approach to the mitigation options assessment is considered to be best practice and provided significant opportunities for community input through the Steering Committee.

4.1.1 The final preferred option

The final preferred option was identified in the Carisbrook Flood Mitigation and Drainage Management Plan (feasibility stage) and shown in figure 10-1. The final option is also shown on drawings in the Investigation and Design of Carisbrook Flood and Drainage Mitigation Treatments - Detailed Design Report (General Arrangement Plan – EHT-CA-DR-001A). This option was described as:

- A Western Floodway and Levee to divert overland flows to the west of the township - A 3 km long levee extending from the southern end of the Curraghmoor Road Reserve northwards past the Pyrenees Highway, running parallel to Pleasant Street, past the Railway Line and then into the crown land on which the Maryborough Harness Racing Club lies.
- A smaller levee near Williams Road to divert additional overland flow into McCallums Creek through the existing bluestone drain.
- A non-return valve on culverts under Landrigan Road near Camp Street.
- Vegetation works on Tullaroop and McCallums Creek extending from Camp Street to downstream of the railway bridge.

- A long-term recommendation that the highway bridge be replaced with a clear-span structure when the bridge is due for replacement (or when funding becomes available).

4.2 Review of detailed design

Typically, in a project such as the development of a flood mitigation scheme, there is a feasibility stage and this is followed by a detailed design stage. The purpose of the feasibility stage is to assess different options to determine a preferred option. This is then used as the basis to obtain funding and, if successful, a detailed design stage is undertaken. During this stage, the designs are confirmed and often minor changes are made as additional information becomes available such as geotechnical information and service locations. This process occurred in the Carisbrook Flood and Drainage Mitigation Treatment.

For the Carisbrook flood mitigation measures the channel clearing was completed by NCCMA and the detailed design or engineering works were tendered. The long-term recommendation of replacing the Pyrenees Highway bridge has not yet been funded.

4.2.1 Vegetation works

The channel clearing was completed at the time of the site inspection on the 23rd November 2017. This is demonstrated in Figure 4.1 although the extent is different to that in the adopted flood mitigation plan. The effectiveness of the different extents for channel clearing was tested by Water Technology (2016) who concluded that the vegetation cleared by the NCCMA on behalf of Central Goldfields Shire provided the same level of protection to the Carisbrook community.

In addition, the bluestone drains throughout Carisbrook have been cleared as demonstrated by comparing Figure 4.2 taken during the site visit and Figure 4.3 taken as part of the Carisbrook flood and Drainage Plan on the 20th December 2011.

4.2.2 Engineering works

The engineering works included the Western Levee, the Williams Road Levee and the culverts under Landrigan Road near Camp Street. Observations from the site visit are listed below against the different elements of the detailed design. In summary, the works completed to date are:

- The Williams Road Levee and associated works
- The Western Levee along Pleasant Street to the railway line and associated works

The works not completed to date, but designed are:

- The Western Levee south of the railway line and associated works
- Floodgate or non-return value on the culverts under Landrigan Road near Camp Street

The Western Levee south of the railway line has not been constructed at the time of writing as the required land has not yet been obtained and the Goldfields Shire Council are still in the process of negotiating with the land holder.

A number of changes to the adopted plan have been made and these are outlined below, however, the main changes were:

- The Western Levee along Pleasant Street and the Williams Road levee have been constructed by raising the level of the road rather than building the levee in private property. This is considered to be a pragmatic and appropriate approach.

- The drainage to the west of the Western Levee has been adjusted to work with the natural fall of the land and this has resulted in the direction of flow into the Harness Race Track. This is considered to be an appropriate adjustment.

These changes do not fundamentally affect the performance of the levees. However, a review of the crest levels of the levees in the detailed design report indicates that in certain locations the 300mm freeboard has not been achieved and in one location the crest of the levee is below the 1% AEP flood level. These are listed in Table 4.1.

The locations where there has been a loss of freeboard should be investigated and actions developed to re-establish the freeboard where this is essential. These actions could be temporary or permanent and are not envisaged to be significant. For instance, temporary sandbagging may be suitable for short lengths where there is a constraint on achieving the desired levee heights. More permanent work to raise the levels may be a suitable solution in other circumstances. In the location where the levee is not set above the 1% flood level, the impact should be confirmed as if this is at the end of the levee there would be no impact.

Table 4.1 : Location where 300mm freeboard on levees are not achieved

Levee	Crest level - m AHD	1% AEP flood level - m AHD	Freeboard (m)	Location
Western levee	195.70	195.65	0.05	Southern side of Pyrenees Highway
Western levee	193.80	193.79	0.01	Chainage 1981.50
William Road levee	197.30	197.26	0.04	Western side of Landrigan Road
William Road levee	196.35	196.42	-0.07	Chainage 738

Therefore, with the exception of the non-return value on the culverts under Landrigan Road near Camp Street, the adopted Carisbrook Flood Mitigation Plan has been delivered as far as currently possible.

Changes from adopted plan to detailed design

During the development of the detailed design stage a number of changes were listed in the Investigation and Design of Carisbrook Flood and Drainage Mitigation Treatments Detailed Design Report and are repeated below.

- William Road Levee:
  - Williams Road will be raised on the western side of Landrigan Road instead of constructing a levee next to it. This was completed as shown in Figure 4.4 and Figure 4.5 taken during the site visit.
- Western Levee:
  - A new pipe culvert will be required at around chainage 450 to ensure environmental flow passes under the levee into the wetland on the eastern side of the levee. This culvert has been designed to pass a peak flow of 0.1 m^3/s which compares to the 1% (1 in 100) AEP event peak flow for the smallest local catchment of 4.1 m^3/s.
  - The location of the levee/culvert crossing Pyrenees Highway has been changed. The following have not been completed at this stage as land to the south of the Pyrenees Highway has not been secured for the required levee.
    i. On the southern side of the highway the levee was shifted onto the western property.

ii. On the northern side, Pleasant Street was planned to be raised.

iii. A skewed culvert was deemed suitable in order to minimise the impact on the northern property

- The drain has been redirected west along the southern side of Wills Street before passing under Wills Street and then through the race course land to direct flows into an existing dam at the request of the client. Completed as shown in Figure 4.6 which was taken during the site visit.
- The existing culvert under Pleasant Street and the existing culvert under Wills Street at their intersection are to be removed at the request of the Central Goldfields Shire. This was observed to have been completed during the site visit.
- A new culvert was introduced under Wills Street in the southern-northern direction at approximately 270m from its junction with Pleasant Street.
- Wills Street was planned to be raised gradually, for 50m, before reaching Pleasant Street to match its new top level. This was observed to have been completed during the site visit.
- The Racecourse Access Road was planned to be raised gradually, for 50m, before reaching Pleasant Street to match its new top level. This was not observed during the site visit but is understood to have been completed.
- The levee was extended further north along Pleasant Street to chainage 2700m to take advantage of the higher ground in this location and reduce the length and height of the levee running through the race course land. Completed as shown in Figure 4.7 which was taken during the site visit.
- The channel planned on the western side of the Western Levee between chainages 1000 and 1550m was extended to the entire length of the levee. This was mainly because of concerns raised by the property owners that normal rain will flow through their property for almost any rainfall. Also they were worried about the drainage after the flood started to recede. Completed as shown in Figure 4.8 which was taken during the site visit.

4.3 Scheme outcome for Carisbrook

The preferred flood mitigation scheme adopted for Carisbrook and outlined in the detailed design report represents the preferred option outlined in the Plan. The flood modelling in the Plan and the Detailed Design have demonstrated the effectiveness of the adopted scheme to protect Carisbrook against flood events up to the 1% AEP event, but there remains a residual flood risk. Specifically, there is a risk of the overtopping of levees which is exacerbated in locations where freeboard has a not been achieved or the levee is lower than the flood level. No engineering works were undertaken to manage flooding from the Tullaroop / McCallum Creek system. Given the nature of the vegetation clearing works completed to manage flooding, there is no freeboard in this option. Further, at this stage there is no formal agreement for the maintenance of the creek vegetation.

As one of the key objective of the Plan was to gain strong community support, the Plan can be considered to represent the best outcome for Carisbrook. The levees are not yet complete and in some areas do not achieve the performance levels agreed to by the community, so from this perspective the delivered scheme cannot be considered to represent the best outcome for Carisbrook; however, these minor issues that can be readily remedied. While there is a residual flood risk even following the full construction of the adopted scheme, the adopted scheme was the community preferred option and this residual risk was clearly identified in the Plan

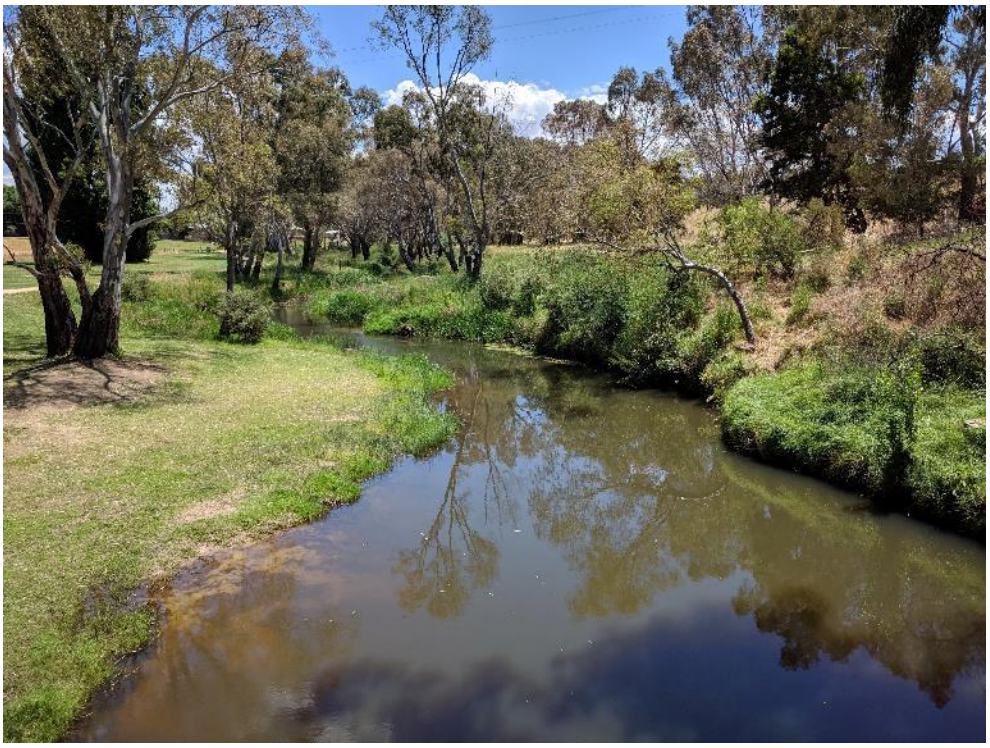

Figure 4.1 : Tullaroop (Deep) Creek immediately downstream of the Pyrenees Highway 23/11/2017

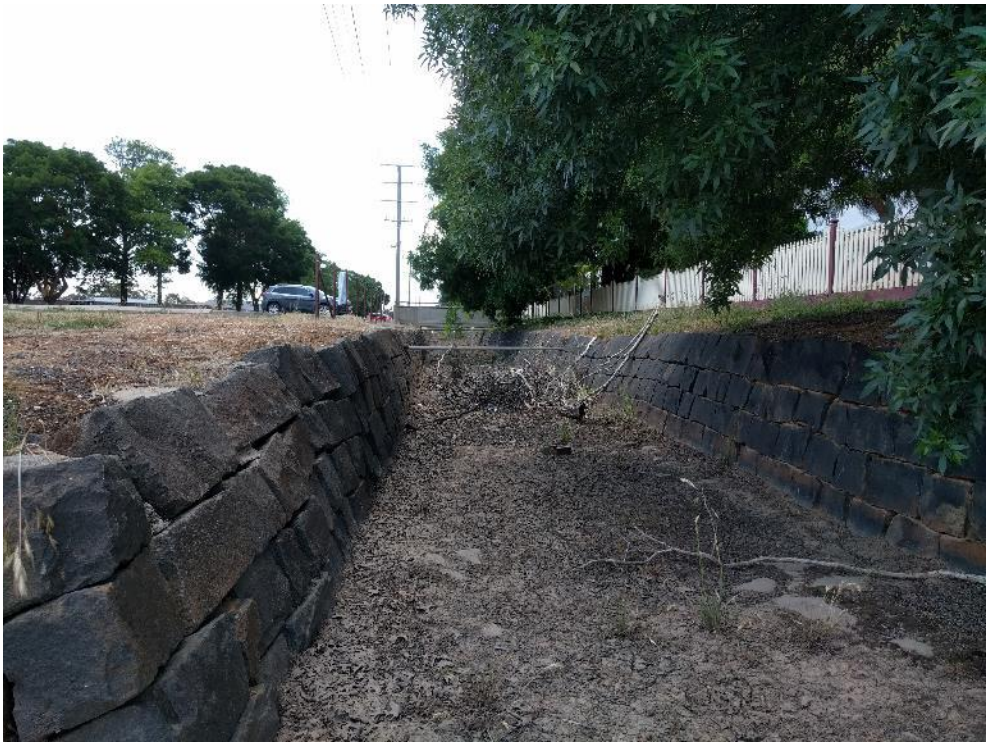

Figure 4.2 : Bluestone drain near corner of Camp Street and Landrigan Road

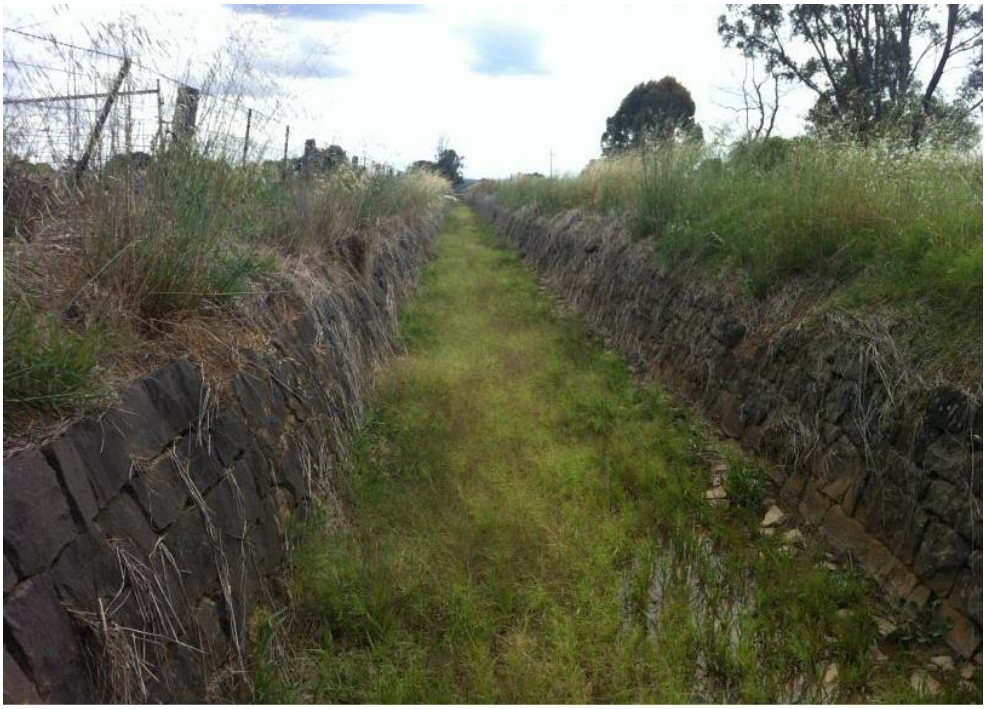

Figure 4.3 : Bluestone drain near Hood Street

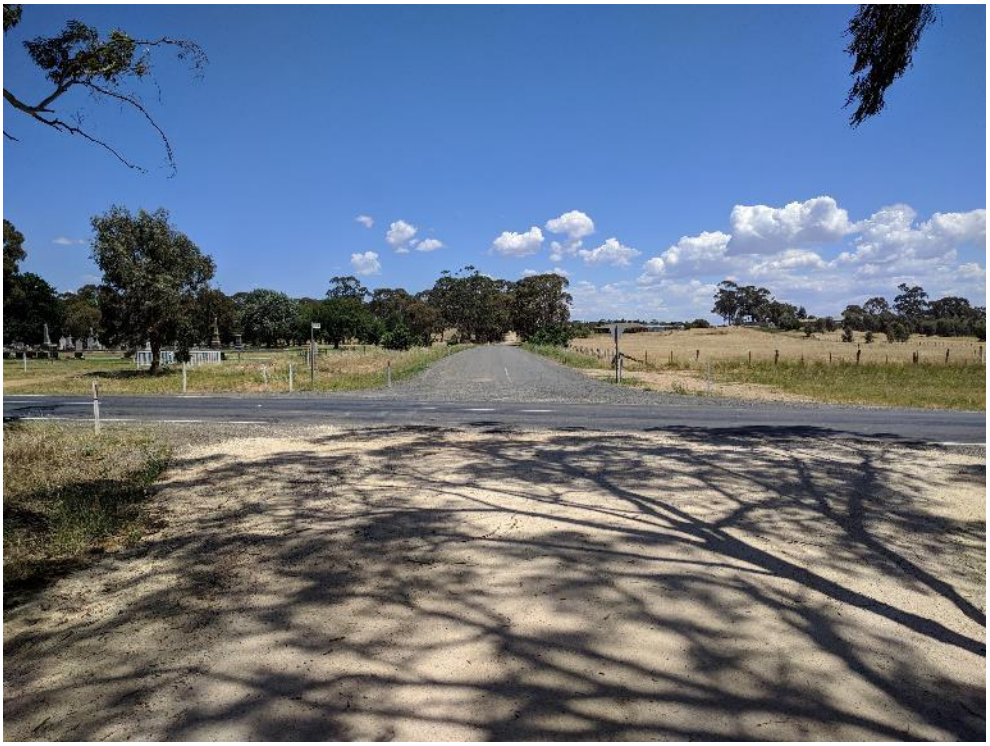

Figure 4.4 : Williams Road Levee at the junction of Williams Road and Landigan Road looking west

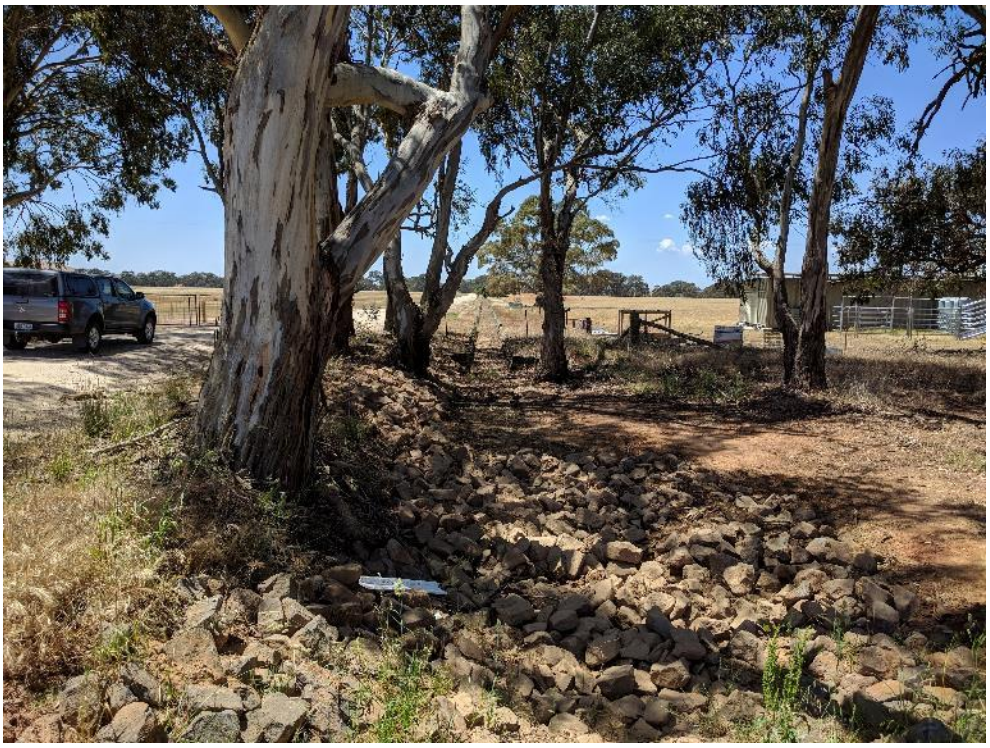

Figure 4.5 : Williams Road Levee and drain at the junction of Williams Road and Landigan Road looking east

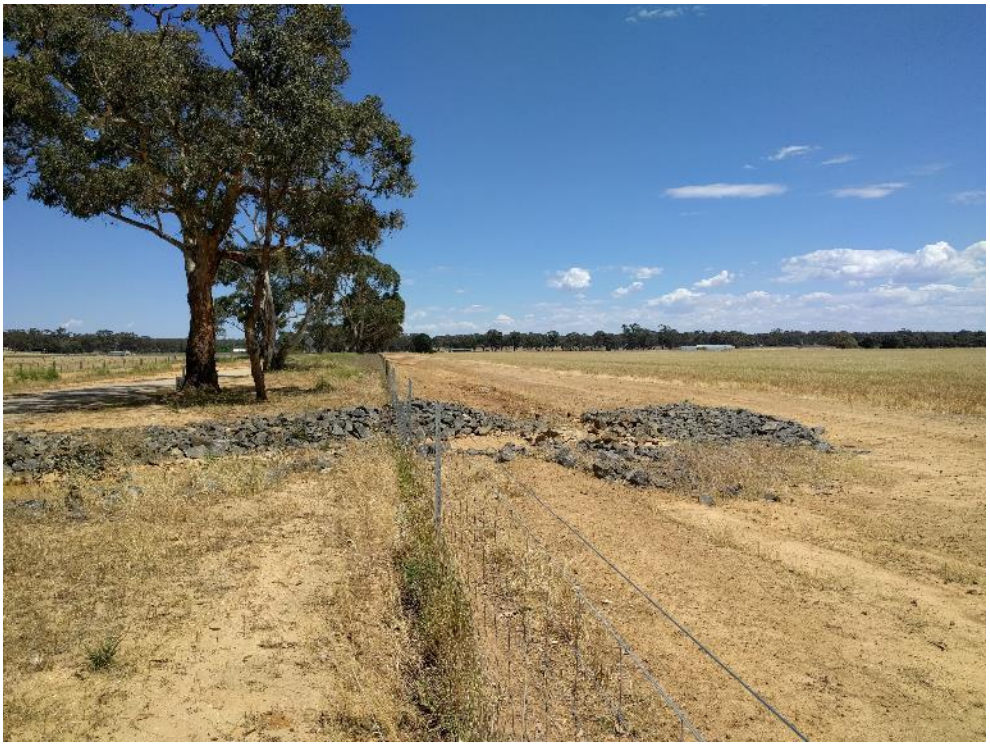

Figure 4.6 : Wills Street Drain being directed towards the Harness Racing Club

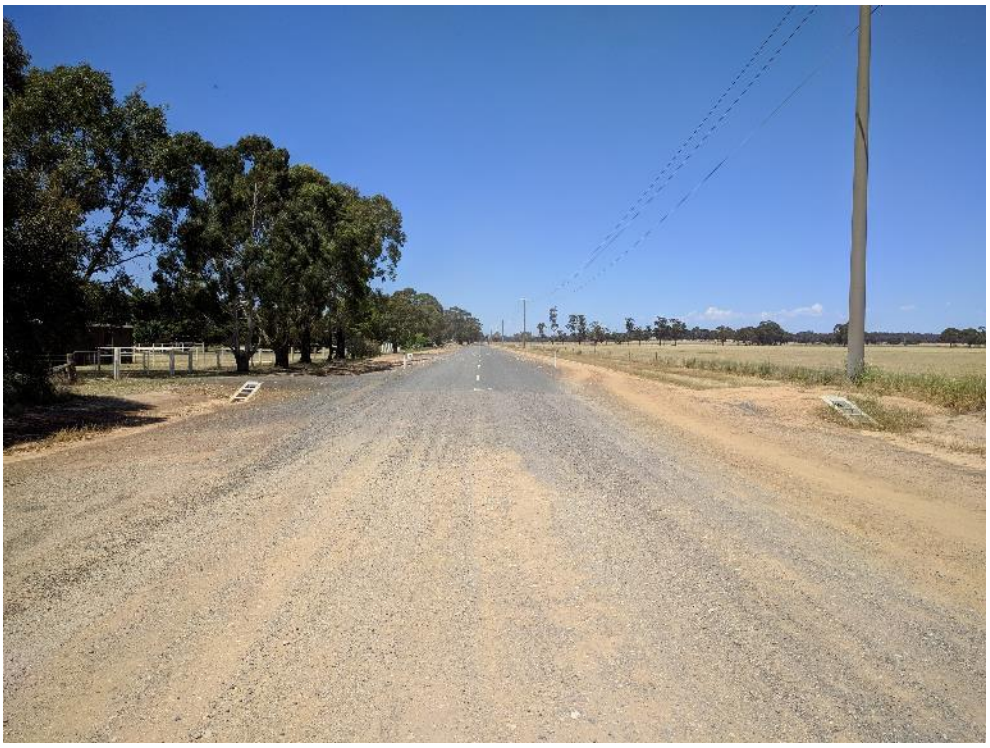

Figure 4.7 : Western levee along Pleasant Street at (approx.) chainage 2700m looking south

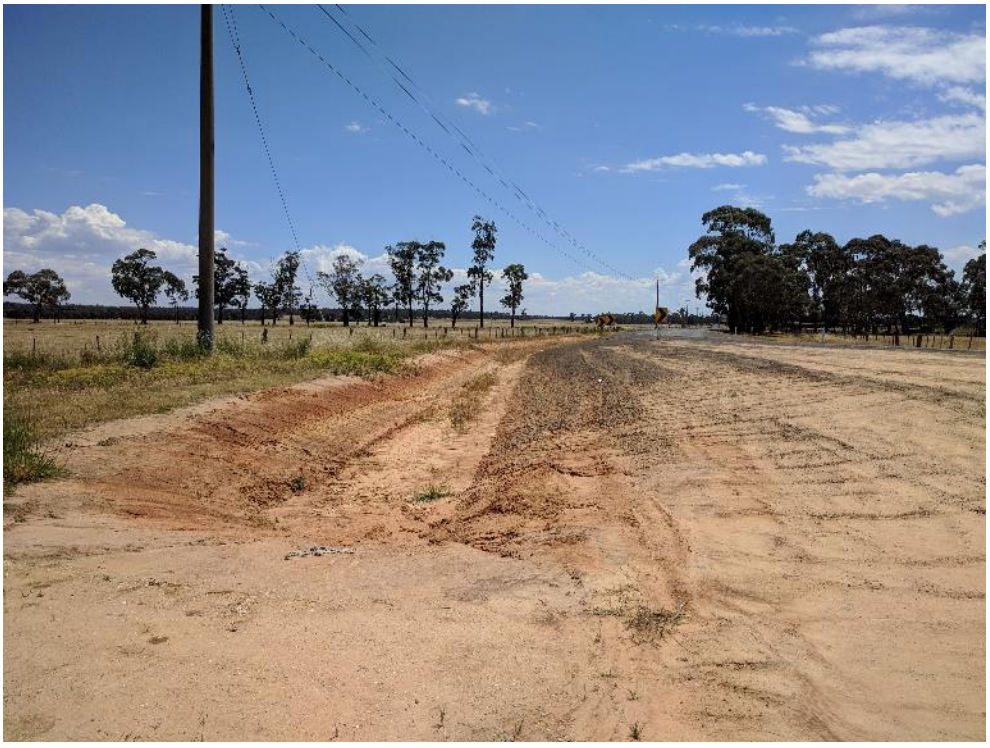

Figure 4.8 : Drain along western side of the levee

5. Actions

This section represents the recommendations of the review. The aims of these recommendation are to either address the areas for improvement in the Plan or to increase community confidence in the mitigation works. These recommendations take into account new information that has become available since the Plan was delivered as is standard practice. These recommendations have been listed in Table 5.1 with a detailed explanation for each action provided below.

Table 5.1 : List of actions

No.	Action	Reason	Timing
5.1	Finalise negotiation with landholders	To allow the delivery of the completed western levee and reduce the flood risk to Carisbrook	As soon as possible
5.2	Complete topographic survey for constructed levee	To confirm design standards and for input into flood model	As soon as practical
5.3	Model the western levee in its current configuration	To understand the current consequences of flooding risk to Carisbrook.	Once Action 5.2 complete
5.4	Identify temporary measures to manage the current flood risk.	To develop a response plan to reduce the current flood risk as far as practical	Once Action 5.3 complete
5.5	Model final design of mitigation in flood model with published levee heights and topographic survey information	To confirm the effectiveness of the final designed scheme and understand the impacts of the loss of freeboard.	Once Action 5.2 complete
5.6	Define flood response arrangements	To manage residual flood risk to Carisbrook through action such as sand bagging etc	Once Actions 5.2 and 5.5 complete
5.7	Investigate shorter duration storms in the western catchments	To ensure that the freeboard of the western levee is appropriate	As soon as practical
5.8	Develop a flood history for Carisbrook	To put flooding in Carisbrook into context and to provide input to at-site FFA	As soon as practical
5.9	Obtain revised flow data from Thiess (now Ventia)	For comparison to previous flows and use in at-site FFA	As soon as practical
5.10	Undertake at-site flood frequency analysis for all gauges in the main creek system	To take advantage of additional data and improve the certainty of flood quantiles.	Once Actions 5.8 and 5.9 are complete
5.11	Prepare a water management plan	To assign responsibilities for the maintenance of flood mitigation measures such as levees and creek clearing	As soon as practical
5.12	Prepare Municipal Flood Emergency Management Plan	To extract relevant information from all project outputs into an emergency response plan	Once Actions 5.4, 5.6, 5.10 and 5.11 are complete

No.	Action	Reason	Timing
5.13	Community consultation	To communicate the current status of the plan and future actions.	To update them on next steps

5.1 Finalise negotiation with landholders

The negotiation with the land owner to the south of the Pyrenees Highway to complete the Western levee should be concluded as soon as possible.

5.2 Topographic survey

Review of the detailed design report indicates that the western levee has not been designed to the stated design standards in a number of locations. For this reason, topographic survey of the levee crest levels should be undertaken to confirm that the required level of service has been achieved for the constructed levee. This piece of quality assurance is a standard when constructing levees. This information can then be used to:

- Be incorporated into the flood model to understand the current level of flood risk taking into account the current configuration of the western levee
- Understand where the levee does not meet design standards and develop actions to manage the risk, such as:
    - Confirming locations where the design freeboard is not met that do not affect the level of protection from flooding to Carisbrook, such as at the end of levees.
    - Identify locations where sand bagging may be required during a flood event to ensure that the levee achieves the design standard.
    - Identify locations where permanent works may be required (if any)
- Develop a flood response plan that reflects the current configuration of the western levee with actions to minimise the impacts of flooding

5.3 Model the Western levee in its current configuration

At present the western levee is incomplete due to issues with land acquisition, which means that Carisbrook is only partially protected from flooding from the western catchments. With the work completed to date the consequences from flooding to Carisbrook are not understood and it is likely that some areas are protected by the completed levees while others are not. There is also a chance that some areas have increased consequences from flooding due to the partially completed levee. To understand the consequences from flooding, the flood model developed for the plan should be run with the current western levee configuration and using the topographic survey.

5.4 Temporary measures to reduce current flood risk

The information from the flood model with the current western levee configuration should then be used in a risk assessment framework to reduce the temporary flood risk. It is envisaged that actions to reduce the consequences of flooding may include sandbagging at strategic locations or temporary flood defenses which can be tested in the flood model. This information can then be used in emergency response. These actions would not involve permanent engineering work and it is unlikely that the same level of protection from the recommended scheme would be achieved.

5.5 Model final mitigation designs

There have been a number changes from the concept developed as part of the steps through to the final detailed design. Whilst flooding modelling was completed to demonstrate the effectiveness of the detailed design, a final model run is recommended that captures all the details of the final design. These results should be made available to Central Goldfields Shire Council, NCCMA and Department of Environment, Land, Water and Planning and the Carisbrook community.

5.6 Define flood response arrangements

As soon as the additional modelling of the current configuration of the western levee and final mitigation design are completed, flood response arrangements should be defined. It is envisaged that this information will eventually be incorporated into the Municipal Flood Emergency Management Plan; however, the timing of this is currently undefined. Developing flood response arrangements as soon as practical will significantly reduce the flood risk to Carisbrook.

5.7 Shorter duration storms

The Plan assumed that the duration of storms causing flood events from the main creek system and the western catchment were the same and consequently short duration storms (less than 2 hours) were not investigated. Further, the work in the Plan demonstrated that there was significant risk from the western catchments. For these reasons, the flood modelling should be extended to examine shorter duration storms, that is, the flood model should be run for the local catchments for durations less than 2 hours. This will ensure that that peak water levels are determined for short duration flooding. This model run should also make appropriate adjustments to the Areal Reduction Factors.

5.8 Flood history for Carisbrook

Community confidence would be substantially increased through compiling a flood history of Carisbrook. This would involve the standard news sources and other reference material and provide a useful output for emergency services and an input into at-site FFA and the Municipal Flood Emergency Management Plan.

5.9 Obtain revised flow data

It is understood that flow data for a number of gauges in the catchment has been revised by Thiess (now Ventia) following the 2010 and 2011 flood events. Further there is now an additional 5-6 years of data that could be used in the analysis including the minor flood in 2016. For these reasons the flow data for the relevant gauges should be obtained from Thiess. Further this data would assist in understanding the rarity of the historic peak flows in the main creek system.

5.10 At-site flood frequency

The FFA should be revised for all gauges in the main creek system using the techniques and guidance in Australian Rainfall and Runoff 2016, the revised data from Thiess and the flood history for Carisbrook. This would improve the certainty of flood quantiles and thus the standard of service provided by the flood mitigation measures.

5.11 Water management plan

A water management plan should be developed outlining the roles and responsibilities for creek clearing and maintenance of other flood mitigation related infrastructure such as the levees. Without this being in place there is a risk of vegetation not being cleared on a regular basis and the flood risk benefit of this will not being realised.

5.12 Municipal Flood Emergency Management Plan

A Municipal Flood Emergency Management Plan (MFEP) is a standard product that follows a detailed flood study. The MFEP outlines the roles and responsibilities during flood events as well as documenting actions to be undertaken as well as triggers for different actions. The MFEP is invaluable during times of flood and should be developed for Carisbrook based on the information in the Plan as well as the information outlined above. A MFEP is most usually undertaken following a flood study.

5.13 Community consultation

The Carisbrook community was heavily involved in the development of the Flood Plan and there is value in re-engaging with the community to disseminate information regarding the process of the Plan and future actions. This action should occur as a result of this review once the way forward has been agreed.

6. Conclusions

A review of the Carisbrook Flood and Drainage Management Plan and the Design of Carisbrook Flood and Drainage Mitigation Treatments has been undertaken. The aim was to review the technical basis of the Plan and the mitigation options assessment. In addition, the review was to confirm whether the engineering works completed to-date align with the Plan and that the adopted mitigation scheme represents the best outcome for Carisbrook. Finally, the review provided recommendations on additional work that could increase community confidence in the mitigation works. Also, during the review some minor issues in the detailed design were noted which should be addressed.

Overall, the technical work that the plan is based was completed to a satisfactory level, although a number of minor issues were identified. In general, these issues do not affect the outcomes of the Plan, with the exception of the assignment of probabilities to peak flows which contain a degree of uncertainty. The Detailed Design, represents the adopted scheme from the Plan with some minor alterations as more detailed and site specific information came to light. The adopted scheme was developed with and endorsed by the Carisbrook community and therefore represented the best outcomes for Carisbrook at that time. This endorsement implicitly accepted the residual flood risk which was explained in the Plan and subsequent communications. However, the Detailed Design cannot, at this stage be considered to represent the best outcome for Carisbrook as the Western Levee has not been designed to the level of service detailed in the Plan (the 1% AEP flood level plus 300m for freeboard). Given the engineering works have not been completed, it is considered that only minor work would be required to address these minor issues.