NSW Public Works

Carisbrook Levee Review Report

Review of Floodplain Management since 2013

Report Number: P-FY20242892-PWO-DAM-RP-001

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Prepared for:

Central Goldfields Shire Council

NSW Public Works

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Carisbrook Levee Review Report

Document control

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Cover photo: View of Tullaroop (Deep) Creek Carisbrook.

Source: Waterway Management Plan for Carisbrook – Final (November 2021).

Executive Summary

After the flooding of Carisbrook in 2010 and 2011 various flood mitigation options were discussed, modelled and designed eventually leading to the construction of the Carisbrook Levee Bank (and other works). While there have been a number of public meetings held, and additional flood (and other) studies undertaken it appears that community concern has persisted which can generally be summarised as:

- Works being undertaken that appear to be different to what was agreed to at the Public Meetings;
- How can what was constructed actually work *"on the ground"*?; and
- Was the flood modelling even done *"correctly"*?

The initial purpose of this report was to review the history of the project and try to determine what was agreed, what (if anything) was changed and, if it changed, why did the change occur. However, it evolved more into

- Reviewing the adequacy of the modelling (both from the 2013 Flood Study and 2019 revised Flood Study)
- Reviewing aspects of the design of the works
- Reviewing the construction standard of the works

This led to a number of issues of concern with both the Flood Modelling and Design being found which need addressing to ensure the flood mitigation measures have a chance of achieving the desired outcome of providing flood protection to Carisbrook from a 1 in 100 AEP flood event.

The issues of concern are:

1. No Internal Flood Study has been undertaken. While there may be protection from an external flood, all rain falling inside the levee banks (i.e., "in town") will still adversely affect the community (as it does now).
2. From the documentation provided, all consultants have assumed that the LIDAR and flood model were "perfect" when in fact there are (always) inherent uncertainties.
3. This belief in the "perfection" of the model has led to a culture of all consultants blindly following what the model said. That is, if *"the model said it will work in the computer, then it <u>must</u> work on the ground"*.
4. No real thought has been given to the practicality of turning theory into practice and just how sensitive / susceptible the modelling is to (very) small inaccuracies in the survey, the inherent uncertainty in the derivation of the rainfall/runoff model and any small change that can (and have) occurred in the landscape. That is, they have taken an "absolute zero risk approach" to their engagements and followed the modelling.
5. From the information provided, only minimal (if any) thought was given to the selection of the nominal 300mm Levee Freeboard. Given the inherent inaccuracies in the modelling, it is considered that 300mm is (at least) *"operating on a very tight tolerance /*

slim margin for error". It is recommended a Freeboard Analysis be undertaken (the same as done for NSW levees) to determine an appropriate freeboard.

6. The entire system (levee, drains, culverts, vegetation management etc.) must be "Operationally Ready" at all times to stand any chance of working as designed.
7. Investigate water flow around the Cemetery area and construct a small levee around the cemetery to prevent flooding.
8. Two (2) stormwater pipes under the levee south of the Pyrenees Highway serve no purpose and are only a source of a failure risk. It is recommended they be removed, or valve fitted and kept permanently closed and padlocked.
9. The culverts and area south of the Pyrenees Highway have been designed as if they were a Stormwater Detention Basin, with the culverts throttling the flow of water. It appears that no one was aware that this was how it had been modelled. A check of all 1 in 100 storm durations needs to be undertaken to ensure the modelled water surface is actually the highest water surface.
10. Since modelling is being undertaken, and there appears to be no reason why the culverts under the Pyrenees should restrict the flow of water, at the end of the above modelling, more culverts should be added to the model to determine what changes would occur.
11. There appears to be an earth bank (and pipe) blocking flow under the railway culvert (approximately halfway between Pleasant Street and Chaplins Road). This must be removed. Additional modelling should be undertaken with additional cuttings / culverts under the railway line to allow for any future "blockages".
12. ALL sections of the levee system where there is less than the required freeboard are to be raised (especially at the intersection of Pleasant Street and High Street).
13. An accurate survey of all State Survey Marks used for the levee bank set-out should be undertaken to ensure the accuracy of the levee crest levels are higher than the LIDAR levels on the floodplain.
14. The Culvert under Edington Road needs to be cleaned of reeds (even though it is not a Council culvert) to ensure the flow of floodwaters. Dams on the downstream side are also blocking the flowpath and also need to be removed.
15. Additional and ongoing vegetation clearing needs to be undertaken in the Creek to ensure that it meets the modelling intent of preventing flooding of Carisbrook, with room to spare.
16. Replacement / enhancement of the Flap Valves at Landrigan Road near Camp Street as they are too heavy and will mainly block stormwater flows.
17. Flap Valves / Gate Valves should be fitted to all stormwater pipes / culverts under Bucknall Street and Pyrenees Highway to ensure no floodwaters enter town.

Contents

Figures

1. Background

In June 2024 NSW Public Works were engaged to provide Central Goldfields Shire Council with a review of the Carisbrook Levee project. At the commencement of the engagement the following was the interpretation of the services required for that review.

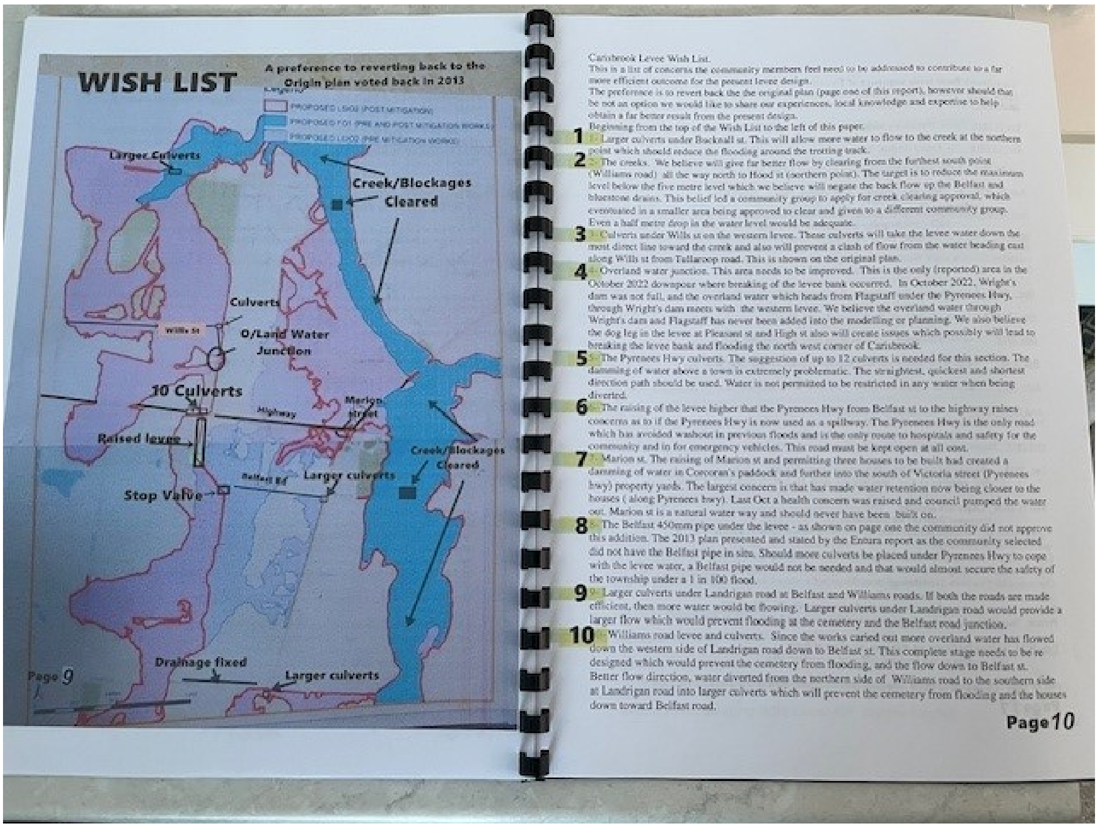
"It is understood that the Carisbrook Levee project has been a project undertaken by North Central Catchment Management Authority and, most recently, by Central Goldfields Shire Council. The project commenced after flooding occurred in 2010/2011 with the development of the Carisbrook Flood and Drainage Management Plan with its' key findings presented to the community in February 2013.

Various flood mitigation options were discussed eventually leading to the construction of the Carisbrook Levee Bank prior to 2019. In addition, a number of public meetings were held, and additional flood studies and other studies being undertaken.

During this time, it appears there has been community concerns which can best be summarised as "works being undertaken that appear to be different to what they agreed to at the Public Meetings".

The purpose of this engagement is to review the history of the project and try to determine what was agreed, what (if anything) was changed and, if it changed, why did the change occur.

While <u>initially</u> it was stated the purposes of this engagement, it is assumed that the community concerns are summarised in the below document provided by Council:



Carisbrook Levee Wish List.
This is a list of concerns the community members feel need to be addressed to contribute to a far more efficient outcome for the present levee design.
The preference is to revert back the the original plan (page one of this report), however should that be not an option we would like to share our experiences, local knowledge and expertise to help obtain a far better result from the present design.
Beginning from the top of the Wish List to the left of this paper.

1 Larger culverts under Bucknall st. This will allow more water to flow to the creek at the northern point which should reduce the flooding around the trotting track.

2 The creeks. We believe will give far better flow by clearing from the furthest south point (Williams road) all the way north to Hood st (northern point). The target is to reduce the maximum level below the five metre level which we believe will negate the back flow up the Belfast and bluestone drains. This belief led a community group to apply for creek clearing approval, which eventuated in a smaller area being approved to clear and given to a different community group. Even a half metre drop in the water level would be adequate.

3 Culverts under Wills st on the western levee. These culverts will take the levee water down the most direct line toward the creek and also will prevent a clash of flow from the water heading east along Wills st from Tullaroop road. This is shown on the original plan.

4 Overland water junction. This area needs to be improved. This is the only (reported) area in the October 2022 downpour where breaking of the levee bank occurred. In October 2022, Wright's dam was not full, and the overland water which heads from Flagstaff under the Pyrenees Hwy, through Wright's dam meets with the western levee. We believe the overland water through Wright's dam and Flagstaff has never been added into the modelling or planning. We also believe the dog leg in the levee at Pleasant st and High st also will create issues which possibly will lead to breaking the levee bank and flooding the north west corner of Carisbrook.

5 The Pyrenees Hwy culverts. The suggestion of up to 12 culverts is needed for this section. The damming of water above a town is extremely problematic. The straightest, quickest and shortest direction path should be used. Water is not permitted to be restricted in any water when being diverted.

6 The raising of the levee higher that the Pyrenees Hwy from Belfast st to the highway raises concerns as to if the Pyrenees Hwy is now used as a spillway. The Pyrenees Hwy is the only road which has avoided washout in previous floods and is the only route to hospitals and safety for the community and in for emergency vehicles. This road must be kept open at all cost.

7 Marion st. The raising of Marion st and permitting three houses to be built had created a damming of water in Corcoran's paddock and further into the south of Victoria street (Pyrenees hwy) property yards. The largest concern is that has made water retention now being closer to the houses (along Pyrenees hwy). Last Oct a health concern was raised and council pumped the water out. Marion st is a natural water way and should never have been built on.

8 The Belfast 450mm pipe under the levee - as shown on page one the community did not approve this addition. The 2013 plan presented and stated by the Entura report as the community selected did not have the Belfast pipe in situ. Should more culverts be placed under Pyrenees Hwy to cope with the levee water, a Belfast pipe would not be needed and that would almost secure the safety of the township under a 1 in 100 flood.

9 Larger culverts under Landrigan road at Belfast and Williams roads. If both the roads are made efficient, then more water would be flowing. Larger culverts under Landrigan road would provide a larger flow which would prevent flooding at the cemetery and the Belfast road junction.

10 Williams road levee and culverts. Since the works caried out more overland water has flowed down the western side of Landrigan road down to Belfast st. This complete stage needs to be re designed which would prevent the cemetery from flooding, and the flow down to Belfast st. Better flow direction, water diverted from the northern side of Williams road to the southern side at Landrigan road into larger culverts which will prevent the cemetery from flooding and the houses down toward Belfast road.

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Figure 1-1 List of Community Concerns

In summary:

1. *Was the flood modelling done correctly?*
2. *Compare the design flood levels to the levee design heights. Note, based on item 4 below, it is assumed the design flood level chosen was a 1 in 100 event.*
3. *Compare the Levee Mitigation Option, as voted for by the community, with what was constructed.*
4. *Refer Item 2. Review "operating instructions" in Council's Levee O&M Manual.*
5. *Would the proposed levee withstand another 2011 Flood. It is unknown if this flood event was even modelled. If it was, it is likely only limited comment could be made on the 1 in 135-year event (given that this seems to be a higher than 1 in 100 flood event) as it might only have been used to calibrate the model. If it was not modelled at all, it is not intended to be remodelled by myself and would need to be part of a separate / future modelling engagement (if Council so wish).*
6. *Appears this is related to the ten (1) items in the "Wish List" provided to Council previously.*

In order to review those concerns, the following is proposed:

1. *Attend (via MS Teams) meeting with Council / community Group on 12th June 2024 to discuss and agree on final scope of works.*
2. *Obtain and review of all background documentation and providing a summary. This would be split into three (3) parts being:*
    a) *Modelling Phase*
    b) *Design / Construction Phase (i.e., review Issue for Tender drawings to ensure conformity to modelling and design intent)*
    c) *Community Consultation – document known issues of concern (likely I would be having an initial phone discussion with them)*
2. *Site visit to:*
    a) *Inspect 3.5km long levee banks as shown on Drg. EHT-CA-DR-001A Rev. 3*
    b) *Meet with Council and obtain any other background information.*
    c) *Meet with concerned Landholders and obtain their issues of concern.*
3. *Prepare Report consisting of*
    a) *Summary of background information*
    b) *Timeline of events - from project inception to completion of levee construction*
    c) *Gap analysis – identify any gaps / issues in what would be expected for this project.*
    d) *Landholder concerns*

        i. *Provide a summary of issues / concerns.*
        ii. *Identify if they have (or have not) been addressed by previous studies / documentation / site inspection.*

    e) *Issue draft report to Council for comment and providing any additional information to address issues of concern.*

4. *Present Draft Report to Council / Concerned Landholders in person to ascertain any remaining issues of concerns.*
5. *Prepare and Issue Final Report*
    a) *While it is hoped that all issues of concern would be addressed, some may not be able to be addressed unless additional "work" is undertaken. As such, recommendations for any additional work / studies would be provided.*

In order to undertake the engagement, the following information (if available) was required:

- *report / modelling / brochures done prior to the completion of the 2013 flood study.*
- *modelling (GIS) files of modelled design flood extent with heights (say in Raster format). Note, these should be available from Water Technology.*
- *geotechnical reports on levee construction (i.e., compaction tests)*
- *work-as-executed drawings*
- *Levee Owner's Manual (i.e., Operations and Maintenance Manual)*
- *List of Landholder issues of concern"*

Following the initial Teams meeting with Council, the amount of documentation for review has increased as well as the number of community questions and concerns expressed during the Site Visit (undertaken between 24th-28th June 2024).

2. List of Background Information

At the commencement of the engagement, a MS Teams was created by Council whereby both Council personnel, Community and NSW Public Works could upload background information to be shared with all parties.

The following is a list of those documents:

- Memo to North Central CMA – Response to AECOM Independent Review Document (Water Technology, May 2013)
- Carisbrook Flood and Drainage Management Plan (Water Technology, June 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, June 2016)
- Technical advice regarding impact of vegetation removal on the hydraulic roughness of waterways at Carisbrook (Water Technology, 2016)
- Carisbrook Flood Study Review (Jacobs, February 2018))
- Updated Hydrology and Hydraulic Report – ARR2016. Carisbrook Flood Mitigation Modelling (Water Technology, 2019)
- Carisbrook Levee Overland Flow Questions (Central Goldfields Shire Council, May 2021)
- Drawing – 36Landrigan Road, Carisbrook (Stantec, 2023)
- Carisbrook Flood warning System Review (Water Technology, 2023)
- (Draft) Carisbrook Levee Management Plan (Engeny, May 2024)

- Various videos posted showing 2022 flood event (Various June / July 2024).
- Various photos and messages posted in the MS Teams environment established by Central Goldfields Shire Council June 2024

3. Modelling Phase

A number of questions and concerns from the community members are centred around the *"accuracy (or otherwise) of the flood modelling"*. These concerns can be summarised into the following areas:

- *the culvert designs are too small to handle the flow* – based on their own assessment or observations during storm events, the community considers the culverts under the Pyrenees Highway, Landrigan Road (at Belfast and Williams Roads), Bucknall Street and Williams Road;
- *can we have the contour plan Council gave the modellers in 2011* – to determine of the modellers included all the catchments in their model*;*
- *the water from Flagstaff does not seem to be included in the model* – the flood maps do not extend to flagstaff*;*

3.1 Type of Modelling – Overland or Internal

The modelling undertaken, in both the 2013 Flood Study and 2019 Flood Study, only model water flows <u>external</u> to town. That is, they are not a "Rainfall-on-Grid" model which models rain falling directly "in town" (i.e., INSIDE the levee system). Rather, the model is only concerned with flows from outside (i.e., flood side) of the levee system and from the creeks.

North Central CMA
Carisbrook Flood and Drainage Management Plan

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

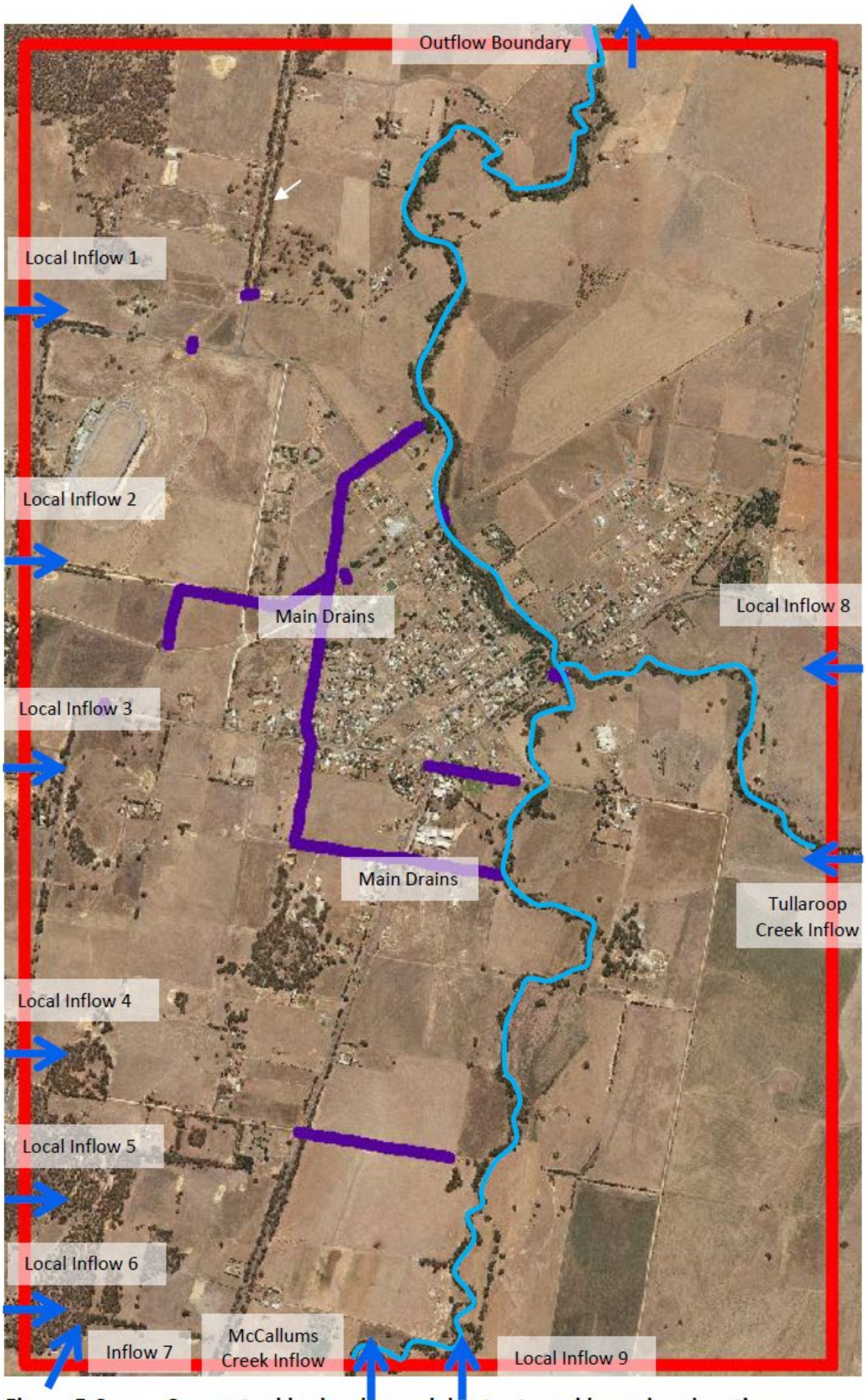

Figure 5-3 Conceptual hydraulic model extents and boundary locations

Figure 3-1 Location of Inflow Points, external to the levee system, from the RORBS Model into the MIKE FLOOD Model – 2013 Flood Study

The modelling undertaken is an "Overland Flow" model and not an "Internal Flood" model.

A number of concerns by the community (such as requested larger culverts on Bucknall Street, raising of Marion Street and housing development damming water etc.) cannot be assessed in this report as no modelling (i.e., Internal Flood Study) has been undertaken. That is, there is no information (i.e., "science") to validate or dispute these concerns.

From the author's more than 35 years' experience, there have been too many instances of landholders complaining about "different" flooding behaviour BEHIND a levee bank AFTER a levee bank has been constructed to ignore. Even though, in some instances, there appears to be no "engineering reason" why there should be any problem. It must be remembered that all levee banks are a "Flood Modification" measure, and this applies not only to water in front of the levee but behind it as well.

It is considered that an Internal Flood Study would (at least) start to address some of these concerns as well as of being of benefit to Council to better direct future growth and development areas within Carisbrook itself.

From the author's experience, it is to be noted that NSW has only undertaken "Internal Flood Studies" as part of Floodplain Management Projects for the last 8 or so years. It is only relatively new.

An Internal Flood Study consists of modelling all the design storm events (from 1 in 5 through to 1 in 200 AEP events) within the levee bank system using a Rainfall-on-grid approach. The storm events would be run when:

- There is NO flooding; and
- There IS flooding.

With flood maps being produced for all events as well as "Difference" maps showing the differences in flooding that occurs between when the creek is in flood and not in flood.

This will also require the flood model to be updated showing all changes that have occurred since 2013 (e.g., new developments, any new drains etc.).

It is recommended that an "Internal Flood" study be undertaken.

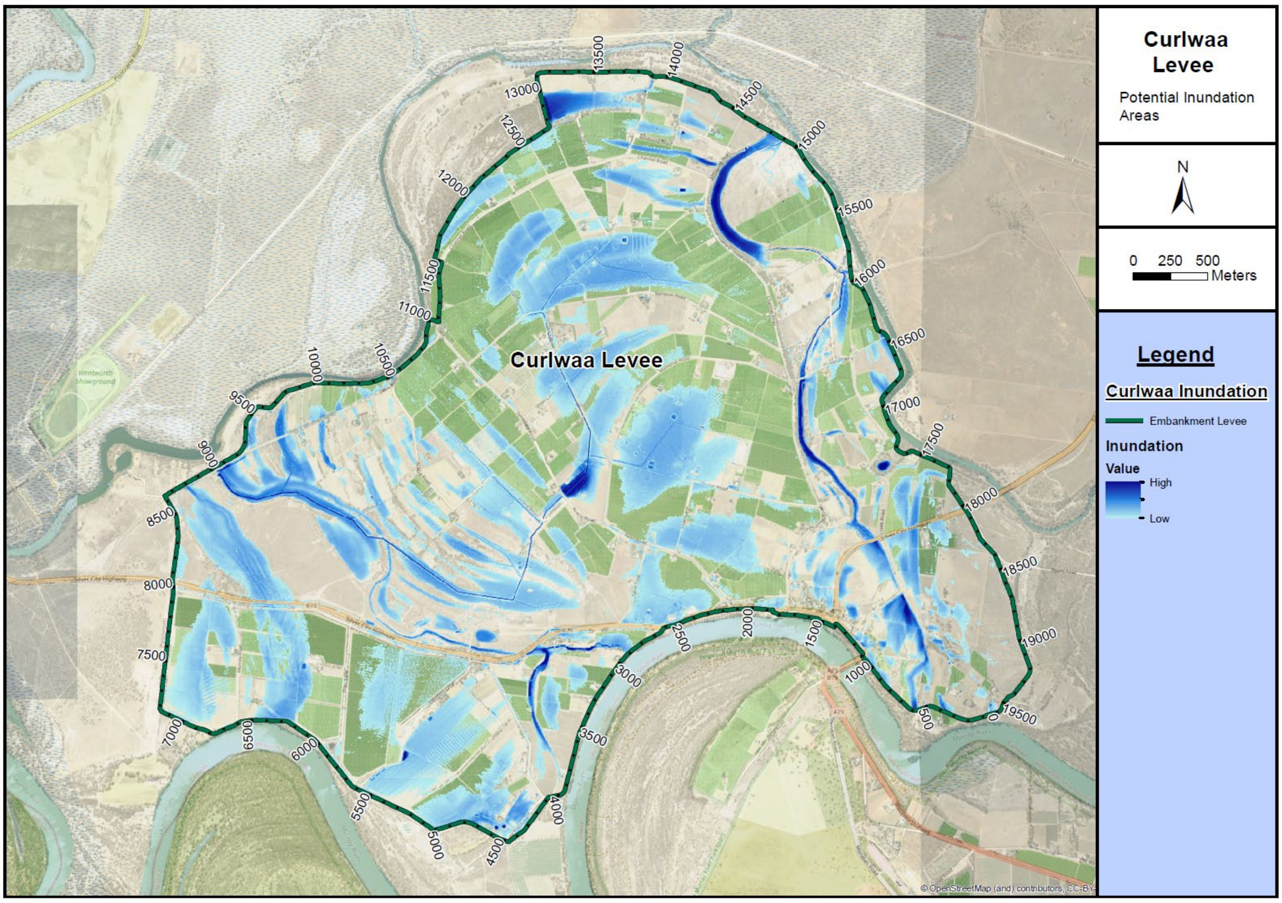

Figure 3-2 Example of Internal Flood Map when stormwater pipes under a levee bank are closed trapping any rainfall occurring within a levee system

3.2 Accuracy of Modelling

It is thought that most of the community concerns doubting the accuracy of the flood model is centred around a misunderstanding of how the computer models work.

The community members are used to how models were created in the past using contour maps with hand-drawn catchment delineation and using a method to work out flow paths and flowrates to particular locations. This method is similar to the Rational Method of rainfall-runoff modelling used by flood modellers in the past. While this method can still be used, there are more sophisticated modelling techniques and computer software used now-a-days.

The 2013 and 2019 Flood Study used computer software called RORB and MIKE FLOOD to model the overland rainfall and runoff heading towards Carisbrook. As well as using LIDAR with an accuracy of 1m (horizontally) and a vertical accuracy of 0.1m with a 67% confidence.

RORB is a "catchment wide" model with the entire catchment being defined in Figure 4-2 of the 2013 Flood Study (as below). This catchment extends as far south as to almost reach the Ballarat Aerodrome, as far north as Eddington, westwards to (well) past Talbot and eastwards to Seaton and includes the entire Tullaroop Creek system as well as McCallums Creek. This includes all water flowing from Flagstaff.

North Central CMA
Carisbrook Flood and Drainage Management Plan

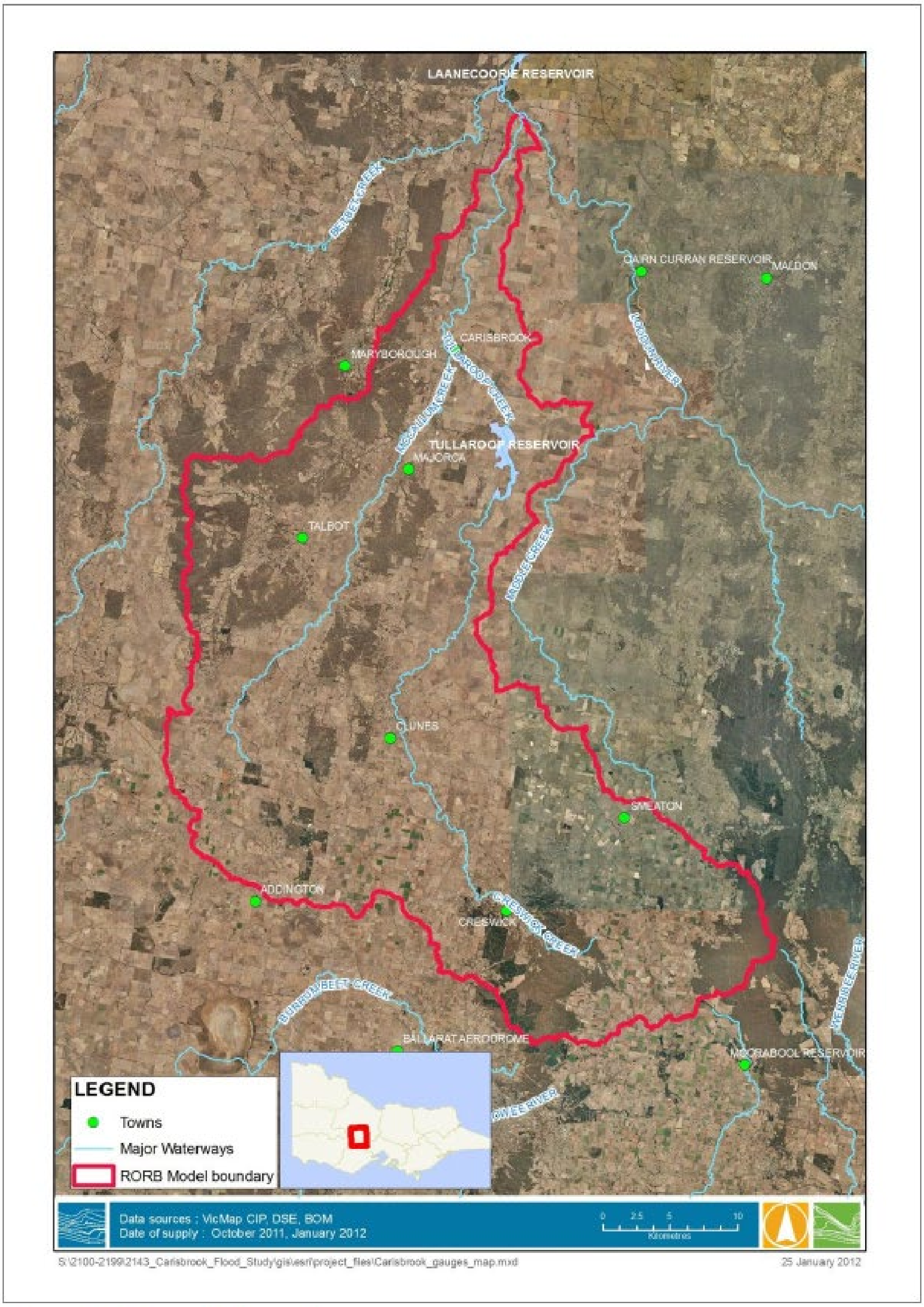

Figure 4-2 RORB model boundary

Figure 3-3 Catchment used in RORB Model

This large catchment was then divided up into approximately 420 smaller sub-catchments to better model the rainfall occurring within each of those catchments in terms of how much water turns into run-off and how long that takes based on different storm sizes and durations.

It is stated in the 2013 report that it was “usual” for a catchment this size to only delineate about 20 sub-catchments, but, with the aid of computer software, they chose to divide it into approximately 420 smaller sub-catchments making for a more accurate model.

An example of part of these sub-catchments is shown in Figure 4-1 of the 2013 Flood Study as shown below:

North Central CMA
Carisbrook Flood and Drainage Management Plan

WATER TECHNOLOGY
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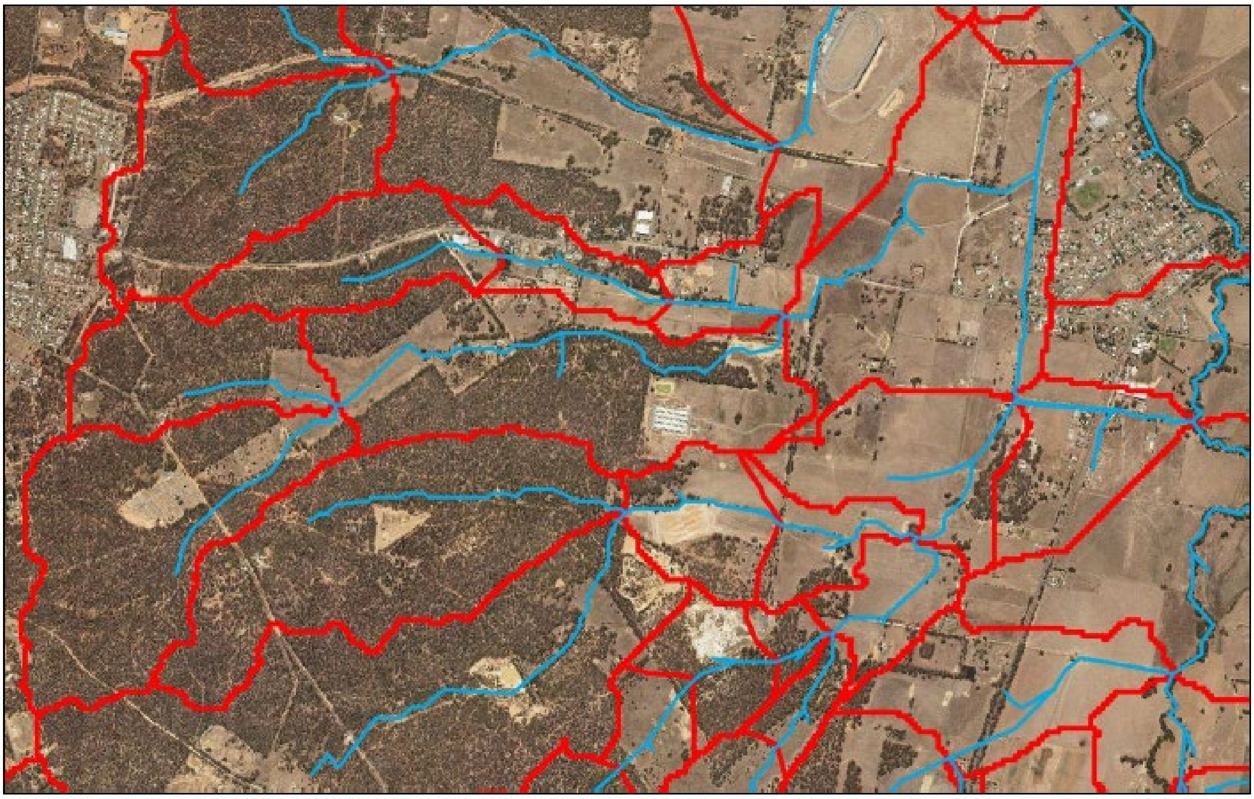

Figure 4-1 RORB sub area delineation around Carisbrook township

Figure 3-4 Sub-catchment delineation and flow paths from Carisbrook to Maryborough (including Flagstaff)

RORB is a sophisticated piece of computer software used extensively by many flood consultants both in Australia and across the world for many years. While the advantage of using RORBS is its’ speed of computation, it does not produce an output that is easily read and understood by the layperson. However, it is common practice to use the output of such models as the input into other flood modelling software that does. To do this the modellers have used MIKE FLOOD. Again, this is a well-known and widely used piece of software that has a long and distinguished history (being developed and enhanced in the Netherlands).

MIKE FLOOD used what is called “2D modelling” to accurately model flows across a floodplain in detail and produce easily read and easily understood flood extent and flood depth maps (amongst other maps). The disadvantage of all 2D modelling software is they require enormous computing power and long run times to produce a result. This is because the software is modelling *“every little twist and turn”* in the landscape.

A Digital Terrain Model was created using the available LIDAR. While this model cannot be read unless the correct software is used, it is accepted that such a model was used (as this is the way a 2D model such as MIKE FLOOD works). An example of a Digital Terrain Model (not Carisbrook) is shown below.

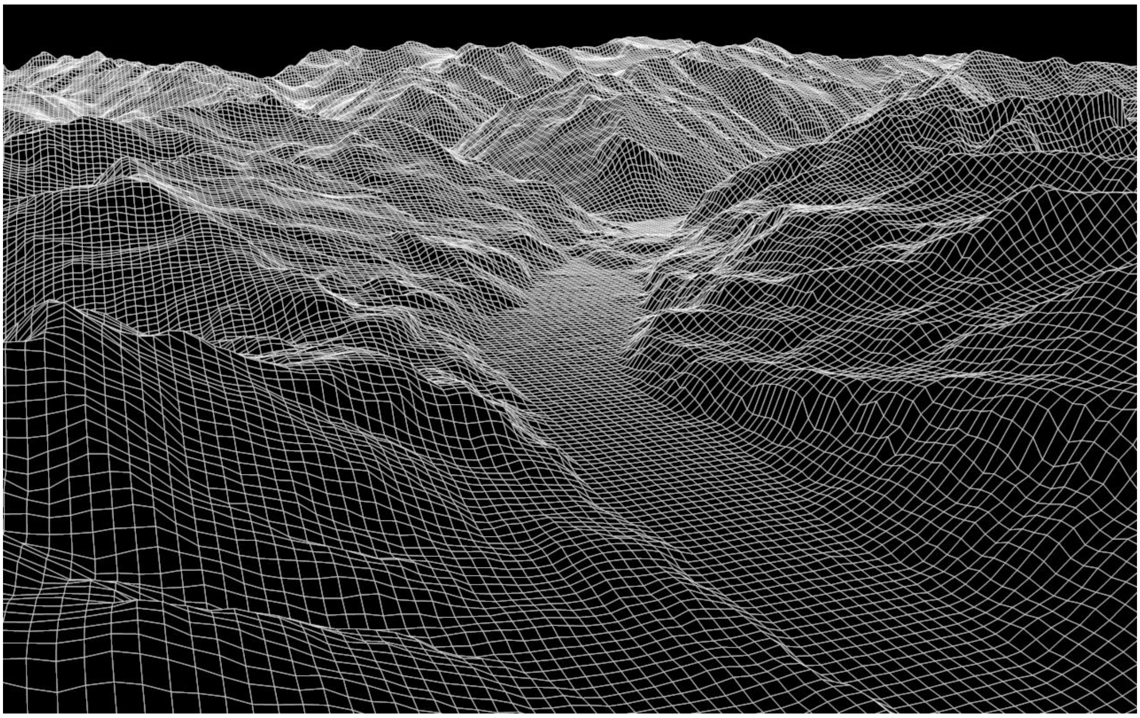

Figure 3-5 Example only (i.e., NOT CARISBROOK) Digital Terrain Model

The Digital Terrain Model is far more accurate and sophisticated than any contour map that Council could (ever) provide to the modellers.

It is to be noted that the 2013 Flood Study also cross-referenced the (older) Rational Method to also determine flows and found that this method, while producing flows of a similar order of magnitude, underestimated flows (by approximately 25%) compared to using RORB.

The 2013 and 2019 Flood Studies show eleven (11) Inflow Points linking the flows generated from the RORB’s model to the MIKE FLOOD model (as shown in Figure 3-6 Location of Inflow Points from the RORBS Model into the MIKE FLOOD Model shown in red – 2013 Flood Study below). This figure also shows the single “outlet” point to the north for all floodwaters.

The inflow locations in the MIKE FLOOD model are the same “sub-catchment” outlet points in the RORB model.

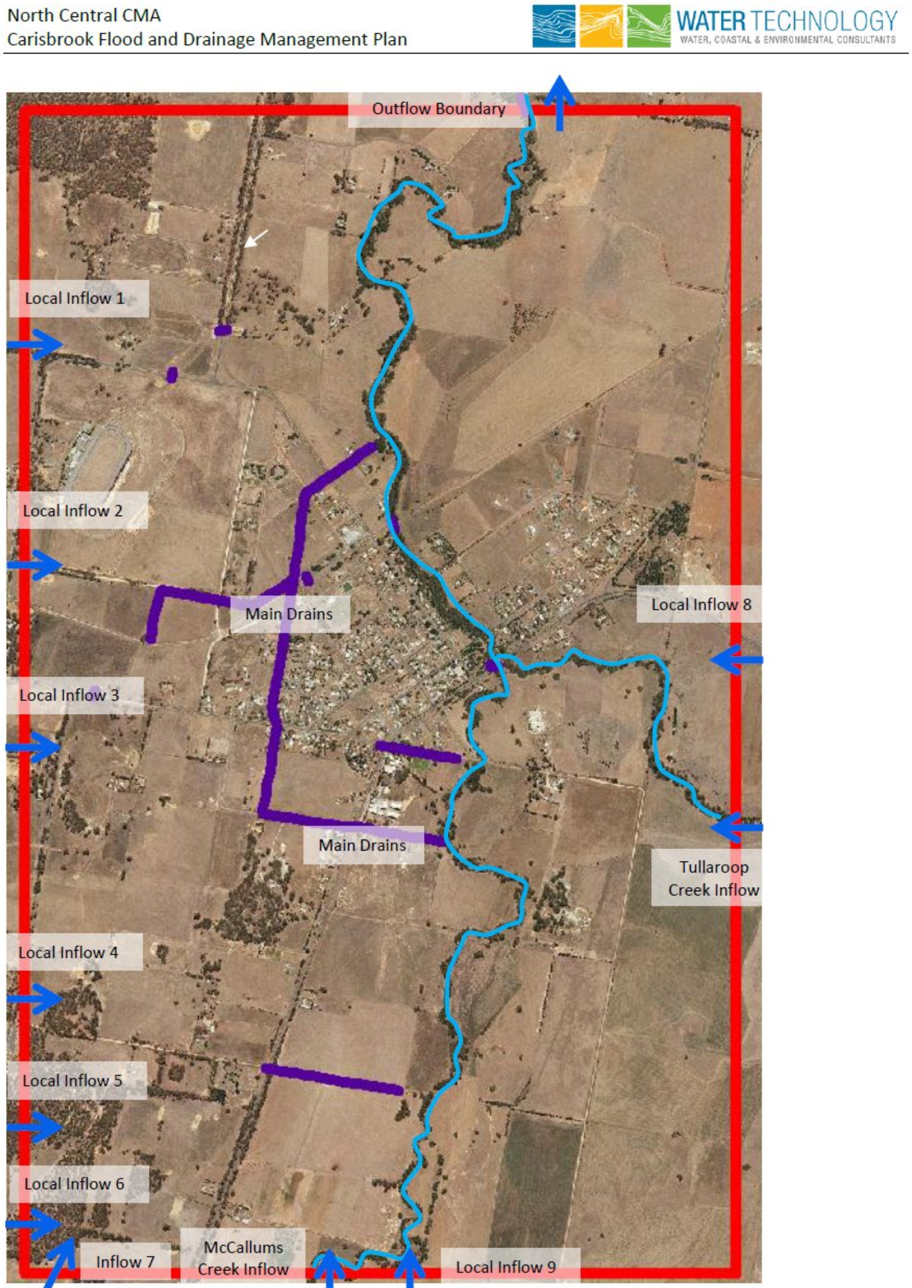

Figure 5-3 Conceptual hydraulic model extents and boundary locations

Figure 3-6 Location of Inflow Points from the RORBS Model into the MIKE FLOOD Model shown in red – 2013 Flood Study

3.2.1 Calibration of Models

The 2013 Flood Study used both the 2010 and 2011 flood events to calibrate the model. It is noted that, for such a large catchment, there was somewhat limited information to work with (especially when flood gauges failed both times).

From a review of the 2013 and 2019 Flood Studies, there is nothing to indicate that they have done anything "wrong". It is noted that there have been reviews undertaken by other consultants (most notably Jacobs in 2018) who did question some aspects of the modelling with Water Technology subsequently stating they have addressed them in the 2019 Flood Study.

Flood "losses" have also been allowed for such as an Initial Loss allowance of 25mm of rain for wetting the catchment / filling up dams and reservoirs etc. This is standard practice.

It is stated that there was not a *"perfect"* fit of the model to all measured data points for both flood events, but it is *"close"* to within an acceptable level. No model is perfect nor, when dealing with natural phenomena such as floods, can it ever expected to be.

This level of uncertainty is best shown when comparing the modelled flood levels with actual surveyed flood levels. It is stated that the overall comparison of surveyed levels to modelled levels was that in 2010 the modelled levels *"…were slightly higher than the surveyed flood levels"* while the 2011 surveyed levels were *"the overall trend showed that the modelled flood levels were slightly lower than the surveyed flood levels"*.

<u>The stated level of accuracy for the 2010 event is between ± 100mm to ± 300mm. And for the 2011 event it was between ± 100mm to ± 250mm.</u>

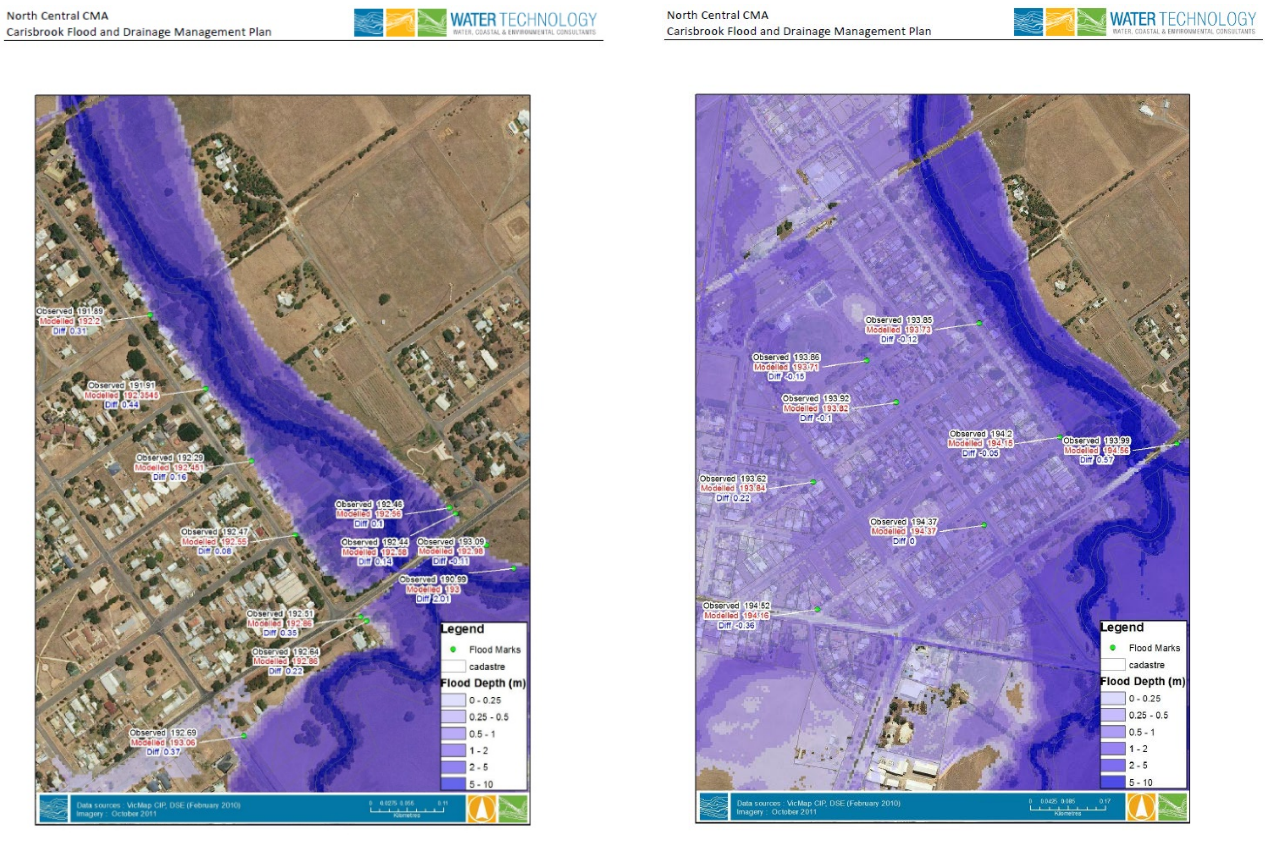

Figure 5-5 Hydraulic model calibration plot – September 2010 (around Pyrenees Hwy bridge)

Figure 5-7 Hydraulic model calibration plot – January 2011 event (central township)

Figure 3-7 Surveyed flood levels versus modelled flood levels – 2013 Flood Study

It is to be acknowledged that the modellers seem to have done the best they could with the limited information they had available to create a workable flood model.

The modelling has included a (very) large catchment area.

Water from Flagstaff (and further west to the outskirts of Maryborough) has been included in the flood modelling.

There was no need to use (far less accurate) contour maps. The LIDAR, used for the modelling, (literally) knows the ground level of every spare metre within the entire catchment.

The RORB and MIKE FLOOD models are well known and well used modelling software. While there is equivalent software available, there are none better.

The modellers have done the best they could with the limited (verifiable) information available to calibrate the models from the 2010 and 2011 flood events.

No computer model is "perfect", they are just "close enough to be useful".

3.2.2 Change in 1 in 100 Design Event Definition

The major change that occurred between the 2013 and 2019 Flood Studies is that Australian Rainfall & Runoff (ARR 2016) was updated in 2016. It is stated these updates included changes for design rainfalls, estimation of rainfall depths, pre-burst temporal patters, short and long duration temporal patters amongst other things.

As stated in the 2019 Flood Study, ARR (2016) *"… had a significant impact on the estimation of rare and extreme rainfalls and the corresponding flood flows"*. This resulted in a reduction of the design inflows for all design 100 AEP event and *"…a smaller flood extent with lower depths (5 to 10 cm lower)"*. That is, the definition of the 100 AEP flood level was reduced at Carisbrook.

TABLE 2-7 PERCENTAGE CHANGES IN DESIGN RAINFALL DEPTHS FOR CARISBROOK.

AEP (1 in Y)	2hr	3hr	6hr	12hr	24hr	48hr	72hr
5	-19%	-17%	-13%	-10%	-5%	-6%	-5%
10	-17%	-16%	-11%	-8%	-3%	-2%	0%
20	-20%	-19%	-14%	-11%	-5%	-2%	1%
50	-22%	-22%	-16%	-14%	-6%	-3%	1%
100	-25%	-25%	-18%	-15%	-8%	-4%	2%

Figure 3-8 Reduction in design rainfall depths – 2019 Flood Study

It is understood from Council that these reduced inflows and reduced levels were used to design the Levee Banks, Culverts and Drainage Channel. However, following a review of the Issued-for-Tender and the As-Build drawings in the Flood Levee Management Plan this is NOT the case. The designs did not change.

It is also stated that the 2013 Flood Study that *"…the town would still most likely be flooded from a January 2011 event as it is larger than the 100 year ARI event and would still overtop the Pyrenees Highway".*

The definition of the 100 AEP Design Level REDUCED (by 5cm - 10cm) in the 2019 Flood Study.

The Flood Intelligence (and other) Information in Appendix C1 of the June 2019 Flood Emergency Plan will need to be updated to reflect these changes.

A January 2011 Flood Event would most likely still flood Carisbrook.

4. Design Phase

In 2015 there was a Preliminary Design Report prepared by Consultants Entura Hydro Tasmania. In 2016 they produced a Detailed Design Report.

Given that the 2019 Flood Study was prepared later, then modified designs must have been prepared to take into consideration the reduced flood levels and flows.

4.1 Design Freeboard (Factor-of-Safety)

In all engineering designs there is a factor of safety used to allow for variability that is inherent in all things. For example, loads used to design bridges and buildings have a factor of safety of 1.2 – 1.5 (amongst other factors of safety used in their design). A climbing rope or crane cable will often have a factor of safety of 3 – 4, not 1.05.

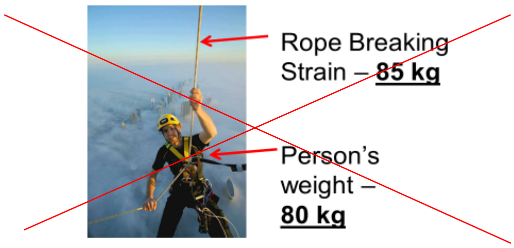

Figure 4-1 Incorrect Factor of Safety

The 2015 Victorian Levee Management Guideline states that a freeboard allowance of 600mm is “general engineering practice”, but that it may be increased or decreased.

5.2.2 Freeboard

Freeboard is an additional height allowance used in the design of levees to cover variables inherent in that design. The variables covered by the freeboard allowance include the difficulty in precise flow estimation and water profile modelling due to an insufficient historical record and also wave action. Freeboard may also assist in short-term protection against bank consolidation (settlement and erosion), but design crest levels should be maintained through regular maintenance.

General engineering practice is to provide a minimum freeboard allowance in urban areas of 600 mm.

Freeboard may be increased or decreased depending on local knowledge and conditions. For example, it may be increased where flood levels cannot be predicted with confidence, but decreased in wide flat floodplains, where the height difference between a minor and major flood event is quite small.

Varying the freeboard allowance over the length of a levee (e.g. lowering freeboard where a section of road is part of the levee system) can create different overtopping levels and problems when design floods are exceeded. It is suggested that uniform crest levels and freeboard allowances be adopted for each system, except where a spillway is incorporated into the system.

Figure 4-2 Extract from Levee Management Guidelines – Dept. of Environment, Land, Water & Planning 2015

The use of 600mm as a standard differs from the (old) NSW standard of 900mm. These two “standards” have an historical basis of being *“2 feet and 3 feet”*. The genesis of these de-facto standards has been lost in time and likely based on *“what someone else did last time”* rather than anything else. That is, there wasn’t any “science” behind them.

The 2015 Preliminary Design Report states that a *“The primary function of a freeboard in the case of a retention levee is to prevent overtopping of the embankment by abnormal and severe wave action and provides a safety factor against dam settlement and larger flood levels than estimated. A nominal freeboard of 300mm has been selected for preliminary design”*. Apart from this statement, there is no other assessment given to what the freeboard should be.

While not used in any other jurisdiction, NSW has endeavoured to put some science / engineering into the derivation of a Freeboard taking into account what the intent is. That is, to also account for unknowns, uncertainties and issues that can (and do) arise during the life (75+ years) of a levee bank.

While the Victorian Guideline does not state to use this approach, it also doesn’t state NOT to use it either. As such, it is recommended that a Freeboard Analysis be undertaken to determine if a 300mm freeboard is appropriate.

It is considered that the same analysis be done on the eastern side of town as Bucknall Street and Pyrenees Highway on the western side of town also act as a Levee.

The revised joint-probably analyses for Main and North Wagga Wagga Levees are given in Table 5 and 6 respectively

Table 5 - Main Levee – Freeboard Allowance (Earthfill Embankment)

Freeboard Item	Allowance (m)	Probability [1]	Joint Probability Component [2]
Wave action • Run-up (incl. wave height) • Set-up	 0.36 0.07	 0.5 0.5	 0.18 0.035
Local water surge	0.1	1	0.1
Uncertainties in Flood Levels	0.30	1	0.30
Levee Settlement	0.025	0.5	0.012
Defects in Levee	0.10	0.5	0.05
Climate Change	0.15	1	0.15
Total			0.83
Recommended Freeboard Allowance			**0.90**

Table 6 North Wagga Wagga Levee – Freeboard Allowance (Earthfill Embankment)

Freeboard Item	Allowance (m)	Probability [1]	Joint Probability Component [2]
Wave action • Run-up (incl. wave height) • Set-up	 0.29 0.04	 0.5 0.5	 0.145 0.02
Local water surge	0.1	1	0.1
Uncertainties in Flood Levels	0.25	1	0.25
Levee Settlement	0.025	0.5	0.012
Defects in Levee	0.10	0.5	0.05
Climate Change	0.15	1	0.15
Total			0.73
Recommended Freeboard Allowance			**0.75**

CONCLUSION

The wave height as result of revised fetch distances have reduced in the orders of 0.22 to 0.02m and the wave run-up height of 0.18 to 0.01m. However, these revised wave height variances only have insignificant impact to the joint-probably analyses. It is still recommended to adopt the flood levee freeboards for the Wagga Wagga Levee upgrade. Based on the freeboard assessment, it is therefore proposed that the levees be designed with freeboards as follows :-

- Main Levee (100 year ARI) 0.9 metres
- North Levee (20 year ARI) 0.75 metres

Figure 4-3 Example Freeboard Analysis

While the example Freeboard analysis has a component for "Wave Action", it is considered that waves would not be able to form in the floodwaters at Carisbrook due to the (very) short fetch distance and the very shallow depth of water. However, this Wave Action component could be replaced with an assessment of the "Rippling" that can occur (based on the 2022 Flood Video taken by a member of the public and posted on Facebook). This analysis can be undertaken by the Reference Group using the above example as a guide.

Having only 300mm of freeboard means that there is very little room for error. EVERYTHING must work "perfectly" and be able to operate "as expected" during a flood event. However, from experience, it rarely does.

Undertake a Freeboard Analysis on the Western and Southern Levees to see if a 300mm freeboard is appropriate.

A similar analysis should also be undertaken along Bucknall Street and Pyrenees Highway along the eastern and south-eastern part of town as they act as a levee bank also (i.e., if it walks like a duck and quacks like a duck…IT'S A DUCK).

It is considered having a 300mm "factor-of-safety" is operating on a very tight tolerance / slim margin for error.

As such, the entire system must be "Operationally Ready" at all times to stand any chance of working as designed. That is, all drains and culverts to be clear of grass, mud and all other blockages as well as the levee crest being perfectly maintained without any depressions or other defects.

4.2 Design Flood Level versus Levee Crest Levels

It is noted that no design drawing / longsection has been produced that shows both the design flood levels and design levee crest levels A basic longsection was produced by Entura in the 2015 Preliminary Design report (albeit a basic longsection was produced by Entura in the 2015 Preliminary Design report). It is usual for these two (vital) pieces of information to be shown on the one drawing. All other levee design plans NSW Public Works have been involved with show both pieces of information.

Instead, in 2016 Entura produced a number of Tables (as shown below). A review of the tables produces some areas of concern where there is less than the 300mm freeboard.

The Table has been checked against the As-Constructed drawings which show that at critical locations, there is even less than the freeboard shown below (e.g., at Pyrenees Highway the As-Constructed levels are from 195.668 – 195.515 with the Design Flood Levels being 195.70 – 195.51.

Table 1 – Locations designed with less than 300mm freeboard.

Chainage (m)	Freeboard (calculated) (mm)	Location
Western Levee		
800	290	
1557.57	50	Pyrenees Highway (southern side)
1562.57	290	Pyrenees Highway (northern side)
1981.50	10	Railway line (southern side)
1988.50	160	Railway line (northern side)
2703.34	160	Levee joining Pleasant Street from Racecourse area
2900	210	End of levee (not constructed) in Racecourse area
Williams Road Levee		
232.55	40	Western side of Landrigan Road
239	40	Eastern side of Landrigan Road
738	-70	Eastern end of levee

Table 5.5: Western Levee crest grading and corresponding flood levels based on 1 in 100 AEP design flood

Levee/Road Raising	Segments	Chainage, m	Crest Level, mAHD	Flood Level, mAHD	Crest Grading
Levee	1	0	198.00	197.47	0.00000 (Horizontal)
		50	198.00	197.45	
	2				0.00175
		450	197.30	196.72	
	3				0.00371
		800	196.00	195.71	
	4				0.00000 (Horizontal)
		1550	196.00	195.65	
	5				0.05386
		1555.57	195.70 (Southern side of Pyrenees Highway)	195.65	
Pyrenees Highway (assumed 7m wide)					
Raising Pleasant Street	6	1562.57	195.51 (Northern side of Pyrenees Highway)	195.22	0.00000 (Horizontal)
		1665	195.51	195.01	
	7				0.00600
		1900	194.10	193.80	
	8				0.00000 (Horizontal)
		1950	194.10	193.80	
	9				0.00952
		1981.50	193.80	193.79	

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Figure 4-4 Flood Level vs Levee Crest level (Segments 1–9) – 2019 Detailed Design Report

Investigation and Design of Carisbrook Flood and Drainage Mitigation Treatments - Detailed Design Report
ENTURA-A31FA

Revision No: 0.0
6 June 2016

Levee/Road Raising	Segments	Chainage, m	Crest Level, mAHD	Flood Level, mAHD	Crest Grading
Railway (assumed 7m wide)					
Raising Pleasant Street	10	1988.50	193.80	193.64	-0.01304
		2000	193.95	193.63	
	11				0.00100
		2150	193.80	193.50	
	12				0.01200
		2200	193.20	192.86	
	13				0.00129
		2703.34	192.46 (levee joining Pleasant Street)	192.32	
Levee	14				0.00186
		2900	192.00	191.79	

Figure 4-5 Flood Level vs Levee Crest level (Segments 10–14) – 2019 Detailed Design Report

Investigation and Design of Carisbrook Flood and Drainage Mitigation Treatments - Detailed Design Report
ENTURA-A31FA

Revision No: 0.0
6 June 2016

Table 5.6: Williams Road Levee crest grading and corresponding flood levels based on 1 in 100 AEP design flood

Levee/Road Raising	Segments	Chainage, m	Crest Level, mAHD	Flood Level, mAHD	Crest Grading
Raising Williams Road	1	0	197.92	197.61	0.00000 (Horizontal)
		166.92	197.92	197.57	
	2	232.55	197.30 (Western side of Landrigan Road)	197.26	0.01
Landrigan Road (assumed 7m wide)					
Levee	3	239.00	197.30 (Eastern side of Landrigan Road)	197.26	0.003
		340	196.94	196.63	
	4				0.002
	5	420	196.75	196.45	0.00000 (Horizontal)
	6	700	196.75	196.42	Grade to existing
		738	196.35	196.42	

Figure 4-6 Flood Level vs Levee Crest level (Williams Rd) – 2019 Detailed Design Report

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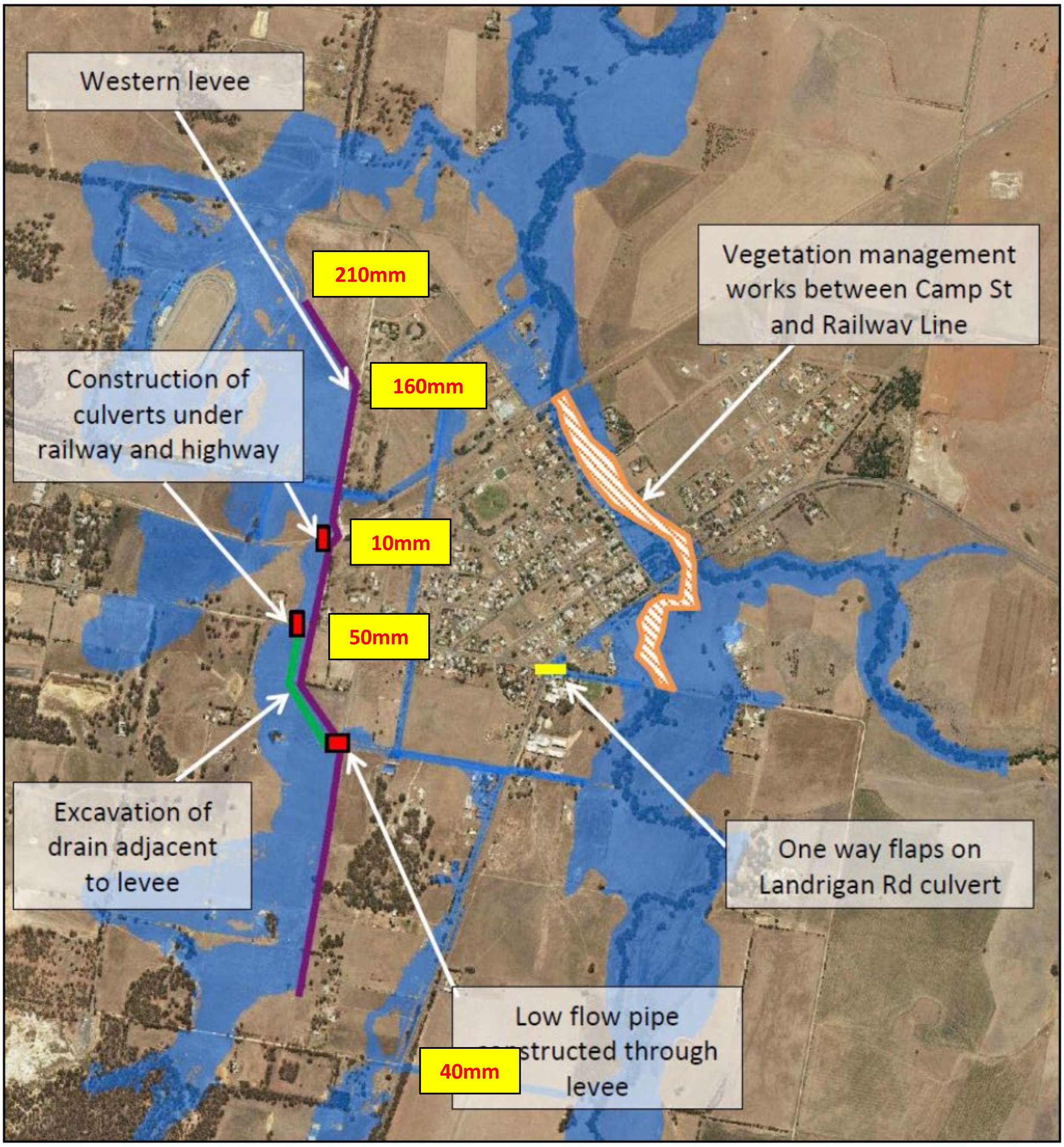

Figure 6-12 Package 4 Mitigation Options

Figure 4-7 Some locations of reduced design freeboard

It is noted that in the Entura Preliminary Design Report (2015), there is a long section of the (then) proposed Williams Road Levee Bank) as below. However, it is noted that levels are only taken at every 50m, not every metre. It is easy to miss critical locations when only looking at 50m intervals in (very) flat floodplains.

Investigation and Design of Carisbrook Flood and Drainage Mitigation Treatments - Preliminary Design Report
ENTURA-95365

Revision No: 2.0
27 February 2015

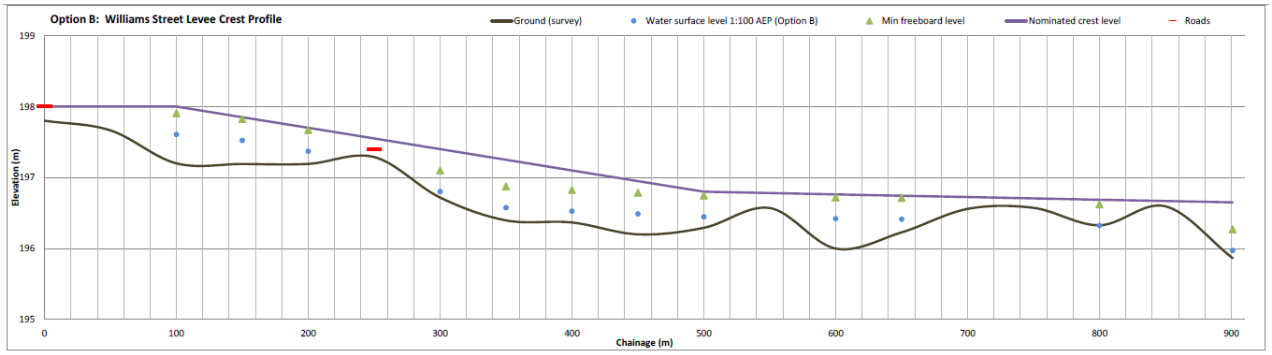

Figure B.2: Option A & B – Williams Street Levee profile (Appendix B for chainage maps)

Figure 4-8 Williams Road design longsection

A long-section of the Williams Road Levee was plotted by NSW Public Works showing ALL Levee Design Levels, ALL Levee As-Built Levels and the Design Flood Water Levels at 1m intervals which identify:

1. Three (3) locations where the levee is significantly below Design Level
2. One section where Design and As-Built Crest levels are below Design Flood Level.

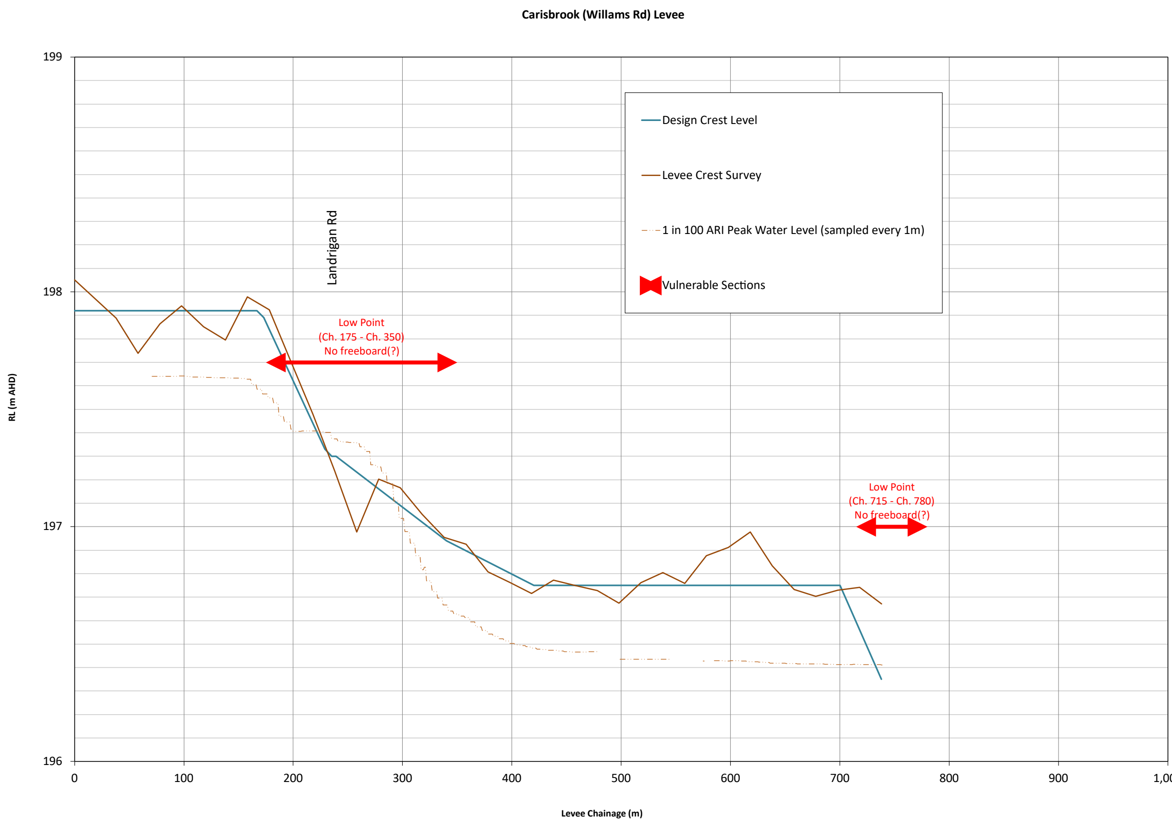

Figure 4-9 Design Levee Crest Level, As-Built Crest Level & Design Water Level – Williams Road

It is further noted that the 2019 Flood Study states that it has included the Williams Road Levee in the modelling and concluded:

"The existing Williams Road levee prevents flood water from overtopping the road and flowing further to the north. The levee and drain redirect flow back to the creek. Water levels are slightly increased on the southern side of Williams Road in rural land west of Landrigan Road. The constructed levee height has adequate 300 mm freeboard except at a low point on the western section near Carisbrook Cemetery where the freeboard is just 210 mm (Figure 4-4). Given that the consequences are low if this levee overtops, this lower level of freeboard may be considered acceptable".

Given the latest (detailed) assessment of the Design, As-Built and Flood Levels as well as concerns expressed by members of the Community and Cemetery Trust, this conclusion is not agreed to. It is VERY flat country and small changes can make big differences in water levels that do not always show up in a Flood Model. Afterall, no model is perfect.

Put EVERY Levee Crest Design Level along with EVERY Levee Crest As-built level along with the Design Flood Levels (sampled at EVERY metre) onto a long section (in a spreadsheet) to locate ALL points / sections where there is less than the required 300mm freeboard.

Undertake a detailed RTK survey (i.e., not LIDAR) of the entire site (cemetery, road, levee, culverts and bluestone drain down to creek) so that water flows can be more precisely determined.

Raise the crest level of all locations where the freeboard is less than 300mm or have a plan in place to construct temporary levees during the emergency (if there is time).

4.3 Western Levee – Design Crest Level

The crest level of the western levee was designed from reading the water surface level from the flood model *"at each 50m interval"*. That is, there was complete reliance on the modelling to have accurately determined the maximum water level. The MIKE FLOOD modelling was based on only running whichever storm produced the largest (instantaneous) flowrate from the RORB's model, not all storm events. As such, only the 6-hour Design Storm duration was chosen (producing, in total, 70.5mm of rain) to run through the MIKE Flood model.

However, it appears what no one has realised is, that the western levee and culverts act as a Retarding Basin which requires particular care when being designed. From discussions with NSW Public Works Dams & Civil team (who regularly design retarding basins), they advise that it cannot always be assumed that a maximum water level will occur from one particular storm event that produced the maximum inflow rate. They ALWAYS model all storm event durations (for the 1 in 100 AEP event only in this case) to confirm (or otherwise) that the maximum water level against the levee embankment has been found. As such, all the other 100 AEP Storms need to be run through the MIKE Flood model.

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TABLE 2-2 DESIGN RAINFALL DEPTHS (MM) FOR VARYING EVENT DURATIONS AND AEP

AEP (1:Y)	2 hr	3 hr	6 hr	9 hr	12 hr	24 hr	36 hr	48 hr	72 hr
5	25.8	29.2	36.8	42.5	47.3	60.6	69.1	75.1	82.8
10	31.5	35.4	44.0	50.5	55.9	71.7	82.3	89.9	99.8
20	37.5	41.9	51.4	58.7	64.8	82.9	95.5	105.0	117.0
50	46.2	51.3	62.0	70.1	77.0	98.2	114.0	125.0	141.0
100	53.4	59.0	70.5	79.3	86.8	110.0	128.0	141.0	161.0
200	60.9	67.3	80.4	90.4	99.0	125.4	145.9	160.7	183.5

Figure 4-10 Different Design Storm Durations from 2019 Flood Study

Re-run the MIKE FLOOD Model for ALL 100 AEP storm durations to confirm (or otherwise) the maximum water level against the Western Levee Bank has been found and the Design Levee Crest Level is correct.

4.4 Western Levee - Environmental Flow Pipe and Low Point Drainage Pipe

4.4.1 Environmental Flow Pipe

The 2016 Entura report states *"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"*.

However, after consultation with the North Central Catchment Management Authority (NCCMA) there is no requirement they are aware of that states that such a pipe should be there and no need for any provision to water anything. The NCCMA thought the origin of this "requirement" may stem from a passing comment during a site inspection that *"the trees may need some water"* and nothing more.

A review of the project's Environmental Assessment also does not mention anything about any Wetland requiring watering. In addition, the pipe does very little "watering" anyway (as below).

Figure 4-11 (Small) flooded area from 2019 flood model

4.4.2 Low Point Drainage Pipe

The 2016 Entura report states *"Of the three culverts, one which is to be located at Ch. 1000 m will be a single 30 m long, 500 mm diameter pipe culvert beneath the levee".*

This location was identified as a low point in the general topography in the 2013 Flood Study where water would sit behind the levee and not be able to drain away (as shown below).

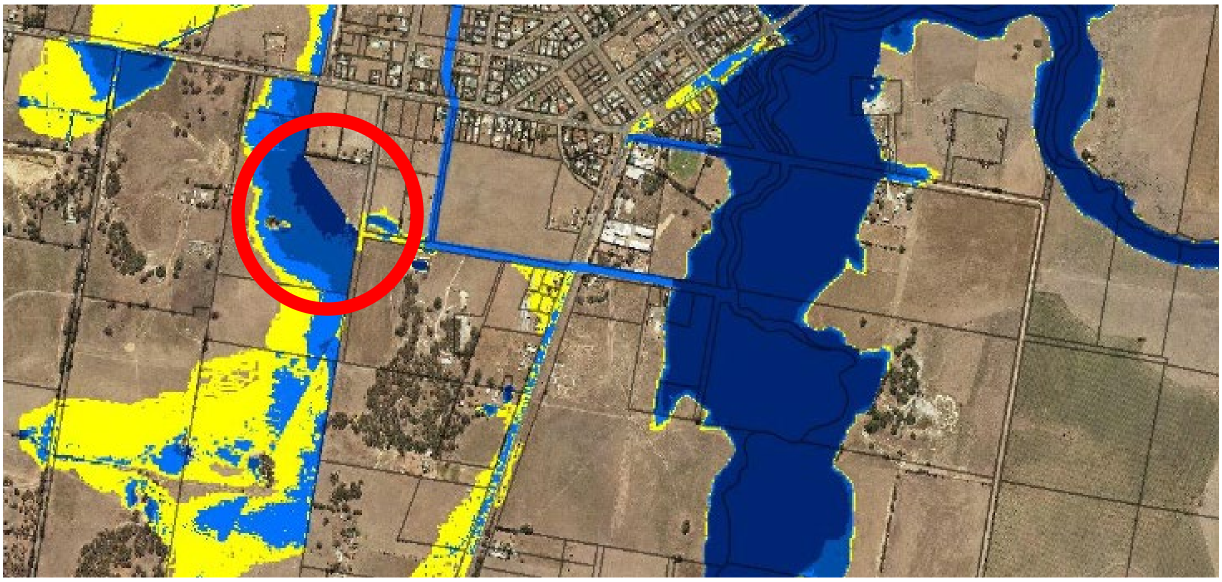

Figure 4-12 Location of "Low Point" in flood model

However, the 2016 Entura report designed a "Low Flow" channel parallel to the Western Levee for its' entire length. This clearly shows that for the entire length of that channel, it falls towards the north ending up in the Racecourse area. That is, this "Low Flow" Channel will drain all remaining flood waters from behind the levee at this "low point" anyway, thus removing the need for any drainage pipe through the levee at this location.

Table 5.8: Summary of the channel characteristics in parallel to Western Levee

Segment	Levee Chainage, m	Channel Chainage, m	Invert Level, mAHD	Top of the topo on the LHS, mAHD	Maximum depth, m	Longitudinal slope
1	0	0	197.95	197.95	0.80	0.1
	8.850	8.85	197.11	197.75	0.64	
2						0.004
	400	400	195.55	196.18	0.63	
3						0.0025
	950	950	194.18	194.80	0.62	
4						0.0005
	1300	1292.57	194.01	194.56	0.55	
5						0.00003
	1550	1550	194.00	194.94	0.94	
Pyrenees Highway culvert with 0.001 slope (including approach and transitions at each end)						
6	1562.6	1581	193.97	194.9	0.93	0.001
	1650	1665.21	193.89	194.65	0.76	
7						0.005
	1950	1959.42	192.41	193.4	0.98	
8						0.001
	1981.5	1972.54	192.40	193.6	1.20	
Railway culvert with 0.001 slope (including approach and transitions at each end)						
8	1988.5	1982.54	192.39	193.4	1.01	0.001
	2100	2102.35	192.27	193.07	0.80	
9						0.0015
	2148.22	2150.57	192.20	192.9	0.70	
Wills Street channel and culvert with 0.001 slope						
10	0.0		192.2	192.7	0.52	0.001
			191.60	192.2		

Figure 4-13 Channel design levels parallel to Western Levee

ALL pipes through a levee should be regarded as a source of risk. The failure probability of any levee is ALWAYS highest at the location of these pipes regardless of how well they are designed or installed. As a levee has a 75+ year life, it is inevitable that these structures will deteriorate over time and be a potential point of risk / leakage.

> *The pipes through the Western Levee at chainages 450 and 1,000 serve no purpose and are only a source of risk. They should either be removed, plugged, or fitted with a Gate Valve that is to be kept locked at all times.*

4.5 Number of Culverts under Pyrenees Highway and Railway

In the 2013 Flood Study, there is reference to a mitigation option involving adding culverts to the Pyrenees Highway Road Bridge (i.e., in town) with six (6) 1.2m x 1.2m culvert (see below).

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Mitigation Option 3

Package 3 consisted of the following options:

- Package 1 options aimed at protecting from local catchment flows. As described above.
- Package 2 options aimed at protecting from the larger watercourses. As described above.
- Complete removal of the highway road bridge from the model. In reality this would involve the replacement of the road bridge with a clear span structure.
- Preliminary modelling was also completed which involved testing the impact of an increased capacity of the highway road bridge through the use of culverts in the eastern approach. The bridge was modelled with an additional 6 x (2.1 x 1.2 m) box culverts. The additional culverts provide an additional 15 m^2 of flow area in large flow events.

Figure 4-14 Mitigation Option 3 - six (6) culverts at Road Bridge – 2013 Flood Study

However, this is not at the Pyrenees Highway on the western side of town where the levee bank is, it is the Pyrenees Highway in town itself over the creek.

There is reference to a Mitigation Option 4 which does talk about the proposed culverts under both the Pyrenees Highway and the Railway line on the western side of town. It is stated that three (3) 1.2m x 0.75m culverts were being proposed under the Pyrenees Highway and three (3) 1.2m x 0.75m culverts under the railway line were being proposed (see below).

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Mitigation Option 4

A western levee to divert local catchment flows was requested by the steering committee as part of a fourth package for detailed modelling. Following further investigation of how the Package 4 options could be implemented the following specific works were included in the mitigation modelling. The Package 4 model included the following works:

- A 3 km long levee extending from the southern end of the Curraghmoor Road Reserve extending 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.
- Construction of culverts under the Pyrenees Highway. Three 1.2 x 0.75 m culverts were used in modelling which allowed 600 mm of cover to the road deck level. Variations on this arrangement may occur with further design work as Vicroads has since advised that only 500 mm of cover would be required.
- Construction of culverts under the railway line. Four 1.2 x 0.45 m culverts were used in modelling which allowed 600 mm of cover to the railway deck level.

Figure 4-15 Mitigation Option 4 – Pyrenees Highway and Railway culverts – 2013 Flood Study

The 2016 Entura Final Design report states *"The culvert at Ch.1550 m will consist of three (3) rows of 1.2 m by 0.75 m by 12 m long box sections"*. Chainage 1550 is at the Pyrenees Highway to the west.

But two (2) 1.2m x 1.2m x 25.6m long culverts were subsequently designed and constructed. The waterway area of 3 off 1.2m x 0.75m culverts is 2.7m^2 and the waterway area of 2 off 1.2m x 1.2m culverts is 2.88 m^2. Therefore, the flow capacity of the two-culvert option is (slightly) better and considered to be equivalent.

4.5.1 Size of Culverts under Pyrenees Highway

A main issue of concern is the sizing of the culverts in comparison to the 1 in 100 inflows, the stated peak flowrates and the duration of that storm event. In particular, the concern is that the culverts are "too small" to convey the flows which would cause the flood water to back up behind the culverts and there not being enough storage volume behind them thus causing the levees to be overtopped.

It is noted that the 2013 Flood Study did not supply the Inflow Hydrographs and only provided the Peak flowrates at each of the Inflow Points and the design storm duration. There was also no mention of how the system was being designed. There is also no mention in the Entura design reports.

There are basically two (2) ways the system could be designed. The first way is to have a "Flow-through / Transparent" system. That is, the entire system (culverts included) can handle the peak inflow rates.

The second way is to have an "Attenuated Flow" system. That is, create a Retarding Basin whereby smaller culverts are used, and water is allowed to pool behind those culverts for the duration of the design storm with the culverts slowly releasing water. The height of the adjacent levee bank is then determined by how high the water pools behind those culverts.

While not stated in the 2013 Flood Study, nor the Design Reports, it appears the second design method was chosen. It is to also be noted that there is only one (1) small reference to that being the case in the 2019 Flood Study. That is, it is a detail that is easily missed, unless someone is looking for it.

There is also no mention of why this design method was chosen. Usually Retarding Basins are designed to slow the flow to either prevent it from reaching some downstream location "earlier" and / or to reduce the extent of flooding at a downstream location. From discussions with Water Technology, the reason it had been designed that way has been forgotten. That is, there does not appear to be any reason to either slow down the flow nor try and reduce the downstream flood extent. As such, it is conjectured that the reason for choosing the smallest number of culverts could simply have been to reduce costs.

It should be noted, there is a house on the northern side of the culverts, however it is some 2m higher than the design flood levels and (very) unlikely to be impacted.

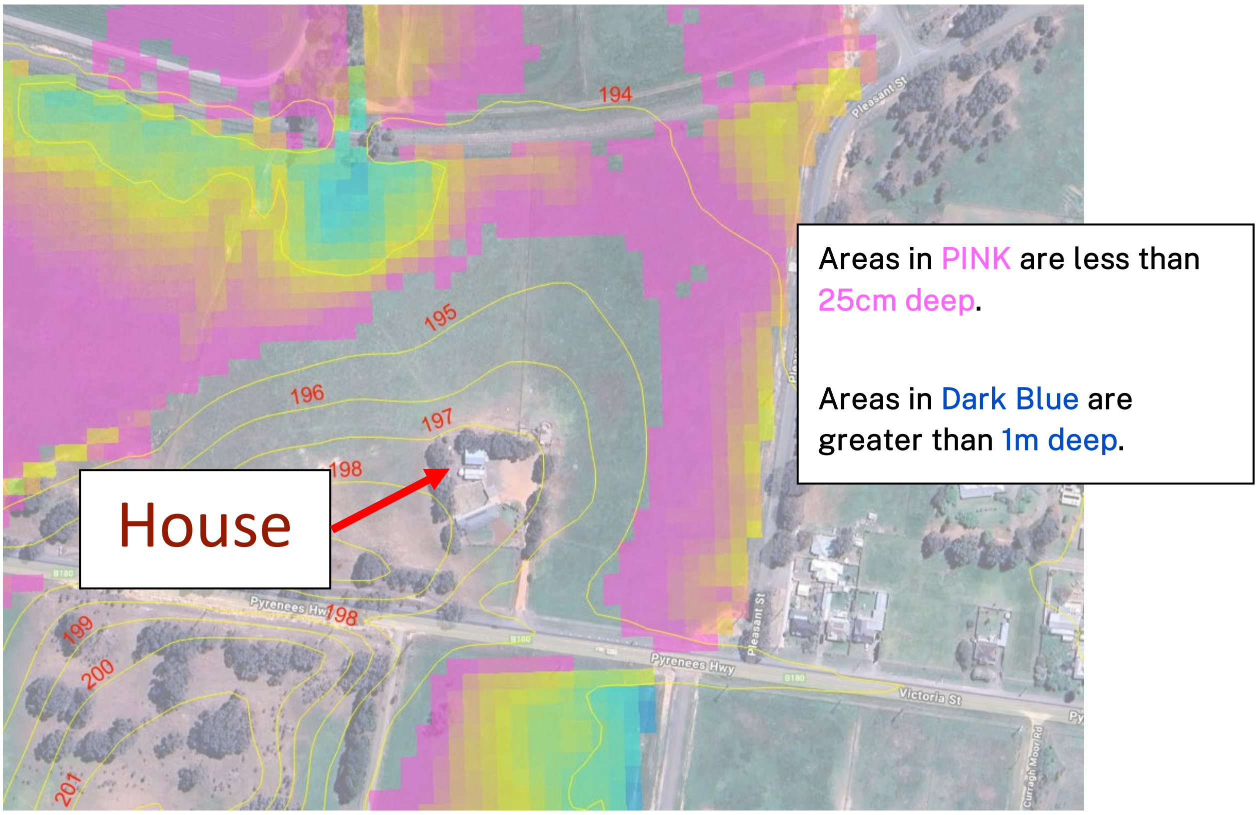


Figure 4-16 House on norther side of Pyrenees Highway culverts

However, increasing the number of culverts may also have reduced the crest level of the levee bank, thus making the cost of the levee construction cheaper thus offsetting (to some extent) the increased cost of any extra culverts.

As it has been recommended previously to re-run all the 1 in 100 AEP design storm durations through the MIKE FLOOD Model, it is recommended for the design storm durations that an additional model run be undertaken with (say) ten culverts underneath the Pyrenees Highway and a larger opening through the railway line (near Pleasant and High Street) to determine what difference this may make to the flood levels and flood extents.

The 2019 Flood Study included the Inflow Hydrographs used for both the 2013 Flood Study modelling and the revised 2019 Flood Study modelling. This allows, for the first time, a way to independently approximate if the "Retarding Basin" culverts at the Pyrenees Highway could work. That is, another way apart from trusting the computer. This was done by running the graph through a computer program to generate points on each of the Inflow Curves (being Inflow Points 4, 5 & 6).

This analysis INDICATED that it could be possible for the culverts to pass 174 ML of floodwater through a culvert which is only capable of passing 23.4 ML/hr. However, this requires that there is at least 88.4 ML of storage behind the culverts that can be used for such storage. The 2013 Flood Study states there is 99 ML of storage (which was not independently verified). AND this only works for the Design Storm Inflow Hydrographs. That is, the Peak Inflow(s) ONLY occur for a relatively short period of time and not for the entire 6-hour storm.

It is recommended that more detailed calculations be undertaken by the Flood Modelers and the outcomes presented in Table form as well as a graphic(s) showing the extent of the Flood Storage area upstream of the Culverts to verify this is the case.

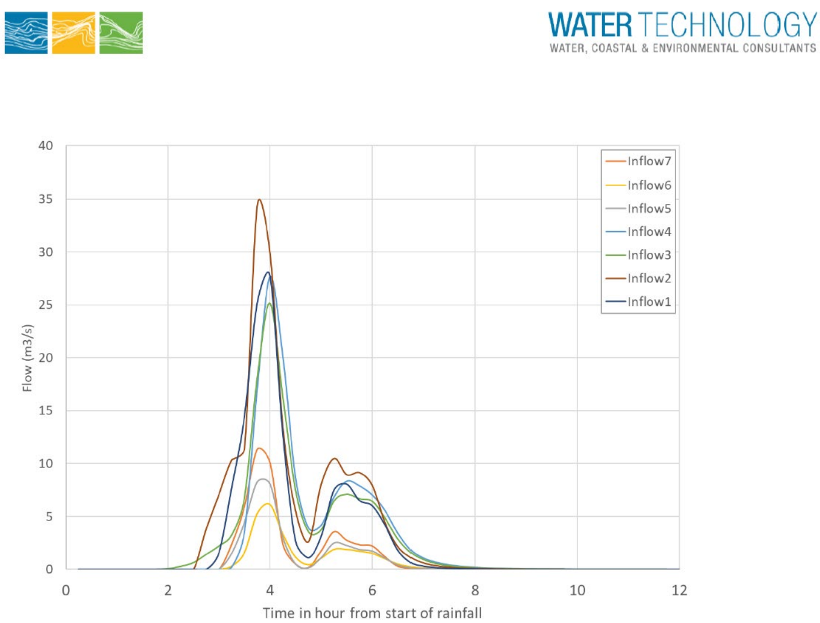


FIGURE 2-14 ARR 2016 1% AEP FLOW HYDROGRAPHS AT SELECTED LOCATIONS

Figure 4-17 Inflow hydrographs – 2019 Flood Study

Duration (hours)	Combined Inflow Volume from Inflow Points 4, 5 & 6 (m3)	Combined Inflow Volume (ML)	Outflow Volume through Pyrenees Culverts at a flowrate of 23.4 ML/h (ML)	Amount stored behind Culverts (ML)	Maximum Combined Inflow Rate (m3/s)
0	0	0	0	0	0
0.5	7,515	8	11.7	0.0	11.3
1	69,426	69	23.4	46.0	42.4
1.5	108,376	108	35.1	73.3	36.0
2	119,450	119	46.8	72.6	8.9
2.5	137,665	138	58.5	79.2	12.8
3	156,671	157	70.2	86.5	11.5
3.5	170,268	170	81.9	88.4	8.4
4	174,148	174	93.6	80.5	2.5
4.5	117,211	117	105.3	11.9	0.6
5	117,780	118	117	0.8	0.3
	Stated maximum storage volume behind culverts =			99	ML

Figure 4-18 Approximate Pyrenees Highway “Retarding Basin” analysis

It should also be noted that the entire area south of the Pyrenees Highway MUST be used to store that water. As such, any interference with that storage (say construction of a contour bank) can seriously change the hydraulics of the flood flows thus jeopardising the safety of the western levee.

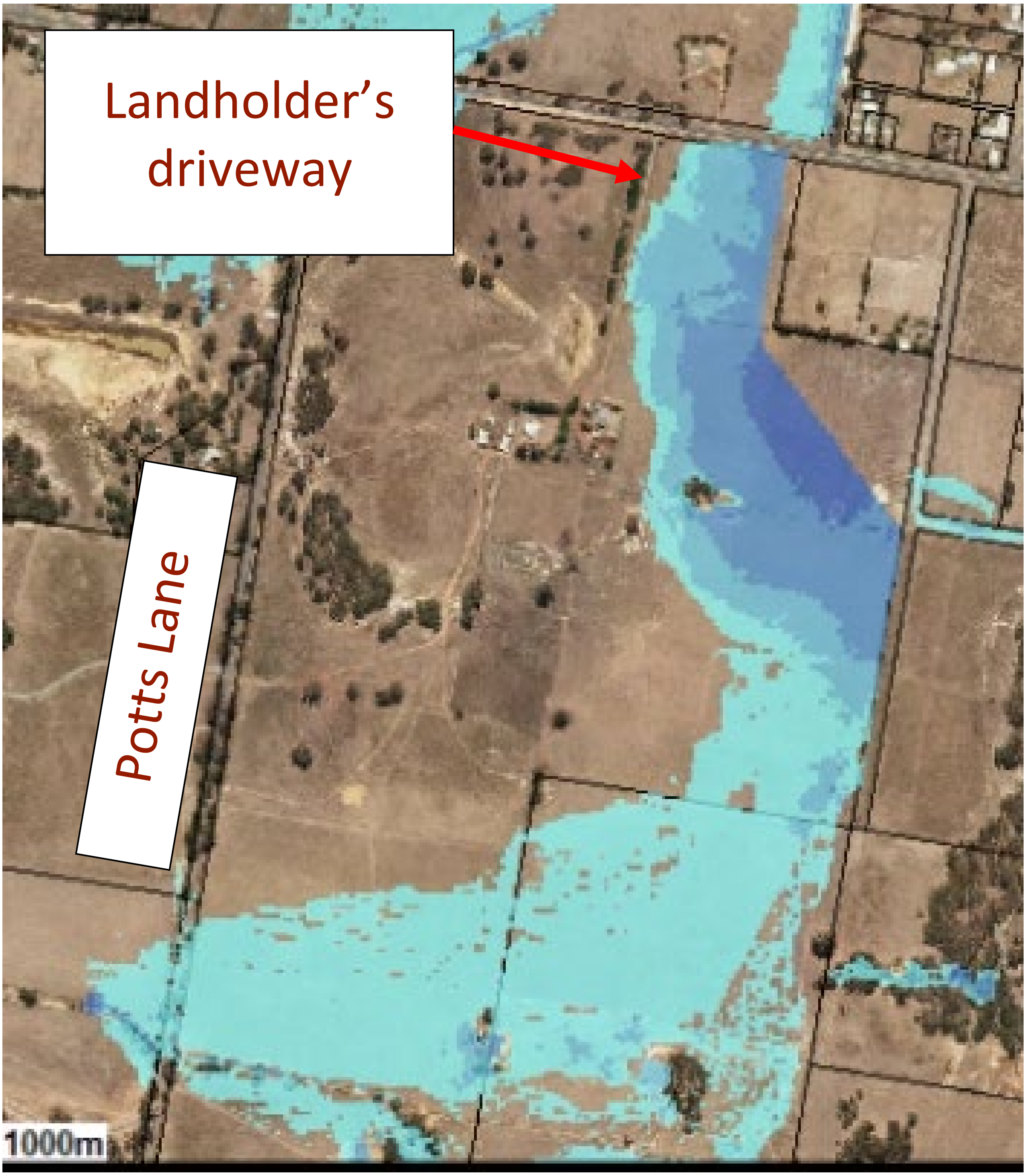


Figure 4-19 Western Levee "Retarding Basin" – from Flood Model Animation Video

It should also be noted that a lot of the flood water is LESS THAN 25cm deep (as per the pink areas below). These small depths are very susceptible to variation both in the inaccuracy of the LIDAR survey, the modelling and any later activities that may (inadvertently) be done.

- For example, the stated accuracy of the LIDAR is ± 10cm (although likely closer to ± 15cm). This is between 1/3 – 2/3 the depth of the water itself.

- What if a farmer decides to plough up a paddock (to say plant feed oats) and changes the level of the paddock?
- What if someone puts in, what they consider to be, a small height contour bank or even a block bank to stop what they consider to be “nuisance” water?

<u>This would change how water behaves on the floodplain</u>.

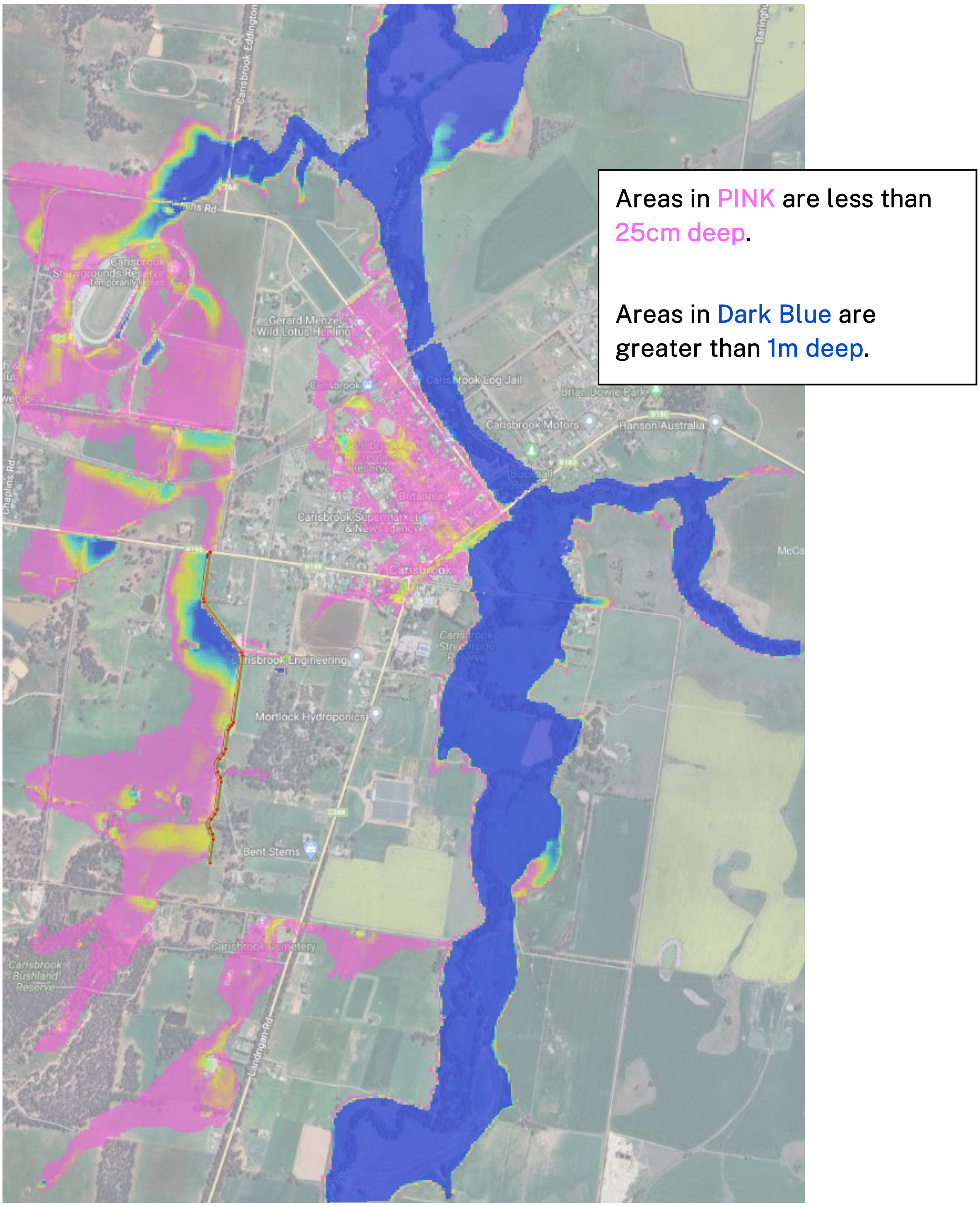


Figure 4-20 Design Flood Depths

For the Critical Design Storm MIKE FLOOD Model run, run an additional scenario with up to (say) ten culverts under the Pyrenees Highway (noting that there is a house to the northwest of the culvert outlet). Include any additional culverts needed underneath the railway line also.

Ensure inspections of the "Retarding Basin" south of the Pyrenees Highway Culverts are undertaken regularly to ensure no impediments have been constructed that would interfere with its' function as a "Flood Storage Area".

The modelling is VERY sensitive to even small changes in the floodplain.

4.5.2 Size of Culverts under / through Railway Line

Another issue of concern is the sizing of the culverts / openings through the railway line in comparison to the 1 in 100 inflows, the stated peak flowrates and the duration of that storm event. In particular, the concern is that the culverts / openings are "too small" to convey the stated peak flows which would cause the flood water to back up behind the culverts and there not being enough volume behind them thus causing the levees to be overtopped.

Unfortunately, there is even less information available to even try and undertake an independent assessment.

For the Critical Design Storm MIKE FLOOD Model run, run an additional scenario with (say) ten culverts under / through the Railway line.

4.6 Design and protection of Culverts, Channels and Levee Bank

Concern has been expressed by the community about the number of curves in the channel, power poles and alignment of the levee bank. In addition, that these pieces of infrastructure have been "moved" over the years.

Following an inspection of the entire levee system, by the author (an experienced Levee Inspection Engineer) the following comments are provided:

1. The Power Poles, while not desirable, can be tolerated as they are always deeply embedded into the ground and the power authority regularly inspects them for defects. As such, they pose a minimal risk.

2. All locations in the "Low Flow" channel that have a change of direction should have rock beaching to provide protection to the embankments and any adjacent levee bank. And this beaching needs to be maintained and "Operationally Ready" at all times.

3. Because the levee north of the Pyrenees Highway is some 7.5m wide at its' crest (much greater than the usual 3m), a certain amount of tolerance can be allowed for defects on its' edges. That is, a lot of the levee would have to be "eaten away" before it could fail.

4. The crest of the levee is MOST vulnerable to failure should there be any settlement, erosion or if any other defect were to occur. Especially with only a 300mm freeboard and, in some cases, a LOT LESS freeboard than that. It is for this reason that (minimum) yearly (if not seasonal) inspections be undertaken, and repair work be undertaken IMMEDIATELY when defects (of any severity) is found. That is, there must be a HIGH level of inspection and diligence (and budget) to ensure the Levee Bank is "Operationally Ready" at all times.

5. Of MAJOR concern is the cutting through the railway line near the intersection of Pleasant and High Street. It is at this location where it is stated there is only 10mm of freeboard. This is backed up by observation from the community that water has been seen "close to the road". Observations in this location shows that there are signs of erosion already occurring in the channel. It is also considered that due to the narrow configuration of this cutting, and the volume of water it is expected to pass, SIGNIFICANT turbulence will occur causing major erosion of both the railway cutting and adjacent levee. It would also be a location where any debris / (i.e., grass, brush, branches etc.) would get caught thus blocking the passage of floodwater causing unforeseen consequences (including overtopping of the levee). The design of this location needs to be reviewed with regards to the required freeboard and significant level of erosion that can occur and potential for blockages. In addition, there must be a HIGH level of inspection and diligence (and budget) to ensure the Levee Bank and "cutting" is "Operationally Ready" at all times.

Figure 4-21 Channel through cutting in railway line near Pleasant and High Street

6. The existing culverts under the railway line further west are a VITAL component of the Flood Protection System. That is, they allow a major portion of the floodwater to pass northwards without going through the cutting near Pleasant Street / High Street. It is vitally important that there is nothing to impede those flows. It is for this reason that (minimum) yearly (if not seasonal) inspections be undertaken, and repair work be undertaken IMMEDIATELY when defects (of any severity) are found. That is, there must be a HIGH level of inspection and diligence (and budget) to ensure the Levee Bank is "Operationally Ready" at all times.

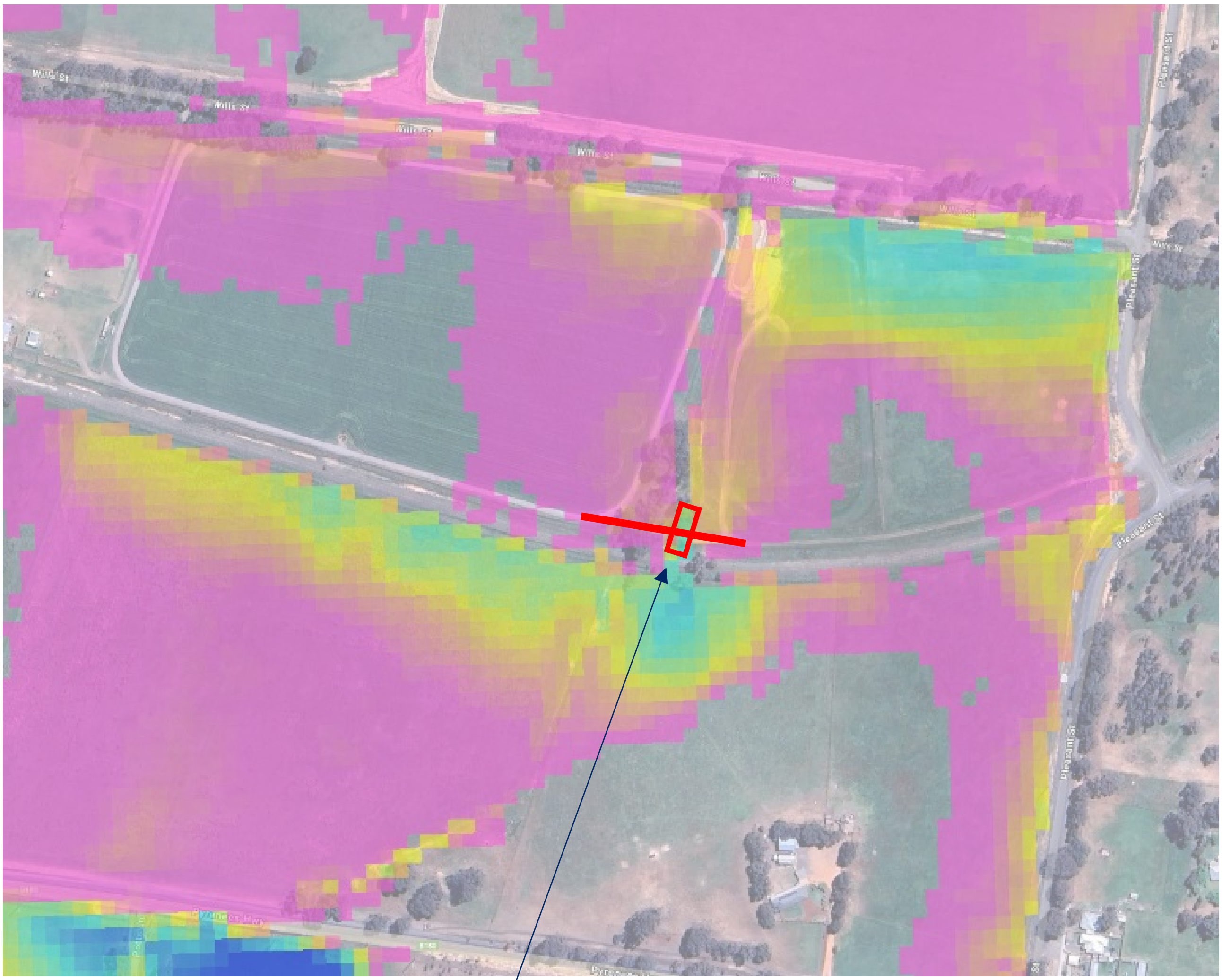


Figure 4-22 Flooding through / under railway line west of Pleasant and High Street

There is already an embankment (with a 700mm diameter pipe through it) <u>blocking</u> the northern side of the 16m wide railway culverts. The <u>modelled</u> depth of water where the block bank and pipe are located is only 750mm. That is, the flow of water through the railway culverts appears to be entirely cut off.

This (4 cell 2m x 0.5m) railway culvert carries all the flow from the Flagstaff area. If it cannot pass under the railway line as designed, it will likely flow further eastwards towards the intersection of Pleasant Street and High Street…where there is only 10mm of freeboard in the levee.

Figure 4-23 Block bank and pipe north of railway line west of Pleasant and High Street

Regarding the design of the culverts, the 2015 Entura Preliminary Design Report states: *"However, in order to cater for concrete ageing, possible higher levels of obstructions during high flood events, and flap valves, this value was increased by Entura from 0.013 to more conservative value of 0.018 on all culverts that had value of 0.013".*

It is noted, the 2016 Entura Final Design Report states: *"Clearing debris and sediment from culverts to ensure that the design hydraulic capacities are maintained"*. And *"A manning's coefficient of 0.022 has been considered for the calculations"*.

Reference is made to the prestigious publication by Chow (1959). This document is the major source of reference and guidance when undertaking any channel hydraulic designs. Within that document is guidance on what manning's roughness can be used depending on various situations taking account of whether a channel is straight or curved, going to be well maintained or not etc.

Manning's n for Channels (Chow, 1959).

Type of Channel and Description	Minimum	Normal	Maximum
4. Excavated or Dredged Channels			
a. Earth, straight, and uniform			
1. clean, recently completed	0.016	0.018	0.020
2. clean, after weathering	0.018	0.022	0.025
3. gravel, uniform section, clean	0.022	0.025	0.030
4. with short grass, few weeds	0.022	0.027	0.033
b. Earth winding and sluggish			
1. no vegetation	0.023	0.025	0.030
2. grass, some weeds	0.025	0.030	0.033
3. dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. earth bottom and rubble sides	0.028	0.030	0.035
5. stony bottom and weedy banks	0.025	0.035	0.040
6. cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. no vegetation	0.025	0.028	0.033
2. light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. smooth and uniform	0.025	0.035	0.040
2. jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. dense weeds, high as flow depth	0.050	0.080	0.120
2. clean bottom, brush on sides	0.040	0.050	0.080
3. same as above, highest stage of flow	0.045	0.070	0.110
4. dense brush, high stage	0.080	0.100	0.140

Figure 4-24 Channel through cutting in railway line near Pleasant and High Street

Photo C2
Slight meandering, regular cross section, well maintained grass channel.

Bankfull: n = 0.028

Figure 4-25 Photo of channel with manning's roughness GREATER than 0.022

7. The design parameters chosen means that ALL Channels and Culverts have to be kept clean at all times. That is, there must be a HIGH level of inspection and diligence (and budget) to ensure the Culverts especially and the Channels are "Operationally Ready" at all times.

8. Any / all block banks and any other obstruction are to be removed from the railway culvert area. Yearly monitoring of ALL floodways are to be undertaken and ALL changes (no matter how small) have to be removed to ensure they function as intended.

4.7 Wills Street Levee - "Now where did I put that Levee"?

There has been some consternation and questions about where the (constructed) levee bank is actually located north of the railway line. Does it continue up Pleasant Street, is it beside the channel, does it go down Wills Street etc.?

It is not an uncommon problem. In fact, some years ago at the National Flood Conference a paper was presented titled "Now where did I put that levee?" as they can *"go missing"* very quickly. It does not help when a design plan labels a channel as a Levee Bank.

The 2016 Entura report states:

"Wills Street was planned to be raised gradually, for 50m, before reaching Pleasant Street to match its new top level" and makes mention of the channel running down Wills Street for 270m to a low point. That corresponds to a description of a ramp only.

The 2019 Flood Study makes no mention of there being a Levee Bank running down Wills Street, nor was it modelled as such. However, the (draft) Flood Levee Management Plan (Engeny May 2024) has labelled 270m of Wills Street as a levee and even produced a long section stating such. Apart from a small ramp off pleasant Street, there is no levee bank on Wills Street.

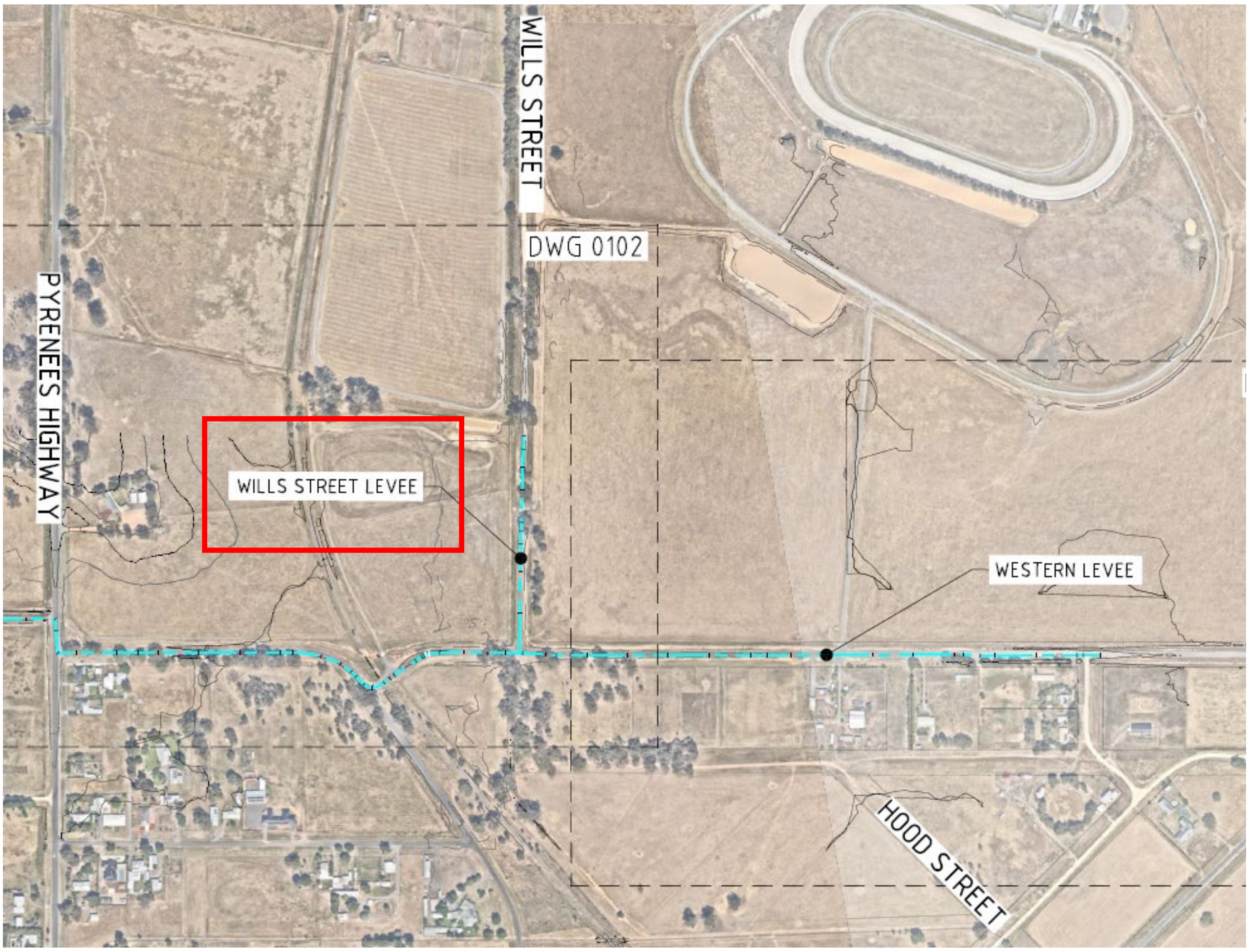
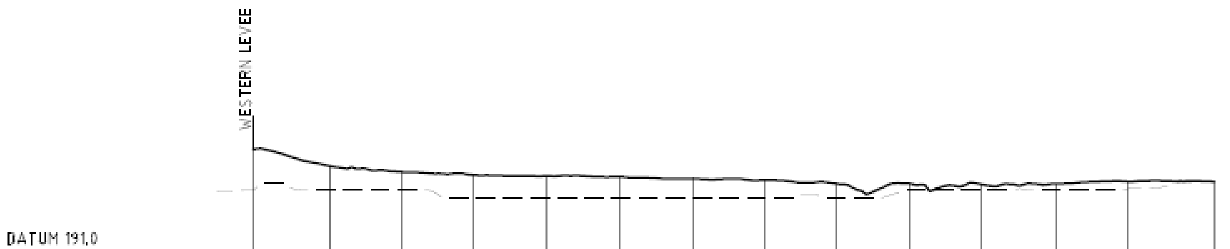


Figure 4-26 Location of Northern end of Western Levee (Engeny 2024)



DEPTHS	1.141	0.676	0.512	0.627	0.598	0.574	0.525	0.487	0.384	0.189	0.167	0.178	0.202	
AS-CONSTUCTED LEVELS	193.941	193.476	193.312	193.227	193.198	193.174	193.125	193.087	192.984	192.989	192.967	192.978	193.043	193.039
EXISTING LEVELS	192.800	192.800	192.800	192.600	192.600	192.600	192.600	192.600	192.600	192.800	192.800	192.800	192.841	
CHAINAGES	0.000	21.200	41.200	61.200	81.500	101.600	121.800	141.800	161.800	181.900	202.000	222.600	242.600	266.520

WILLS STREET LEVEE
SCALE 1:1000 HORIZ
SCALE 1:100 VERT

Figure 4-27 Longsection of the supposed Wills Street Levee (Engeny 2024)

There is NO levee bank on Wills Street. All references to there being one should be deleted from the (draft) Flood Levee Management Plan.

If not already done so, have the entire levee bank centreline digitised and put into Council's Asset Management and GIS systems so it does not get lost again.

4.8 End of Levee at Racecourse

On all the design plans as well as the (draft) Flood Levee Management Plan and the Flood Model all show a levee bank continuing from Pleasant Street across the Racecourse property and terminating. Council advised that they did not construct this section as the ground levels were found to be high enough during construction.

Based on the 10m LIDAR downloaded by Public Works, the ground levels do not appear to be at the design height. The design height of this section varies between 192.47m at Pleasant Street, 192.29 at 77m along and 192.10 at the end being 197m from Pleasant Street.

The LIDAR suggests the ground level along the alignment is 192.0m. It is noted, the modelling shows floodwaters slightly away from that section of the levee itself. But freeboard is to have a factor of safety allowing for variability in the survey, modelling, the design and construction.

The contours generated by Public Works from the 10m LIDAR indicates there is not much height difference in ground levels between the western and eastern side of Pleasant Street (where there are houses). There is a depression however, adjacent the racecourse, that seems to direct water westwards over the track and into a lower area on the northern side of the track and then down to Chaplins Road.

If the actual ground levels, as surveyed by Entura / Council (presumably using State Survey benchmarks not LIDAR), show that the ground levels are higher than the LIDAR, this indicates that the LIDAR may not be correct in their entirety. That is, the design flood levels from the model would be higher than those used to construct the levee bank itself using State Survey benchmarks. Entura did not compare their topographic survey (done in 2014) to the 2011 LIDAR.

There have been other Floodplain Management projects where (early) LIDAR has been found to be incorrect necessitating that LIDAR be re-flown and the flood modelling re-done.

It is acknowledged in the 2013 Flood Study that the LIDAR may not be "perfect" as per:

"LiDAR data for the region was made available from the North Central and consisted of 2 datasets – a floodplain dataset dated 11th February 2011 and a rivers dataset dated 7th December 2011. A comparison of both datasets was undertaken in ARCGIS. Both datasets have the same grid resolutions (1 metre) and are recorded to have the same vertical accuracy of 0.1m with a 67% confidence interval. Upon inspection a mean elevation difference was observed where the two datasets overlap, with the Floodplain LiDAR being generally lower than the Rivers LiDAR with a

mean difference across Carisbrook of approximately 15 cm. Further inspection and comparison against field survey revealed the Rivers LiDAR to be significantly more accurate and better processed than the Floodplain LiDAR".

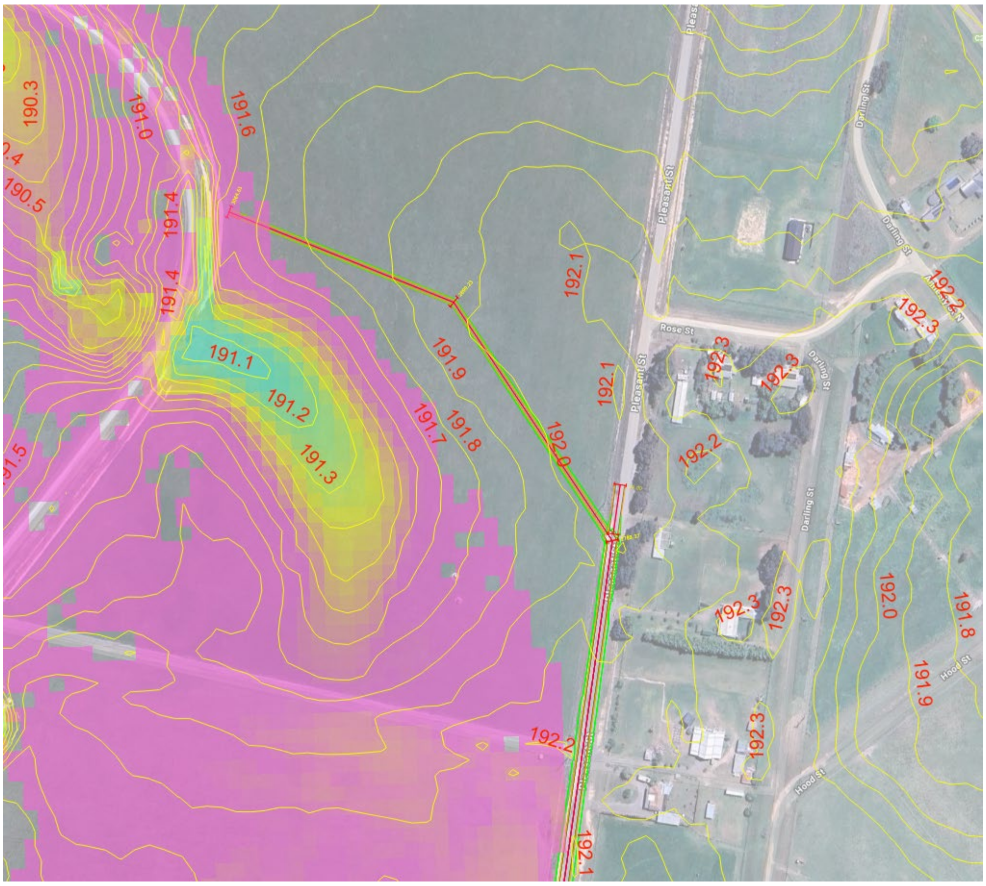


Figure 4-28 End of Levee Pleasant Street / Racecourse

Extend the levee bank across the racecourse as designed (unless ground levels surveyed using RTK method) shows otherwise.

All State Survey Marks (SSM's) used to set out the levee bank are to have a separate Precise Traverse Survey to assess the accuracy (or otherwise) between ALL marks.

Undertake RTK survey cross-sections, from these SSM's, across the floodplains at the Racecourse, west of Pleasant Street (at least two cross-sections) and at least three (3) cross-sections west of the Western Levee south of the Pyrenees Highway and compare to the LIDAR.

4.9 Eddington Road Culvert

The modelling shows that the water depth at the Eddington Road culverts is supposed to be some 2m+ deep. However, an inspection of the culverts showed that it was overgrown with reeds some 3m tall which are impassable. Further east are dams that has been constructed also obstructing the flow of water through the culverts.

Figure 4-29 Eddington Road Culverts overgrown with Reeds

Remove (and keep clean) all the reeds around the culverts. The dams on the downstream side (in private property) are to also be removed to ensure the culvert can function as designed.

4.10 Vegetation Management of The Creek

The 2013 Flood Study states that a part of the final preferred option was *"Vegetation works on Tullaroop and McCallums Creek extending from Camp Street to a point 500 m downstream of the railway bridge"*.

This was modelled and shown to be effective at preventing flooding of Carisbrook. Apart from a One-Way Valve on a Culvert, Vegetation Management is the ONLY mitigation option on the eastern side of town. It is noted that 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)"* was proposed but not specifically modelled.

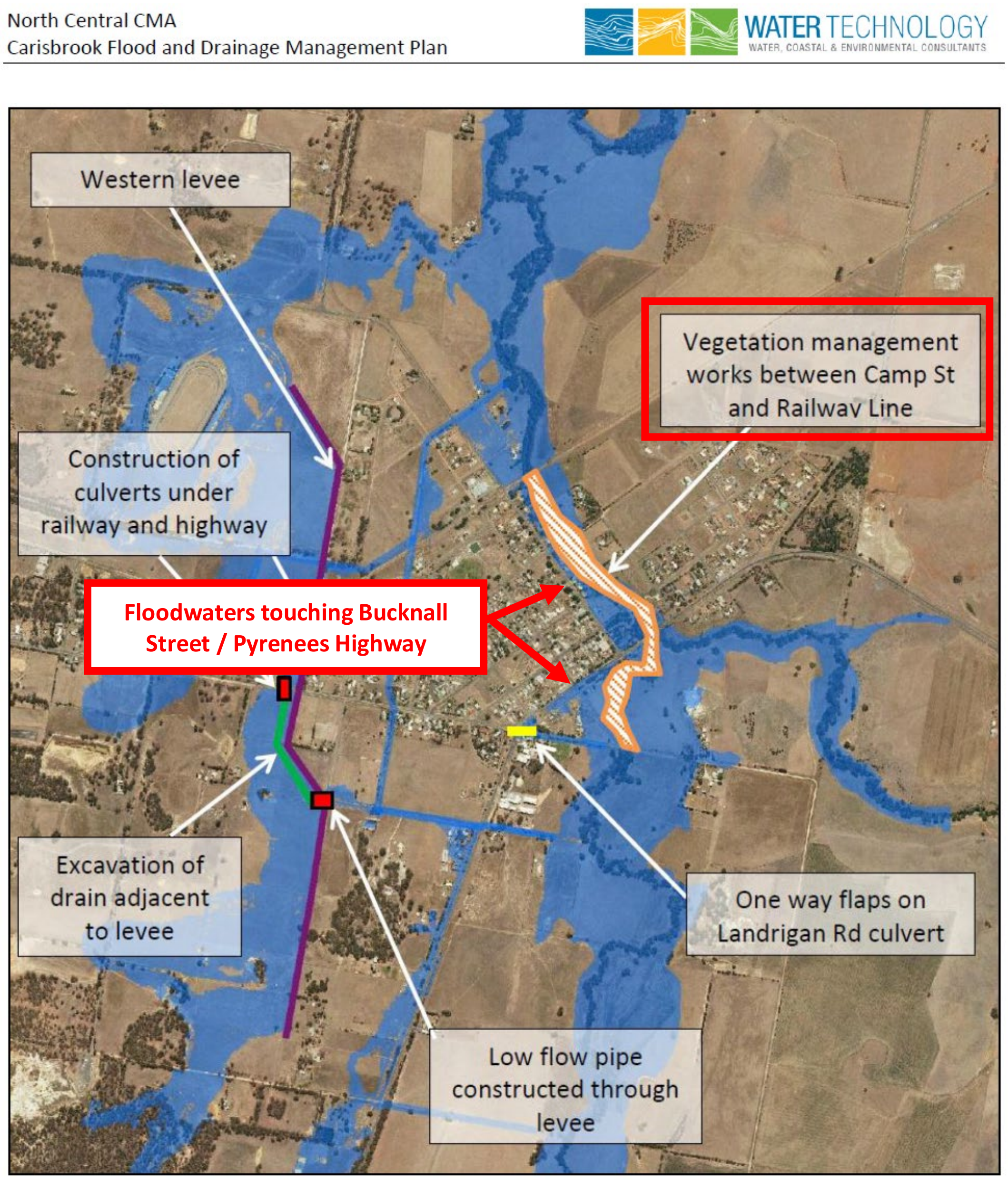


Figure 6-12 Package 4 Mitigation Options

Figure 4-30 Mitigation Options and resultant flooding – 2013 Flood Study

It is noted that it appears this mitigation option is only JUST EFFECTIVE! That is, the design flood level is VERY CLOSE to the top of Bucknall Street and Pyrenees Highway itself.

In 2016 the Flood Modellers wrote to the CMA providing technical advice regarding the impact of vegetation removal on the hydraulic roughness of waterways at Carisbrook. In particular it states that Section 8.1 of the 2013 Flood Study stated:

"Vegetation works was a mitigation option frequently brought up by community and steering committee members. Modelling has demonstrated that the thinning of vegetation along the major waterways in Carisbrook can have a significant impact on lowering flood levels in both small and large events. This option is effective in Carisbrook due to the dense understorey that exists along McCallums and Tullaroop Creek, and the fact that flows are largely confined to the creek even in large flood events. Vegetation works would require significant thinning of the understory and for this option to be effective the works would need to be maintained into the future.

The vegetation works were modelled by applying a reduction in roughness of 0.02 in the dense vegetation which exists adjacent to the channel. While appropriate resources where used to select roughness values there is however, a level of uncertainty in translating "on ground" vegetation thinning to a reduction in roughness values".

It then went on to primarily use the guidance material from Brisbane City Council's Natural Channel Design Guidelines (2003) to review the effectiveness of the works that had been undertaken (primarily clearing existing blockages), trees and branches removed and the removal of dead trees.

While it concluded that *"…it is suggested that a roughness reduction of 0.02 could quite well have been achieved by the vegetation management works"*. It also states that *"The real aim of this assessment is to provide reduced uncertainty regarding the effectiveness of the completed vegetation works in achieving a reduction in the Manning's hydraulic roughness of 0.02 along the identified reach of waterway"*.

However, vegetation grows VERY quickly. This is noted in the statement *"It must be noted that North Central CMA did carry out some post flood debris clearing and minor exotic vegetation removal works around the Pyrenees Highway bridge soon after the January 2011 flood event. Much of this exotic vegetation had regrown by 2014".*

It is also noted that an objective of the vegetation clearing was to have regard to *"…the extent of the works and the need to strike a balance between the hydraulic function of the creek and the environmental and social values of the creek environment*".

It is also stated and acknowledged that for any such assessment *"This is a relatively difficult task"*.

The stated aim is to reduce the manning's hydraulic roughness in the creek from *"0.08 to 0.06"*. While this may sound like a very small change in a number, it has significant effects on flood heights. That is, it is the difference between Carisbrook flooding or not. IT IS THAT IMPORTANT!

It is also noted that the same roughness has been used in the model for the entire length of the mitigation measure. That is, there is no variation to account for any local effects or affluxes.

Further guidance material is also available from the Australian Government in the document “An Australian Handbook of Stream Roughness Coefficients” – Land and Water Australia May 2009. Most of the roughness values stated in this document have been derived from direct measurement.

Location – Acheron River at Taggerty

Channel Roughness – 0.034 to 0.047 (Direct measurement) LESS than the required 0.06.

3.4 Acheron River at Taggerty – Photographs

Figure 2. View downstream from top of reach (1st August 2002, discharge 5.16 m3/s) Acheron River at Taggerty

Figure 3. View downstream from middle of reach (1st August 2002, discharge 5.16 m3/s) Acheron River at Taggerty

Figure 4-31 Acheron River at Taggerty

Location – Merrimans Creek at Stradbroke West

Channel Roughness – 0.076 to 0.080 (Direct measurement) GREATER than the required 0.06.

3.10 Merimans Creek at Stradbroke West - Photographs

Figure 1. View downstream from top of reach (1st April 2003, discharge (recorded downstream at Seaspray) 0.047m3/s) - Merrimans Creek at Stradbroke West.

Figure 2. View upstream from bottom of reach (1st April 2003, discharge (recorded downstream at Seaspray) 0.047 m3/s) - Merrimans Creek at Stradbroke West.

Figure 3. View downstream from middle of reach (1st April 2003, discharge (recorded downstream at Seaspray) 0.047 m3/s) - Merrimans Creek at Stradbroke West.

Figure 4-32 Merrimans Creek at Stradbroke West

As can be seen by the above examples, there can be <u>very little difference between what constitutes a Roughness of 0.06 and what doesn't</u>. It is quite difficult to turn theory into practice. In fact, the difference can be measured in *“a just few years of regrowth and an opinion”*.

Another way of looking at this issue is from a Stream Geomorphology perspective. *“Stream Geomorphology is the study of the physical features that result from water flowing through a bounded channel and its valley. A stream morphological analysis builds on observational findings from a Stream Visual Assessment and a Stream Morphological Analysis by adding careful quantitative measurement and analysis to calculate stream discharge and stream velocity”.* That is, it look at what is actually happening in the stream itself over the years. This is done by looking for signs that water is (say) slowing down or speeding up (often seen in the deposition or removal of sand), the sinuosity or straightness of riverbeds and other such features of the creek itself as well as any changes occurring over time.

Observations of the creek shows that there is a lot of sand deposition occurring (especially upstream of the bridges) as well as regrowth of reeds, grasses and saplings in those and other locations. These are signs that water flows there are “slower” than other locations just upstream. And, as water is slowed, the faster water behind “catches up” resulting in increased flood heights (locally).

Figure 4-33 Example of Reed growth in Creek downstream of road bridge.

Given that the selection of an appropriate Roughness is highly variable, there needs to be an appropriately high Factor of Safety (i.e., “Vegetation Freeboard”) for the Vegetation Clearing Mitigation Option to succeed in all conditions. This is exactly the same concept as a Levee Bank freeboard. That is, the Vegetation Clearing should be done to such a level and extent that there is "*room the spare*" to account for any variation to occur. And this needs to keep being done on an annual (or semi-annual) basis. Basically, *"when in doubt, go harder"*.

Undertake Vegetation Clearing in the creek to a GREATER level than thought necessary to allow enough of a Factor-of-Safety for this (highly) variable Mitigation Option. *For this option to be effective the works would need to be maintained into the future. Prepare and implement a plan whereby Vegetation Clearing is undertaken on an Annual (or semi-annual) basis.*

4.11 2019 Flood Modelling – No Vegetation Removal

It is to be noted that the 2019 Flood Study did NOT model the Vegetation Management works as part of the Ultimate Flood Mitigation" option. This is why the modelling results show that Carisbrook is flooded albeit to depths (mostly) between 10cm and 25cm.

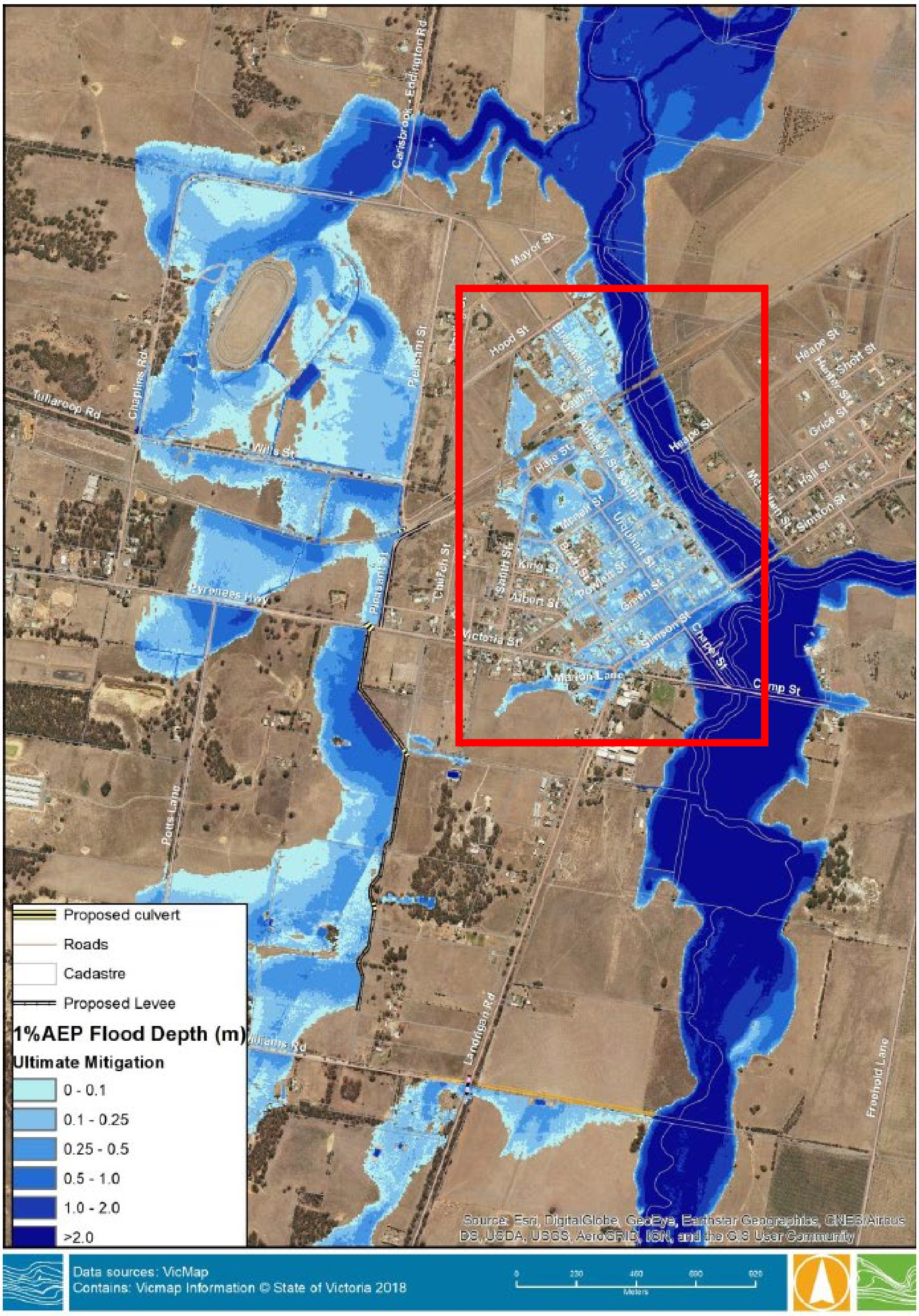
It was stated *"The design hydraulic modelling adopted previous study design roughness in the creek (<u>no post debris and veg removal work</u>)"*.

This is another indication of how sensitive the modelling is to small changes in the creek (and on the floodplain) as well as small errors in the survey and modelling itself.

That is, no model is ever "perfect".

It is unknown why this was not modelled in the 2019 Flood Study given that it was an (essential) part of the final Mitigation Options selected in the 2013 report.

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS



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Central Goldfield Shire Council | 30 August 2019
Carisbrook Flood Mitigation Modelling

Figure 4-34 No Vegetation Management of Creek – Carisbrook Floods

Model the effect of Vegetation Clearing in the creek in the 2019 Flood Model and produce a Flood Map showing it's effects.

4.12 One-way Flap Valve

The 2013 Flood Study states one of the Final Preferred Mitigation Option was *"A non-return valve on culverts under Landrigan Road near Camp Street"*.

The Preliminary Design Report states:

"Under normal operating conditions a floodgate will limit flow, requiring a minimum water level upstream to overcome the weight of the gate before it can open. For this reason smaller rain events may result in pooling of water on the upstream side.

It is recommended to use commercially available box culvert floodgates with the following specifications:

- *Moulded fibreglass reinforced polyester floodgate material".*

When inspected, during the week of the 24th of June, the Flap Valves that had been installed are:

- VERY heavy to lift - took two people to lift one leaf,
- Was jammed open with a small log,
- Did not shut properly until debris was cleaned out from behind it.

As stated in the Preliminary Design Report, it is considered that the flaps will SIGNIFICANTLY limit the flow of normal stormwater, backing up rainwater and likely flood properties when they otherwise would not have been flooded during local rain events as well as posing a risk that they will not close properly during a flood event. And even if they are inspected prior to an oncoming flood, there is a risk that they could be forced open if there is a stormwater event that pushes debris against the Flap jamming it open.

To assist with eliminating the backup of water during normal (i.e., non-flood) storm events an opening / closing device can be fitted to the flap as shown below. During flood times, this lifting arm would need to be operated necessitating it's inclusion in the Levee Management Plan. Alternatively, they could be replaced with Sluice Gate Valves.

There will also be a need for a Permanent Pump Station (or very large temporary pump that is quickly deployable), to be used to pump internal stormwater over the closed flap during flood events.

Figure 4-35 Lifting Arm on Flap Valves

Figure 4-36 Example of Sluice Gate Valve

Fit lifting lockable Lifting Device to Flap Valves or replace with Sluice Gate Valves and include its' operation into the Levee Management Plan*.*

Construct Permanent Pump Station (or easily deployable temporary Pump),

4.12.1 Existing culverts under Bucknall Street and Pyrenees Highway De-facto Levee

The is an underground stormwater drainage network of pipes in Carisbrook (as shown below) but these relatively smaller pipes were not used in the Flood Model because they do not convey any significant flow relative to the large flood events being modelled. This is normal practice. The 2013 Flood Study states *"It should be noted however that this study is not to consider the entire stormwater system, and will be concentrating on larger flood events"*.

However, attempts have been made by the community in the past to clean out and plug the pipes and culverts under Bucknall Street and Pyrenees Highway prior to (and during) an approaching flood event. It is human nature that they attempted to do so. And they will continue to do so prior to future flood events as it is seen as *"protecting their homes and community"*.

Rather than there being "home-made" attempts to plug pipes, there are better ways of making these culverts watertight. This may be done using a combination of rubber plugs, small light-weight flap valves and Sluice Gate Valves which are installed / closed at pre-set rainfall amounts and/or flood levels.

Regardless of whether flaps etc. are installed or not, it is likely small pumps will be needed to pump out internal stormwater from various low areas around town.

It is expected that there may be more pipes and culverts under Bucknall Street and Pyrenees Highway than are shown in Council's Asset Register.

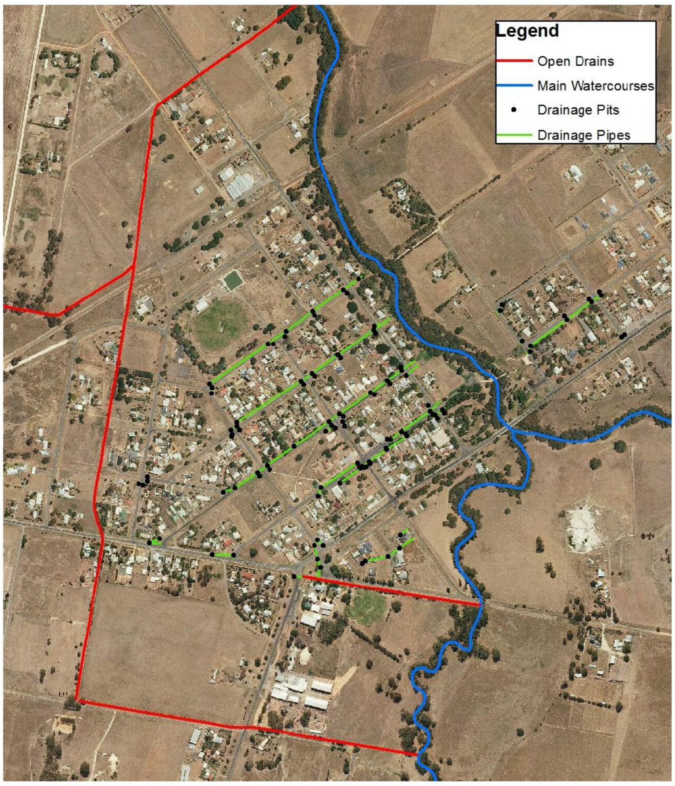


Figure 3-6 Carisbrook Drainage Network (Central Goldfield Shire)

Figure 4-37 Stormwater Pipe Network

With the community's assistance (i.e., Reference Group), supply / install a combination of rubber plugs, small light-weight flap valves and Sluice Gate Valves on stormwater outlets and culverts under Bucknall Street and Pyrenees Highway.

The installation / closure at pre-set rainfall amounts and/or flood levels are to be included in the Levee Management Plan.

Regardless of whether flaps etc. are installed or not, it is likely small pumps will be needed to pump out internal stormwater from various low areas around town. Make a supply of small pumps available for use during flood events.

4.13 Cemetery

From Pers comm Cemetery Trust Secretary / Public Works dated 10/07/2024 10:15am:

Flooding in the cemetery has ALWAYS been a problem because of water coming in from behind (i.e., from the south). She has been secretary for 26 years and her father was also for a long time before that. They also owned some land on the southern side of the cemetery so know the history of flooding at the cemetery.

In 2022 a lot of water was in the cemetery. But 2022 and 2011 were unusual years. The Trust are now trying to put in a small levee "behind" the cemetery to prevent water from entering the cemetery from that way.

Damage is being done to the gravestones whereas, in the past, there has not been. Water historically has pooled in areas within the cemetery and in from, but it always got away.

Figure 4-38 Water sitting in and around Cemetery

Figure 4-39 Cemetery Trust Secretary's recollection of "usual" water flow

It is noted, no modelling results have been presented in either the 2013 or 2019 Flood Study Reports showing the modelled flood behaviour around the Cemetery for "small" (e.g., 10%, 20% etc.) events.

As the modelled depth of water is less that 25cm, the below shows how small differences in the terrain in many locations in and around the cemetery would have on flow directions. For example, a blockage in a drain, the model not picking up ALL subtle drainage lines and details around the cemetery etc. All would make a BIG difference to how the water behaves and where it flows.

Given that a Levee Bank (on Williams Road) is a FLOOD MODIFICATION measure it is not surprising that water *"now goes where it didn't before"* as has been reported doing so. Afterall, the whole purpose of a Levee Bank is to redirect water flow.

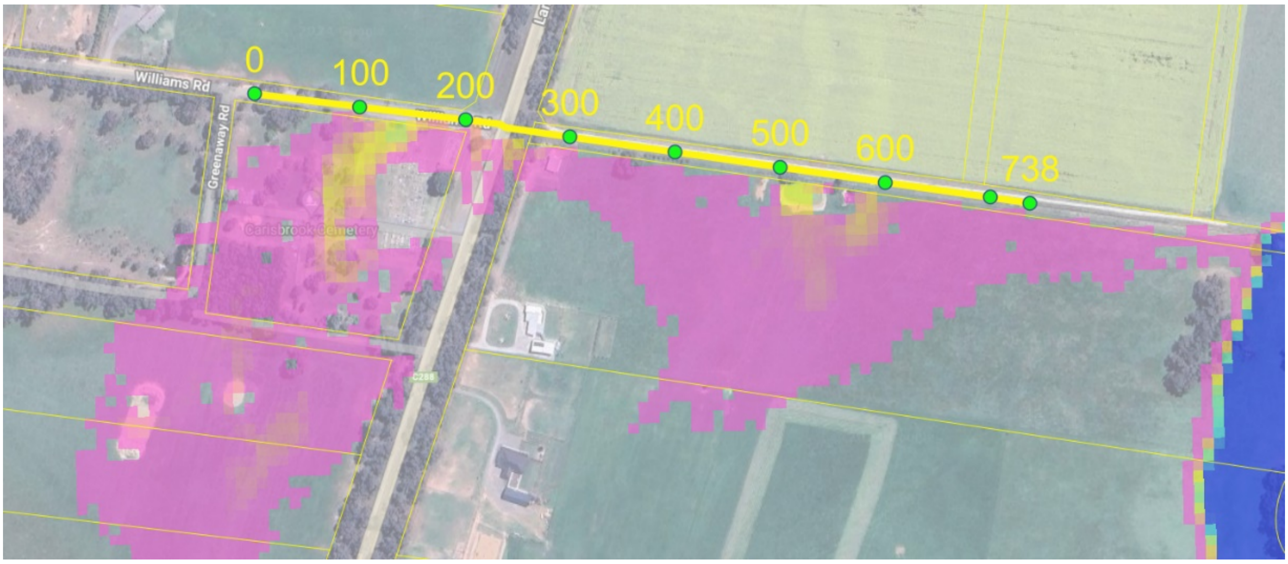


Figure 4-40 Modelled depth of flood water around Cemetery (mostly less than 25cm)

From a visual inspection of the culvert under Landrigan Road and the start of the Bluestone Drain heading east, it appears that invert level of the culvert is much lower than the invert level of the drain. If this is found to be the case, this would mean that the culvert is *"effectively 80% blocked"* and would cause water to back up into and sit in the Cemetery for a longer period of time and to a greater extent.

Given that the water depth in a 1 in 100 event is "less than 25cm", a small levee around the cemetery could be constructed and water directed around it by excavating the table drains to direct flow to the culvert under Landrigan Road. A further feature survey should be undertaken, using RTK survey not LIDAR, to map out the ACTUAL (subtle) flowpaths around this area. The 1m LIDAR is not even accurate enough to pick up the actual flowpaths. It would take a trained and experienced surveyor to do so.

Construct small height (say 300mm high) bank around Cemetery.

Survey (using RTK survey methods, not LIDAR) the area around the cemetery and determine all flowpaths to put in a Model to better reflect actual conditions.

Annual inspections and cleaning of all drains and culverts are required to ensure flows go where modelled.

5. Construction Phase

The main test for determining the structural integrity of a newly constructed levee bank is to test the amount of soil compaction and moisture content achieved.

A series of compaction test results were reviewed for the western levee which showed that the amount of compaction was above 98% Standard and, where this was not achieved in a few locations, the levee was reworked and retested.

From the soil test results obtained, construction of the Levee Banks met or exceeded specification requirements.

5.1 De-facto "Eastern Levee

In the 2013 Flood Study there is reference to the Pyrenees Highway (between the bridge and Chapel Street) being the first to overtop during the 2011 flood event:

- *"Levels in both McCallums and Tullaroop Creeks continued to rise through the night and the modelling indicates that once the combined flows in McCallums and Tullaroop Creek reached approximately 900 m3/s upstream of the Pyrenees Highway Bridge the flood waters overtopped the Pyrenees Highway between Chapel Street and the Pyrenees Highway bridge. Anecdotal reports and the modelling indicate that this occurred from around 9:30am on the 14th of January 2011".*

And looking at the modelling results for Mitigation Option 4, Bucknall Street also acts as a levee bank.

There have been many instances when a Council has been asked to "locate their levee on a map" and they have not been able to for the fact that part of it is a road. This is because people do not often think of a road as a levee bank but expect a "stand-alone embankment" that is used for no other purpose other than providing flood protection. However, a levee can serve two purposes and often times a “road embankment” becomes a “levee bank” by nothing more than “it is there stopping water”. That is, it functions as a levee bank.

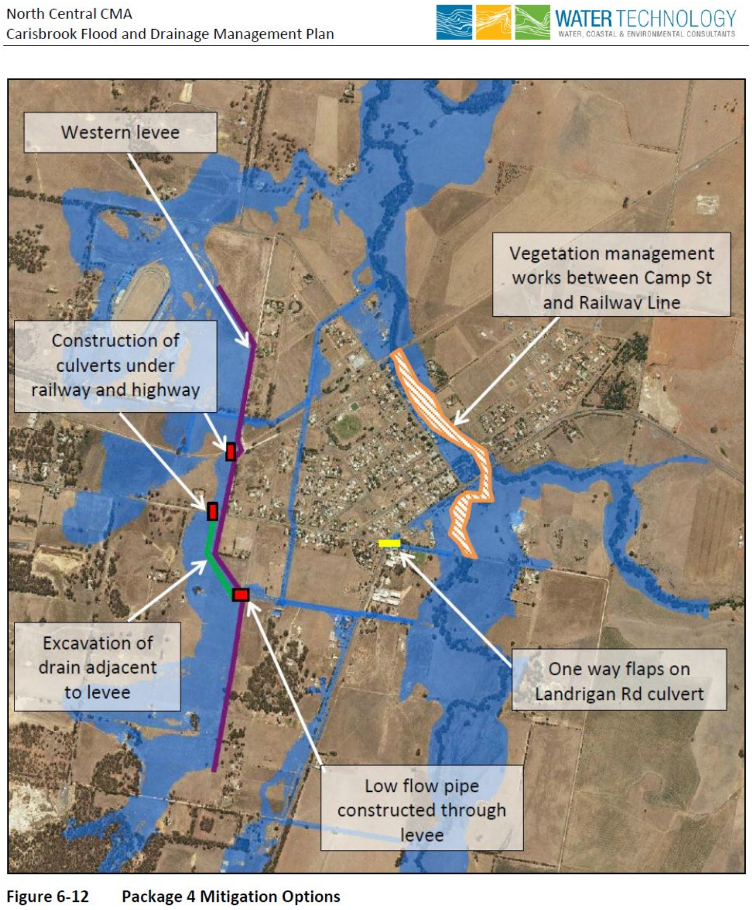


Figure 5-1 Modelling results – 2013 Flood Study

In addition, the 2013 Flood Study states:

- *“<u>There is a small flood levee to the south of the town</u> adjoining a drainage line and the <u>Pyrenees Highway is also elevated slightly</u>. It is unclear from the field investigations…whether the levee is a formal piece of Council infrastructure.”*

Figure 5-2 De-facto "Eastern" Levee Bank

Start thinking of the Pryenees Highway (between the Bridge and Chapel Street) and Bucknall Street as a (de-facto) levee bank. Basically, "If it walks like a duck and quacks like a duck...it's a duck!".

All culverts under this "levee" should either have Flap Valves or (preferably) Gate Valves fitted or Plugs to be placed in them during a flood event. The location and operation (where, when and who operates) are to be specifically included in the Levee Management Plan.

5.2 Flood Cache – A "Response Modification" Measure

It is a common problem, encountered many times, that small communities seem to receive little to no assistance during major flood events (at least it can be felt that way in comparison to larger communities). It is considered this is because when there is major flooding in these smaller communities, there is also major flooding occurring in (many other) larger communities and surrounding areas requiring the use of (scarce) emergency resources.

It is also a characteristic of major emergencies that there are *"never enough resources and never enough time"* to send assistance everywhere at once.

The NSW SES have found one way of overcoming this by providing Flood Caches into these smaller communities so they can *"help themselves"*. These caches (stored in Shipping Containers) have such things as sandbags, shovels, scoops etc. that can be used by the community themselves. In addition, they could also contain "Floodsax" that are an alternative to sandbags as they expand to full-size when placed in water. That is, they are useful when there is a need to deploy "bags" quickly as they do not have to be filled with sand prior (as they already contain a water-absorbing polymer material). Small pumps, useful for pumping local rainwater from premises, can also be included in the cache.

The keys to the containers are given to selected Community Members who can be relied upon to be there prior to and during a flood event.

Figure 5-3 Flood Storage Container North Wagga Wagga

Flood Cache - An option that Council (and Vic SES) may wish to consider for use at Carisbrook.

6. Community Consultation

The 2013 Flood Study talks about Community Consultation being undertaken. At the end of the report, it is stated that the key findings from the report were presented to the community on 15th February 2013 along with the mitigation packages and preferred option being proposed with 113 submissions being received.

It is also stated, of the 113 respondents 100 supported the “preferred package”. However, a information regarding those 113 responses has not been able to be provided.

It is noted there have been minor changes to the exact alignment of the levee and location of the culvert at Wills Street. A comparison between the Preliminary Design drawings and the Final Design drawings shows those differences.

It is considered the power poles in the channel, while not desirable, will not have a detrimental impact on the operation of the channel.

The 45-degree alignment of the culverts under the Pyrenees Highway towards Pleasant Street and not 90 degrees straight across the road is not desirable as it directs floodwaters directly against the levee itself. However, the outflow has been protected with rock and Pleasant Street is some 7m wide so would not be “washed away”. However, the main concern is any local water surge that could overtop the levee itself (with a house directly on the other wide). But this issue would be addressed with a revision of the levee freeboard (recommended earlier).

Moving the levee onto Pleasant Street means the levee bank ended up being wider than the 3.5m. It also shows the Williams Road Levee.

It should be noted that the 2015 Entura Preliminary Design alignment of the culverts was at 90 degrees to the Pyrenees Highway and showed the length being only 12m. By going at 45 degrees meant that the length of the culvert doubled to 25.6m. As such, there was a missed opportunity to have doubled the number of culverts under the Highway (to four), thus doubling the flow rate of floodwater, for a similar cost. This would have meant that the change would have needed to be remodelled, but this could have been quickly and easily done at minimal cost.

9. COMMUNITY CONSULTATION

A key objective of the Plan was to ensure strong community engagement and to demonstrate strong community support for the final Plan. A key aspect of all community engagement was to provide information to ensure community understanding and then to seek feedback verbally at meetings and through more formal feedback methods. Three public meetings held at various stages of the Plan development were all strongly attended. Feedback from these meetings guided the development of the Plan.

Key findings of the Draft Carisbrook Flood Mitigation and Drainage Management Plan were presented to the community in a public meeting held on 15th February 2013. A summary brochure outlining the mitigation packages and preferred option along with a feedback form was provided to all meeting attendees and a three week consultation period then ensued.

Following the period of public consultation a total of 113 submissions were received from the community, with 100 submissions supporting the preferred option and 13 not supporting the preferred option or unsure.

The results of the feedback are summarised below:

- 100 of the 113 respondents supported the 'preferred' package of works which was Option A the Western Levee and vegetation works.
- 13 of the 113 respondents did not support the preferred package of works or were unsure
- A very small number of respondents elected to remain anonymous.

As a result of the extensive community consultation, and public feedback, it is clear that the steering committee's proposed scheme for Carisbrook has strong community support.

10. FINAL PREFERRED OPTION

Based on the study results, steering committee discussions and the community consultation feedback the preferred option of the steering committee remained the same. The steering committee's final preferred option was:

- 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 final preferred options are shown in Figure 10-1

Figure 6-1 Extract from 2013 Flood Study

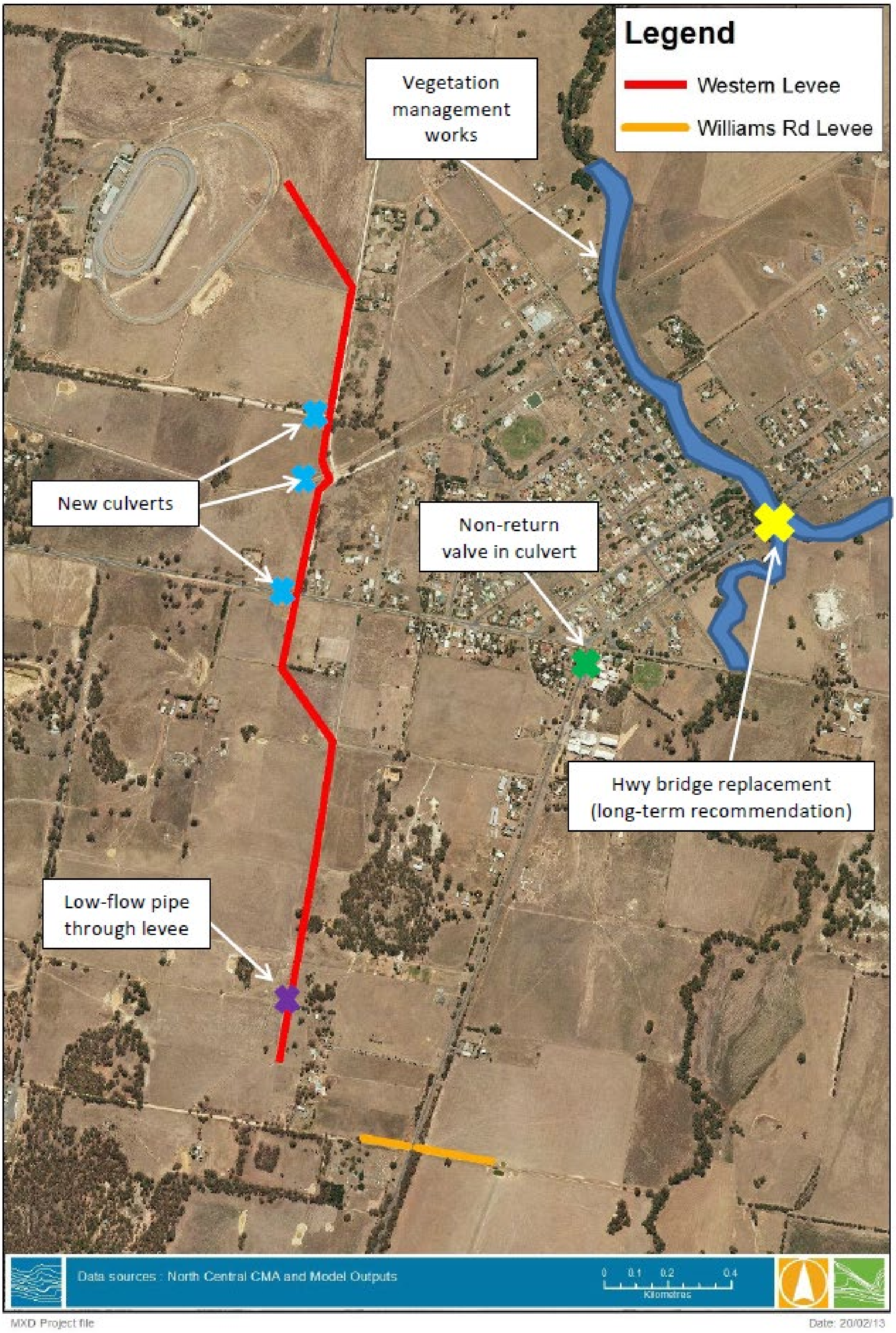


Figure 10-1 Final Preferred Options for Carisbrook

Figure 6-2 Extract from 2013 Flood Study – Final Preferred Option

7. Antecedent Condition and Initial "Losses"

The Antecedent Conditions (i.e., how wet or how dry) the ground is prior to flooding Is an important component of all flood models. The "Initial loss" allowed for in the flood model accounts for these conditions with an initial amount of rainfall that is assumed to soak into the ground, fill low points, gullies, reservoirs etc. in the (dry) catchment before any runoff (i.e., flooding) starts to occur.

A review of the 2013 and 2019 Flood Studies shows that an Initial Loss of 25mm was used in both reports (which is stated to be in accordance with guidance from Australian Rainfall & Runoff). This value corresponds to average Antecedent Condition. At the Reference Group meeting (6th August 2024) discussion was held regarding the possible variability of the Initial Loss to be used in the Flood Model. That is, how wet or how dry the catchment could be in previous different events.

The 2013 Flood Study states *"The results of the sensitivity analysis show that the design losses have a <u>significant impact</u> on flows at Carisbrook"*.

A direction is also to be found in the 2019 Flood Emergency Plan - Appendix C1 (page 49) for Carisbrook which states that *"If the catchment is very wet, move up one level"*. This <u>suggests</u> that what may be a 50-year flood on a "Dry" catchment, could be a 100-year flood on a "Very Wet" catchment.

It was also stated at the Reference Group Meeting that in some previous flood / storm events that they had been preceded by *"heavy rainfall a week or so beforehand"* thus (significantly) wetting the catchment prior to the heavy / flooding rains that subsequently occurred.

As such, due to this high variability, a desire was expressed by the Reference Group that a different Initial Loss should also be modelled to determine just how much of an effect it can have on flood levels. The Reference Group agreed that they would consult with local farmers to determine an appropriate Initial Loss for a Very Wet Catchment for the flood modellers to use.

It is to be noted that the derived Loss Model equations and recommended Initial Loss values provided in Australian Rainfall and Runoff (ARR) for different regions are based on <u>median</u> (i.e., average) loss values in only 38 catchments across Australia. It is to also be noted that the recommended range of Initial Losses, as stated in Australian Rainfall and Runoff (ARR), can vary from 0mm to 80mm depending on the catchment and other circumstances.

When the previously recommended remodelling is undertaken, a 100 AEP model run should be undertaken assuming a "Very Wet" Initial Loss value to determine what effect this has on flood levels at Carisbrook. The Initial Loss value used is to be determined by the Reference Group based on local knowledge of the catchment.

8. Climate Change

The impacts of Climate Change are already being allowed for by many Local and State Government Authorities. Often this manifests itself in the setting of floor levels of houses or business, that are intended to be constructed on a floodplain, and most often takes the form of an additional height of the floor level over and above all other modelling calculations undertaken.

It is noted the 2013 Flood Study considered the implications of what Climate Change might be expected to be by undertaking a sensitivity analysis of rainfall. This modelling suggested:

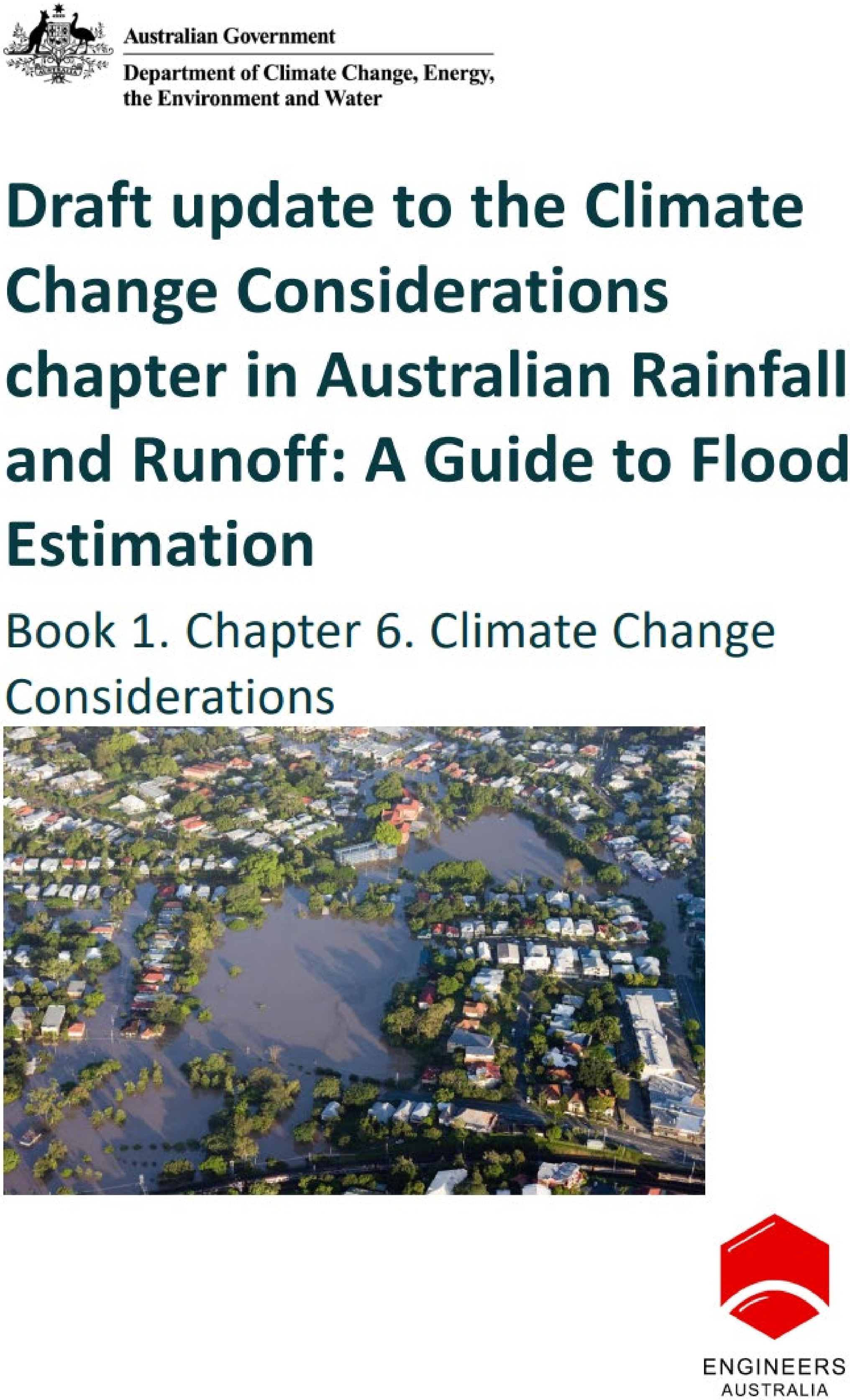
- *"a significant increase in peak flow rates across all three scenarios"*; and
- *"With climate change, extreme events such as January 2011 would become considerably more frequent"*.

No changes were made to any of the modelling other than providing these comments (and undertaking a preliminary assessment). Nor were the effects of Climate Change mentioned in the Design Reports when mentioning what freeboard should be allowed.

In 2024 Engineers Australia published a *"Draft update to the Climate Change Considerations chapter in Australian Rainfall and Runoff: A Guide to Flood Estimation - Book 1. Chapter 6. Climate Change Considerations"*.

It is understood that Council is in the process of obtaining new LIDAR. As such, this new LIDAR should be used to re-run the flood model and, at the same time, use should be made of the draft guideline document to better understand the implications of Climate Change to flooding at Carisbrook.

Council to obtain new LIDAR and re-run the Flood Model, including the implications of Climate Change using the new draft ARR Guidelines.



Australian Government

Department of Climate Change, Energy, the Environment and Water

Draft update to the Climate Change Considerations chapter in Australian Rainfall and Runoff: A Guide to Flood Estimation

Book 1. Chapter 6. Climate Change Considerations

ENGINEERS AUSTRALIA

Figure 8-1 Engineers Australia Draft Climate Change Guidelines

9. A Lesson to Learn from Eugowra NSW

In 2022 the community of Eugowra was flooded causing 2 deaths and damaging / destroying a significant number of homes. Even now, some 2 years later, many residents still do not have adequate housing.

Unfortunately, a number of characteristics of what happened at Eugowra prior to 2022 are eerily similar to the situation at Carisbrook:

1. All the locals "knew" that flooding only came from Puzzle Flat Creek (from the east). Long time locals had seen what happens in previous floods and assumed they knew what happened always,

2. It was considered flooding from Mandagery Creek to the north was *"easily manageable"* and had never been a *"real"* problem in the past,

3. A levee had been constructed 2 years earlier to contain flood flows from Puzzle Flat Creek and that would *"save the town from flooding"*,

Unfortunately, they were wrong!

There HAD been devastating flooding from Mandagery Creek before…but that was back in the 1890's.

No one living was 150 years old, and no one had *"seen it all"*.

No one had experienced flooding from Mandagery Creek before to know what it was really like.

Residents had been lulled into a false sense of security thinking they had seen (and knew) everything….but they hadn't.

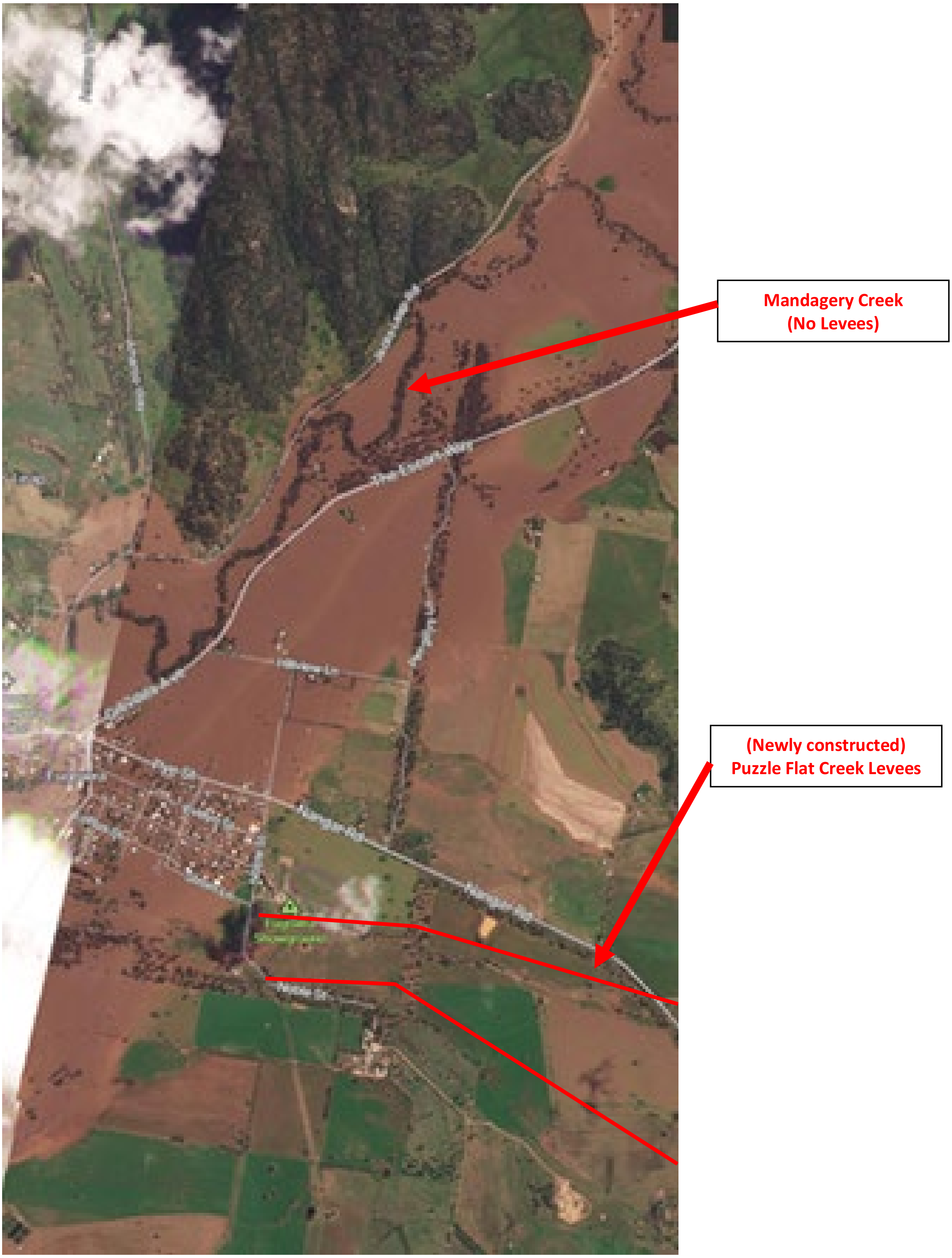


Figure 9-1 Satellite Image of Eugowra being flooded from the north

Appendix A A Quick Ready-Reckoner of Flood Modelling

- An Intensity-Frequency-Duration (IFD) Chart specific to Carisbrook was prepared and used in the model,
- Based on the IFD Chart, for the "western" catchment, the model used 70.5mm of rain in a 6-hour duration storm event to undertake the modelling (as this was the worst case),
- A number of different (hourly) Design Storms patterns (from Australian Rainfall & Runoff 2016) were used to obtain the Design Flows,
- (Hourly) Design Storms used in Australian Rainfall & Runoff 2016 are based on real storms,
- The Design Storms selected were for the region where Carisbrook is situated,
- Design Storm (Temporal Pattern) No. 23 was chosen to model the rainfall in the Western Catchment (as out of all the available patterns this produced the worst flooding). While this pattern has not been provided, the rainfall pattern would vary hour-by-hour until 70.5mm of rain had fallen in 6 hours,
- This 70.5mm of Rainfall was turned into Runoff using the catchment wide RORBS model. This provided the input into the MIKE FLOOD Model used to model flows in and around Carisbrook itself,
- The first 25mm of rain was "not counted" as it just "filled up dams and reservoirs". That is, the modelling did not allow this first amount of rain to produce any flooding,
- Having hourly (or better still half-hourly) rainfall is CRITICAL to understanding flooding around Carisbrook, especially from the western side of town.

While not strictly correct, the below illustrates most of the principles of the Flood Model (using hourly rainfall figures from Clunes for the 2011 Flood Event).

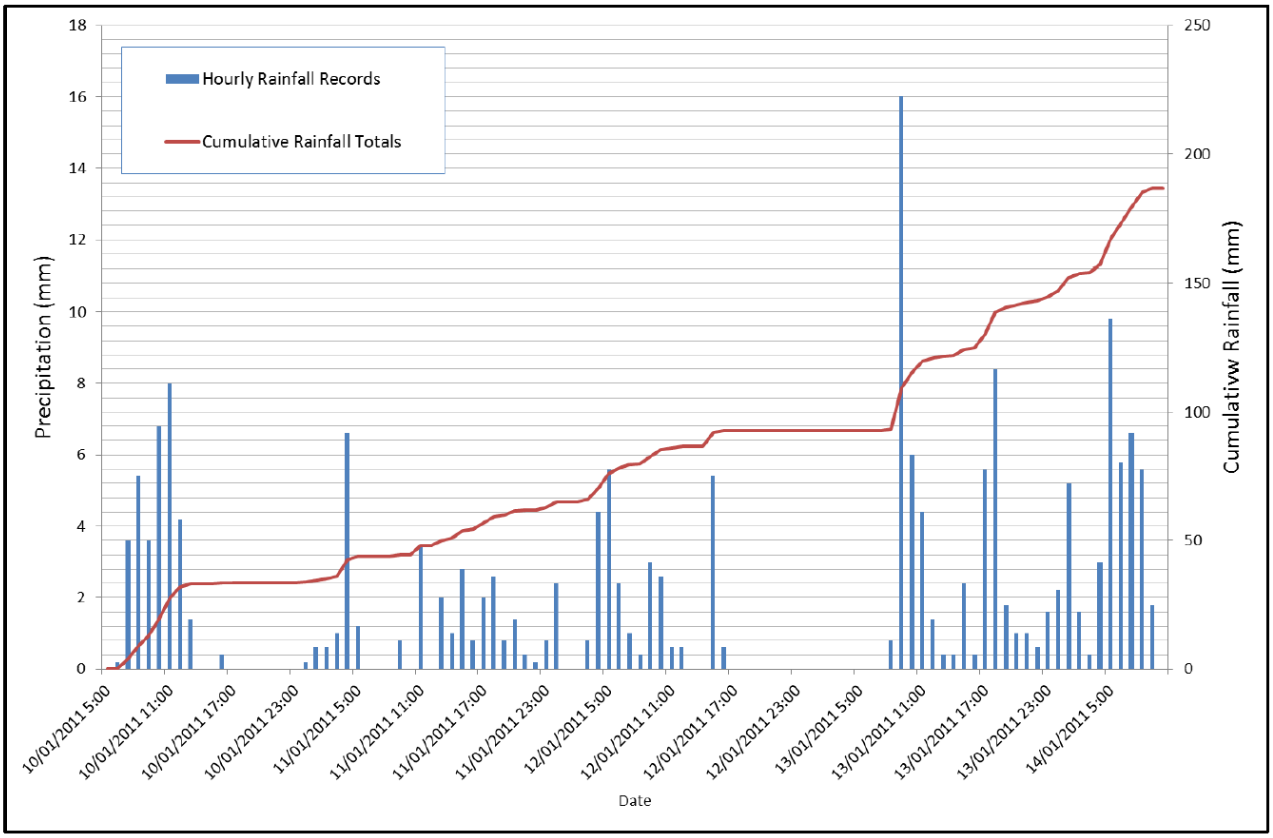


Figure 4-12 Clunes pluviograph – January 2011

Figure 9-2 Hourly rainfall at Clunes for 2011 Flood Event

This shows that the rainfall is quite variable from hour to hour.

- Sometimes it is small,
- Sometimes there is a large spike,
- Sometimes there is a lull,
- It is never constant!

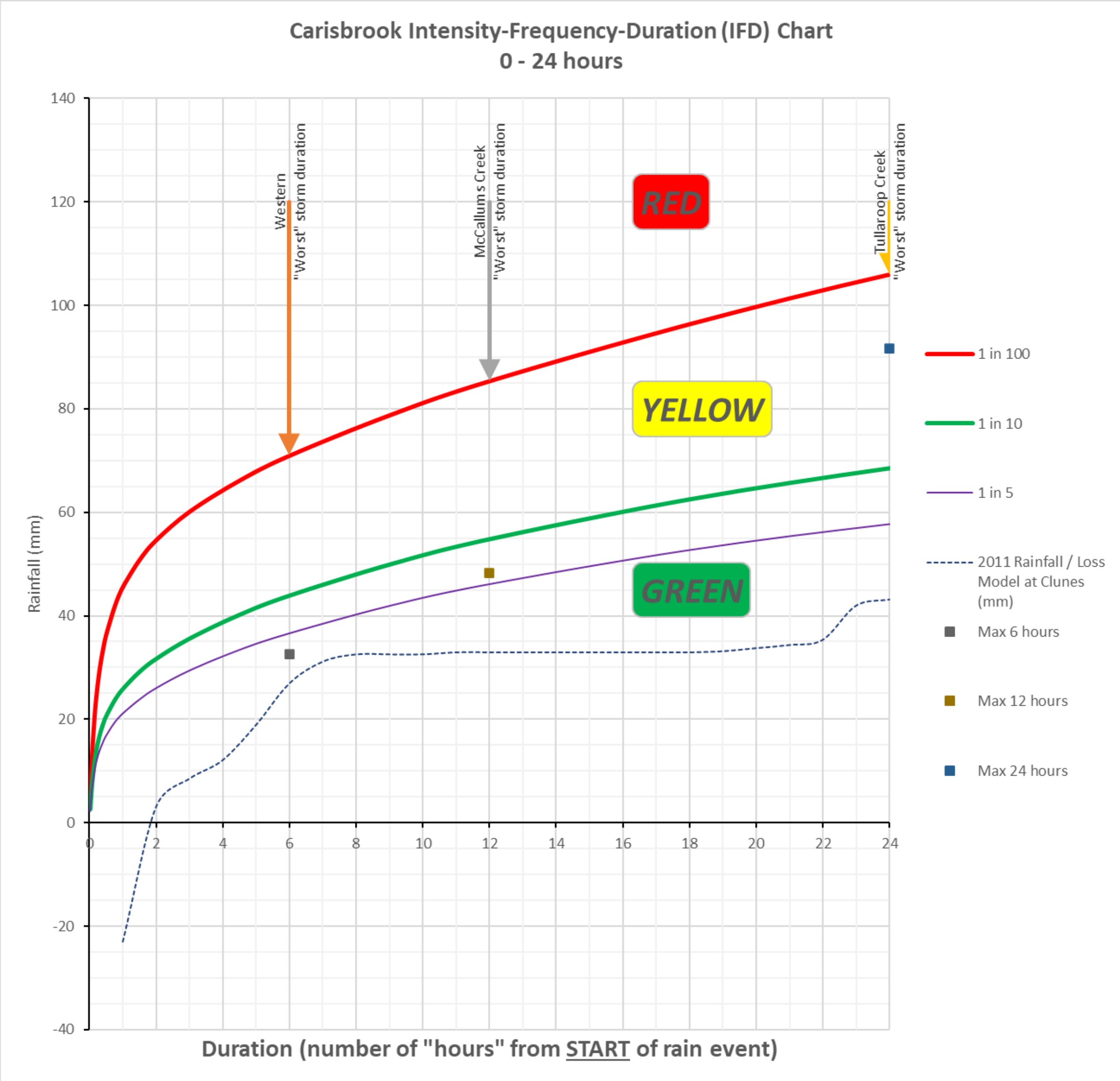


Figure 9-3 Rainfall-Frequency-Duration at Carisbrook for 2011 Flood Event – 0 to 24 hrs from start of first storm event

Note: This is the same as the IFD Chart in the 2019 Flood Study expect it shows millimetres (mm) of rain instead of millimetres / hour (mm/h) of rain on the vertical axis.

The first 25mm of rain in the model doesn't result in flooding. It just wets the ground and fills the dams / reservoirs.

The first storm event didn't result in flooding, but it made everything wet.

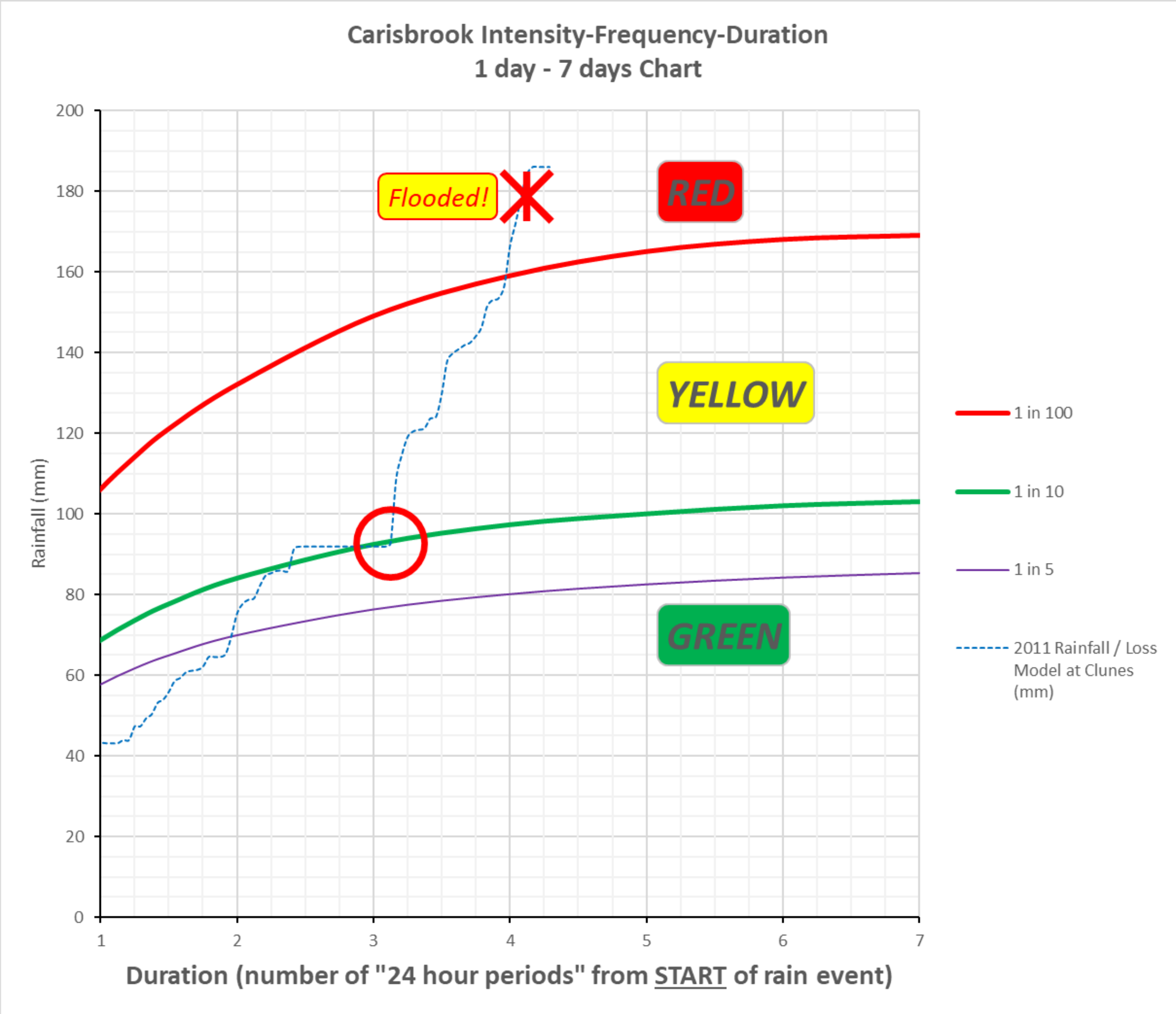


Figure 9-4 Rainfall-Frequency-Duration at Carisbrook for 2011 Flood Event – 1 day to 7 days from start of first storm event

Part way through the second storm event, it is likely flooding in town occurred (as it was probably overwhelming the major (bluestone) drains).

The third storm event *"put the head on it"* and really produced the devastating flooding that occurred.

If the 2011 flood event were to occur now, it is likely Carisbrook would be flooded again.

There is a similar IFD chart in Council's Flood Emergency Plan (that needs updating).

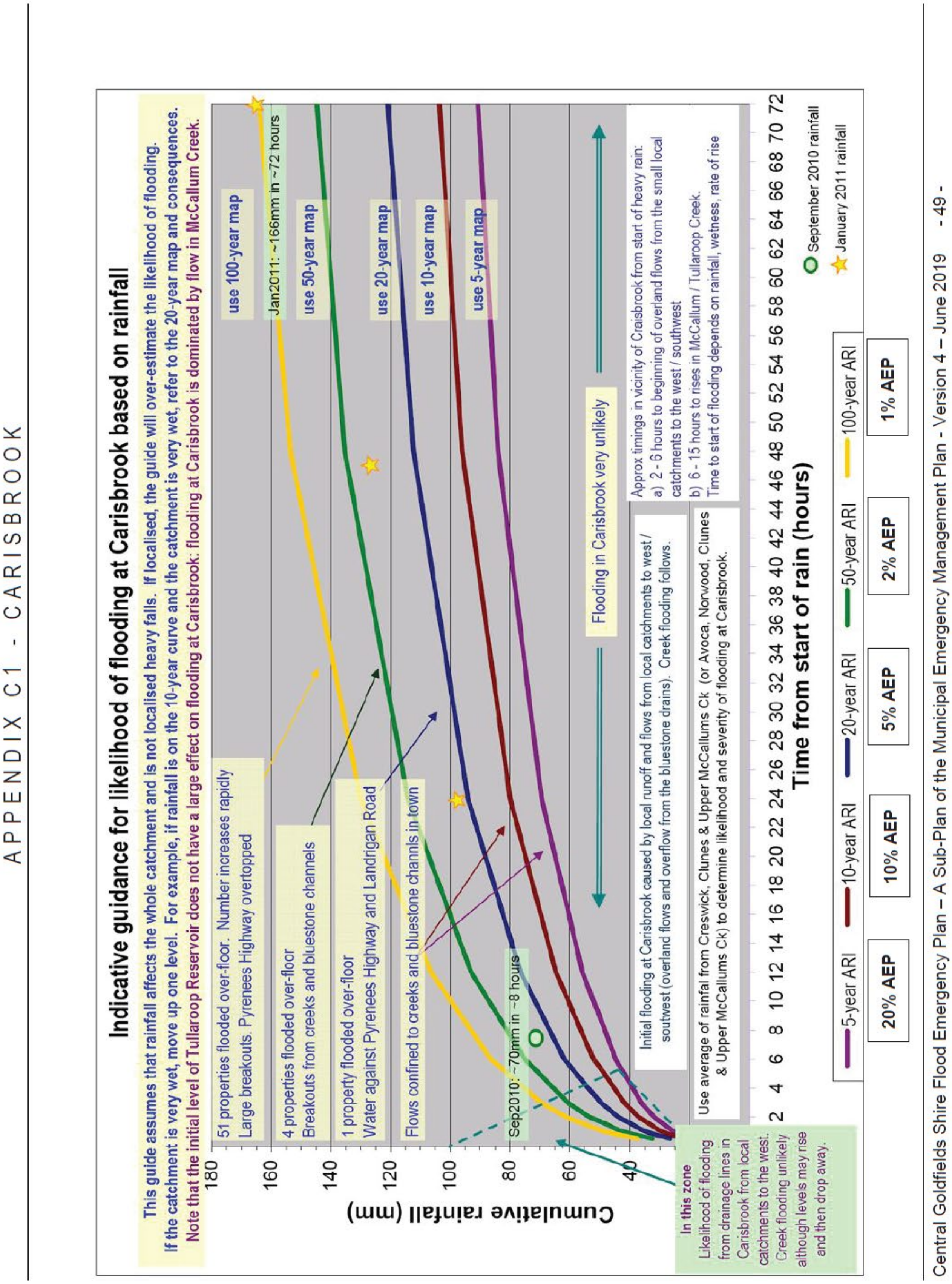


Figure 9-5 Page 49 of the Central Goldfields Shire Flood Emergency Plan – A Sub-Plan of the municipal Emergency Management Plan - Version 4 – June 2019