AECOM

AECOM Australia Pty Ltd
Level 9
8 Exhibition Street
Melbourne VIC 3000
Australia
www.aecom.com

+61 3 9653 1234 tel
+61 3 9654 7117 fax
ABN 20 093 846 925

24 May 2013

David Sutcliffe
Central Goldfields Shire Council
PO Box 194

MARYBOROUGH VIC 3465

Dear David

Review of Carisbrook Flood and Drainage Management Plan - Final Study Report

This letter has been prepared in response to a request from the Central Goldfields Shire Council to undertake a review of the "Carisbrook Flood and Drainage Management Plan – Final Study Report, prepared by Water Technology Pty Ltd, May 2013.

This high level review covers only the Final Study Report, as provided by Council, and does not include review of any models or data analysis. The focus of the review was the applicability of the recommended mitigation option, and the technical assessment of that option.

1.0 Hydrologic assessment

Findings from our review of the hydrologic modelling section of the Final Study Report (as summarised in tables 1 to 6 of this letter) are discussed below. [Please note that reference to other table numbers (e.g. Table 4.18) refers to tables in the Final Study Report].

Table 1 Interpretation of tables 4-7 and 4-9 – RORB model calibration of peak flows

Event	Tullaroop Creek @ Tullaroop Reservoir	Creswick Creek @ Clunes	Tullaroop Creek @ Clunes
Sept 2010 recorded	60 m^3/s	175 m^3/s	405 m^3/s
Sept 2010 modelled	50 m^3/s	198 m^3/s	N/A
% difference for Sept 2010 event	**-17%**	**13%**	**N/A**
Jan 2011 recorded	363 m^3/s	262 m^3/s	401 m^3/s
Jan 2011 modelled	399 m^3/s	462 m^3/s	726 m^3/s
% difference for Jan 2011 event	**10%**	**76%**	**81%**

N/A – Not Available

The results shown in Table 1 indicate that the modelled flows are up to 80% higher than the recorded flows for the January 2011 flood event. The report attributes the difference in flows at Tullaroop Creek at Clunes, to poor data quality at the peak of the flood event. No explanation is given for the 76% difference between recorded and modelled flows for the Creswick Creek at Clunes gauge.

A review of Table 4-18 (Comparison between Design Flows and Rational Method Calculations) in the Final Study Report shows that the design flows are consistently higher than the Rational Method calculations, for the 100 year ARI flood event. The design flows are up to 100% higher for the local catchments and up to 149% higher at McCallum Creek. The report states that, the differences for McCallum Creek may be due to limitations with

Rational Method calculations for large rural catchments. The report attributes the discrepancies in the local catchment flows to “a number of factors such as land use”.

The flows in McCallums Creek (which are estimated to be three times greater than flows in Tullaroop Creek upstream of the confluence of the two creeks, for the 100 year ARI flood event) have not been calibrated in the RORB. This is reportedly due to lack of data at the McCallums Creek gauges for the two calibration flood events.

A review of the RORB calibration factors and the factors adopted for the design events highlights the following:

- A kc value of 10.5 was adopted for the upper reaches of the catchment and 4.79 for the lower reaches of the catchment. These values are significantly lower than the recommended values obtained by using calculations as specified in the report. For example, Table 4-15 of the report shows that the calculations for the kc value using regional estimates, for the upper catchments, range from 50 to 77, whereas the adopted kc value is 10.5. The report states that this is due to a “finer delineation of sub catchments”, and that “despite this discrepancy the calibration process was robust and the results demonstrate that the model provides an excellent representation of catchment behaviour in the study area”.
- The initial loss value adopted for the design events is lower than that specified for Burst 1 in both calibration events, but is higher than the average IL applied over all bursts for the calibration events. This value appears reasonable, but may be slightly conservative.
- The continuing loss value adopted for the design events is higher than the values used for the September 2010 calibration and the CL value for Burst 3 of the January 2011 event (which the first paragraph of section 4.8.2 states, has the highest proportion of the rainfall for this flood event). The combination of initial and continuing losses utilised in this investigation are recommended in Australian Rainfall and Runoff (AR&R).

Results from the sensitivity analysis outlined in the Final Study Report are summarised in Tables 3 to 6.

Table 2 Interpretation of tables 4-19, 4-20 and 4-21 on Design Loss sensitivity analysis – percentage change in peak flow estimates for the 100 year ARI flood event, compared to Scenario 1 (i.e. the adopted design losses).

Scenario	Details	Initial Loss (mm)	Continuing Loss (mm/h)	Tullaroop Creek flow	McCallums Creek flow	Local catchment flow
1	AR&R design losses (upper end of range)	25	2.5	272 m^3/s	817 m^3/s	16.4 m^3/s
2	AR&R design losses (lower end of range)	20	2.5	+42%	+8%	-24%
3	Hill et al. (baseflow index of 0.3)	26.1	3.7	-6%	-27%	-39%
4	Hill et al. (baseflow index of 0.2)	28.6	2.9	-2%	-20%	-40%
5	Hill et al. (baseflow index of 0.1)	31.5	2.0	+12%	-13%	-41%

Table 3 Interpretation of tables 4-22 and 4-23 on Spatial Pattern Sensitivity Analysis – percentage change in peak flow estimates for the 100 year ARI flood event, compared to uniform distribution.

Spatial Pattern	Storm duration	Tullaroop Creek flow	McCallums Creek flow	Local catchment flow
Jan 11 pattern	72 hour	-12%	+17%	+6%
Jan 11 pattern	18 hour	-16%	+27%	+8%

Table 4 Interpretation of table 4-25 on Spatially-Varied IFD Parameters Sensitivity Analysis – percentage change in peak flow estimates for the 100 year ARI flood event, compared to uniform distribution

Spatial Pattern	Storm duration	Tullaroop Creek flow	McCallums Creek flow	Local catchment flow
Upper/lower (spatially-varied)	72 hour	+18%	-24%	-19%

Table 5 Interpretation of tables 4-27, 4-28 and 4-29 on Results of Climate Change Analysis – percentage change in peak flow estimates for adapted climate change conditions compared to existing conditions.

Average Recurrence Interval	Tullaroop Creek flow	McCallums Creek flow	Local catchment flow
100 year ARI	+71%	+56%	+45%
10 year ARI	+208%	+95%	+60%
5 year ARI	+157%	+131%	+72%

Observations on Sensitivity Analysis are summarised as follows:

- The results of Table 3 are consistent with the expected changes in flow due to changes in losses, except for the predicted reduction in local catchment flow for scenario 2. A reduction in the initial loss should result in an increase in flow at all locations, if the continuing loss is kept constant.
- Varying the design losses, within acceptable limits, can change the peak flows by ±40%.
- Changing the design rainfall from a uniform distribution to the spatial pattern from the January 2011 storm event results in changes in peak flows varying from -16% to +27%.
- Applying a spatially-varied IFD pattern results in changes in flows from -24% to +18%.
- Applying an increase in rainfall intensity of 32% (representative of 2100 climate change conditions) results in up to 70% increase in the 100 year ARI design flows and a 208% increase in flows for the 10 year ARI design flood event. The predicted increase in flows for the 10 year ARI flood event appear to be inconsistent with other results within this table and should be investigated further.

  These results highlight the fact that the 100 year ARI design flows could be significantly higher under projected climate change conditions, and events such as the January 2011 flood event may occur more frequently. It may therefore be prudent to adopt conservative model parameters for the hydrologic modelling.

The following statements summarise the hydrologic analysis. However, design flows could be significantly higher under predicted climate change conditions.

- The RORB model was calibrated at two gauge locations: Tullaroop Creek at Tullaroop Reservoir and Creswick Creek at Clunes, for the September 2010 and January 2011 flood events.
- The peak flow for the 100 year ARI flood event in McCallums Creek upstream of Carisbrook, is approximately three times larger than the peak flow in Tullaroop Creek upstream of Carisbrook (based on the results in Table 4-17). However, due to lack of confidence in the gauge data for McCallums Creek, the flows were not calibrated at this location.
- The results in Table 1 indicate that the modelled flows are up to 80% higher than the recorded flows for the January 2011 flood event.
- A review of Table 4-18 shows that the design flows are up to 100% higher than the Rational Method calculations for the 100 year ARI flood event for the local catchments.
- Varying the design losses (within acceptable limits) can change the peak flows by ±40%.

- Changing the design rainfall from a uniform distribution to the spatial pattern from the January 2011 storm event results in changes in peak flows varying from -16% to +27%.
- Applying a spatially-varied IFD pattern results in changes in flows from -24% to +18%.
- Applying an increase in rainfall intensity of 32% (representative of 2100 climate change conditions) results in up to 70% increase in the 100 year ARI design flows.

2.0 Hydraulic assessment

The following observations were made with regard to the hydraulic model calibration, as documented in the Final Study Report:

- The report states that the modelled flood levels were “slightly higher” than the recorded flood levels for the September 2010 flood event.
- The report states that the modelled flood levels were “slightly lower” than the recorded flood levels for the January 2011 flood event. The concern with this statement is the inconsistency with the results of the RORB model calibration, which states that the modelled flows are up to 80% higher than the recorded flows for the same event.
- Increasing the roughness values (open grassed agricultural areas from 0.04 to 0.05, waterways from 0.035 to 0.045 and bluestone drains from 0.02 to 0.03) and changing the hydraulic structures (no details on these changes have been documented in the report) resulted in an increase in water levels of approximately 100-200mm.
- Figure 5-2 – (2D hydraulic model roughness grid) doesn’t indicate what the blue colour represents. As this is believed to represent ‘dense vegetation’, which is one of the key considerations of the mitigation assessment, it should be shown on this figure.
- The report states that flooding of the Carisbrook Township occurs when the Tullaroop Creek overtops, at a flow of around 900 m^3/s.
- The peak flow in Tullaroop Creek downstream of the confluence with McCallums Creek was estimated at 779 m^3/s for the September 2010 event and 1000 m^3/s for the January 2011 event. The 100 year ARI design flow at this location is estimated to be 882 m^3/s.
- Flood levels on Tullaroop Creek, upstream of the Pyrenees Highway were estimated to be 1.6m higher in the January 2011 event than in the September 2010 event.
- Flood levels on Tullaroop Creek, upstream of the rail bridge were estimated to be 1.3m higher in the January 2011 event than in the September 2010 event.

The following observations were made with regard to the design flood modelling:

- The Manning’s ‘n’ roughness value for the main bluestone drains was changed from 0.03 for the calibration runs to 0.025 for the design runs, to represent the clearing of silt and weeds by the Central Goldfields Shire Council. It is unusual to modify parameters such as the Manning’s roughness following calibration of a model unless it is to reflect permanent mitigation works. Of concern with this representation is the assumption that the bluestone drains will be regularly maintained to be free of silt and weeds.
- The extent of flooding for the 100 year ARI design flood event shows that flood water breaks out of Tullaroop Creek, which results in significant overland flow through Carisbrook. Comparing this to the modelled flood extent for the September 2010 flood event, in which the flow was contained within Tullaroop Creek, it can be deduced that the 100 year ARI flood event only just exceeds the capacity of Tullaroop Creek through Carisbrook. The 100 year ARI flow downstream of the confluence of Tullaroop and McCallums Creek is estimated to be 882 m^3/s, which is 13% higher than the September 2010 peak flow estimate of 779 m^3/s at the same location. This shows that flooding of Carisbrook is very sensitive to the peak flow estimate for the 100 year ARI flood event in Tullaroop Creek, and a small reduction in flows or flood levels may prevent the break out.

3.0 Revised Mitigation Packages

The Final Study Report includes several sections on the mitigation options proposed to reduce flooding, and the process of selecting the preferred mitigation options for further assessment. From the documentation, it appears that following modelling of the preferred mitigation options, additional refinement and revision of these mitigation options was undertaken. These sections are of the Final Study Report are difficult to follow, and the reasons for certain decisions are not clear.

Table 7 summarises our understanding of the findings in this section of the report.

Table 6 Summary of mitigation options.

	Option A	**Option B**	**Option C**	**Option D**
Description	**Western Levee and Vegetation Works**	**Belfast Road Levee and Vegetation Works**	**Pyrenees Highway Bridge upgrade**	**Strategic Levee**
Reduction in flood levels in Tullaroop Creek	0.25m	0.25m	0.02m	N/A
Reduction in flooding from local catchments	yes	yes	no	no
Estimated reduction in AAD*	$33,099	$33,099 (based on Option A calculations)	N/A	$29,026 (includes vegetation works in Tullaroop Creek)
Construction cost	$1,651,373	$742,252	$7,100,000	$402,269 (excludes vegetation works in Tullaroop Creek)
Land acquisition required	yes	no, upgrades to an existing levee proposed	no	yes
Benefit cost ratio*	0.1	N/A	N/A	N/A
Adverse impacts	None stated	Increased flood levels at one property	None Stated	Increased flood levels for properties south of the levee
Steering committee support	yes	No	no	no

* Based on Table 7-2 Benefit Cost Analysis

N/A – Not Available

It is not clear what information was utilised to represent floor levels for the flood damage assessment.

3.1 Option A – Western Levee and Vegetation Works

This option consists of a construction of a western levee and floodway, vegetation works on Tullaroop Creek, a small levee near Williams Road and a non-return valve on culverts under Landrigan Road near Camp Street.

The Western Floodway is highlighted in the executive summary as being the preferred option. This option has been designed to protect the town from the local catchment flows by using a combined earthen levee and channel running north-south to the west of the town.

We have the following concerns on the documentation provided for this option:

- The levee only 'protects' from the local catchment flooding, and doesn't address flooding from Tullaroop Creek.

- Relies on regular and on-going 'maintenance of the waterways' to reduce flood levels in Tullaroop Creek and prevent the breakout of flow through Carisbrook.

  This has been represented in the modelling as a change in Manning's 'n' values from 0.045 to 0.040 in the channel and 0.080 to 0.040 in the trees and dense vegetation adjacent to the channel. Section 6 of the report specifies that this change in Manning's 'n' value results in an approximate reduction in flood levels of 0.25m in Tullaroop Creek upstream of the highway bridge. This reduction in flood levels prevents the break out of flow from Tullaroop Creek through the Township.

  The applicability of this reduction in Manning's 'n' values and the resultant reduction in flood levels cannot be confirmed without an understanding of the calibration of the hydraulic model, sensitivity of the modelling to this factor and existing and proposed vegetation species. No information has been provided on what works would be required to achieve and maintain these roughness values. A guidance note or specification should be provided to advise how these roughness values can be achieved, and what maintenance works will be required, and who should undertake these works.

  The applicability of 'maintenance of the waterways' as a long term flood protection measure also requires confirmation. What mechanisms will be put in place to ensure that the assumed maintenance regime will be undertaken in the future?

  The area of waterway maintenance proposed has been restricted to the section of Tullaroop Creek between Camp Street and the Railway Bridge. It is possible that debris from further up in the catchment could be carried down in flood waters, resulting in an obstruction to the waterway (especially at structures such as the Pyrenees Highway and railway bridges), which could negate part of this decrease in flood levels. The potential for blockage of structures doesn't appear to have been allowed for in any of the modelling.

- Proposes construction of a 3km long levee, to direct flow from the south to the north. The levee crosses the Pyrenees Highway and the Railway line. It is not clear how levee be will be constructed over or along existing roads, or over what appears to be an existing drain near the corner of Pleasant St and Darling/Wills St. Another concern with the construction of this levee is the potential for it to block existing flow paths, which may lead to reduced flow into farm dams on the other side of the levee.

  The visual or social impact of this levee has not addressed in the report.

- Construction of culverts under the railway line. It is proposed that 4 x 1.2m by 0.45m reinforced concrete box culverts (RCBC's) be installed under the railway line with 600mm cover. Reinforced Concrete Pipes (RCP's) are generally used in flat areas, rather than RCBC's to ensure self-cleansing velocities are achieved for lower recurrence interval events. Due to the vibration and heavy loads of trains, 1.2m of cover is usually required for any culverts under a rail line. This requirement may lead to constructability issues with this mitigation option.

- One-way flaps on culverts. A recommendation has been made to install one-way flaps on the Landrigan Road Culverts. All one-way valves or flaps require a level of maintenance to ensure that they are functioning when required. If this maintenance is not carried out they may not be effective under flood conditions. Therefore, maintenance requirements for these should be taken into consideration.

3.2 Option B – Belfast Road Levee and Vegetation Works

The purpose of Option B is to divert flows from south of the town, east to McCallums Creek, by upgrading a series of existing levees and drains near the Cemetery and Belfast Road. Vegetation clearing works will also be implemented in Tullaroop Creek.

The following observations were made regarding the documentation of this option:

- The use of vegetation clearing as a mitigation option (as previously described in Section 3.1 of this report).

AECOM

- Increase in flood levels south of Belfast Road. A "15cm increase in flood levels" is predicted for the property at 7 Belfast Road. This property has existing above floor flooding, which may need to be addressed with localised mitigation measures.
- As no modelling was undertaken for this option, a flood damage assessment and cost benefit analysis were not performed. Based on the text in Section 8.2 of the report, it can be assumed that the reduction in flood extent will be similar to that proposed for Option A, which estimates a reduction in Average Annual Damages of around $33k. However, the increased flood liability for the property at 7 Belfast Street may reduce this. When comparing the construction costs for Option B to Option A, we find they are around $909k lower. If a cost benefit analysis were undertaken on this data, it is expected that a higher benefit-cost ratio would be achieved than for Option A.

3.3 Option C – Pyrenees Highway Bridge upgrade

Option C includes the replacement of the existing Pyrenees Highway Bridge over Tullaroop Creek with a clear span structure. This option is reported to reduce flood levels by approximately 0.02m. The estimated cost of this option is $7.1M. However, this option would need to be constructed by VicRoads. Due to the high cost and small reduction in flood levels, this is not considered to be an efficient flood mitigation measure for Carisbrook.

4.0 Option D – Strategic Levee

Option D includes the construction of a strategic levee south of the Pyrenees Highway, to mitigate against riverine flooding from Tullaroop Creek.

We have the following concerns regarding the documentation of this option:

- Construction of the levee: it is not clear what will happen to properties on the "wrong side of the levee". How will this levee be constructed over or along existing roads? The visual impacts and potential for social dislocation of this option have raised but not addressed in the report.
- Construction costs have been estimated to be up to $402k. No allowance has been made for land acquisition or implementation of an easement on private land. Also the social impacts of this levee have not been investigated or costed.

5.0 Conclusions

This review has been undertaken based on the information provided by the Central Goldfields Shire Council. The following is a summary of the key findings from the review.

The document is generally well written, but includes several editorial errors and inconsistencies. . Below is an indication of some of these (please note that this is not an exhaustive list, as the purpose of this assignment was to undertake a technical, not editorial review).

- Table 4-7 title "RORB model calibration peak flows – September 2010 event" with the first column labelled "January 2011".
- Inconsistency with naming of locations eg Table 4-17 "RORB model design peak flows and critical storm durations at selected locations" includes a lable for "Local Tributary D/S of Carisbrook Reservoir"
- Spelling of "Cumulative" as "Cumulativw" on the second y axis on Figures 4-9 and 4-11.

5.1 Hydrologic Analysis

a) The results in Table 1 indicate that the modelled flows are up to 80% higher than the recorded flows for the January 2011 flood event.

b) A review of Table 4-18 shows that the design flows are up to 100% higher than the Rational Method calculations for the 100 year ARI flood event for the local catchments.

c) Varying the design losses (within an acceptable range) can change the peak flows by ±40%.

d) Changing the design rainfall from a uniform distribution to the spatial pattern from the January 2011 storm event results in changes in peak flows varying from -16% to +27%.

e) Applying a spatially-varied IFD pattern results in changes in flows from -24% to +18%.

f) Applying an increase in rainfall intensity of 32% (representative of 2100 climate change conditions) results in up to 70% increase in the 100 year ARI design flows.

5.2 Hydraulic Analysis

g) The report states that the modelled flood levels were “slightly higher” than the recorded flood levels for the September 2010 flood event.

h) The report states that the modelled flood levels were “slightly lower” than the recorded flood levels for the January 2011 flood event. The concern with this statement is the inconsistency with the results of the RORB model calibration, which states that the modelled flows are up to 80% higher than the recorded flows for the same event.

i) Flood levels in Tullaroop Creek upstream of the Pyrenees Highway were estimated to be 1.6m higher in the January 2011 event than in the September 2010 event. Flood levels in Tullaroop Creek upstream of the rail bridge were estimated to be 1.3m higher in the January 2011 event than in the September 2010 event.

j) The Manning’s ‘n’ roughness value for the main bluestone drains was changed for the design runs. It is unusual to modify parameters such as the Manning’s roughness following calibration of a model.

k) Modelling shows that a 13% increase in flow from the September 2010 peak of 779 m^3/s to the 100 year ARI design peak of 882 m^3/s results in breaching of the banks of the creek and inundation of Carisbrook. This shows that flooding of Carisbrook is very sensitive to the peak flow estimate for the 100 year ARI flood event in Tullaroop Creek, and a small reduction in flows or flood levels may prevent the break out.

5.3 Revised Mitigation Packages

l) The focus of the preferred mitigation option is ‘protection’ from flooding of the local catchments. The proposed Western Levee will not reduce flood levels in Tullaroop Creek or prevent flooding of Caribrook caused by the break out of flow from Tullaroop Creek.

m) The reliance on ‘maintenance of the waterways’ to reduce flood levels through the township is not recommended. Based on the information provided in the Final Study Report, it is not possible to determine what these works will include and how they will be implemented and maintained. We do not believe that this is a sustainable mitigation option, and should not be included in any mapping outputs of this investigation that are used for planning or emergency services purposes. The long term viability of this option is questioned.

n) Comparing Option A to Option B indicates that both options are expected to achieve similar reductions in flood levels, with the cost of Option A (the preferred option) being more than double that of Option B.

5.4 Summary

The following observations summarise this review:

- The hydrologic model does not appear to reflect recorded conditions very well, with significant differences between recorded and modelled flow (up to 80%), especially for the January 2011 event.
- There is significant uncertainty in the design flow estimates (in the order of ±40% change in flows due to the selection of design losses alone).
- The dominant flooding mechanism in Carisbrook is breakout flow from Tullaroop Creek. The 100 year ARI design flood event results in a breakout from Tullaroop Creek, which floods Carisbrook.

- The potential impact of climate change on increased rainfall intensities will increase 100 year ARI flows by up to 70%, which will result in an increase in the frequency of breakout flows from Tullaroop Creek through Carisbrook.
- Construction of Options A or B will protect some properties from local flooding but will not protect from flooding in Carisbrook due to breakout flows from Tullaroop Creek.
- Maintenance of the waterways is not considered to be a sustainable mitigation option that will protect the town from flooding. The 0.25m reduction in flood levels achieved by changing modelling factors cannot be translated into a technical specification that can be implemented and maintained. The sensitivity of the breakout to this reduction in levels for the 100 year ARI flood event has not been explored or explained sufficiently to give confidence that it can be achieved with physical works, and there is no guarantee that it will be adequately maintained. We believe that these works will assist in reducing flood levels in Tullaroop Creek and should be undertaken if possible, but should not be relied on to provide flood protection for Carisbrook.
- The increased construction cost of the preferred option (Option A, $1,651,373) over option B ($742,252), needs to be considered in terms of the increased benefits of Option A over Option B.

If you have any queries or require additional information, please contact me.

Yours faithfully

Melanie Collett
Associate Director – Water Resources
melanie.collett@aecom.com

Mobile: +61 413 188 052
Direct Dial: +61 3 9653 8947
Direct Fax: +61 3 9654 7117