Executive summary

The city of Bundaberg and surrounding areas have recently experienced a number of major flood events that have had a significant impact on the local community. In order to reduce the adverse impacts of future large Burnett River floods on people, property and infrastructure, Bundaberg Regional Council committed to the development of a Floodplain Action Plan. The Floodplain Action Plan is comprised of a number of activities including:

- A comprehensive flood modelling project;
- A flood warning & evacuation route mapping project; and
- A Floodplain Risk Management Study (FRMS) and Floodplain Risk Management Plan (FRMP).

As the first step in the FRMS and to meet State Government requests, BRC engaged GHD to undertake a Preliminary Options Assessment in order to identify a range of large-scale flood mitigation measures that would increase community resilience to flooding. Over the coming months, the FRMS will consider the full range of floodplain management practices including early flood warning systems, land use planning, emergency management planning, evacuation capabilities, as well as large-scale flood mitigation projects.

The options under consideration in this report are large-scale projects with a focus on flood modification. If taken forward, these projects would require a substantial commitment of resources from government. It is noted that these large-scale options only represent one aspect of best-practice floodplain management. In general terms, floodplain management practices can span the categories listed in Table 1-1.

### Table 1-1 Floodplain management practices

<table>
<thead>
<tr>
<th>Theme/category</th>
<th>Types of measures, ideas, options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flood prevention</td>
<td>Designing measures to alter the behaviour of the flood itself by reducing flood levels and/or velocities or by excluding flood waters from areas at risk. Options may include, but is not limited to, levees, river dredging and vegetation removal.</td>
</tr>
<tr>
<td>modifications</td>
<td></td>
</tr>
<tr>
<td>2. Property modifications</td>
<td>Modifications to existing buildings to reduce flooding impacts. Options may include measures to improve property resilience and house raising.</td>
</tr>
<tr>
<td>3. Development controls</td>
<td>Reviewing building and planning codes such as setting minimum floor heights and changed land uses to reduce the risk of flood impacts.</td>
</tr>
<tr>
<td>4. Response modifications</td>
<td>Increasing the ability of people to respond appropriately in times of flood and/or enhancing the flood warning and evacuation procedures in an area. Options may include, but is not limited to, improving community awareness, improving flood warning systems, and updating local flood and evacuation plans.</td>
</tr>
</tbody>
</table>

The full spectrum of floodplain management practices will be considered and addressed as part of the final FRMS report, due later in 2014. Section 1.5 includes a description of some of the activities that are currently underway and that will be included in the final report. It is critical that decision makers consider all of these flood management practices, not just the large-scale projects presented herein, when determining funding priorities.

The key stages and outcomes of the current assessment are summarised below.
**Study area**

The area of focus for the current study is the lower Burnett River floodplain extending from below Paradise Dam (130km AMTD) to the river mouth at Burnett Heads (0km AMTD). For the purpose of this report, the floodplain is defined as those areas within the riverine Probable Maximum Flood extents as defined in the Burnett River Flood Study (GHD 2013).

**Identification of potential large-scale options**

For this report, a range of potential large-scale flood mitigation measures were identified by GHD, Council and the community. In accordance with best practice floodplain management principles, a comprehensive community consultation program was undertaken to better understand which options and strategies they would like Council to consider as part of the overall Floodplain Action Plan. This public ideas collection was supported by a dedicated, independently facilitated Community Reference Group that will remain in place until the Action Plan is adopted by Council. In addition to the public ideas collection, technical input from key stakeholder organisations, known as the Technical Working Group, was also sought.

The community provided feedback across the full range of flood management practices outlined in Table 1-2. From those suggestions, GHD, BRC and the CRG developed a list of potential large-scale flood mitigation projects for assessment. A wide range of measures was considered including dredging, levees, diversion channels, river widening works, vegetation clearing, road and bridge upgrades and removal of structures such as the Ben Anderson Barrage. Some of these options were discounted upon initial review (as discussed in Section 6.5) and the remaining list of twenty proposals was taken forward to the next phase of the study (as discussed in Section 6.4).

At this stage in the process, due to the large number of options under consideration, high-level assumptions were made about potential levee alignments and heights, dredging extents and depths, and diversion channel dimensions. Conceptual designs based on engineering advice would later be developed for those options that appeared most viable.

It is noted that development controls and flood response measures (e.g. improving the flood warning system) were not included in this preferred list of large-scale options as they are being investigated in a later phase of the Floodplain Action Plan.

**Identification of preferred options (multi – criteria analysis)**

The list of potential large-scale mitigation options was then fed into a multi-criteria analysis (MCA) to highlight those options that might best meet the expectations of the community. As part of the MCA process, a set of social, environmental and economic criteria was established and each flood mitigation option assessed (scored) against these criteria. The MCA was used as a tool to help focus efforts on a smaller list of options given the time constraints for this project.

The social, environmental and economic criteria used in the assessment are summarised in Table 1-2 below.
Table 1-2 MCA Criteria

<table>
<thead>
<tr>
<th>Social Criteria</th>
<th>Environmental Criteria</th>
<th>Economic Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication / notification during a flood event</td>
<td>Impact on terrestrial environment (flora / fauna)</td>
<td>Overall cost-benefit</td>
</tr>
<tr>
<td>Flood warning time</td>
<td>Impact on aquatic / riparian environment (flora / fauna)</td>
<td>Cost of implementation</td>
</tr>
<tr>
<td>Frequency and duration of flooding or isolation / effects of isolation</td>
<td>Difficulty of environmental approvals</td>
<td>Cost of maintenance / upkeep</td>
</tr>
<tr>
<td>Impact on direct exposure to flood hazard / safety</td>
<td>Impact on river stability / sedimentation</td>
<td>Inundation of agriculture land</td>
</tr>
<tr>
<td>Visual amenity</td>
<td>Erosion / scour to floodplain</td>
<td>Impact on local business / commercial land</td>
</tr>
<tr>
<td>Cultural heritage</td>
<td></td>
<td>Impact on residential properties</td>
</tr>
<tr>
<td>Impact on community infrastructure</td>
<td></td>
<td>Impact on municipal infrastructure / utilities</td>
</tr>
<tr>
<td>Impact on evacuation routes</td>
<td></td>
<td>Impact on fisheries</td>
</tr>
<tr>
<td>Impact on recovery / accommodating the displaced victims of a flood</td>
<td></td>
<td>Impact on tourism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impact on developable land</td>
</tr>
</tbody>
</table>

Of the range of identified options, the MCA process helped to identify the following eight options that were taken forward for more detailed assessment:

- Construction of a levee and floodgate in East Bundaberg;
- Regional Bridge Upgrades;
- Bundaberg North Evacuation Route Upgrades;
- Funding for house raising / restumping;
- Construction of a levee in North Bundaberg;
- Dredging of the Burnett River in the town reach;
- Construction of a low-level levee in North Bundaberg; and
- Widening the Burnett River at Millaquin Bend.
Existing conditions flood damages assessment

Within the study area (defined by the extents of the Probable Maximum Flood on the Burnett River between the Paradise Dam and the river mouth), a flood damages assessment was undertaken to establish a baseline for assessing the reduction in flood damage costs provided by each of the flood mitigation options. Probable tangible flood damages were assessed for residential, commercial, industrial and agricultural land use types within the Burnett River floodplain. The damage estimation methodology adopted used stage-damage curves to estimate average annual flood damages (AAD) for ‘existing’ and ‘mitigated’ conditions and the total reduction in average annual flood damage for each option.

The estimated damage costs presented herein are an approximation only, and were determined in accordance with the standard limited methodology normally used in these assessments. The damages are not intended to represent the full economic impact of a flood event. For instance, building damage is based on standard recommended “damage curves” rather than actual insurance data, and assessment of agricultural damage is limited to loss of sugar cane crops and damages to farm buildings only. Improvements to these estimates could be achieved if recent and specific insurance flood damage information was available. Nonetheless, the methodology is appropriate for the intended purpose of highlighting the relative severity of flood impacts in various areas as well as comparing various mitigation measures. Care should be taken when interpreting the damage and benefit-cost ratios (i.e. the costs in the benefit cost ratio calculation do not take into account the full range of socio-economic impacts).

Table 1-3, Table 1-4 and Table 1-5 provide a summary of the number of properties that experience above floor flooding for the range of design flood events, a breakdown of damages by property type, and the estimate of the total and annual average damages.

Table 1-3 Number of properties with above floor flooding

<table>
<thead>
<tr>
<th>Flood event</th>
<th>Residential</th>
<th>Commercial</th>
<th>Industrial</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% AEP</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>10% AEP</td>
<td>6</td>
<td>5</td>
<td>8</td>
<td>19</td>
</tr>
<tr>
<td>5% AEP</td>
<td>50</td>
<td>21</td>
<td>62</td>
<td>133</td>
</tr>
<tr>
<td>2% AEP</td>
<td>533</td>
<td>92</td>
<td>211</td>
<td>836</td>
</tr>
<tr>
<td>1% AEP</td>
<td>1194</td>
<td>136</td>
<td>396</td>
<td>1726</td>
</tr>
<tr>
<td>0.5% AEP</td>
<td>2364</td>
<td>175</td>
<td>558</td>
<td>3097</td>
</tr>
<tr>
<td>0.2% AEP</td>
<td>3165</td>
<td>226</td>
<td>741</td>
<td>4132</td>
</tr>
<tr>
<td>PMF</td>
<td>10877</td>
<td>633</td>
<td>1603</td>
<td>13113</td>
</tr>
</tbody>
</table>

Table 1-4 Summary of flood damages by property type

<table>
<thead>
<tr>
<th>Flood event</th>
<th>Residential ($)</th>
<th>Commercial ($)</th>
<th>Industrial ($)</th>
<th>Agricultural ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% AEP</td>
<td>148,000</td>
<td>0</td>
<td>211,000</td>
<td>36,000</td>
</tr>
<tr>
<td>10% AEP</td>
<td>945,000</td>
<td>248,000</td>
<td>474,000</td>
<td>167,000</td>
</tr>
<tr>
<td>5% AEP</td>
<td>7,093,000</td>
<td>3,975,000</td>
<td>4,042,000</td>
<td>452,000</td>
</tr>
<tr>
<td>2% AEP</td>
<td>54,411,000</td>
<td>13,380,000</td>
<td>22,314,000</td>
<td>588,000</td>
</tr>
<tr>
<td>1% AEP</td>
<td>115,647,000</td>
<td>19,806,000</td>
<td>38,133,000</td>
<td>1,954,000</td>
</tr>
<tr>
<td>0.5% AEP</td>
<td>225,121,000</td>
<td>26,629,000</td>
<td>73,283,000</td>
<td>2,210,000</td>
</tr>
<tr>
<td>0.2% AEP</td>
<td>338,202,000</td>
<td>36,240,000</td>
<td>100,083,000</td>
<td>2,405,000</td>
</tr>
<tr>
<td>PMF</td>
<td>1,496,798,000</td>
<td>136,194,000</td>
<td>217,208,000</td>
<td>6,447,000</td>
</tr>
</tbody>
</table>
Table 1-5  Estimated total & annual average damages within study area

<table>
<thead>
<tr>
<th>AEP (%)</th>
<th>Existing Conditions Damage ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>$748,000</td>
</tr>
<tr>
<td>10%</td>
<td>$2,909,000</td>
</tr>
<tr>
<td>5%</td>
<td>$21,786,000</td>
</tr>
<tr>
<td>2%</td>
<td>$120,445,000</td>
</tr>
<tr>
<td>1%</td>
<td>$234,366,000</td>
</tr>
<tr>
<td>0.5%</td>
<td>$424,361,000</td>
</tr>
<tr>
<td>0.2%</td>
<td>$620,779,000</td>
</tr>
<tr>
<td>PMF (0.00001%)</td>
<td>$2,472,272,000</td>
</tr>
</tbody>
</table>

Average Annual Damage within Study Area: $11,131,000
Net Present Value (NPV) of Damages (Existing Conditions) $153,614,000

**Concept design & detailed flood modelling**

For each of the eight selected options, conceptual designs were developed based upon the experience and expertise of a range of civil engineering, marine engineering and environmental specialists (refer to Section 8). The purpose of these concept designs was to enable the estimation of high-level project costs, key implementation risks and environmental issues. It also allowed a detailed assessment of the options using the calibrated hydraulic model of the Burnett River developed as part of the Burnett River Flood Study (GHD 2013).

Detailed flood modelling was undertaken to assess the hydraulic impacts of the dredging, levee and river widening options. This included modification of the ‘existing conditions’ hydraulic model to include the proposed mitigation options and simulation of the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF design flood events. The hydraulic impacts of the modelled flood mitigation options are outlined in Section 8.

**Flood mitigation option cost estimates**

High level cost estimates have been determined for each of the selected flood mitigation options. The cost estimates are preliminary in nature and will need to be refined during conceptual and detailed design project phases. Key investigations such as geotechnical studies would have to be undertaken to arrive at more accurate costs for any option that is to be taken forward. Detailed information on each of the cost estimates is provided in Section 8.

**Benefit cost analysis**

A benefit cost analysis was undertaken to assess the economic viability of each of the selected dredging, levee and river widening options. The analysis was based on the reduction in probable tangible flood damages calculated from the results of the detailed hydraulic modelling. A benefit cost ratio was not established for the road, bridge and house raising options as no hydraulic modelling was undertaken for those. Detailed information on each of the benefit cost ratio calculations is provided in Section 8.

**Environmental issues**

In considering each of the selected options, potential environmental issues and management measures were considered. The potential issues range from direct disturbance of flora and fauna, to water quality impact and noise, light and dust issues. Detailed information on the potential environmental issues is provided in Section 8.
**Recommended large-scale flood mitigation options**

Following consideration of the hydraulic modelling results, cost estimates, benefit-cost ratios and potential environmental issues, recommendations can be made as to the most viable flood mitigation options. For further detail on each of the recommended options refer to Section 8.

**East levee and floodgate**

The east levee and floodgate proposal has emerged from detailed assessment as the most viable levee project for the Bundaberg area. While the estimated outright costs of this option ($71M capital works) are substantial, a preliminary assessment of the benefits (reduction in tangible flood damage) is favourable. An estimated total of 741 properties would have a greatly reduced risk of experiencing above-floor flooding in a 1% AEP event if the levee were constructed. With a benefit-cost ratio of 0.77, this option warrants further consideration. If this option is to be taken forward, a geotechnical assessment and a local flood assessment should be undertaken to underpin the preliminary design.

**Millaquin bend widening works**

Widening the river at Millaquin bend appears favourable following detailed assessment despite the substantial estimated costs ($32.1M capital works and $2.1M/yr on-going maintenance). Benefits in terms of reduced flood levels are experienced across Bundaberg, including areas on both the south and north sides of the river. An estimated total of 436 properties would have a greatly reduced risk of experiencing above-floor flooding in a 1% AEP event if the works were constructed. The overall benefit-cost ratio of 0.50 justifies further consideration of this proposal. Further detailed design iteration and optimisation would follow the completion of geotechnical and environmental surveys.

**Funding for house raising**

This proposal is a potentially beneficial flood mitigation scheme. BRC should consider the selection of eligibility criteria so that any funds made available for this scheme maximise the benefit to the community in terms of both equity and flood damage reductions.

**Perry River Bridge upgrade**

The construction of a new Perry River Bridge 8 m higher than the existing bridge would bring this crossing up to an equivalent flood immunity standard to the St Agnes Creek Bridge. The upgrading of this crossing at an estimated cost of $17.3M would be the most effective means of improving the evacuation capabilities and general access to the Good Night and Morganville communities in the event of a flood.

As an alternative to the Perry River Bridge upgrade, an evacuation route may be available through the Goodnight Scrub National Park and along Kalliwa Road to Gayndah-Mount Perry Road. This option would require additional investigation to determine the existing flood immunity to the Perry River and other creek flood sources, but at a minimum would require raising of the earth embankment over Mingham Creek to above Paradise Dam backwater levels. Based on further investigations, this option may prove to be a more cost effective solution than the Perry River Bridge upgrade. Either the bridge upgrade or the alternative evacuation route would service an estimated population of 400 – 600.

**Pine Creek, Givelda and Electra alternate evacuation routes**

For a total estimated cost of approximately $1M plus on-going yearly maintenance, an alternate 4WD evacuation route could be secured for the Pine Creek, Givelda and Electra communities.
Hinkler Avenue upgrade

While the estimated costs of this upgraded are substantial ($104M capital works), the establishment of a reliable connection between the north and south sides of the Burnett River at Bundaberg warrants further consideration as part of strategic emergency management planning activities. The benefits of this route are substantial and include improved evacuation access to established recovery facilities on the south side of the river and improved emergency access to the north side of the river.

Mount Perry Rd & Fairymead Rd upgrades

The raising of Mount Perry Rd & Fairymead Rd to provide more reliable flood evacuation routes at an estimated upfront cost of $7.4M would also deliver substantial benefits to the community.

Bartholdt Drive alternative evacuation route

Upgrading Bartholdt Drive would provide a high immunity (i.e. above the PMF level) evacuation route servicing an approximate population of 1150 for an estimated cost of $1.4M.

Combined flood mitigation schemes

The scope and timeframe of this current study has limited the assessment of the ways in which individual flood mitigation strategies could be beneficially combined. On the basis of limited information, it is recommended that the potential benefits of the following combined mitigation strategies be investigated further:

- East levee and Millaquin bend works – These two projects could be combined to provide flood mitigation benefits to communities on both the north and south sides of the river. The lowering of river flood levels afforded by the bend widening works could either reduce the height and expense of the East levee or reduce the frequency of the East levee overtopping event.

- Low level North levee or North levee and Millaquin bend works – Further investigations may reveal that the Millaquin bend works may help to alleviate some of the adverse impacts associated with the construction of levees on the north side of the river.

- Low level North levee or North levee and Gardens channel works – Further investigations may reveal that the Gardens channel works may help to alleviate some of the adverse impacts associated with the construction of levees on the north side of the river.

Other recommendations for flood management measures

As part of the continuing work on the FRMS over the coming months, BRC and GHD will examine a wide range of flood management measures in addition to the large-scale mitigation options considered in this preliminary report. These other measures will nonetheless require a commitment of funds. The below list of flood management measures is provided for the purposes of flagging the possible recommendations of the FRMS. These initiatives have been developed based on community consultation and feedback, and are currently being explored by BRC and GHD. If implemented, these measures would form part of a comprehensive flood risk management strategy and provide substantial value to the community. As a guide, it is anticipated that all of the below measures could be implemented for less than $2.5M.

- Ongoing funding for Flood Resilience Officers over the next 5 years. BRC currently has two officers temporarily funded who network amongst community groups and could educate the community on flood risk once the FRMS is complete.
• Implementation of physical flood markers as public art. These could function as meeting points during disasters for disseminating information, evacuation points and could help educate the community on probable and historical flood risk;

• Flood Education / Notice Boards with electronic message boards for direct communications to at risk communities during event. These boards could also be a designated place for BRC’s “meeting trees”, provide central points for community members to source direct and dedicated information regarding flood risk and could be placed close to the flood markers for community education in non-flood times. Display messages might include current or predicted upstream gauge readings and inundation alerts for local communities. These sites could also be meeting places for emergency radio networks (UHF/VHF) that Council has established with SES groups;

• Improve the understanding of storm surge, tsunami and coincident flood events with the Burnett River;

• Implement a Disaster Management Portal making flood risk data easy to interpret and practical for use during events by disaster management personnel.

• Include evacuation routes into Council's flood gauge mapping system with “time to closure”;

• Direct mail outs for community education campaigns based on flood risk, including detailed flood information for their property and Get Ready campaign material;

• Physically marking evacuation route zones for each property. This could include a colour coding system for wheelie bin lids, electricity poles, street signs and road pavement/footpath markings. Develop public signage at key locations on evacuation routes at locations which aren’t alarming or threatening to the community;

• Implement CCTV cameras at key points on river for boats coming and going to improve situational awareness and allow commercial and recreational boat users to better understand conditions;

• Additional rain gauges on tributaries of the Lower Burnett;

• Mapping of overland flow paths for tributaries leading to the Burnett River to assist refinement of evacuation routes;

• Work with the Bureau of Meteorology to integrate flood warnings to flood gauge mapping and improve early warning predictions for Paradise Dam;

• Further improve the BoM Enviromon base station to improve data interpretation (i.e. assess IFD curves against actual rainfall to better quantify risks).

**Options not currently considered viable**

In addition to the projects not considered viable upon initial consideration (refer to Section 6.5) and following the MCA process (refer to Section 7.6), several of the options taken forward for detailed assessment proved to be problematic or ineffective as flood mitigation measures. Based on the assessment undertaken to date, these options are not recommended.

**Other levees**

Both the North levee (cost $45M and benefit-cost ratio of 0.11) and the low levee North levees (cost $44M and benefit-cost ratio of -0.07) were selected for detailed assessment based on their potential to protect parts of the severely flood affected North Bundaberg area. Of all the various levees considered for the North Bundaberg area, these two proposals were considered the most viable. Following conceptual design and further hydraulic assessment across the full range of
design flood events, it is seen that the downsides to these options outweigh any potential benefits.

Adverse flood level impacts outside of the levees, as well as the potential for increased flood levels behind the levees when they are overtopped, means that on balance they do not represent viable flood mitigation schemes.

**Dredging**

An initial assessment of dredging the Burnett River was undertaken for the following scenarios:

- Dredging the river from the Burnett River mouth to Ben Anderson Barrage; and
- Dredging targeted sections of the Burnett River only.

Based on an assessment of hydraulic, social, environmental and economic factors, dredging the river from the mouth to the Ben Anderson Barrage was found by GHD, Council and the CRG to not be a viable flood mitigation option. The potential benefits of such a proposal in terms of flood level reduction was not compatible with the extremely high costs and volumes of spoil, especially when compared to other selective dredging options.

A hydraulic assessment of selective dredging of certain sections of the river indicated that this option could effectively reduce nearby flood levels. However, based on further detailed assessment, it is seen that the ability to dredge the river in critical locations is severely limited by the depth, width and steepness of the existing river banks. In the absence of detailed geotechnical information, assumptions on maximum stable dredge batter slopes restrict the amount of material that could be dredged from critical locations such as Millaquin bend.

While it is possible to dredge the wider, shallower sections of the river upstream of the town reach bridges, the hydraulic assessment has shown that such works do not result in substantial flood level reductions.

For both the town reach dredging scenarios subject to detailed assessment, the costs ($43.2M to $56.9M upfront and $3M / year on-going maintenance) coupled with the small reductions in flood level resulted in unfavourable benefit cost ratios (0.02 – 0.05).

Any further consideration of dredging as a flood mitigation measure would have to be based on a favourable geotechnical assessment that supports steep dredge batter slopes while not impacting on bank stability. This would allow more effective targeted dredging of smaller critical sections of the river.

**Other bridge upgrades**

Of the various bridges upgrades initially considered, the Pine Creek Bridge and the Cherry Creek Bridge upgrades are not considered viable in light of the available alternate evacuation route.

The St Agnes Creek Bridge already has a higher degree of flood immunity than other bridges in the area, and raising the bridge further would be considered impractical. The Perry River Bridge upgrade discussed in Section 9.1.3 would nonetheless significantly improve evacuation and access capabilities for the Good Night and Morganville communities.

**Other road upgrades**

Of the various North Bundaberg evacuation route upgrades taken forward for detailed consideration, the Batchler’s Rd option is not considered a viable option unless problems emerge for the Mount Perry Rd route.
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Appendices

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Appendix D Multi Criteria Analysis Scoring & Results
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Appendix F Environmental Overlay Maps
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Appendix H Perry River Bridge & Alternate Evacuation Route Supporting Information
Appendix I North Bundaberg Evacuation Route Options Supporting Information
1. **Introduction**

1.1 **Introduction**

GHD Pty Ltd (GHD) was commissioned by Bundaberg Regional Council (BRC) to prepare a Floodplain Risk Management Study for the lower Burnett River floodplain as part of the Burnett River Floodplain Action Plan. This report (the Burnett River Floodplain Action Plan – Preliminary Options Assessment Report) forms the first phase of the Floodplain Risk Management Study.

1.2 **Floodplain management framework**

The Burnett River Floodplain Risk Management Study framework is based on a range of best practice floodplain management principles and guidelines such as those outlined in Floodplain Management in Australia – Best Practice and Principles (CSIRO, 2000) and the NSW Floodplain Development Manual – the Management of Flood Liable Land (DIPNR, 2005).

The framework adopted for the Burnett River includes the following key project phases:

![Burnett River floodplain management framework](image)

*Figure 1-1 Burnett River floodplain management framework*
The options under consideration in this report are large-scale projects that, if taken forward, would require a substantial commitment of resources from government. It is noted that these large-scale options only represent one aspect of best-practice floodplain management. In general terms, floodplain management practices can span the categories listed in Table 1-1.

**Table 1-1 Floodplain management practices**

<table>
<thead>
<tr>
<th>Theme/category</th>
<th>Types of measures, ideas, options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flood prevention modifications</td>
<td>Designing measures to alter the behaviour of the flood itself by reducing flood levels and/or velocities or by excluding flood waters from areas at risk. Options may include, but is not limited to, levees, river dredging and vegetation removal.</td>
</tr>
<tr>
<td>2. Property modifications</td>
<td>Modifications to existing buildings to reduce flooding impacts. Options may include measures to improve property resilience and house raising.</td>
</tr>
<tr>
<td>3. Development controls</td>
<td>Reviewing building and planning codes such as setting minimum floor heights and changed land uses to reduce the risk of flood impacts.</td>
</tr>
<tr>
<td>4. Response modifications</td>
<td>Increasing the ability of people to respond appropriately in times of flood and/or enhancing the flood warning and evacuation procedures in an area. Options may include, but is not limited to, improving community awareness, improving flood warning systems, and updating local flood and evacuation plans.</td>
</tr>
</tbody>
</table>

The full spectrum of floodplain management practices will be considered and addressed as part of the final Floodplain Risk Management Study report, due in 2014. Section 1.5 includes a description of some of the activities that are currently underway and that will be included in the final report.
### 1.3 Purpose of this report

The purpose of this report is to identify a number of preferred large-scale flood mitigation options that have the potential to reduce the adverse impacts of large Burnett River floods on the local community and to outline the methodology used to determine these options.

This format adopted for the Options Assessment process is shown in Figure 1-2 below.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
| **1** | • Understand existing flood behaviour.  
        • Understand the nature of riverine flood risk and potential flood damages. |
| **2** | • Inform the community on flood behaviour and risk.  
        • Engage with the community and collect flood mitigation ideas. |
| **3** | • Collate and review community feedback.  
        • From community feedback, develop a list of potential flood mitigation options. |
| **4** | • Engage with the community to determine criteria and weightings for a multi-criteria analysis (MCA).  
        • Undertake the MCA in order to filter the list of options down to those that best address the concerns of the community. |
| **5** | • Further develop a set of selected options to better understand potential costs, benefits, implementation strategies, environmental issues and key project risks. |
| **6** | • Put forward a range of viable flood mitigation projects for consideration by the community and decision-makers. |

**Figure 1-2 Flood mitigation options assessment process**

### 1.4 Study area

The area of focus for the current study is the lower Burnett River floodplain extending from below Paradise Dam (130km AMTD) to the river mouth at Burnett Heads (0km AMTD). For the purpose of this report, the floodplain is defined as those areas within the riverine Probable Maximum Flood extents as defined in the Burnett River Flood Study (GHD 2013).
1.5 Concurrent & subsequent activities

In addition to the Preliminary Options Assessment, there are a number of concurrent and subsequent activities that will form part of the Floodplain Action Plan and Floodplain Risk Management Study. These include:

- The development of a set of flood warning maps that indicate flood levels and extents at incremental gauge heights on the Paradise Dam, Walla and Bundaberg Stream Gauges;
- An evacuation capability assessment and preparation of evacuation route maps;
- The development of flood risk maps which identify the level of risk to people, property and infrastructure;
- Assessment and recommendations regarding the existing flood warning system;
- Further development of a full range of flood management practices other than the large-scale options considered in this report;
- The development of a Floodplain Risk Management Plan;

1.6 Previous studies

The Preliminary Options Assessment follows a number of previous studies including:

- Burnett River Flood Study (GHD, 2004);
- Burnett River Flood Study (GHD, 2013);
- Burnett River – North Bundaberg Flood Levels – Report for Gooburrum Shire Council (Kinhill Cameron McNamara, June 1992).
- Burnett River Floods AMTD 0 to 98.5km Report (Water Resources Commission, Department of Primary Industries, December 1991).
1.7 Acknowledgements

The completion of this study was made possible through the combined efforts of a number of key contributors including:

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bundaberg Regional Council</td>
<td>Andrew Fulton, Dwayne Honor, Rob Calligaris, Robyn Laing</td>
</tr>
<tr>
<td>Community Reference Group</td>
<td>Headed by Rowan Bond</td>
</tr>
<tr>
<td>GHD</td>
<td>Ben Regan, Dan Copelin, Leila Macadam, Jon Williams,</td>
</tr>
<tr>
<td></td>
<td>Kerry Neal, Leanne Martin, Anthony Folan and the rest of</td>
</tr>
<tr>
<td></td>
<td>the GHD project team.</td>
</tr>
</tbody>
</table>
1.8 Disclaimer and Limitations

This report has been prepared by GHD for Bundaberg Regional Council and may only be used and relied on by Bundaberg Regional Council for the purpose agreed between GHD and the Bundaberg Regional Council.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report. This report is an interim deliverable prepared as part of the overall Floodplain Risk Management Study. The full context for flood risk management planning and decision making, including consideration of the full range of flood risk management measures, will be included in the final FRMS report.

GHD otherwise disclaims responsibility to any person other than Bundaberg Regional Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD as described throughout the report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Bundaberg Regional Council and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

GHD has prepared the preliminary Cost Estimates set out in Section 8 of this report using information reasonably available to the GHD employee(s) who prepared this report; and based on assumptions and judgments made by GHD as described in Section 8.

The Cost Estimates have been prepared for the purpose of a high level comparison of flood mitigation options and must not be used for any other purpose.

The Cost Estimates are high-level preliminary estimates only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimates and may change. Unless as otherwise specified in this report, no detailed quotation has been obtained for actions identified in this report. GHD does not represent, warrant or guarantee that the mitigation options can or will be undertaken at a cost which is the same or less than the Cost Estimates provided.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

The purpose of this report is to identify potentially viable flood mitigation options for further consideration. The ‘existing’ or ‘baseline’ floodplain and river conditions represent the floodplain and river conditions that existed prior to the January 2013 flood event. The study does not seek to restore the river to ‘natural’ conditions nor does it adopt ‘natural’ river conditions as a baseline.

This report does not consider flooding from other sources such as storm tide, tributary rivers and creeks to the Burnett River, or overland flow. It also does not consider issues relating to nuisance drainage.

As described above, Cost Estimates have been prepared for the purpose of a high level comparison of flood mitigation options and must not be used for any other purpose. Further work is required on all options included preliminary and detailed design phases. A number of further studies (e.g. geotechnical investigations) are needed to determine the final viability of flood mitigation options.
2. Flooding Behaviour

GHD’s understanding of flood behaviour on the lower Burnett River is based on the Burnett River Flood Study (GHD 2013). That study, undertaken over approximately two years from 2011 to 2013, involved detailed investigations into past flood behaviour, the development and calibration of hydrologic and hydraulic models of the catchment, and the use of standard techniques to estimate potential future flooding (i.e. design flood events).

Many people in the community have first-hand experience with flooding in the Burnett River as well as in other areas. The computer-based modelling undertaken as part of the Burnett River Flood Study can complement the community’s knowledge, and can highlight the different factors that contribute to flooding along of the river. This section of the report includes information on the following points:

- The sheer size and scale of the Burnett River catchment, and the magnitude of flows in the river in a major flood event.
- The influence of tides and ocean levels on flood levels.
- The key “constrictions” in the river that control local flood levels.
- The patterns of flooding in and around Bundaberg that have different implications for flood mitigation strategies (i.e. slow backwater flood versus fast breakouts).

The summarised information in this section provides the context for flood mitigation decision making. A sound understanding of the river’s catchment, hydraulic capacity and constraints, and floodplain flow patterns helps focus attention on efficient and effective flood mitigation strategies.

Also included in this section is a discussion on the history of flooding on Burnett River, a description of some of the most significant past flood events, and information on the theoretical design flood events that are used for planning and decision making purposes.

The reader is referred to the full Burnett River Flood Study report for more detailed information on the hydrologic and hydraulic modelling.

2.1 Catchment & Rainfall

The Burnett River catchment is one of the largest catchments in Queensland. At Bundaberg, the upstream catchment area is approximately 32,820 km². By comparison, the Brisbane River has a catchment area of approximately 13,600 km². A map of the Burnett River catchment is provided as Figure 2-1 with key features provided in Figure 2-2.

The Burnett River originates in the Dawes Range to the north of Monto and flows in a southerly direction through Eidsvold and Mundubbera. Upstream of Mundubbera, the Burnett River is joined by the Nogo and Auburn Rivers which drain large areas of the western part of the catchment, and the Boyne River which drains the basin area to the south. Downstream of Mundubbera, the Burnett River flows in a north-easterly direction towards the coast. Between Gayndah and Mt Lawless the Barker-Barambah Creek system joins the Burnett River.

At approximately 70 km south-west of Bundaberg City, the Burnett River flows through an opening in the coastal range, thus creating a narrow catchment area over the downstream reach of the river. The Paradise Dam, with a full supply volume of 300 GL, was constructed at this location in 2005.
Annual average rainfall throughout the Burnett River catchment is highly variable based on the distance from the coast, ranging from 1200mm in the east to 800mm further inland. There is also a high degree of variability in regard to monthly rainfall. Records show that the summer months dominate rainfall totals within the catchment.

Different patterns of rainfall over the catchment can give rise to different types of floods. Floodwaters reaching Bundaberg can originate from the upper catchment as far away as Kingaroy or Monto, and may take days to reach the city. In other cases, significant amounts of rain can fall on catchments such as the Perry River and St Agnes Creek downstream of Paradise Dam, causing flood levels in Bundaberg to rise in less than a day. In general terms, the worst floods will occur when a large weather system causes significant rainfall over widespread, rather than localised, areas.
2.2 Behaviour of the Burnett River during normal (non-flood) conditions

During most of the year, Bundaberg residents will observe that the lower reaches of the Burnett river located below the Ben Anderson barrage are tidal, while the upstream reaches consist of both deep and shallow sections with generally very little flow. Artificial hydraulic structures such as the Ben Anderson Barrage and Ned Churchward weir hold back water under normal flow conditions, and upstream water levels are normally elevated.

2.3 Behaviour of the Burnett River during large flood events

During a major flood event, the Burnett River behaves differently than it does under normal flow conditions. The influences of upstream catchment discharges, the shape of the river and floodplain, and tidal conditions interact to create circumstances that are significantly different to those observed under normal flow conditions. The behaviour of the river during large flood events is described below.

2.3.1 Floodplain dynamics

An analysis of historical flood patterns and results from detailed flood modelling indicate that the behaviour of flooding in the Bundaberg city area is generally characterised by the following floodplain dynamics:

- North Bundaberg Backwater: Significant rural and urban areas of the North Bundaberg floodplain are inundated by backwater originating from several south westerly breakouts in the vicinity of Paddy Island (Ch 13.9km AMTD). The backwater associated with these breakouts combines with the northern breakout resulting in the majority of the flooded area in the North Bundaberg region to experience high to extreme levels of flood hazard.

- Northern Breakout: Once the Burnett River reaches it maximum bank full channel capacity of approximately 9,000 m3/s, the river overtops its northern banks and forms a significant overland breakout that conveys excess river flows across Hanbury Street and later Perry Street and into and across Northern Bundaberg. The depth of flow and velocity associated with the breakout has the potential to cause a high to extreme level of flood hazard across urban and rural areas in the North Bundaberg floodplain. The impact of this breakout was evident during the 2013 event with a number of properties on Hinkler Avenue opposite the Hinkler Park experiencing significant levels of flood damage due to high flow depths and velocities.

- East Bundaberg Backwater: Flooding south of the river at Bundaberg predominantly occurs due to backwater from the Burnett River into Saltwater and Bundaberg Creeks (Ch16.8km AMTD), adjacent parkland, residential and commercial areas. Model results indicate that high to extreme levels of flood hazard are likely in this region due to reasonably deep backwater flood depths. It is noted that parts of East Bundaberg are at risk of isolation due to this backwater effect.
2.3.2 Influence of river constrictions during a flood

There are a number of river constrictions or “pinch points” located along the city reach that influence the behaviour of flooding across the Burnett River floodplain in the vicinity of the city. The location of these constrictions is provided in Figure 2-3 below.

Immediately upstream of the hydraulic constrictions, flood levels are higher than they would be if the constriction did not exist, and flood levels are slightly lower than they would be immediately downstream of the constrictions. Figure 2-4 illustrates the flood profiles (water surfaces) for a range of design flood events in the vicinity of the city reach and the steepening of the flood profile at locations immediately upstream of the pinch points.

Due to the hydraulic behaviour of the river constrictions, moderate reductions in flood levels at locations downstream of a pinch point will not necessarily propagate upstream of the pinch point and create an equivalent reduction in flood levels at upstream locations. As such, flood mitigation measure that aim to reduce flood levels at locations downstream of a river constriction will not necessarily exert a benefit (reduction in flood levels) at locations upstream of the pinch point. However, changes to the river geometry that increase the conveyance of the river at the location of a constriction (e.g. river widening) have the potential to reduce upstream flood levels.

Given that river constrictions act as hydraulic controls and influence upstream flood levels, the hydraulic behaviour at river constrictions have been kept in mind when considering potential flood mitigation options.

2.3.3 Influence of tides and river mouth conditions on upstream flood levels

During large flood events, the impact of tidal flows is dampened by river flows and tidal levels tend to only exert an influence on peak flood levels in the lower reaches of the Burnett River in the vicinity of the Burnett River mouth.

A sensitivity assessment of the impact of tidal levels during large flood events was undertaken as part of the flood study. Results indicate that during a large flood event, tidal levels only exert an influence on peak flood levels to a distance of 10km upstream from the river mouth (refer to Figure 2-5) and do not influence flood levels in the city reach (which is located approximately 17km upstream of the river mouth). As a result of these investigations, it is understood that the existing river mouth configuration or alternate river mouth conditions (e.g. increases in capacity or reductions in level) will not result in reductions in flood levels in the city reach.

2.3.4 Influence of existing hydraulic structures during a flood

During large flood events, the impact of the Ben Anderson Barrage and Burnett River bridge crossings on peak flood levels is negligible.

The Ben Anderson Barrage has a relatively low crest height of 2.1m AHD and during large flood events it is overtopped by several meters (e.g. 12m during the January 2013 flood). As a result, it does not act as a significant obstruction to flow and does not cause an appreciable increase in upstream flood levels.

The Burnett River bridge crossings only reduce the effective cross sectional flow area of the Burnett River by less than 1% and as a result do not exert a significant hydraulic impact on flood levels during large flood events.

As part of the flood study, removal of the Ben Anderson Barrage and the Burnett River bridge crossings was investigated and found to reduce flood levels by only 1 to 2 cm during a large flood event similar in magnitude to the January 2013 event.
Figure 2-3 Location of River Constrictions

- Foundry Constriction
- Constriction at Millaquin bend
- Constriction upstream of barrage

Figure 2-4 Longitudinal Flood Profiles

- Main hydraulic constrictions
2.4 Past flood events

The Commonwealth Bureau of Meteorology (BOM) has documented the flooding nature of the Burnett River in their web page document entitled “Flood Warning System for the Burnett River” (BoM, 2011). A copy of this document is provided in Appendix D of the Burnett River Flood Study, and BOM’s record of highest annual flood peaks at Bundaberg from 1875 to 2011 is reproduced below as Figure 2-6.

According to BOM, major flooding in the Burnett River is relatively infrequent. However, under favourable meteorological conditions such as a tropical low pressure system, heavy rainfalls can occur throughout the catchment which can result in significant river rises and floods. These floods can cause considerable damage to rural properties along the rivers and to the commercial and residential areas in some of the smaller towns in the area and at Bundaberg.

Major floods have been recorded at Bundaberg in 1875, 1890, 1893 (twice in 2 weeks), 1928, 1942, 1954, 2010 and January 2013. The most recent significant event was in January 2013 when the river rose to 9.53 metres at Bundaberg, about 7.34 meters above Highest Astronomical Tide (HAT). The December 2010 event rose to 7.92 metres at Bundaberg, about 5.7 metres above Highest Astronomical Tide (HAT). HAT at Bundaberg is 2.19m on the flood gauge in Targo Street. Further specific detail on the 1942 and 2013 flood events is included below.
2.4.1 January 1942 flood event

The January 1942 flood event is the second largest event to occur this century and the fourth largest flood on record behind the 1890, 1893 and 2013 flood events. The 1942 flood was the first time since 1890 that the Burnett River had broken its northern banks at Bundaberg. Historically, the 1942 flood event has been used for planning purposes.

A significant feature of the 1942 flood was the large area of backwater south of Tantitha Road from the Burnett River across Fairymead Road near Patersons Road. In the 1942 flood, this inundation covered a large area across Batchlers Road almost to the Bundaberg – Gin Gin Road. Despite a significant amount of recorded flood level data for this event, a level of uncertainty has remained, particularly in relation to the flood levels on the North Bundaberg floodplain.

The 1942 flood event caused significant damage in the Bundaberg region. Hundreds of residential properties were inundated, in addition to hundreds of acres of agricultural lands which resulted in several thousands of tons of cane being destroyed. More than 100 people required evacuation via boat from their homes in the region of Fairymead, and it was reported that 20 head of draught horses and at least 60 head of cattle were lost at Harriet Island and Tomato Island respectively. The Bundaberg Harbour Board suffered major losses as all wharf sheds and a large sugar loading warehouse were washed into the sea. One Aircraftman by the name of Francis William Tippett drowned while attempting the rescue of a family near Hanbury Street, and civilians were reportedly drowned at Mundubbera and Monto.

2.4.2 December 2010 & January 2011 events

The December 2010-January 2011 flood events across the Australian eastern seaboard were a result of heavy rainfall caused by cyclone Tasha, exacerbated by the 2010 La Nina event. The La Nina event was the strongest experienced since 1973. Bundaberg received 573 mm of rain in December; the highest monthly rainfall recorded history for the month. Between the 29th - 31st of December 2010 a major flood peak was recorded on the Burnett River at Bundaberg, with 208 houses inundated and 90% of businesses affected. Following this flooding, the Burnett River at Bundaberg exceeded its minor flood level again between the 10th and 15th of January.
2.4.3 January 2013 flood event

In late January 2013, tropical cyclone Oswald formed in the Gulf of Carpentaria before moving down the east coast of Australia in the form of a tropical low. As a result, most of the east coast of Queensland, and parts of the New South Wales coast experienced very heavy rainfall during the period from 22 to 29 January. This rainfall resulted in severe flooding in many areas within 200 kilometres of the east coast, with the city of Bundaberg experiencing its largest flood in recorded history. The flood reached a height of 9.53 metres at the Targo Street flood gauge in Bundaberg, approximately 7.34 meters above the Highest Astronomical Tide (HAT) level of 2.19m AHD.

Significant flooding was experienced in North Bundaberg - initially as backwater south of Tantitha Road from the Burnett River across Fairymead Road (near Patersons Road), and then as a result of north easterly flow breakouts across the Bundaberg-Gin Gin Road. High flood depths (up to 3m) and high flow velocities (up to 5m/s) were experienced in parts of North Bundaberg during the event. Significant levels of flooding also occurred in East Bundaberg due to backwater inundation across the floodplain in areas adjacent to Saltwater and Bundaberg Creeks.

A large number of people were evacuated due to flooding, including approximately 5000 residents from north Bundaberg. In addition, the January 2013 flood resulted in a significant amount of flood damage including inundation of over 4000 homes, significant scour and scour-induced building damage, and widespread impacts to both public infrastructure (including bridges, roads, sewerage and water lines) and agricultural activities (sugar cane cropping, livestock, small crops and fishing).

2.5 Design flood events

As part of the Burnett River Flood Study, GHD estimated the magnitude of flooding associated with the 2%, 1%, 0.5% and 0.2% AEP theoretical design flood events, as well as the Probable Maximum Flood (PMF). The 20%, 10% and 5% AEP design flood events were later estimated as part of the subsequent Burnett River Flood Warning Mapping project. These design flood events represent deterministic estimates of the likelihood and magnitude of future flooding and are useful for planning purposes.

In this context, the 1% AEP event, for example, represents the best estimate based on current information of a flood that has a 1% chance, on average, of being equalled or exceeded in any one year. Averaged over a very long time frame, the 1% AEP is expected to occur once every 100 years. However, the magnitude of flooding in any one year is random and major flood events may happen more or less frequently than suggested by long term averages. Further discussion on this random behaviour and its implications for flood management is presented in Section 3.

The PMF is a theoretical estimate of the largest conceivable flood that might occur in the Burnett River catchment, and is an exceptionally rare and unlikely event. It is based on estimates of the Probable Maximum Precipitation (PMP), which is the “theoretical maximum precipitation for a given duration under modern meteorological conditions” (WMO, 2009). For the purposes of floodplain management and planning, the extents of the PMF define the maximum envelope of flood prone land. Locations outside the extents of the PMF can, for practical purposes, be considered at no risk of riverine flooding.
### Table 2-1 Design Event Peak Flood Levels at Bundaberg Gauge & Impacts

<table>
<thead>
<tr>
<th>AEP (%)</th>
<th>Peak Flood Level (m AHD)</th>
<th>Impacts of flooding</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>3.97</td>
<td>Flood waters are largely confined to the river corridor, with negligible flooding to developed areas. Some roads and bridges are cut, isolating rural communities.</td>
</tr>
<tr>
<td>10%</td>
<td>5.73</td>
<td>Some flooding occurs to very low-lying developed areas in East Bundaberg and elsewhere. The river breaks its banks near Paddy’s Island, Rubyanna and Fairymead, inundating low-lying agricultural land. More roads and bridges along the river and adjacent creeks are cut.</td>
</tr>
<tr>
<td>5%</td>
<td>7.33</td>
<td>By this level, a substantial number of low-lying residential, commercial and industrial properties in Bundaberg East, South, Central North are inundated, along with more extensive agricultural areas. The river has broken its banks at Hanbury Street, sending flood waters north past the botanical gardens, cutting Hinker Avenue.</td>
</tr>
<tr>
<td>2%</td>
<td>8.86</td>
<td>This large, damaging flood breaks the river’s banks along Perry Street and causes widespread inundation of the developed part of Bundaberg North. A roughly equal number of properties are also inundated in the Bundaberg East, Central and South backwater. Some isolation of higher land occurs. Inundation has spread through additional agricultural land.</td>
</tr>
<tr>
<td>1%</td>
<td>9.45</td>
<td>Two new breakouts occur on the north bank of the river; one at Hanbury Street near the Bundaberg Golf Club and another at Cummins Street. Properties on higher ground near North School hill and the Princess Street / Victoria Street area in Bundaberg East are now inundated. The high ground in these areas is now isolated. Some properties at the Port of Bundaberg are under water, as are the properties on the northern half of Mill Street in Wallaville. Further agricultural land is impacted.</td>
</tr>
<tr>
<td>0.5%</td>
<td>9.97</td>
<td>Approximately 90% of the developed parts of Bundaberg North are inundated, as well as previously isolated high-ground in both Bundaberg North and East. The Port of Bundaberg, Wallaville and other regional areas and agricultural land are severely impacted.</td>
</tr>
<tr>
<td>0.2%</td>
<td>10.53</td>
<td>95% of the high ground in Bundaberg North is inundated, as are all previously isolated areas in Bundaberg East. Additional properties on the fringe of the 0.5% AEP are also under water. A new breakout has occurred on the southern bank of the river at Burrum Street, isolating the CBD.</td>
</tr>
<tr>
<td>PMF</td>
<td>16.11</td>
<td>The flooding associated with the very low probability PMF event is extensive, covering all urban areas in north Bundaberg and approximately 50% of the urban area to the south. Rural areas from the river mouth to Paradise Dam, along with other communities such as the Port of Bundaberg and Wallaville, are completely submerged.</td>
</tr>
</tbody>
</table>
2.6 Climate change

A climate change assessment was undertaken as part of the Burnett River Flood Study (GHD, 2013) to determine the impact of assumed 2050 and 2100 climate change scenarios on existing flood levels. Results indicate that:

- 1% AEP design event flood levels are predicted to increase by approximately 0.5 m during by the year 2050 in the Bundaberg city area due to a 10% increase in rainfall intensity; and
- 1% AEP design event flood levels are predicted to increase by approximately 1.4 m by the year 2100 in the Bundaberg city area based on an assumed 20% increase in rainfall intensity.

As part of the Flood Mitigation Options Assessment, the increase in flood damage costs to the community due to climate change has been assessed for the 1% AEP design event and is presented in Section 4.
3. **Probability, Hazard & Risk**

This section of the report describes key aspects of probability and risk that should underpin decision making with respect to flood management and mitigation.

### 3.1 Flood risk

Existing floodplain management practice describes flood risk as the relationship between Likelihood and Consequence.

#### 3.1.1 Likelihood

Likelihood is the probability of occurrence of a specific flood event, or range of events occurring. The concept of likelihood in the context of design flood events is discussed in Sections 2.5 and 3.2.

#### 3.1.2 Consequence

Consequence is an evaluation of what is affected by the event and how. Quantifying consequence requires an understanding of flood behaviour (hazard) and the exposure, vulnerability and tolerability of people, property and infrastructure to a flood of that likelihood.

The factors which may be relevant to determining the hazard associated with flooding, and those factors which may influence the consequences for life, buildings and infrastructure potentially affected by flooding are summarised in Table 3-1 below.

### Table 3-1 Factors Contributing to Flood Hazard and the Urban and Social Impacts of Consequence

<table>
<thead>
<tr>
<th>Flood Hazard</th>
<th>Urban &amp; Social Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of inundation</td>
<td>Risks to life</td>
</tr>
<tr>
<td>Flood velocities</td>
<td>Damage to buildings, infrastructure and contents</td>
</tr>
<tr>
<td>Duration of inundation</td>
<td>Restoration capability / resilience of built form</td>
</tr>
<tr>
<td>Rates of rise of floodwaters</td>
<td>Community vulnerability and resilience to economic and social impacts</td>
</tr>
<tr>
<td>Water volume</td>
<td>Community response to risk</td>
</tr>
<tr>
<td>Warning times</td>
<td></td>
</tr>
<tr>
<td>Evacuation capabilities</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Design life and encounter probability

The concepts of “design life” and “encounter probability” which, when linked with the return period, also provide a useful framework for risk management decision making. These various elements are linked by the following formula (Borgman 1963):

\[ T = \frac{-N}{\ln(1-p)} \]

Where \( P = \) encounter probability 0 to 1, \( N = \) the design life (years), \( T = \) the return period (years)

This equation describes the complete continuum of risk when considering the prospect of at least one event of interest occurring.

Figure 3-1 below illustrates the above equation graphically. It presents the variation in probability of at least one event occurring (the encounter probability) versus the period of time considered (the design life).

Table 3-2 below illustrates the probabilities of a flood of a given magnitude occurring at least once in a 70 year period.

**Table 3-2 Encounter probability**

<table>
<thead>
<tr>
<th>Size of Flood (Chance of Occurrence in any year) ARI . (AEP)</th>
<th>Probability of Experiencing the given flood at least once in a period of 70 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in 10 (10%)</td>
<td>99.9%</td>
</tr>
<tr>
<td>1 in 20 (5%)</td>
<td>97.0%</td>
</tr>
<tr>
<td>1 in 50 (2%)</td>
<td>75.3%</td>
</tr>
<tr>
<td>1 in 100 (1%)</td>
<td>50.3%</td>
</tr>
<tr>
<td>1 in 200 (0.5%)</td>
<td>29.5%</td>
</tr>
</tbody>
</table>

The level of risk acceptable is a policy decision. Figure 3-1 is provided to assist in this decision making process by showing a selection of risk options. For example, accepting only a 5 per cent chance of flood inundation occurrence in a design life of 50 years means that planning needs to be undertaken and/or infrastructure needs to be designed for a 1 in 1000 year return period event. A similar design criteria (1 in 1000 year ARI) is required if a 1 per cent probability of exceedance is acceptable during a period of 10 years. By comparison, a 1 in 100 year return period event has a 10 per cent chance of occurrence in a 10 year period. Concepts relating to annual average damages can be introduced to help determine appropriate design criteria for key infrastructure that balances the cost of construction against the potential risks and costs of inundation or failure.
Figure 3-1 Encounter Probability for Floods of Various ARI’s
3.3 When will the next big flood occur?

In Section 2.5 it was explained that the return period or average recurrence interval is the “average” number of years between successive events of the same or greater magnitude over very long time periods. For example, if the 100 year return period flood level is 8.9 m AHD at a certain location then, averaged over a very long time period, a 8.9 m AHD flood level or greater can be expected to occur once every 100 years. In reality, this level is likely to be reached by flooding in periods more and less frequently than 100 years.

Ignoring the potential influence of climatic trends that may “load the dice” during certain periods, floods are a random occurrence and it can be generally assumed that the chance of major flooding in any particularly year is completely independent of the time since the last major flood. If the 100 year event were to occur now, then there is still a finite possibility that it could occur again soon, even in the same year, or that the 1000 year event could occur, for example, next year. Conversely, there may be very long stretches of time between large floods. All of these possibilities are permitted by the stochastic (i.e. “random”) nature of floods.

In a similar manner, it is a possibility that a flood event equal or equivalent to the magnitude of the Burnett River January 2013 flood event could occur next year or there may be a long period before the next flood of a similar size.
4. Flood Damages

4.1 Methodology

A flood damage assessment has been undertaken to assess the aggregate cost of flood impacts and the economic benefit of flood mitigation options (reduction in damage costs). The flood damages assessment follows an accepted method to establish the social-economic costs experienced within the study area for the full range of design flood events modelled under baseline and mitigated scenarios. The flood damage assessment has identified priority regions in terms of flooding damage, and in particular provides the basis for monetary comparison of mitigation scenarios. Probable tangible flood damages were assessed for residential, commercial, industrial and agricultural land use types within the Burnett River floodplain.

The estimated damage costs presented herein are an approximation only, and were determined in accordance with the standard limited methodology normally used in these assessments. The damages are not intended to represent the full economic impact of a flood event. For instance, building damage is based on standard recommended “damage curves” rather than actual insurance data, and assessment of agricultural damage is limited to loss of sugar cane crops and damages to farm buildings only. Improvements to these estimates could be achieved if recent and specific insurance flood damage information was available. Nonetheless, the methodology is appropriate for the intended purpose of highlighting the relative severity of flood impacts in various areas as well as comparing various mitigation measures. Care should be taken when interpreting the damage and benefit-cost ratios (i.e. the costs in the benefit cost ratio calculation do not take into account the full range of socio-economic impacts).

A full description of the methodology adopted for the flood damages assessment is included in Appendix A. In summary, the key steps involved in this process are outlined below:

1. Create a consolidated database of residential, commercial and industrial buildings and floor levels, as well as areas used for agricultural (i.e. sugar cane cropping).
2. For each class of property within the database, determine a relationship between flooding (i.e. depth, velocity or inundation area) and resulting damage based on accepted methods and publications.
3. For each property in the database, calculate the depth, velocity or area of inundation and the resulting flood damage for each design flood event.
4. Calculate the Annual Average Damages ($AAD), which represents the long-term average yearly damages that can be expected based on the full range of design flood events.
4.2 Results

4.2.1 Flood damage per land use type

The below tables summarise the number of buildings subject to flooding during the full range of design flood events, as well as the resulting estimates of tangible flood damages.

**Table 4-1 Number of properties with above floor flooding**

<table>
<thead>
<tr>
<th>Flood event</th>
<th>Residential</th>
<th>Commercial</th>
<th>Industrial</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% AEP</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>10% AEP</td>
<td>6</td>
<td>5</td>
<td>8</td>
<td>19</td>
</tr>
<tr>
<td>5% AEP</td>
<td>50</td>
<td>21</td>
<td>62</td>
<td>133</td>
</tr>
<tr>
<td>2% AEP</td>
<td>533</td>
<td>92</td>
<td>211</td>
<td>836</td>
</tr>
<tr>
<td>1% AEP</td>
<td>1194</td>
<td>136</td>
<td>396</td>
<td>1726</td>
</tr>
<tr>
<td>0.5% AEP</td>
<td>2364</td>
<td>175</td>
<td>558</td>
<td>3097</td>
</tr>
<tr>
<td>0.2% AEP</td>
<td>3165</td>
<td>226</td>
<td>741</td>
<td>4132</td>
</tr>
<tr>
<td>PMF</td>
<td>10877</td>
<td>633</td>
<td>1603</td>
<td>13113</td>
</tr>
</tbody>
</table>

**Table 4-2 Number of properties with above or below floor flooding**

<table>
<thead>
<tr>
<th>Flood event</th>
<th>Residential</th>
<th>Commercial</th>
<th>Industrial</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% AEP</td>
<td>29</td>
<td>10</td>
<td>13</td>
<td>52</td>
</tr>
<tr>
<td>10% AEP</td>
<td>117</td>
<td>28</td>
<td>46</td>
<td>191</td>
</tr>
<tr>
<td>5% AEP</td>
<td>495</td>
<td>71</td>
<td>204</td>
<td>770</td>
</tr>
<tr>
<td>2% AEP</td>
<td>1654</td>
<td>173</td>
<td>392</td>
<td>2219</td>
</tr>
<tr>
<td>1% AEP</td>
<td>2695</td>
<td>214</td>
<td>625</td>
<td>3534</td>
</tr>
<tr>
<td>0.5% AEP</td>
<td>3687</td>
<td>266</td>
<td>787</td>
<td>4740</td>
</tr>
<tr>
<td>0.2% AEP</td>
<td>4615</td>
<td>352</td>
<td>965</td>
<td>5932</td>
</tr>
<tr>
<td>PMF</td>
<td>12044</td>
<td>650</td>
<td>1674</td>
<td>14368</td>
</tr>
</tbody>
</table>

**Table 4-3 Summary of flood damages by property type (excludes structural damage)**

<table>
<thead>
<tr>
<th>Flood event</th>
<th>Residential ($)</th>
<th>Commercial ($)</th>
<th>Industrial ($)</th>
<th>Agricultural ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% AEP</td>
<td>148,000</td>
<td>0</td>
<td>211,000</td>
<td>36,000</td>
</tr>
<tr>
<td>10% AEP</td>
<td>945,000</td>
<td>248,000</td>
<td>474,000</td>
<td>167,000</td>
</tr>
<tr>
<td>5% AEP</td>
<td>7,093,000</td>
<td>3,975,000</td>
<td>4,042,000</td>
<td>452,000</td>
</tr>
<tr>
<td>2% AEP</td>
<td>54,411,000</td>
<td>13,380,000</td>
<td>22,314,000</td>
<td>588,000</td>
</tr>
<tr>
<td>1% AEP</td>
<td>115,647,000</td>
<td>19,806,000</td>
<td>38,133,000</td>
<td>1,954,000</td>
</tr>
<tr>
<td>0.5% AEP</td>
<td>225,121,000</td>
<td>26,629,000</td>
<td>73,283,000</td>
<td>2,210,000</td>
</tr>
<tr>
<td>0.2% AEP</td>
<td>338,202,000</td>
<td>36,240,000</td>
<td>100,083,000</td>
<td>2,405,000</td>
</tr>
<tr>
<td>PMF</td>
<td>1,496,798,000</td>
<td>136,194,000</td>
<td>217,208,000</td>
<td>6,447,000</td>
</tr>
</tbody>
</table>
Table 4-4 Summary of total damages in each design flood event (including structural damage)

<table>
<thead>
<tr>
<th>Flood event</th>
<th>Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% AEP</td>
<td>748,000</td>
</tr>
<tr>
<td>10% AEP</td>
<td>2,909,000</td>
</tr>
<tr>
<td>5% AEP</td>
<td>21,786,000</td>
</tr>
<tr>
<td>2% AEP</td>
<td>120,445,000</td>
</tr>
<tr>
<td>1% AEP</td>
<td>234,366,000</td>
</tr>
<tr>
<td>0.5% AEP</td>
<td>424,361,000</td>
</tr>
<tr>
<td>0.2% AEP</td>
<td>620,779,000</td>
</tr>
<tr>
<td>PMF</td>
<td>2,472,272,000</td>
</tr>
</tbody>
</table>

4.2.2 Average annual damages

One method of valuing flood impact is by assessment of the mean annual impact, as represented by the average annual damage (AAD). While it is not possible to know what future flood events will occur, the AAD assesses the monetary cost of flood damage weighted by the probability of the full range flood events. The estimated average annual damages for the baseline flood damage in the study area, based on the flood damages assessment described above, is $11,131,000 as shown in Table 4-5. For the purposes of assessing potential flood mitigation options, this is the baseline value of flood damages that could be expected to occur each year, on average, over an extended period of time.

Table 4-5 Estimated Average Annual Damages

<table>
<thead>
<tr>
<th>AEP (%)</th>
<th>Existing Conditions Damage ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Annual Damage:</td>
<td>11,131,000</td>
</tr>
<tr>
<td>Discount Rate</td>
<td>7%</td>
</tr>
<tr>
<td>Evaluation Period</td>
<td>50 years</td>
</tr>
<tr>
<td>Net Present Value (NPV) of Damages - Existing Conditions</td>
<td>$153,614,000</td>
</tr>
</tbody>
</table>

AAD was also assessed at the level of each Bundaberg locality, based solely on tangible damages to residential, commercial and industrial buildings. The AAD for the 10 regions experiencing the maximum flood damage risk is provided in Table 4-6.

Table 4-6 AAD for 10 most at-risk Bundaberg localities

<table>
<thead>
<tr>
<th>Locality</th>
<th>Total AAD ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bundaberg North</td>
<td>$2,555,000</td>
</tr>
<tr>
<td>Bundaberg East</td>
<td>$1,517,000</td>
</tr>
<tr>
<td>Bundaberg South</td>
<td>$1,013,000</td>
</tr>
<tr>
<td>Bundaberg Central</td>
<td>$978,000</td>
</tr>
<tr>
<td>Avoca</td>
<td>$243,000</td>
</tr>
<tr>
<td>Branyan</td>
<td>$196,000</td>
</tr>
<tr>
<td>Sharon</td>
<td>$196,000</td>
</tr>
<tr>
<td>Millbank</td>
<td>$193,000</td>
</tr>
<tr>
<td>Bundaberg West</td>
<td>$181,000</td>
</tr>
<tr>
<td>Burnett Heads</td>
<td>$142,000</td>
</tr>
</tbody>
</table>
5. **Community Consultation**

In accordance with the best practice floodplain management framework adopted for this study, a significant amount of community consultation was undertaken with the lower Burnett River community to better understand which options and strategies they would like Council to consider as part of the Burnett River Floodplain Action Plan. The following sections provide a summary of the consultation activities, key findings and ongoing activities.

5.1 **Summary of consultation activities**

From mid-September to early October 2013, Bundaberg Regional Council sought ideas and feedback from the community to better understand what options and strategies they would like Council to consider as part of the Burnett River Floodplain Action Plan.

This public ideas collection was supported by a dedicated, independently facilitated Community Reference Group that will remain in place until the Action Plan is adopted by council. In addition to the public ideas collection, technical input from key stakeholder organisations, known as the Technical Working Group, was sought at critical points in the process.

The ideas and feedback from the public, Community Reference Group members, and the Technical Working Group representatives have been summarised in a detailed Consultation Report (the Burnett River Floodplain Action Plan Consultation Report, GHD, 2013) and fed into the Multi-Criteria Assessment process described in Section 7.

To encourage community-wide interest and participation, GHD undertook a range of activities in the lead-up to the public consultation phase. Activities included:

- Media relations leading to interviews on ABC Wide Bay, 4BU and Seven and editorial coverage in the Bundaberg NewsMail newspaper;
- Updates on the Council website in prominent locations;
- Re-establishment of the dedicated email: floods@bundaberg.qld.gov.au;
- Stakeholder briefings and presentations;
- Advertisements in three local papers; and
- Facebook posts and Tweets reaching 4,000+ people.

There were over 280 people who participated at 10 Community Information Sessions at six locations including North Bundaberg Progress Hall, East State School Hall, St George Hall, Wallaville Hall, Avoca State School Hall and Goodnight Scrub. The atmosphere was open, informative, engaging and relaxed, and allowed people to access project information in a number of ways such as through formal presentations, one-on-one enquiries with project team members and by viewing the visual materials available around the room.

There were four main ways people could provide their ideas:

5. Public submissions received via floods@bundaberg.qld.gov.au;
6. Community questionnaire (hardcopy);
7. Anecdotal feedback at the Information Sessions; and
8. Community Reference Group as a portal to their communities..
There were a total of 328 ideas and feedback received via these four main mechanisms. Of the total recorded ideas received, 215 were written submissions and anecdotal feedback, 82 were community questionnaires and 31 were post-it note ideas from the Information Sessions.

The project’s Community Reference Group members also received further ideas, options, and feedback directly from their own community networks.

### 5.2 Key findings

The four key themes that emerged from the community’s feedback include ideas about:

1. Flood prevention modifications to alter the behaviour of the flood itself by reducing flood levels and/or velocities or by excluding flood waters from areas at risk;
2. Property modifications to existing buildings to remove them from flooding by undertaking things like re-zoning and house raising;
3. Applying development controls such as reviewing building and planning codes such as changed ground floor heights and land uses to reduce the risk of flood impacts, and;
4. Flood response modifications to increase the ability of people to respond appropriately in times of flood and/or enhancing the flood warning and evacuation procedures in an area – initiatives could include improving community awareness, improving flood warning systems, and updating local flood and evacuation plans.

The key themes did not deviate from the ‘typical’ set of floodplain resilience options or ideas that the team were anticipating. It is a strong indication of a close alignment between the technical possibilities, and the communities’ aspirations and wishes.

These themes were used to help analyse and identify which type of floodplain resilience options is considered the important or valuable by the Bundaberg community.

Key findings include:

- 71% of questionnaire respondents were flood affected;
- 57% were from North Bundaberg;
- Almost half of all respondents were flood affected residents of North Bundaberg;
- The community rated the flood response initiatives as the most important – early flood warning initiatives, evacuation plans, community awareness initiatives, flood gauge markers are all considered highly important;
- Those not impacted by floods placed greater emphasis on the importance of reviewing planning and building codes;
- Flood-affected people saw early warnings as more important than flood modifications (noted as ‘structural’ on the questionnaire); and
- Interestingly, those not affected, saw structural projects (flood modifications) as more important than those who were affected.

Based on the analysis of findings from the written submissions, questionnaire, and anecdotal feedback and response at the Information Sessions, the floodplain resilience measures/options which the community would like to see considered for inclusion in the Action Plan, includes:

i. Early flood warning initiatives such as the incremental flood gauge maps which help explain the relationship between the water level upstream at Paradise Dam, and the corresponding water level downstream in the Bundaberg floodplain, including how long it takes for flood waters to reach Bundaberg. When this project was explained at the Information Sessions, people were very keen to learn more.
ii. Emergency response initiatives such as evacuation plans and maps, community awareness initiatives to help people get better prepared for how and when to evacuate, a review of how to best provide emergency communication updates to the Bundaberg community, introducing more visual reminders and guides for what areas are most flood prone such as flood gauge markers.

iii. Flood modification projects which may include levee specifically to protect areas at greatest risk such as North Bundaberg, dredging of relevant areas of the Burnett River, a review of the effectiveness of the Ben Anderson Barrage/other weirs.

Considered less important for inclusion in the Action Plan was:

iv. A review of building and planning codes such as changed ground floor heights and land uses to reduce the risk of flood impacts

v. Building modifications to existing properties such as raising and restumping.


5.3 On-going engagement with the CRG

In addition to the collection and development of flood mitigation options and strategies that they would like Council to consider, the CRG has an on-going role in the development of the Floodplain Risk Management Study and the broader Flood Action Plan. The role of the CRG is summarised in the CRG Terms of Reference and includes:

- Communicate information and update their respective networks to ensure they are kept informed of the project’s progress;
- Act as a conduit for community feedback on the plan’s development to the consultant (GHD) and Bundaberg Regional Council;
- Collectively agree to the floodplain management options assessment criteria and weighting used during the Multi-Criteria Assessment (refer Section 7);
- Represent the community by submitting a report to Council in early December 2013 detailing the CRG’s preferred list of floodplain management options. This will be facilitated by the chairperson and require 70% consensus of the CRG members.

The CRG will report and provide feedback on issues raised in the course of the development of the Burnett River Floodplain Action Plan.

This group will also enable community access to information on the project as well as supporting the opportunity for the community to contribute to, and comment on, the development of the Burnett River Floodplain Action Plan.
6. **Flood Mitigation Options**

This section of the report provides an overview of the range of high level large-scale flood mitigation options that were initially identified by the CRG, Council and GHD, and also provides the results of a preliminary hydraulic analysis of the mitigation options.

As part of the continuing work on the FRMS over the coming months, BRC and GHD will examine a wide range of flood management measures in addition to the large-scale mitigation options considered in this preliminary report. These initiatives will be developed in response to community consultation and feedback.

6.1 **Option Development**

In consultation with BRC, a list of potential flood mitigation options was developed from community suggestions (refer to Section 5) and Council / GHD’s knowledge of the river system (refer to Section 2). This list of options was then fed into the multi-criteria analysis in order to highlight those options that might best meet the expectations of the community (refer to Section 7). Those options that appeared most viable after the MCA process were taken forward for more detailed assessment in Section 8.

The flood mitigation options presented herein are identified with numbers from 1 through 41, based on the numbering adopted in an interim memorandum to the Community Reference Group. For consistency with communications between GHD, BRC and the CRG, the same numbering has been retained for this report.

6.2 **Assumptions and Limitations**

When reviewing the many community suggestions and then developing specific flood mitigation concepts, the constraints on available, effective and viable flood mitigation options were taken into account. These constraints include the size of Burnett catchment and associated flood discharges, as well as the location of existing development on critical parts of the floodplain.

Due to the large number of options initially identified, the concepts described in this section have been considered on a high-level conceptual basis only. Broad assumptions were made about the nature and extent of works. All options contained in this section and in other sections of this report, are conceptual only and would be subject to significant further investigation and alteration if taken forward for implementation.

Some options were included on the basis of strong community support despite appearing marginal or problematic on an initial assessment. This provided the opportunity for open dialogue with the Community Reference Group and allowed a fair assessment to be made as part of the MCA (refer to Section 7). However, some other prominent suggestions were not taken forward. Reasoning for the exclusion of those suggestions is provided in Section 6.5.

As stated in Section 1.2, this report only deals with large-scale flood mitigation projects, and doesn’t consider other floodplains management measures such as flood warning systems, evacuation capability assessments and planning, flood risk information products for residents and improved communication strategies during flood events. These and other options will be considered as part of the overall Floodplain Risk Management Study.
6.3 Preliminary hydraulic modelling

To facilitate decisions on which options would be taken forward into the MCA, and to then underpin the MCA scoring process, a preliminary hydraulic assessment of each option was undertaken using the calibrated hydraulic model developed as part of the Burnett River Flood Study (GHD 2013). Where relevant, the options have been assessed against the January 2013 event, and the results have been analysed to determine the afflux (change in peak water level) caused by the mitigation option. A series of afflux maps for each of the preliminary flood mitigation options considered is provided in Appendix B.

6.4 Potential flood mitigation options

A concise list of the 20 options taken forward for the MCA is provided in Appendix B. A general description of the options and their intended function is provided below. Plans showing the location and alignment of the various projects, as well as the results of preliminary hydraulic modelling and afflux, are provided in Appendix C, as described in Section 6.3 above.

6.4.1 Levees

Levees can effectively exclude floodwaters from protected areas behind the levee up to their design flood event. The benefits of levees can include substantial reductions in flood damages and social impacts of flooding. In general, levees should be located in areas of relatively low velocity and where the levee will not result in a displacement of floodwaters that causes adverse impacts elsewhere or compromises the safety of the levee itself.

However, even well designed and located levees have certain inherent issues. Any levee is only effective to a certain point, and there is always a finite risk that a flood that exceeds the design event will cause the levee to overtop. In addition, the presence of a levee can lead to complacency and a belief that the protected community is “flood proof”. Protected communities need to be informed of the risks of potential levee overtopping or failure, and the presence of the levee should not justify the intensification of development in the protected area. Generally, these issues would be incorporated in an overall management plan for any potential levee.

Of a range of levees that were initially considered, those outlined below are to be taken forward as part of the MCA (refer to Section 6.5.1 for those that were excluded). Unless stated otherwise, for the purposes of the MCA it is assumed that the levees could be constructed to a height greater than the 2013 flood but would be overtopped in certain rare and extreme events. Further discussion of levee design heights is provided in Section 8.

- Option 1 - North levee – a levee extending from the rail line adjacent to the Bundaberg Golf Course, then north along high ground through the Botanical Gardens and the North School hill and along Fairymead Road to Tantitha Road. This levee would protect parts of North Bundaberg from large flood events. The works would involve a variety of construction types, a significant drainage structure, and some impacts to the properties and infrastructure along the levee alignment.

- Option 2 - East levee and floodgate – a levee from Quay St, crossing Bundaberg Creek to Quay St East, then running north past the Millquin Mill, the Bundaberg Distillery and the East Treatment Plant, terminating to the north of McGills Rd. The levee could effectively exclude river flood waters from the entire East Bundaberg area. This levee would involve a substantial floodgate structure on Bundaberg Creek and other drainage structures, a variety of construction types, and impacts to some affected properties and underground services. The potential for increased local Bundaberg and Saltwater Creek flooding due to construction of the floodgate would need to be managed.
• Option 10 - Low level North Bundaberg levees – comprises two levees constructed to the height of the 2% AEP (50-year ARI) design flood event. Below this event, the levees would effectively exclude flood waters from the part of North Bundaberg worst hit in the January 2013 flood events. Levee overtopping would occur during flood events in the order of the 50-year ARI event and above. The southern component of this levee system would be constructed along Perry Street and Hanbury Street and would prevent breakouts from the Burnett River into North Bundaberg. The northern component would be an earth embankment levee from the North School hill, along Mount Perry Road and across cane fields to Mariner’s Way. This levee would prevent the ingress of backwater flooding from the direction of Paddy’s Island.

• Option 11 - Port of Bundaberg levee – a levee or sea wall along the river bank to protect the urban area at the Port of Bundaberg. The levee would involve impacts to the riverfront properties in this location, but would prevent the ingress of flood waters to the properties behind during large flood events.

• Option 12 - Wallaville levee – this levee could be constructed to the north of the Wallaville township to protect against a flood equivalent to the 2013 flood, or as a full ring levee surrounding the urban area to protect against a 0.2% AEP (500-year ARI) event.

6.4.2 Diversion channels

If located and designed appropriately, diversion channels can provide relief for floodwaters and reduce flood levels in the main stream by carrying excess floodwaters away. However, diversion channels have to be large to convey significant flows and can increase flood levels at their downstream end.

Of a range of diversion channels that were initially considered, those outlined below are to be taken forward as part of the MCA (refer to Section 6.5.4 for those that were excluded).

• Option 19 - Gardens channel 2 – a nominally 250m wide and 2m deep flood bypass channel constructed near the Botanical Gardens, extending from the rail line in the south to Fairymead Road in the north. The channel would involve a substantial volume of excavation, resumptions of a number of properties, and would require new or upgraded bridges on the rail line, Hinkler Avenue and Mount Perry Road.

• Option 20 - Rubyanna bypass channel – a nominally 500m wide diversion channel with an invert level of -2m AHD to improve the river’s flood carry capacity in the Rubyanna area. This option would entail a very substantial volume of excavated material and removal of a large area of mangrove vegetation.

• Option 41 - Fairymead diversion channel 3 – a nominally 300m wide diversion channel with an invert level of -5m AHD to allow flood waters to bypass the critical construction at Fairymead bend and discharge directly to Skyringville passage.

6.4.3 Dredging

Dredging the river has the potential to reduce flood levels by increasing the cross-sectional area of the river and hence its flood conveyance capacity. Dredging will be generally more effective in areas where flood levels are controlled by the in-bank capacity of the river, and less effective where floodwaters are spread across wide, flat floodplains. Dredging is also more effective in locations where tides do not have a dominant influence on major floods (refer to Section 2.3).

Potential issues associated with dredging include impacts on river bank stability, contaminants (including acid sulphate soils) in the dredged material, disposing of soil to an approved location, mobilisation of sediments during dredging operations, impacts on water quality and potential loss of habitat for important species. Dredging may also alter fluvial geomorphological
processes in a way that leads to increased sedimentation (and therefore maintenance dredging requirements).

The feedback received from the community was taken into account when developing a range of high-level dredging options for inclusion in the multi-criteria analysis. These options are described below:

- Option 23 - Selective dredging of only the town reach from upstream of Harriet Island to downstream of Millaquin bend.
- Option 24 - Dredging of the entire length of the Burnett River from the Ben Anderson Barrage to the Port of Bundaberg.
- Option 25 - Selective dredging of only critical constrictions in the river at the foundry, Millaquin bend and Fairymead bend.

For the purposes of the MCA, it has generally been assumed that the river can be deepened by a uniform 3 m within the extent of works. Further investigation would be required to determine stable bank angles of repose to inform the detailed design of any dredging option.

**6.4.4 River widening & vegetation removal**

With due consideration to the key constrictions and flood level controls described in Section 2.3, a number of options for improving the flood-carrying capacity of the river were identified. These options would mitigate flooding by increasing the amount of water the river could carry before breaking its banks, thereby reducing the frequency of flooding in adjacent developed areas and reducing the peak flood levels and velocities in larger events.

The identified options are described below:

- Option 27 - Removal of mangroves from the town reach of the river, along with artificial reinforcement to preserve bank stability.
- Option 29 - Remove sediment (nominal 0.5m depth) from the north bank of the town reach and Harriet Island to improve the flood carry capacity of the river. Some vegetation removal would be required, but vegetation would be allowed to re-establish to preserve bank stability.
- Option 30 - Reopen Skyringville passage by removing the sea wall opposite the Port of Bundaberg, substantial areas of mangrove vegetation and large quantities of accumulated sediment through the passage. This would restore the original mouth of the river and provide an additional outlet for flood waters.
- Option 31 - Widen the river adjacent to Millaquin Mill and Mariner’s Way by excavating material from the inside of the bend (north-west bank). The works would entail some excavation within private properties, removal of an area of mangroves, and rock revetment walls for stabilisation.
- Option 35 - Widen the river along the town reach by excavating material from the north bank of the river from Edina Street Park adjacent Harriet Island to Mariner’s Way. These works would involve partial or full resumption of some affected properties including the foundry, removal of mangroves, and rock revetment walls. There would also be modifications needed to the foundations of the three major bridges along the town reach.

Other river widening options that were excluded following initial review are described in Section 6.5.2.
6.4.5 Bridge and evacuation route upgrades

Some communities along the Burnett River are not directly impacted by floodwaters, but can be isolated for extended periods of time due to flooding of key roads and bridges and can also have their ability to safely evacuate compromised. Upgrading some of these key pieces of infrastructure could provide substantial benefits to the isolated communities, including improved evacuation capability, improved access to emergency and recovery services and a general reduction in disruption due to flooding.

The options put forward for consideration in the MCA are as follows:

- **Option 38 - Regional bridge upgrades** – The Perry River Bridge (Walla Rd), the St Agnes Creek Bridge (Walla Rd) and Booyal Crossing (Causeway Rd), when cut by floodwaters, isolate the communities in the Morganville and Good Night areas. In addition, closure of the Cherry Creek and Pine Creek Bridges on Pine Creek Rd isolate the residents in Givelda, Electra and parts of Pine Creek. If upgraded, these crossings would improve access to these communities during and after flood events.

- **Option 39 - North Bundaberg evacuation route upgrades** – A number of roads in North Bundaberg (including Hinkler Avenue, Mount Perry Rd (or Batchler’s Rd) and Fairymead Rd are key evacuation routes in the event of a flood. Raising these roads (or constructing a new viaduct in the case of Hinkler Avenue) would improve evacuation capability. The key aspect of this project would be providing a resilient and reliable connection between the north and south sides of the river at Bundaberg.

Following the completion of the MCA and the preliminary mitigation options assessment process, BRC requested that GHD include an additional evacuation route upgrade project at Bartholdt Drive, Branyan. This project was developed independently by BRC to address a known evacuation issue and has been included in the report for consideration by decision makers in allocating funding. A brief description of this project is as follows:

- **Bartholdt Drive evacuation route upgrade** – Works to formalise approximately 630 m of existing unformed road at the western end of Bartholdt Drive. The project involves earthworks, pavement and drainage works. The project would provide an alternative high-immunity evacuation route for approximately 460 properties (estimated population of 1150 based on an average 2.5 people per household) that are currently isolated when the McCoys Creek crossing on Branyan Drive is cut by river backwater or creek flooding. Approximately 45 of the properties are located off Daveys Drive and are isolated due to the early closure of the Branyan Drive crossing at Branyan Creek.

6.4.6 Other

The final two options put forward for consideration in the MCA are as follows:

- **Option 26 - Removal of Fairymead levees** – The existing levees at Fairymead, originally constructed to protect the old Fairymead sugar mill, could be removed. This would allow floodwaters to escape over the floodplain to the north and west, thereby relieving river levels upstream. Potential downsides to this project could include increases in flood levels in land behind the levee.

- **Option 40 - Funding for house raising and restumping** – Funds could be provided for the raising and restumping of highly flood prone houses.
6.5 Other proposals not taken forward

Several other proposals were put forward for consideration that were not deemed viable upon initial review. These are discussed below. Where noted, plans showing the location and alignment of the various projects, as well as the results of preliminary hydraulic modelling and afflux, are provided in Appendix C.

6.5.1 Levees in North Bundaberg

During the initial stages of this study, a range of levee options (Options 3, 6, 7, 8 and 9 among others not included in this report) were explored with the aim of protecting the most vulnerable parts of North Bundaberg from high depth and velocity breakouts form the Burnett River. In contrast to the low level North Bundaberg levees (Option 10), this set of proposals would seek to protect against flood events equivalent to the 2013 flood and greater. The height of these levees would have to exceed 3 m in many places.

All of these options proved problematic upon review, as demonstrated by the afflux maps in Appendix C. As North Bundaberg is a zone of high conveyance of flood waters, as opposed to a backwater as in the case of East Bundaberg, all of these levees would displace and redirect significant flows. The consequences of this displacement are significantly increased flood levels outside and upstream of the levee, significantly increased velocities in the river corridor, and high velocities across the face of the levee itself. Combined with the relatively poor (sandy) geotechnical conditions in the parts of North Bundaberg closest to the river, any levees would be at a substantial risk of failure due to scour and erosion of the flooded side or due to seepage through the porous substrate.

In contrast, the low level North Bundaberg levees would be relatively low structures designed to protect against relatively small flood events. Therefore both the amount of water displaced and the forces on the levee wall would be smaller in turn. The displaced water and increased flood levels and velocities could be offset by other projects such as diversion channels, dredging or bend widening.

6.5.2 Other river widening options

In Section 2.3.2, the effect of river constrictions is described. In general, these constrictions cause water levels upstream to be higher than normal and water levels downstream to be slightly lower than normal. In addition to those river widening options described in Section 6.4.4 above, the following projects were also considered (refer to Appendix C for the indicative alignment, extents and preliminary hydraulic modelling results):

- Option 32 – Edina St Park widening
- Option 33 – Foundry widening
- Option 34 – Fairymead bend widening
- Option 36 – Removal of Harriet Island
- Option 37 – Deepen and widen channel north of Harriet Island

As demonstrated by the afflux maps in Appendix C, none of these options have clear benefits that outweigh the potential downsides. The results of the preliminary hydraulic modelling show that these options tend to have some impact on reducing upstream flood levels, but also increase flood levels immediately downstream. For these options, the increased flood levels impact on existing developed areas.

This is in contrast to the Millaquin bend widening (Option 31) and the full town reach widening (Option 35), where the location and extent of the works are such that the resulting small area of increased flood levels is constrained to the river corridor itself, away from developed land.
6.5.3 Dams or weirs as flood storage

There were several suggestions to utilize dams and other storages on the Paradise Dam as flood mitigation measures, as is the case on the Brisbane River with the Wivenhoe Dam and elsewhere. In general, the size of storage required to significantly mitigate Burnett River flooding would be impractical in terms of cost and feasibility. This is primarily due to the very large size of the Burnett River catchment (nearly 3 times as large as that of the Brisbane River), and the relatively small size of the existing impoundments (Wivenhoe Dam on the Brisbane River has almost 9 times as much storage as Paradise Dam). By contrast, the Fred Haigh Dam on the Kolan River has a very substantial flood mitigation function due to the large size of the storage relative to its catchment area.

Reducing the full supply level (FSL) of Paradise Dam (i.e. lowering the water level below 100% prior to the wet season), or installing flood gates for controlled discharge of flood waters, would have negligible impact on a flood equivalent to the 2013 event. Sensitivity testing undertaken as part of the Burnett River Flood Study indicates that if Paradise Dam were completely empty prior to January 2013, the peak flow rate downstream would have been reduced by only 2% (a reduction in peak flood levels of approximately 0.15m relative to the Bundaberg gauge).

Additionally, a simple hydrologic analysis was undertaken to show that a three-fold increase in the volume of Paradise Dam would be required to reduce flood levels in Bundaberg by approximately 0.5m in a 2013-equivalent flood. It is unlikely that such a project would deliver flood mitigation benefits commensurate with its costs, even ignoring the practical and physical constraints on tripling the dam’s volume.

6.5.4 Burnett River to Elliot River diversion channel

Several suggestions were put forward for large-scale diversion channels to redirect floodwaters from the Burnett River upstream of Bundaberg to either the ocean or other river systems, such as the Elliot River to the south. Similar systems do exist around the world, such as the Morganza Floodway on the Mississippi River which diverts approximately 17,000 m$^3$/s of floodwater into an adjacent river through a spillway with 125 large steel gates. However, a large-scale diversion is impractical as a flood mitigation measure for the Burnett River.

Based on a review of the regional geography, several Burnett-to-Elliot diversion schemes were developed as concepts to demonstrate order-of-magnitude effects. The concepts were supported by preliminary calculations to estimate invert levels, dimensions, flow capacity and earthworks volumes. Two routes were identified as described below (refer to the maps in Appendix C for details):

1. Route 1 (17 km in length) – From the Burnett River at Branyan (CH 27km AMTD), across the Isis Highway, Bundaberg Ring Road and Goodwood Road to the Elliot River following the line of Yellow Waterholes Creek.

2. Route 2 (22 km in length) – From the Burnett River at the Woongarra Pump Station (CH 38km AMTD), across the Isis Highway and ending several kilometres to the east of Goodwood Rd, following the line of the Elliot River.

For each route, two options were developed; one that conveys 3,000 m$^3$/s and one that conveys 10,000 m$^3$/s. In an event similar to the January 2013 flood, these options would lower water levels in Bundaberg by approximately 0.5 m and 5 m respectively. Simplified Manning’s equation calculations were undertaken to determine the upstream and downstream invert levels and the required width of the channel. These dimensions were then used to estimate approximate earthworks volumes. A summary of these calculations are presented below in Table 6-1, with full details including longitudinal profiles provided in Appendix C.
Table 6-1 Estimated Elliot River diversion channel dimensions

<table>
<thead>
<tr>
<th>Option</th>
<th>Discharge (m³/s)</th>
<th>Upstream &amp; Downstream Invert Levels (m AHD)</th>
<th>Channel base width (m)</th>
<th>Maximum depth of excavation (m)</th>
<th>Approximate volume of excavation (m³)</th>
<th>Approximate bulk earthworks costs ($)¹</th>
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</thead>
<tbody>
<tr>
<td>Route 1</td>
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<td></td>
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<tr>
<td>Option A</td>
<td>3,000</td>
<td>5 &amp; 0</td>
<td>125</td>
<td>28</td>
<td>63,000,000</td>
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<tr>
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<tr>
<td>Option B</td>
<td>10,000</td>
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<tr>
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<td>10,000</td>
<td>15 &amp; 5</td>
<td>1600</td>
<td>32</td>
<td>600,000,000</td>
<td>$6 billion</td>
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Table 6-1 illustrates that due to the large volume of material required to be excavated, the bulk earthworks costs are extremely high. The costs, disruptions, construction issues and environmental impacts of such a project would far outweigh any benefits, especially when compared to other smaller projects described elsewhere in this report. On top of this would be the costs associated with property resumptions, a number of substantial bridges over the channel, disposal of spoil, engineered stabilisation of the channel and diversion and control structures among other items. The environmental impacts of such a channel on the receiving environment would be significant, and would entail substantial disruptions to the natural system in the Elliot River. There would also be widespread flooding of land near the outlet of the channel.

While other alternatives to concepts presented above may exist (with different routes, invert levels, widths and design discharges), it is unlikely that the overall economics would be significantly different. Large-scale river diversions have therefore been excluded from further consideration as part of this study.

6.5.5 Removal of Ben Anderson barrage

There were numerous suggestions to remove the Ben Anderson barrage as a means to reduce flood levels. The suggestions focused on two aspects; the direct impact of the structure on flood levels, and the effect of the barrage on river sedimentation. The first aspect is discussed in this section, and the second aspect is discussed below in Section 6.5.6.

As part of the Burnett River Flood Study, GHD conducted a sensitivity test on the hydraulic model whereby the Ben Anderson barrage was removed from the model. The change in flood level for the 2013 event was then calculated. The removal of the barrage (and bridges) only reduces flood levels by 1 or 2 cm. This is not a significant effect, and is not an effective method for mitigating flooding.

The primary reason for this very small effect is that the barrage is a relatively low structure (crest level 2.1m AHD) and the 2013 flood level at the barrage was about 12m higher than the top of the structure (flood level ~14m AHD at that location). The barrage was therefore completely drowned and exerted no significant impact on peak flood levels. This is true for all significant floods. The barrage would have a more pronounced impacted during minor river flows (where the water level downstream of the barrage is not much higher than the crest), however these flows are generally below the threshold of damaging floods and reducing water

¹ Note: Costs calculated at an assumed order-of-magnitude rate of $10 / m³. This number is not intended to be an actual estimate, but is provided of discussion purposes. Actual costs would vary significantly based on the construction methodology and geotechnical conditions encountered. However, given the large volume of excavation required, bulk earthworks costs are likely to remain extremely high regardless of the rate adopted.
levels in these situations will not deliver benefit to the community. The effect of the barrage is insignificant compared to the critical river constrictions discussed elsewhere in this report.

Another issue is the potential cost of removing the barrage, which would have to be weighed against its benefits and the cost versus benefits of the other viable options under consideration. The substantial costs would include sourcing an alternate supply for agricultural and domestic consumption and constructing infrastructure to deliver water to Bundaberg, and sourcing additional supply to maintain the current level of water security during droughts. With the negligible benefits described above, GHD is confident that removal of the barrage is not a viable option for directly mitigating damaging floods.

6.5.6 Removal of Paradise Dam and other impoundments to reduce sedimentation

Several community suggestions focused on removing the Paradise Dam and other river impoundments, including the Ben Anderson barrage, to indirectly reduce flooding by reducing sedimentation of the lower reaches of the river. In general, this view is not supported by the available evidence as outlined below.

From very early records, it is known that the Burnett River is naturally very shallow in some locations and is heavily laden with sediment. It is also known that the river bed naturally changes over time due to the influence of tides and freshwater flooding, even without human interference. The Burnett River, as with other rivers in Queensland, has likely also been impacted by the clearing of land for agriculture. It is believed by some that man-made structures such as the Ben Anderson Barrage (built in 1974-75) have led to the accumulation of additional sediment and a reduction in river capacity through the town reach and elsewhere. There is certainly evidence (both anecdotal and from other sources such as aerial photograph) that intertidal mudflats (with accompanying mangrove growth) and sub tidal sediments have accumulated on the northern bank of the town reach over the period from 1942 to 2010. Whether this was due to the construction of the barrage or simply natural processes is a question that can be partially answered through engineering investigation.

In the past there have been two detailed hydraulic analyses (Queensland Government Hydraulics Laboratory, 1985 and 1994) of the impacts of the Ben Anderson Barrage on downstream sedimentation and channel depths. These studies were carried out in response to concerns that the barrage had caused a reduction in river depth in the town reach. While there were some limitations to these studies, the general finding was that the barrage had no significant impact on the accumulation of sediment downstream during both tidal and flood conditions. Based on these results, the observed accumulation of sediment in the town reach might be better explained by the lack of significant flood events between the time the barrage was constructed and 2010 or other natural or human-induced (i.e. soil loss due to agriculture) processes that have been occurring since before the barrage’s construction.

Detailed surveys of the river bed from 2010, 2012 and 2013 show that recent flooding has removed significant quantities of sediment (up to 3m or more in places) from parts of the river bed, although some of the intertidal mudflats on the north bank remain. This supports the view that floods are the dominant factor contributing to the erosion and deposition of sediment in the Burnett River system. Further detailed investigations (geomorphological and sediment transport studies using modern computer simulations that model the flow of water in 2- or 3-dimensions and include fine silts and muds) would be necessary to conclusively determine whether removing the dam, weirs and barrages (or some combination thereof) would indirectly mitigate flooding in populated parts of the Burnett River floodplain by reducing the accumulation of sediment. This is because the processes that govern the mobilisation and deposition of sediments (gravels, sands, silts, muds, etc.) are complex, and a change in one part of the river might have both positive and negative impacts on the capacity of the river in other locations.
However, based on the currently available evidence described above it is not anticipated that the barrage has any significant impact on the accumulation of sediment through the town reach. Conventional wisdom and experience at many other river impoundments suggests that the most significant impact on sedimentation is actually upstream of the structure, where reduced flow velocities are likely to increase the rate of accumulation. Given this fact, the removal of the dam, barrage or other structures may have detrimental effects on the town reach and below due to the release of this accumulated material.
7. Multi Criteria Assessment

In order to identify a set of preferred floodplain mitigation options from the comprehensive list of potential options identified by GHD, Council and the CRG – a Multi Criteria Assessment (MCA) was undertaken on the full range of options. This chapter describes the MCA framework, methodology and results of the MCA process.

7.1 Purpose

The primary purpose of the MCA is to discriminate between the various options and allow future efforts to focus on those options that may be most viable and best address the concerns of the community. The MCA process is not intended to be definitive, but serves as a useful tool to differentiate between more and less promising options.

7.2 MCA framework

The framework of the MCA was comprised of a matrix of:

- Flood mitigation options;
- A range of social, environmental and economic criteria that each flood mitigation option was assessed (scored) against; and
- A set of criteria weightings that represent the relative importance of each of the assessment criteria; and
- For each of the mitigation options:
  - A set of scores in the range 1 to 100 was assigned to each of the assessment criteria (100 indicating a highly beneficial / desirable option); and
  - An overall score for the option based on the score assigned to each of the assessment criteria and the relative weightings was assigned to each of the assessment criteria.

An example of the MCA framework is provided below with the full MCA framework provided in Appendix D.

Table 7-1 Example MCA framework

<table>
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<th>Aspect: Criteria:</th>
<th>Criteria 1</th>
<th>Criteria 2</th>
<th>Criteria 3</th>
<th>Criteria 4</th>
<th>Criteria 5</th>
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<th>Rank (Weighted)</th>
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7.3 Methodology

In undertaking the MCA, the following methodology was adopted:

- Identification of potential floodplain mitigation options by GHD, Council, the CRG and the community consultation process;
- In consultation with the CRG, a list of 20 assessment criteria across the categories of social, environmental and economic factors was established;
- In a workshop, the CRG determined the weighting (relative importance) of each of the assessment categories and criteria;
- Where practical, preliminary flood modelling for each flood mitigation was undertaken to identify potential hydraulic advantages and disadvantages;
- GHD scored each potential flood mitigation option against each of the assessment criteria. A set of scores in the range 1 to 100 was assigned to each of the assessment criteria (100 indicating a highly beneficial / desirable assessment against that criteria);
- The MCA framework was used to determine an overall score for each option based on the score assigned to each of the assessment criteria and the relative weightings assigned to each of the assessment criteria.
- Based on the overall score, each mitigation option was categorised as being viable, marginally viable or unviable.
- Sensitivity testing was undertaken on the impact of the weightings assigned to each of the assessment criteria on the overall score for each option.

A description of the assessment criteria, criteria weightings, scoring and MCA categories is provided below.

7.3.1 Assessment criteria and weightings

The social, environmental and economic criteria and associated weightings, as determined by the CRG, that were used to assess each of the potential flood mitigation options are summarised in Table 7-2. The criteria were determined by the CRG members in a workshop facilitated by BRC and GHD, and later formally adopted by the CRG.

The criteria weightings as determined by the CRG place a high importance on social factors such as reducing the frequency and duration of flooding and isolation, reducing the community’s exposure to flood hazards, as well as environmental factors such as minimising the impact on the aquatic and riparian environmental and minimising impacts on river stability and sedimentation. Conversely, the CRG placed a relatively low weight on cost of implementation. The extent to which these weightings influence the final ranking has been explored through sensitivity testing described in Section 7.5.
<table>
<thead>
<tr>
<th>Category</th>
<th>Criteria</th>
<th>Criteria Weight</th>
<th>Category Weight</th>
<th>Overall Contribution to Final Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social</td>
<td>Communication / notification during a flood event</td>
<td>18%</td>
<td>40%</td>
<td>7.2%</td>
</tr>
<tr>
<td>Social</td>
<td>Flood warning time</td>
<td>17%</td>
<td>40%</td>
<td>6.8%</td>
</tr>
<tr>
<td>Social</td>
<td>Frequency and duration of flooding or isolation / effects of isolation</td>
<td>17%</td>
<td>40%</td>
<td>6.8%</td>
</tr>
<tr>
<td>Social</td>
<td>Impact on direct exposure to flood hazard / safety</td>
<td>14%</td>
<td>40%</td>
<td>5.6%</td>
</tr>
<tr>
<td>Social</td>
<td>Visual amenity</td>
<td>1%</td>
<td>40%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Social</td>
<td>Cultural heritage</td>
<td>3%</td>
<td>40%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Social</td>
<td>Impact on community infrastructure</td>
<td>5%</td>
<td>40%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Social</td>
<td>Impact on evacuation routes</td>
<td>11%</td>
<td>40%</td>
<td>4.4%</td>
</tr>
<tr>
<td>Social</td>
<td>Impact on recovery / accommodating the displaced victims of a flood</td>
<td>14%</td>
<td>40%</td>
<td>5.6%</td>
</tr>
<tr>
<td>Environmental</td>
<td>Impact on terrestrial environment (flora / fauna)</td>
<td>19%</td>
<td>35%</td>
<td>6.7%</td>
</tr>
<tr>
<td>Environmental</td>
<td>Impact on aquatic / riparian environment (flora / fauna)</td>
<td>29%</td>
<td>35%</td>
<td>10.2%</td>
</tr>
<tr>
<td>Environmental</td>
<td>Difficulty of environmental approvals</td>
<td>4%</td>
<td>35%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Environmental</td>
<td>Impact on river stability / sedimentation</td>
<td>29%</td>
<td>35%</td>
<td>10.2%</td>
</tr>
<tr>
<td>Environmental</td>
<td>Erosion / scour to floodplain</td>
<td>19%</td>
<td>35%</td>
<td>6.7%</td>
</tr>
<tr>
<td>Economic</td>
<td>Overall cost-benefit</td>
<td>8%</td>
<td>25%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Economic</td>
<td>Cost of implementation</td>
<td>3%</td>
<td>25%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Economic</td>
<td>Cost of maintenance / upkeep</td>
<td>6%</td>
<td>25%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Economic</td>
<td>Inundation of agriculture land</td>
<td>15%</td>
<td>25%</td>
<td>3.8%</td>
</tr>
<tr>
<td>Economic</td>
<td>Impact on local business / commercial land</td>
<td>17%</td>
<td>25%</td>
<td>4.3%</td>
</tr>
<tr>
<td>Economic</td>
<td>Impact on residential properties</td>
<td>22%</td>
<td>25%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Economic</td>
<td>Impact on municipal infrastructure / utilities</td>
<td>14%</td>
<td>25%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Economic</td>
<td>Impact on fisheries</td>
<td>11%</td>
<td>25%</td>
<td>2.8%</td>
</tr>
<tr>
<td>Economic</td>
<td>Impact on tourism</td>
<td>1%</td>
<td>25%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Economic</td>
<td>Impact on developable land</td>
<td>3%</td>
<td>25%</td>
<td>0.8%</td>
</tr>
</tbody>
</table>

Note: the Category Weight refers to the weight assigned to the social, environmental and economic categories with a criteria’s Overall Weight determined by multiplying the Criteria Weight by the Category Weight.
7.3.2 Scoring

Each flood mitigation option has been scored from 1 – 100 against each criteria. The assigned scores reflect a subjective engineering judgement of the performance of each option against each criterion, based on the following scoring system:

**Table 7-3 Scoring System**

<table>
<thead>
<tr>
<th>Score</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Highly beneficial / desirable</td>
</tr>
<tr>
<td>90</td>
<td>Very beneficial / desirable</td>
</tr>
<tr>
<td>70</td>
<td>Moderately beneficial / desirable</td>
</tr>
<tr>
<td>50</td>
<td>Neutral (i.e. no significant positive or negative impact)</td>
</tr>
<tr>
<td>20</td>
<td>Moderately constrained / detrimental</td>
</tr>
<tr>
<td>10</td>
<td>Highly constrained / detrimental</td>
</tr>
<tr>
<td>1</td>
<td>Fatal flaw / prohibitive</td>
</tr>
</tbody>
</table>

It is noted that the adopted list of criteria contains several items which may not have direct relevance to the large-scale mitigation options under consideration at this stage. Such items include flood warning and communication / notification during a flood event, which are issues that the large-scale mitigation options have not been specifically formulated to address. For the purposes of the MCA, the various options have hence been assigned mostly neutral scores against those criteria. Nonetheless, the importance the community places on such outcomes will be reflected in the recommendations of the overall Floodplain Risk Management Study, which will consider a broader range of management measures.

GHD has reviewed, where possible, relevant high-level information such as preliminary hydraulic modelling results and environmental overlays to assign scores to each of the options. GHD has also considered preliminary feedback received from the Technical Working Group (TWG) and the CRG. However, due to constraints on time and the large number of options and criteria involved in the analysis, the scoring process has been primarily subjective in nature. In most cases, scores were assigned based on subjective judgements and then reviewed to ensure consistency. The cost-benefit and cost-related criteria, for instance, were scored based on order-of-magnitude estimates rather than actual objective estimates. This methodology is considered appropriate for the MCA, given that further detailed assessment will be undertaken on the most viable options in Section 8.
7.3.3 MCA Categories

Due to the high-level conceptual nature of the options developed in Section 6 and the subjective nature of the MCA scoring process, the results of the MCA were used to sort the viability of the options into the following categories:

Table 7-4 MCA result categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viable (V)</td>
<td>Based on the CRG’s criteria and weightings, and broad assumptions about the nature of the flood mitigation project, these options appear to be viable.</td>
</tr>
<tr>
<td>Marginally viable (MV)</td>
<td>Options in this category were outperformed by those in the viable category. Generally, these options either have marginal flood mitigation benefits or have substantial negative impacts that offset potential upsides. Some of these options may warrant further consideration at a later stage, depending on available funding or emergent issues with other projects.</td>
</tr>
<tr>
<td>Unviable (UV)</td>
<td>These options are either not effective at mitigating floods, or entail substantial negative impacts that clearly overwhelm any potential flood mitigation benefits.</td>
</tr>
</tbody>
</table>
7.4 Results

The results of the MCA process are summarised in Table 7-5. The raw scores assigned to the options against each criterion are presented in Appendix D.

The most viable options (blue shading) are those that specially address the concerns of the community while minimising adverse or unmanageable environmental outcomes.

Marginal options (yellow shading) are those that either have marginal flood mitigation benefits or have substantial negative impacts that offset potential upsides.

Those options deemed unviable (red shading) are costly and cause significant adverse environmental impacts while not delivering substantial benefit to the community.

Table 7-5 Overall Rankings Based on Adopted Weightings

<table>
<thead>
<tr>
<th>Option Number</th>
<th>Description</th>
<th>Viability</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>East Levee &amp; Floodgate</td>
<td>V</td>
</tr>
<tr>
<td>38</td>
<td>Regional Bridge Upgrades</td>
<td>V</td>
</tr>
<tr>
<td>39</td>
<td>Bundaberg North Evacuation Route Upgrades</td>
<td>V</td>
</tr>
<tr>
<td>40</td>
<td>Funding for house raising / restumping</td>
<td>V</td>
</tr>
<tr>
<td>1</td>
<td>North Levee</td>
<td>V</td>
</tr>
<tr>
<td>23</td>
<td>Town Reach Dredging</td>
<td>V</td>
</tr>
<tr>
<td>10</td>
<td>Low Level North Bundaberg Levees</td>
<td>V</td>
</tr>
<tr>
<td>31</td>
<td>Millaquin Bend widening (north bank)</td>
<td>V</td>
</tr>
<tr>
<td>12</td>
<td>Wallaville Levee</td>
<td>MV</td>
</tr>
<tr>
<td>25</td>
<td>Selective dredging at foundry, Miliquin Bend and Fairymead Bend</td>
<td>MV</td>
</tr>
<tr>
<td>31</td>
<td>Town reach widening (north bank)</td>
<td>MV</td>
</tr>
<tr>
<td>24</td>
<td>Barrage to Port Dredging</td>
<td>MV</td>
</tr>
<tr>
<td>11</td>
<td>Port of Bundaberg Levee</td>
<td>MV</td>
</tr>
<tr>
<td>19</td>
<td>Gardens Channel 2</td>
<td>MV</td>
</tr>
<tr>
<td>29</td>
<td>Removal of sediment from north bank and Harriet Island</td>
<td>MV</td>
</tr>
<tr>
<td>26</td>
<td>Removal of Fairymead Levees</td>
<td>UV</td>
</tr>
<tr>
<td>27</td>
<td>Removal of mangroves from town reach</td>
<td>UV</td>
</tr>
<tr>
<td>30</td>
<td>Reopen Skyringville Passage</td>
<td>UV</td>
</tr>
<tr>
<td>20</td>
<td>Rubyanna Bypass Channel</td>
<td>UV</td>
</tr>
<tr>
<td>41</td>
<td>Fairymead Diversion Channel 3</td>
<td>UV</td>
</tr>
</tbody>
</table>

Note: V=Viable, MV=Marginally viable, UV=unviable.
7.5 Sensitivity testing

A range of alternate weighting scenarios have been assessed to test the sensitivity of the final ranking to changes in assigned weightings. Truly desirable options should be robust and rank highly regardless of the assigned weightings, whereas marginal options may demonstrate significant swings in rank when the assigned weightings are altered. The sensitivity testing scenarios conducted as part of the MCA are as follows:

- Overall Raw Unweighted Rank – No weightings of any kind are applied, and hence all criteria have an equal influence on the outcome.
- Overall Criteria Weighted Rank – Weightings are only applied at the criteria level, with no weightings applied at the category level.
- Alternate Weightings 1 - Weak Economic Category Bias (40% economic / 30% social / 30% environmental) – Originally adopted criteria weightings are used, with the category weightings altered to give a weak bias to the economic category.
- Alternate Weightings 2 - Weak Social Category Bias (30% economic / 40% social / 30% environmental) – Originally adopted criteria weightings are used, with the category weightings altered to give a weak bias to the social category.
- Alternate Weightings 3- Weak Environmental Category Bias (30% economic / 30% social / 40% environmental) – Originally adopted criteria weightings are used, with the category weightings altered to give a weak bias to the environmental category.
- Alternate Weightings 4 - Strong Economic Category Bias (60% economic / 20% social / 20% environmental) – Originally adopted criteria weightings are used, with the category weightings altered to give a strong bias to the economic category.
- Alternate Weightings 5 - Strong Social Category Bias (20% economic / 60% social / 20% environmental) – Originally adopted criteria weightings are used, with the category weightings altered to give a strong bias to the social category.
- Alternate Weightings 6 - Strong Environmental Category Bias (20% economic / 20% social / 60% environmental) – Originally adopted criteria weightings are used, with the category weightings altered to give a strong bias to the environmental category.

The sensitivity testing results are presented in Appendix E. The results show that the best performing options are generally robust with respect to changes in the applied weightings, which provides confidence in the overall ranking.

However, some options do demonstrate significant swings in rank between each of the scenarios. The most significant sensitivity is exhibited by Option 14 – Barrage to Port Dredging (ranked 12 overall), which ranks at number 4 when a strong social bias is applied and at number 17 when a strong environmental bias is applied. This is a reflection of the fact that dredging the entire river would deliver substantial reductions in flooding across a widespread area, but would also entail significant environmental impacts and other issues compared to other options. More generally, Option 14 is outperformed by other smaller, targeted mitigation measures that deliver comparable benefits at a much lower cost and with a greatly reduced environmental impact.
7.6 Discussion of results

The adopted criteria and weightings place a large importance on reducing the community’s direct exposure to flood hazard, reducing the frequency and duration of isolation due to flooding, and minimising environmental impacts. A relatively low importance was placed on cost and other factors. The results of the MCA generally reflect this.

7.6.1 Levees

Of the various levee options, the East levee (Option 2) performed most favourably. While the costs associated with this levee and its associated floodgate would be high, it would effectively protect a large number of residential, commercial and industrial properties without causing significant external negative impacts or unmanageable environmental issues. In line with the CRG’s adopted criteria and weightings, this levee therefore scored favourably. The North levee (Option 1) also ranked highly due to the relatively large area protected and because the levee would protect key evacuation routes connecting parts of North Bundaberg, Fairymead and Gooburrum to Mount Perry Road.

The low level North Bundaberg levees (Option 10) ranked highly because of the partial protection of a large number of properties that were badly affected in January 2013. However, the potential for increased flood levels in larger events as well as potential impacts on erosion and stability in the river corridor due to increased velocities means that additional mitigating or compensatory works should be considered in conjunction with this project.

The Wallaville and Port of Bundaberg levees, which would only protect small numbers of properties against relatively rare flood events, ranked relatively lowly. However, as these projects do not entail any significant environmental impacts, they could be implemented for a relatively low cost.

7.6.2 Dredging

Due to the potential environmental impacts and costs associated with dredging, the two dredging options that target only small sections of the river (Option 23 and 25) outperform the whole-of-river dredging option (Option 24). The afflux mapping in Appendix B based on an assumed 3 m reduction in river bed levels shows that while Option 24 results in more widespread reductions in flood levels, Option 23 results in comparable reductions in the major developed parts of Bundaberg. For a greatly reduced cost, footprint and impact, the targeted dredging of the town reach could provide reductions in flooding to residences and businesses.

7.6.3 River widening & vegetation removal

The Millaquin Bend widening works (Option 31) rank highly because of the substantial reductions in flooding in developed parts of Bundaberg, and because the relatively small project footprint limits the potential environmental impacts. This is in contrast to the town reach widening works (option 35) that has a much larger footprint and impact for only marginally additional flood mitigation benefits.

The removal of mangroves from the town reach (Option 27) and the removal of sediment from Harriet Island (Option 29), when viewed against the adopted criteria and weightings, is seen to have significant adverse environmental impacts as well as impacts on river bank stability and erosion. These factors outweigh any flood level reduction benefits.
7.6.4 Diversion channels

To illustrate the relative flood mitigation effectiveness of the various diversion channels being considered, the potential reductions in peak flood level (based on preliminary hydraulic modelling of the January 2013 event) are summarised in Table 7-6. The five geographical locations are shown in Figure 7-1. Of all the diversion options considered in this assessment, the results show that only the Millaquin Bend widening works result in a substantial reduction in flood levels in highly developed and flood prone parts of the floodplain (represented by locations 1, 2 and 3 in Figure 7-1. The afflux maps in Appendix B present the potential flood level reduction effects of each channel option.

Table 7-6 Change in peak flood level (January 2013 event)

<table>
<thead>
<tr>
<th>Id</th>
<th>Location</th>
<th>Option 31</th>
<th>Option 21</th>
<th>Option 22</th>
<th>Option 41</th>
<th>Option 30</th>
<th>Option 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bundaberg Gauge (Targo St)</td>
<td>Millaquin Bend</td>
<td>Fairymead</td>
<td>Fairymead</td>
<td>Fairymead</td>
<td>Skyringville</td>
<td>Rubyanna</td>
</tr>
<tr>
<td></td>
<td></td>
<td>widening channel</td>
<td>diversion</td>
<td>diversion</td>
<td>diversion</td>
<td>Passage works</td>
<td>bypass channel</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>-0.68</td>
<td>-0.07</td>
<td>-0.06</td>
<td>-0.08</td>
<td>0</td>
<td>-0.09</td>
</tr>
<tr>
<td>2</td>
<td>Hinkler Central (East / South Bundaberg</td>
<td>-0.65</td>
<td>-0.08</td>
<td>-0.07</td>
<td>-0.09</td>
<td>0</td>
<td>-0.11</td>
</tr>
<tr>
<td></td>
<td>backwater)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Northway Plaza (North Bundaberg)</td>
<td>-0.26</td>
<td>-0.11</td>
<td>-0.1</td>
<td>-0.13</td>
<td>-0.01</td>
<td>-0.15</td>
</tr>
<tr>
<td>4</td>
<td>Fairymead Road / McKenzies Rd</td>
<td>0</td>
<td>-0.18</td>
<td>-0.16</td>
<td>-0.22</td>
<td>-0.01</td>
<td>-0.25</td>
</tr>
<tr>
<td>5</td>
<td>Port of Bundaberg (Geary St)</td>
<td>0</td>
<td>-1.05</td>
<td>-0.25</td>
<td>-0.6</td>
<td>-0.26</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Figure 7-1 Flood Level Comparison Points
The largest scale projects in this category (reopening Skyringville passage (Option 30), the Rubyanna bypass channel (Option 20) and the Fairymead diversion channel 3 (Option 41)) perform poorly as they do not provide flood mitigation benefits commensurate with their cost, footprint and environmental impacts. While Options 30 and 41 do result in some reduced flooding in the Port of Bundaberg area, their costs and impacts far outweigh more targeted measures such as the Port of Bundaberg levee (Option 11) or other measures that directly address the factors controlling flood levels in Bundaberg, such as the Millaquin Bend widening works (Option 31).

The Gardens channel 2 (Option 19) is not considered a viable option on its own, as reductions in flood levels along the river corridor are offset by increases in flood levels in parts of North Bundaberg. However, this channel could form part of flood protection schemes involving the low level North Bundaberg levees and would act to offset potential increases in river flood levels and velocities.

### 7.6.5 Bridge and road upgrades

Given the potential to greatly reduce the frequency and duration of isolation due to flooding in certain communities, and the relatively small environmental impacts, the regional bridge upgrades (Option 38) and the North Bundaberg evacuation route upgrades (Option 39) ranked highly.

In addition to those options considered in the MCA process, the Bartholdt Drive upgrade (refer to Section 6.4.5) should also be included for further consideration given the potential benefits to the relatively large local population.

### 7.6.6 Other

Funding for house raising and restumping (Option 40) is a viable project due to the potential for significant benefits in terms of reduced exposure to flood hazards, reduced damage to residential areas and the lack of any significant environmental downsides.

The removal of the Fairymead levees (Option 26) ranked poorly due as any reductions in flood levels in the river corridor are offset by potential increases in flood level across the floodplain towards Moore Park (refer to the afflux maps in Appendix B).
8. **Assessment of Selected Options**

A set of flood mitigation strategies were identified from the options assessed in the MCA to take forward for further detailed assessment. The list of options as agreed with Bundaberg Regional Council is as follows:

- East levee and floodgate (Option 2)
- North levee (Option 1)
- Low levee North Bundaberg levees (Option 10)
- Town reach dredging (Option 23)
- Millaquin bend widening works (Option 24)
- Regional bridge upgrades (Option 38)
- Gardens channel 2 (Option 19)
- Bundaberg North evacuation route upgrades (Option 39)

For each of the above options, a concept design was developed to help determine expected flood mitigation impacts, high level cost estimates, identify key project risks and implementation issues, and outline the potential environmental impacts that would have to be managed if these options were taken forward. All of the identified options would require further investigation, design iteration and refinement. The design and alignments are in no way intended to represent a final design. Consultation with any affected land owners and residents along the alignment or near the footprint of works should be carried out during the future design of any option if it were taken forward.

Where applicable, additional hydraulic modelling has been undertaken based on the conceptual nature and extent of the works. A benefit-cost ratio was then calculated using the flood damages estimation methodology outlined in Section 4. The benefit-cost ratio is defined as the ratio of the Net Present Value (NPV) of the project's potential reduction in flood damages to the NPV of the cost of the mitigation project.

**8.1 East levee & floodgate (option 2)**

**8.1.1 Project description**

The East Levee is a combination of concrete wall, road raising and earth embankments and with flood gates at two creek crossings in East Bundaberg. The indicative levee alignment and design used as the basis of estimates in this section is shown in Appendix E.

Starting from Quay Street, the levee crosses over Bundaberg Creek along Quay Street East to Scotland Street and into Cran Street. From here the levee traverses private property, another waterway, and along the river edge of Millaquin Mill and the Bundaberg Distillery, before passing along the back of the Sewage Treatment plant, across Alexandra Street and terminating at a high point in private property.

The levee has been based on a nominal design level equivalent to the existing 0.5% AEP design flood plus 0.6 m freeboard. This initial assumption should be reviewed during further investigation, and options to increase the height of the levee should be explored following a thorough risk-based assessment of levee overtopping.

It is assumed that the main gate structure on Bundaberg Creek would be closed when Burnett River flood levels are expected to exceed local creek flood levels. Further investigations are necessary to determine the impacts and management measures for local creek floods that may...
occur while the gates are closed. As river flooding dominates the effects of local flooding for most parts of East Bundaberg during large river flood events, it is envisaged that reductions in river flooding due to the levee and gate will outweigh any potential increases to local flooding. The Kendall’s Flat and Baldwin Swamp areas also provide flood storage volume below the threshold of damaging floods, and hence have some capacity to store local flows when the floodgates are closed.

8.1.2 Flood mitigation benefits

The proposed levee and floodgate configuration would protect areas in East Bundaberg from river flood inundation. Based on the conceptual design of the works developed for this section, additional hydraulic modelling has been undertaken. The conceptual levee alignment has been assessed in the hydraulic model for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events as well as the PMF. The afflux plot for the 1% AEP event is included in Appendix E.

A summary of the approximate number of properties (residential, commercial and industrial) that would have a greatly reduced risk of above floor flooding if the levee were constructed is provided in Table 8-1.

**Table 8-1 Number of properties with above floor flooding**

<table>
<thead>
<tr>
<th>AEP (%)</th>
<th>Base case</th>
<th>Mitigated case</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>19</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>133</td>
<td>40</td>
<td>93</td>
</tr>
<tr>
<td>2</td>
<td>879</td>
<td>423</td>
<td>456</td>
</tr>
<tr>
<td>1</td>
<td>1726</td>
<td>985</td>
<td>741</td>
</tr>
<tr>
<td>0.5</td>
<td>3097</td>
<td>2087</td>
<td>1010</td>
</tr>
<tr>
<td>0.2</td>
<td>4132</td>
<td>2882</td>
<td>1250</td>
</tr>
<tr>
<td>PMF</td>
<td>13113</td>
<td>13113</td>
<td>0</td>
</tr>
</tbody>
</table>

The levee and floodgate would be effective at preventing flooding in the protected areas of East Bundaberg, while not resulting in any appreciable flood level increases elsewhere. In the 0.2% AEP event, which is greater than the assumed design flood event, floodwaters can enter the protected area when breaking out of the river in the vicinity of Burrum Street and McLean Street. Depending on the duration of flooding above this critical level, partial or total inundation of the protected area may occur.

8.1.3 Design considerations

If this project is taken forward, the levee must be designed to be structurally stable for the water load (both from Burnett River and local creeks), have sufficient erosion protection, able to be safely maintained, have provision for local drainage around and under the levee and be designed for stability and seepage control.

The various assumed types of wall construction along the length of the levee are highlighted on Appendix E.

*Free standing concrete wall*

For parts of the levee that are within a constrained alignment, a free standing concrete wall ranging in height up to 3 m has been adopted. The concrete walls are required along parts of Quay St, Quay St East, and along the river side of the Millaquin Mill and the Bundaberg Distillery.
**Local creek gate structures**

The levee would cross Bundaberg Creek and East Bundaberg Creek to the south of the Bundaberg Distillery.

The Bundaberg Creek Floodgate will be a very significant structure, located downstream of the heritage listed former railway bridge. The proposed structure comprises the following:

- Three 8 m wide, 10 m high double seal vertical lift gates on wheels with 6 m travel
- Reinforced concrete apron extending 10 m upstream and downstream of the Floodgate axis
- A seepage cutoff wall in line with the Floodgate axis
- Two reinforced concrete blade piers supporting the lift gates, approximately 2 m thick
- A single lane maintenance access bridge upstream of the gates
- Overhead winch equipment supported on an upper access bridge

The level of the overhead winch equipment will be approximately RL 18 m, and as such the top of the structure will be approximately 10 m above the surrounding landscape.

The above concept was sized allowing for the following:

- Retaining 10 m of water from the river side, with zero water on the land side
- Retaining 5 m of water on the land side, with zero water on the river side
- Triangular uplift distribution varying from full water pressure head on the upstream side to zero water pressure at the cutoff
- Geotechnical conditions are unknown. The assumption has been made that good quality basalt rock is near the surface of the creek bed
- The gates may need to open or close into flow, thus wheeled gates were adopted despite the higher cost

At this concept stage, it is proposed that a vertical gate system would be used for both locations. Although a structure of this size would be high and large and not as aesthetic pleasing as other structures, this structure is preferred over a double leaf system (which would reduce the height but is a much more complicated structure) or a butterfly gate with vertical spindles (smaller structure but impedes the flood passage and obstructs flow and debris).

Further refinement and design of this structure would need to be undertaken at detail design stage. If this option is pursued, the design of these structures will require further consideration in the context of managing local flooding impacts. For the Bundaberg Creek Floodgate, a set of operating rules and procedures would need to be developed that identifies the risk of coincident local flooding and defines the conditions under which the gates would be opened and closed.

**Combined concrete wall and road reconstruction**

Along Quay Street West, the levee assumed to be a combined concrete wall and earth embankment. The 4.5 m high wall (approx. RL 10.5 m) has a 4.0 m wide high level access at RL 9.0 m with 1 in 4 (V:H) batters to the properties on the Burnett River side of the wall. Potential access issues to some of the low lying properties on the northern side of Quay Street West may need to be resolved during further design stages if this option is taken forward. On the opposite side, the base of the concrete wall forms part of the local access driveways to existing residential properties at the Scotland Street end and connects to Kendall Street.

All road intersections and driveways will be reconstructed to suit the new road levels. Further investigation to the pavement design needs to be undertaken.
Road reconstruction

Where the levee crosses or runs parallel to roads, the road would be reconstructed to the new design levels matching the existing cross section of the road. Further investigation to the pavement design would also need to be undertaken during detailed design.

All road intersections and adjoining driveways will be reconstructed to suit the new road levels.

Earth levee

Where the available space permits an earth embankment, a 4.0 m wide crest with 1 in 4 (V:H) batters has been assumed. With the current lack of geotechnical information; the levee is costed assuming a homogenous fill. The batters will be topsoiled and hydromulched,

The crest width is based on being able to maintain light vehicle access during the floods. This width is consistent with the accessible minimum width able to be constructed with typical machines.

The embankment slope is based on long term maintenance and geotechnical stability. A 1 in 4 (V:H) slope allows the ongoing maintenance with normal mowing equipment.

Further investigation on the velocity of the flood water against the levee needs to be undertaken and erosion protection may be required to be placed on the batter slopes.

Private property

The levee works may impact on several private properties along the alignment. For the purposes of high-level assessment, assumptions have been made about potential costs associated with compensation and resumption where necessary. Any further design of this option would need to involve close consultation with any affected parties and consideration of alternate alignments.

Other issues

A cane railway line crosses the proposed levee alignment near its northern end. It is proposed that a section of the cane railway line be replaced by trackslab in this area and a temporary stop log provided at the crossing.

A main trunk sewer pipe follows part of this route along Quay Street East and will require avoidance where possible and protection elsewhere.

This levee alignment assumes multiple service relocations along Quay Street East and Scotland Street, and in other locations where required. Individual property service connections may also need to be to be adjusted or concrete encased where they will pass under the levee structure.

Where local drainage crosses the levee alignments, concrete encased pipes and headwalls need to be provided with small manually operated penstocks. Smaller pipes can be provided with temporary gates which can be manually fitted prior to an expected flood, and stored securely off site at other times.

8.1.4 Key project risks

The Bundaberg Creek Floodgate structure is a significant piece of infrastructure. Only very preliminary concept level design has been performed. No geotechnical information is available, and if the conditions are not the expected high level basalts the cost of this structure may increase significantly.

At this concept stage, it is proposed that a vertical gate system would be used. Although a structure of this size would be high, large and not aesthetic pleasing as other structures, this
structure is preferred. Further refinement and design of this structure would need to be undertaken at detail design stage.

Fish passage at the gated structure will need to be confirmed, to ensure all fish requirements such as velocity and shadowing are allowed for.

No geotechnical information is available. Conservative assumptions for allowable hydraulic gradient have been made but should the ground conditions could be poorer than expected, and the width of the levee structures may need to be increased.

Recommendation is made that prior to any further improvements to the design that field and geotechnical investigation be undertaken as no geotechnical investigations and stability/seepage analysis has been undertaken.

As the proposed levee alignment is located behind the Sewage treatment plant, no checking has occurred to any sewer pipelines (including trunk mains) or other facilities in the vicinity.

While the levees will remain unused for long periods, they will still require regular maintenance to preserve the level, cross-section and general standard of the levee. The DNR&E 2002 Levee Guide provides a list of items that constitute part of a regular maintenance routine.

Overtopping and failure risks should be included in the levee management plan.

8.1.5 Key environmental issues

The east levee and flood gate will be designed to prevent the ‘backfilling’ of the Bundaberg and Saltwater Creeks from flooding in the Burnett River. Under normal flow conditions, the flood gate will remain open so as to avoid impact to the hydrological and physical connectivity of the waterway. This will avoid impact to dispersal or migration of species that use the creeks for breeding or other life cycle benefits. As most freshwater taxa undergo migratory or dispersal events at the early onset of flooding, it is unlikely that the closure of the flood gate during peak flows will disturb patterns of movement and impact aquatic communities.

However, the possible design of the east levee does present some potential issues surrounding the release of water post-flood. The quality of this stored water may need to be monitored and tested prior to release to determine whether it meets the receiving environment criteria for release conditions. Water not meeting these conditions will need to be stored or treated until it can be safely released. This may require staged release and water quality testing pre-release.

The east levee will pass through a small portion of ‘least concern’ mapped regional ecosystem (refer to the environmental overlay maps in Appendix F). High value regrowth, endangered (dominant) regional ecosystems, areas of ecological significance, a wetland management area, the Baldwin Swamp Environment Park and Lake Ellen are located upstream of the east levee. These areas should not be directly impacted by the east levee; however, if flood water was to back up in the catchment during times when the flood gate is closed, it is possible that the vegetation may be inundated, which could potentially result in vegetation dieback. As the frequency of flood inundation is assumed to be lower following construction of the levee, ‘drowning’ of additional terrestrial habitat is not predicted to occur.

As the potential construction footprints are located in close proximity to the Burnett River, sediment and runoff and potential erosion will need to be closely managed during the construction phase to avoid inputs to nearby waterways. Banks and slopes will require stabilisation and management under an erosion and sediment control plan. Design of the levees will need to account for potential erosion under wet season inundation/flood conditions to avoid slippage of the levee into the waterway. If vegetation is to be used for bank stabilisation, selection of species will need to take into account native vegetation, weed management and use of species appropriate for the regional vegetation community types.
Noise, light, dust and other pollution/waste releases may occur as a result of construction of the levee. Measures to manage these impacts will form part of the permitting reporting for the project and are expected to be consistent with standard construction operational controls applicable for earthworks activities within urban landscapes.

8.1.6 Cost estimate

The high-level cost estimate for the East levee and floodgate is $71 million.

The assessment of the material volumes is based on the embankment lengths determined from sketches and the areas estimated from the concept details. Sketches are provided in Appendix E.

At this concept stage, the cost estimate has been produced using quantities produced from the provided LiDAR survey, which may result in differences in volumes calculated once detail survey is undertaken.

No geotechnical or field investigations have been undertaken; therefore the estimate has assumed that location and founding conditions are acceptable for the levee to be built as shown.

This cost estimate has been prepared using quantities derived from the drawings, and current construction rates for similar work in Queensland. As such, the cost estimate may vary to reflect both conditions uncovered at the time of construction, and for local variability in construction rates prevailing in the local area. Construction rates will fluctuate with variation in industry workload and availability of construction personnel and equipment. Construction costs will vary based on the techniques and temporary works adopted by the constructor, which may vary between construction teams. Because of this potential variation in construction cost, a contingency allowance has been provided commensurate with the expected variability. The client is advised to check construction cost estimates with construction specialists or their own construction staff.

GHD has contacted a supplier of the flap gates and penstocks. GHD have not undertaken any independent design checks for proprietary products, all liability for product design rests with the supplier, and any proprietary products identified indicate the required standard and do not indicate preference for any particular supplier.

No prices have been included for service adjustments for electricity, telecommunications, or Council water and sewer assets. These prices will vary given the authorities’ requirements and the finalised impact to the services. An indicative sum representing un-estimated costs has been included in the overall estimate.

Inclusions

- Cost Estimate is in AUD.
- Inclusive of contingency at 30 % of direct and indirect costs.
- These prices are based on the rate derived from first principle and material quotes from suppliers.
- The construction work on site is based on the availability of the work on whole area basis with minimal interruptions.
- Assumed laydown area to be in close proximity of construction.
- Estimate is based on assumption that water supply is available at site free of charge for whole project duration for all construction work including backfilling.
- It is assumed that available roads are sufficient for transporting excavated material from borrow areas to the levee alignment with minimal interruption in traffic flow and sufficient bypass in travel route. Most of the flow will be unrestricted access.

**Exclusions**
- No allowance for Goods and Services Tax (GST).
- No allowance for OPEX costs.
- No allowance for costs prior to project Notice to Proceed (NTP).
- No allowance for cost of supply of water and electricity.
- No allowance for any shire fee or tip fee for disposal of any Unsuitable Material
- No allowance for deferred capital cost all work is assumed to be available in One time Mobilisation and Demobilisation
- No allowance for escalation.
- No allowance for any application and approval of Ground Disturbance Permits (GDP’s), Statutory permits.
- No allowance for the value of Principal supplied items or any additional cost due to shortage of backfill material availability.
- No allowance for charges and costs levied by Authorities, Councils and Service Bodies.
- No allowance for Legal fees.
- No allowance made for abnormal weather conditions.
8.1.7 Benefit-cost assessment

Table 8-2 outlines a benefit-cost assessment based on the existing case flood damages presented in Section 4 and developed conditions damage estimates derived from the results of hydraulic modelling discussed in Section 8.1.2.

Table 8-2 Cost benefit assessment for the East levee option

<table>
<thead>
<tr>
<th>AEP (%)</th>
<th>Existing Conditions</th>
<th>Developed Conditions East Levee</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Damage ($)</td>
<td>Damage ($)</td>
</tr>
<tr>
<td>20%</td>
<td>$748,079</td>
<td>$622,837</td>
</tr>
<tr>
<td>10%</td>
<td>$2,909,306</td>
<td>$1,275,455</td>
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<td>5%</td>
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<td>$6,753,067</td>
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<tr>
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<td>$130,311,525</td>
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<td>0.5%</td>
<td>$424,361,107</td>
<td>$259,940,136</td>
</tr>
<tr>
<td>0.2%</td>
<td>$620,779,274</td>
<td>$404,302,418</td>
</tr>
<tr>
<td>PMF (0.00001%)</td>
<td>$2,472,272,491</td>
<td>$2,472,272,491</td>
</tr>
</tbody>
</table>

**Average Annual Damage:**

- Existing Conditions: $11,130,883
- Developed Conditions East Levee: $7,158,114

**Discount Rate**: 7%

**Evaluation Period**: 50 years

**Net Present Value (NPV) of Damages - Existing Conditions**: $153,614,495

**Net Present Value (NPV) of Damages - Developed Conditions**: $98,787,310

**NPV of Reduction in Damages**: $54,827,184

**Cost of Mitigation**: $71,000,000

**Benefit Cost Ratio**: 0.77
8.2 North levee (option 1)

8.2.1 Project description

The North levee is a combination of embankment levee and gabion walls of varying height, including one substantial local creek gate structure. The indicative levee alignment and design used as the basis of estimates in this section is shown in Appendix E.

The levee starts alongside the main railway line behind properties in Lakeview Drive and crosses into Park View Terrace, and through the botanic gardens. It then continues behind the North School to the Hinkler Avenue/Mount Perry Road roundabout and continues behind properties located in Barlow Street to Queen Street. From here, the levee runs then alongside Fairymead Road to Whittingtons Road. The levee continues behind properties in Fairymead Road and Daniel Drive, across McKenzie’s Road and continues through private property through to Fairymead Road south of Patersons Road and then to Tantitha Road.

The levee has been based on a nominal design level equivalent to the existing 0.5% AEP flood plus 0.6 m freeboard. This initial assumption should be reviewed during further investigation, and options to increase the height of the levee should be explored following a thorough risk-based assessment of levee overtopping.

8.2.2 Flood mitigation benefits

The levee and floodgate would protect areas in North Bundaberg from river flood inundation up to the current adopted design event. Based on the conceptual design of the works developed for this section, additional hydraulic modelling has been undertaken. The conceptual levee alignment has been assessed in the hydraulic model for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events as well as the PMF. The afflux plot for the 1% AEP event is included in Appendix E.

The levee would be effective at preventing flooding in the protected areas of North Bundaberg in the 2%, 1% and 0.5% AEP flood events. In addition, the critical evacuation routes for parts of North Bundaberg, Fairymead and Gooburrum along Fairymead Rd and Mount Perry Rd would be protected. The earth embankment at the northern end of the levee between Fairymead Rd and Tantitha Rd could be constructed to function as a temporary evacuation route during floods.

The following negative impacts are also observed:

- A small area outside of the levee near Thornhill St and Park View Tce experiences increases in flood level of up to 0.25 m in the 1% AEP event and 0.44 m in the 0.5% AEP event.
- A broader area of North Bundaberg, extending between the North levee and the foundry, experiences flood level increases of 0.05 to 0.1 m in the 1% AEP event and 0.1 to 0.2 m in the 0.5% AEP event.
- In the 0.5% AEP event, ponding against the levee wall occurs in the vicinity of the Bundaberg Golf Course, leading to increased inundation depths on the golf course and some surrounding properties.
- In the 02% AEP event, which exceeds the current adopted design event for the levee, flood levels in most parts of North Bundaberg, as well as parts of the CBD and East Bundaberg, are higher than under existing conditions.

The community will likely consider these increases in flood levels to be unacceptable and compensatory works (such as the Millaquin bend widening works or some form of the Gardens channel) would likely be required if the North levee were to proceed. Further study is necessary.
to determine whether the adverse impacts of the North levee could be fully mitigated by these compensatory works.

Based on the current assumed design and hydraulic modelling, levee overtopping occurs in the vicinity of the Bundaberg Golf Course in the 0.5% AEP event, due to ponding of flood waters against the levee wall. More widespread overtopping occurs during the 0.2% AEP event.

8.2.3 Design considerations

if this project is taken forward, the levee must be designed to be structurally stable for the water load (both from Burnett River and local creeks), have sufficient erosion protection, able to be safely maintained, have provision for local drainage around and under the levee and be design for stability and seepage control.

The various assumed types of wall construction along the length of the levee are highlighted on Appendix E.

Earth levee

The earth embankment has a 4.0 m wide crest with 1 in 4 (V:H) batters, with the lack of geotechnical information; the levee is costed assuming a homogenous fill. Batters will be topsoiled and hydromulched.

Between Fairymead Road and Tantitha Road the crest width of the earth embankment levee is increased to 8.0 m wide to cater as a two way temporary evacuation route in the event of a flood.

The crest width is based on being able to maintain light vehicle access during the floods. This width is consistent with the accessible minimum width able to be constructed with typical machines.

The embankment slope is based on long term maintenance and geotechnical stability. A 1 in 4 (V:H) slope allows the ongoing maintenance with normal mowing equipment.

Further investigation on the velocity of the flood water against the levee needs to be undertaken which may require erosion protection to be placed on the batter slopes.

Local creek gate structures

A flood gate will be required at Tanitha Creek. This is proposed to comprise a bank of concrete encased pipes with headwalls, with manually operated penstock gates. The number of pipes required for this creek crossing would need to be determined following a local drainage investigation, which has not been performed at this time.

Road reconstruction

Where the levee crosses or traverses along roads, the road is reconstructed to the new design levels matching the existing cross section of the road, with a minimum of width 8.0 m pavement.

All road intersections and driveways would be reconstructed to suit the new road levels. Further investigation to the pavement design needs to be undertaken.

Gabion wall

Where constrained by space along the alignment, particularly where the levee passes along the rear of private properties, a gabion wall with a clay core has been adopted. Ranging from a height of 1 to 4 m high, the gabion wall is designed with a 4.0m wide clay filled central impervious section.
The designed is based on a typical section within the Maccaferri product catalogue, however no assessment has been undertaken to check its stability given the local ground and founding conditions.

**Private property**

The levee works may impact on several private properties along the alignment. For the purposes of high-level assessment, assumptions have been made about potential costs associated with compensation and resumption where necessary. Any further design of this option would need to involve close consultation with any affected parties and consideration of alternate alignments.

**Other issues**

A cane railway line crosses the levee alignment near its northern end. It is proposed that a section of the cane railway line be replaced by trackslab in this area and a temporary stop log provided at the crossing.

This alignment assumes multiple service relocations. Individual property service connections may also need to be be adjusted or concrete encased where they will pass under the levee structure.

Where local drainage crosses the levee alignments, concrete encased pipes and headwalls need to be provided with small manually operated penstocks. Smaller pipes can be provided with temporary gates which can be manually fitted prior to an expected flood, and stored securely off site at other times.

**8.2.4 Key project risks**

The northern end of the levee alignment was chosen to reduce the number of gated creek structures required, and it is envisaged that the levee will form a two way temporary evacuation route in the lowest sections of Fairymead and Tantitha roads in times of large flood events.

It is noted that cross drainage will be required to convey runoff from the Tanitha Creek catchment through the levee. A local drainage analysis has not been performed at this stage to quantify the cross drainage requirements at this location.

The proposed design has been assumed with no geotechnical investigations and stability/seepage analysis being undertaken. Recommendation is made that prior to any further improvements to the design that field and geotechnical investigation must be undertaken.

While the levees will remain unused for long periods, they will still require regular maintenance to preserve the level, cross-section and general standard of the levee. The DNR&E 2002 Levee Guide provides a list of items that constitute part of a regular maintenance routine. Overtopping and failure risks should be included in the levee management plan.

**8.2.5 Key environmental issues**

The majority of the area within and adjacent to the North levee is developed, and has been cleared for agricultural and housing purposes. However, there are some areas of ecological significance, with high value regrowth, and endangered (dominant) regional ecosystems within or alongside the North levee footprint.

The development of the North levee would not require the removal of vegetation within mapped regional ecosystems; however, some areas of ecological significance would need to be removed (refer Figure 3 in Appendix F). The levee would also pass through the trigger area for a wetland of high ecological significance, but not within the wetland itself (refer Figure 2 in
It is possible that this wetland may be impacted by the establishment of the levee, as it will become disconnected from overland flows.

Impacts to areas of ecological significance and wetland protected areas will be permanent and permits to achieve works will need to be sourced prior to commencement of works. These permits will require information including area and value of habitat to be affected and regional consequence of habitat loss.

The levee will also need to pass through part of the Bundaberg Botanic Gardens, which (it is anticipated) has potential to impact upon protected plant species and wildlife using this artificially created environment. Design of the levee will need to minimise risk of interfering with the ecology of the gardens and the functionality of the gardens for use by visitors. This may require additional consultation to identify how the levee could become a landscape feature of the gardens and not detract from their social and environmental value.

By its very nature, the construction of the North levee will disconnect part of the floodplain from the Burnett River. Inundation from floods may perform important ecological services (e.g. dispersal of organic materials) for the wetland. This linear infrastructure will inhibit the lateral movement of aquatic flora and fauna, water and suspended materials from the river to the floodplain. This environmental alteration could impact the breeding, dispersal and migration patterns of aquatic communities in this reach of the Burnett River. As flooding inundation is generally very infrequent impacts are not considered to be pivotal to the successful survival, dispersal or maintenance of ecological values within the area.

In general the North levee footprint avoids potential habitat for terrestrial and aquatic flora and fauna, and it is unlikely that this proposed levee will have a significant direct impact on ecological communities and habitats. Banks and slopes will require stabilisation and management under an erosion and sediment control plan. Design of the levees will need to account for potential erosion under wet season inundation/flood conditions to avoid slippage of the levee into the waterway. If vegetation is to be used for bank stabilisation selection of species will need to take account to native vegetation, weed management and use of species appropriate for the regional vegetation community types.

Noise, light and dust and other pollution/waste releases may occur as a result of construction of the levee. Measures to manage these impacts will form part of the permitting reporting for the project and are expected to be consistent with standard construction operational controls applicable for earthworks activities within urban landscapes.

8.2.6 Cost estimate

The high-level cost estimate for the North levee is $64 million.

The assessment of the material volumes is based on the embankment lengths determined from sketches and the areas estimated from the concept details. Sketches are provided in Appendix E.

At this concept stage, the estimate has been produced using quantities produced from the provided contour surface, which may result in differences in volumes calculated once detail survey is undertaken.

No geotechnical or field investigations have been undertaken; therefore the estimate has assumed that location and founding conditions are acceptable for the levee to be built as shown.

This cost estimate has been prepared using quantities derived from the drawings, and current construction rates for similar work in Queensland. As such, the cost estimate may vary to reflect both conditions uncovered at the time of construction, and for local variability in construction
rates prevailing in the local area. Construction rates will fluctuate with variation in industry workload and availability of construction personnel and equipment. Construction costs will vary based on the techniques and temporary works adopted by the constructor, which may vary between construction teams. Because of this potential variation in construction cost, a contingency allowance has been provided commensurate with the expected variability. The client is advised to check construction cost estimates with construction specialists or their own construction staff.

GHD has contacted a supplier of the flap gates and penstocks. GHD have not undertaken any independent design checks for proprietary products, all liability for product design rests with the supplier, and any proprietary products identified indicate the required standard and do not indicate preference for any particular supplier.

No prices have been included for service adjustments for electricity, telecommunications, or Council water and sewer assets. These prices will vary given the authorities’ requirements and the finalised impact to the services. An indicative sum representing un-estimated costs has been included in the overall estimate.

**Inclusions**

- Cost Estimate is in AUD.
- Inclusive of contingency at 30% of direct and indirect costs.
- These prices are based on the rate derived from first principle and material quotes from suppliers.
- The construction work on site is based on the availability of the work on whole area basis with minimal interruptions.
- Assumed laydown area to be in close proximity of construction.
- Estimate is based on assumption that water supply is available at site free of charge for whole project duration for all construction work including backfilling.
- It is assumed that available roads are sufficient for transporting excavated material from borrow areas to the levee alignment with minimal interruption in traffic flow and sufficient bypass in travel route. Most of the flow will be unrestricted access.

**Exclusions**

- No allowance for Goods and Services Tax (GST).
- No allowance for OPEX costs.
- No allowance for costs prior to project Notice to Proceed (NTP).
- No allowance for cost of supply of water and electricity.
- No allowance for any shire fee or tip fee for disposal of any Unsuitable Material
- No allowance for deferred capital cost all work is assumed to be available in One time Mobilisation and Demobilisation
- No allowance for escalation.
- No allowance for any Application and approval of Ground Disturbance Permits (GDP’s), Statutory permits.
8.2.7 Benefit-cost assessment

Table 8-2 outlines a benefit-cost assessment based on the existing case flood damages presented in Section 4 and developed conditions damage estimates derived from the results of hydraulic modelling discussed in Section 8.2.2.

Table 8-3 Benefit-cost assessment for the North levee option

<table>
<thead>
<tr>
<th>AEP (%)</th>
<th>Existing Conditions Damage ($)</th>
<th>Developed Conditions North Levee Damage ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>$748,079</td>
<td>$622,837</td>
</tr>
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<td>10%</td>
<td>$2,909,306</td>
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<td>$6,753,067</td>
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</tr>
<tr>
<td>PMF (0.00001%)</td>
<td>$2,472,272,491</td>
<td>$2,472,272,491</td>
</tr>
</tbody>
</table>

Average Annual Damage: $748,079 $622,837

<table>
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<th>Discount Rate</th>
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<tr>
<td>Evaluation Period</td>
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<tr>
<td>Net Present Value (NPV) of Damages - Existing Conditions</td>
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<tr>
<td>Net Present Value (NPV) of Damages - Developed Conditions</td>
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<td>NPV of Reduction in Damages</td>
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<tr>
<td>Cost of Mitigation</td>
<td>$64,000,000</td>
</tr>
<tr>
<td>Benefit Cost Ratio</td>
<td>0.08</td>
</tr>
</tbody>
</table>
8.3 Low level north Bundaberg levees (option 10)

8.3.1 Project description

This option comprises two levees constructed to the height of the existing 2% AEP (50-year ARI) design flood event with no freeboard. Below this event, the levees would effectively exclude flood waters from the part of North Bundaberg worst hit in the January 2013 flood events. Levee overtopping would occur during flood events in the order of the 50-year ARI event and above.

The design intent for these levees would be to protect against smaller, more frequent flood events while minimising as far as possible the potential for adverse impacts in larger events. This option was developed in response to the unfavourable initial assessment of a range of other higher levees in the North Bundaberg area that were found to have unacceptable impacts on flood levels and velocities. Of all levee options considered for the low-lying parts of North Bundaberg, the low level levees or some scheme involving parts of these levees are considered the most viable. However, as seen in the hydraulic assessment below, even these levels entail significant downsides that would have to be managed through the implementation of compensatory schemes such as the Millaquin bend widening works or some form of Gardens channel.

The northern of the two levees starts at the North School hill roundabout, with Mount Perry Road requiring reconstruction to Queen Street. The alignment then runs as an earth embankment through private properties to a high spot near Mariners Way, requiring road raising at Agnes Road and Waterview Road. This levee would stop the ingress of backwater flooding into the North Bundaberg area from the direction of Paddy’s Island up to the design event.

The southern levee starts alongside the southern side of the main railway line as an earth embankment. It crosses the main railway line west of Hinkler Avenue, then runs along the centre of Perry Street, and along the edge of Gladwell Street and Gavin Street to Waterview Road as a free-standing concrete wall. It then runs through private property to Mariner Way as an earth embankment. This levee would stop breakouts from the Burnett River in the vicinity of Hanbury St and Perry St up to the design event.

8.3.2 Flood mitigation benefits

The conceptual levee alignment has been assessed in the hydraulic model for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events as well as the PMF. The afflux plot for the 1% AEP event is included in Appendix E.

A description of the impacts of the levee in each design event is included below:

- The levee has no impacts on flooding in the 20% and 10% AEP events, as the levee alignment is generally outside of those flood extents.

- In the 5% AEP event (and up to some point below the 2% AEP event), the levee protects a number of properties in the North Bundaberg area. Increases in flood level in the Burnett River outside of the levee are negligible in the 5% AEP event, but become noticeable as flood levels rise above that point.

- In the 2% AEP event, the southern levee is overtopped along Hanbury St and Perry St due to increases in river flood levels in the order of 0.1 to 0.3 m. Despite the levee overtopping, some properties behind the southern levee experience a reduction in flood levels of 0.1 to 0.6 m. Other properties closest to the northern levee experience increases in flood level of 0.1 to 0.45 m, as flood waters pond behind the northern levee before it too overtops. Outside of the levee, properties along the southern bank of the river and in East Bundaberg experience increases in flood level of 0.2 m and 0.07 m respectively.
The impacts in the 1% AEP event are similar to the impacts for the 2% AEP event. Properties immediately to the north of the southern levee experience a reduction in flood level (between 0.1 and 0.5 m), while properties behind the northern levee experience an increase (between 0.1 and 0.2 m). Flood levels along the south bank of the river and East Bundaberg are increased by 0.25 m and 0.07 m respectively.

As flood levels rise above the 1% AEP level and the low level levees become inundated and drowned, the impacts of the levees on flood levels diminish. At the 0.5% AEP level, increases and decreased in flood level are generally less than +/- 0.1 m. The changes in flood level decrease to below +/- 0.05 m in the 0.2% AEP event. Impacts on flood levels during the PMF event are negligible.

Impacts on peak flood velocities are mixed. In general, this option would result in both increased and decreased peak flow velocities in the protect area between the levees in the 2% AEP design flood event and above. In some areas, the southern levee wall along Perry St would act to deflect and reduce peak velocities. In other areas, particularly behind the northern levee, flood velocities are increased due to the ponding and associated redistribution of flow as a result of the earth embankment structure. In the river corridor and through Millaquin bend, centre stream velocities are increased by 0.3 – 0.4 m/s for the 2% AEP event and above.

Based on this hydraulic assessment for the full range of design flood events, the low level levees are seen to have a probable net negative impact on flooding across Bundaberg. On their own, the low level levees do not represent a viable flood mitigation strategy. As with the North levee, the adverse impacts of the low level levees would have to be offset through compensatory schemes such as the Millaquin bend widening works. Further discussion on combinations of flood mitigation projects is included in Section 9.1.9.

8.3.3 Design considerations

Due to constraints on space and generally unfavourable foundation conditions, the majority of the southern levee would be constructed as a free-standing concrete barrier wall. The northern levee can be constructed as a combination of road embankment and earth fill.

if this project is taken forward, the levee must be designed to be structurally stable for the water load (both from Burnett River and local creeks), have sufficient erosion protection, able to be safely maintained, have provision for local drainage around and under the levee and be design for stability and seepage control.

Earth levee

Geotechnical information: the levee is costed assuming a homogenous fill. Batters will be topsoiled and hydromulched.

The crest width is based on being able to maintain light vehicle access during the floods. This width is consistent with the accessible minimum width able to be constructed with typical machines.

The embankment slope is based on long term maintenance and geotechnical stability. A 1 in 4 (V:H) slope allows the ongoing maintenance with normal mowing equipment.

Further investigation on the velocity of the flood water against the levee needs to be undertaken and erosion protection may be required to be placed on the batter slopes.

Concrete wall

A reinforced concrete levee wall is required from Hinkler Avenue to Waterview Road along this alignment, for space and property access reasons. A number of inputs drive the design of the structural levee wall, as follows:
- The hydraulic gradient along the wall base / foundation interface
- Expected flow behaviour adjacent to the structure
- Required levee wall height
- Road geometry

**Wall type C3**
Due to fairly high expected flow speeds running parallel to the levee wall, upstream ground surface protection will be required. This has led to the use of railway slab tracks in this location, as the railway line is immediately upstream of the levee alignment. The levee is low height at this location, and can be cast into the track slab as an upstanding section on the downstream edge.

A downstream concrete apron has also been provided to protect the road surface in the event of levee overtopping.

**Wall type C2**
This wall runs down the centreline of Perry Street. Due to the fairly high expected flow speeds' running parallel to the levee wall, and the poor foundation conditions, the full width of the road has been sealed with a structural slab.

Gaps in the concrete wall will be provided at each intersection, where temporary stop logs will be installed during flood events.

The existing disused railway line between Kolan Street and Gavin Street will be demolished.

**Wall type C1**
The largest wall heights for the structural levee walls occur along this section. As the wall runs along the upstream side of the road, a structural slab cannot be incorporated into the upstream side. Therefore, stability needs to be obtained via the use of concrete self-weight.

The final section is similar to a typical concrete gravity weir structure, with a 0.4 m wide flat crest and a 1 in 1 slope to the downstream face. It is noted that at the highest point of the levee, Gavin Street is reduced to single lane width.

**Road reconstruction**
Along Mount Perry Road, the road will be reconstructed to the new levels with an 8.0 m wide road pavement.

At Agnes Road and Waterview Road, the roads will be raised by up to 3.5 m across the levee using the existing road section.

The adjoining roadway next to any concrete wall will be reinstated to match the existing road requirements.

Further investigation to the pavement design needs to be undertaken.

**Main railway line**
The levee runs across and alongside the Main Railway Line along Perry Street from Hinkler Avenue to Kolan Street. The concrete wall is required assumes that the electrified railway line will need to be reconstructed to form an integral part of the wall structure.

Consultation will need to be undertaken with the rail owner to ensure that the design meets any specific requirements and that construction is possible.
**Other issues**

This alignment assumes multiple service relocations along where in runs along or crosses road reserves. Individual property service connections may also need to be to be adjusted.

Where local drainage crosses the levee alignments, concrete encased pipes and headwalls need to be provided with small manually operated penstocks. Smaller pipes can be provided with temporary gates which can be manually fitted prior to an expected flood, and stored securely off site at other times.

### 8.3.4 Key project risks

The proposed design has been assumed with no geotechnical investigations and stability/seepage analysis being undertaken. Recommendation is made that prior to any further improvements to the design that field and geotechnical investigation must be undertaken.

While the levees will remain unused for long periods, they will still require regular maintenance to preserve the level, cross-section and general standard of the levee. The DNR&E 2002 Levee Guide provides a list of items that constitute part of a regular maintenance routine.

The work adjacent and impacting on the Main Railway Line needs to be confirmed with the rail owner who may have specific requirements on the levee wall.

### 8.3.5 Key environmental issues

The proposed low level north Bundaberg levees are located wholly within non-remnant vegetation that has been cleared for agricultural and housing purposes (refer to the environmental overlay maps in Appendix F). These levees do not fall within any areas of ecological significance. However, some small sections of the levee footprints may fall within the trigger zone for the wetland management area in the Burnett River. If this occurs, permits will need to identify what area of the wetland management area will be affected by levee works and the controls to be applied during project activities to avoid impacts and manage potential environmental risks.

As the potential construction footprints are located in close proximity to the Burnett River, sediment and runoff and potential erosion will need to be closely managed during the construction phase to avoid inputs to nearby waterways. Banks and slopes will require stabilisation and management under an erosion and sediment control plan. Design of the levees will need to account for potential erosion under wet season inundation/flood conditions to avoid slippage of the levee into the waterway. If vegetation is to be used for bank stabilisation selection of species will need to take account to native vegetation, weed management and use of species appropriate for the regional vegetation community types.

Noise, light and dust and other pollution/waste releases may occur as a result of construction of the levee. Measures to manage these impacts will form part of the permitting reporting for the project and are expected to be consistent with standard construction operational controls applicable for earthworks activities within urban landscapes.

In general, the footprint avoids habitat for terrestrial and aquatic communities, and it is unlikely that construction will result in significant impacts to flora and fauna. However, the footprint will pass through private land or alter the vista of private residences. Social considerations will need to include egress to surrounding lands, use of the natural environment and potential to impact upon residents. Consultation with community and other relevant stakeholders is being completed under this option assessment project and this is facilitating community discussion of levee solution acceptability. Detailed design, should this option be selected, should take account of community and stakeholder views obtained under this project, and if necessary be
conducted in conjunction with additional relevant consultation works to avoid community conflict with preferred solution implementation.

8.3.6 Cost estimate

The high-level cost estimate for the North levee is $48 million.

The assessment of the material volumes is based on the embankment lengths determined from sketches and the areas estimated from the concept details. Sketches are provided in Appendix E.

At this concept stage, the estimate has been produced using quantities produced from the provided contour surface, which may result in differences in volumes calculated once detail survey is undertaken.

No geotechnical or field investigations have been undertaken; therefore the estimate has assumed that location and founding conditions are acceptable for the levee to be built as shown.

This cost estimate has been prepared using quantities derived from the drawings, and current construction rates for similar work in Queensland. As such, the cost estimate may vary to reflect both conditions uncovered at the time of construction, and for local variability in construction rates prevailing in the local area. Construction rates will fluctuate with variation in industry workload and availability of construction personnel and equipment. Construction costs will vary based on the techniques and temporary works adopted by the constructor, which may vary between construction teams. Because of this potential variation in construction cost, a contingency allowance has been provided commensurate with the expected variability. The client is advised to check construction cost estimates with construction specialists or their own construction staff.

GHD has contacted a supplier of the flap gates and penstocks. GHD have not undertaken any independent design checks for proprietary products, all liability for product design rests with the supplier, and any proprietary products identified indicate the required standard and do not indicate preference for any particular supplier.

No prices have been included for service adjustments for electricity, telecommunications, or Council water and sewer assets. These prices will vary given the authorities’ requirements and the finalised impact to the services. An indicative sum representing un-estimated costs has been included in the overall estimate.

Inclusions

- Cost Estimate is in AUD.
- Inclusive of contingency at 30% of direct and indirect costs.
- These prices are based on the rate derived from first principle and material quotes from suppliers.
- The construction work on site is based on the availability of the work on whole area basis with minimal interruptions.
- Assumed laydown area to be in close proximity of construction.
- Estimate is based on assumption that water supply is available at site free of charge for whole project duration for all construction work including backfilling.
- It is assumed that available roads are sufficient for transporting excavated material from borrow areas to the levee alignment with minimal interruption in traffic flow and sufficient bypass in travel route. Most of the flow will be unrestricted access.
Exclusions

- No allowance for Goods and Services Tax (GST).
- No allowance for OPEX costs.
- No allowance for costs prior to project Notice to Proceed (NTP).
- No allowance for cost of supply of water and electricity.
- No allowance for any shire fee or tip fee for disposal of any Unsuitable Material.
- No allowance for deferred capital cost all work is assumed to be available in One time Mobilisation and Demobilisation.
- No allowance for escalation.
- No allowance for any Application and approval of Ground Disturbance Permits (GDP’s), Statutory permits.
- No allowance for the value of Principal supplied items or any additional cost due to shortage of backfill material availability.
- No allowance for charges and costs levied by Authorities, Councils and Service Bodies.
- No allowance for Legal fees.
- No allowance made for abnormal weather conditions.
8.3.7 Benefit-cost assessment

Table 8-2 outlines a benefit-cost assessment based on the existing case flood damages presented in Section 4 and developed conditions damage estimates derived from the results of hydraulic modelling discussed in Section 8.3.2.

**Table 8-4 Benefit-cost assessment for the low level North levee option**

<table>
<thead>
<tr>
<th>AEP (%)</th>
<th>Existing Conditions Damage ($)</th>
<th>Developed Conditions Low Level Levees Damage ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>$748,079</td>
<td>$696,504</td>
</tr>
<tr>
<td>10%</td>
<td>$2,909,306</td>
<td>$2,854,753</td>
</tr>
<tr>
<td>5%</td>
<td>$21,785,701</td>
<td>$20,763,910</td>
</tr>
<tr>
<td>2%</td>
<td>$120,444,637</td>
<td>$113,310,439</td>
</tr>
<tr>
<td>1%</td>
<td>$234,366,265</td>
<td>$224,145,137</td>
</tr>
<tr>
<td>0.5%</td>
<td>$424,361,107</td>
<td>$411,295,014</td>
</tr>
<tr>
<td>0.2%</td>
<td>$620,779,274</td>
<td>$608,872,229</td>
</tr>
<tr>
<td>PMF (0.00001%)</td>
<td>$2,472,272,491</td>
<td>$2,467,344,965</td>
</tr>
</tbody>
</table>

**Average Annual Damage:**

<table>
<thead>
<tr>
<th>Discount Rate</th>
<th>$11,130,883</th>
<th>$10,764,684</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation Period</td>
<td>7%</td>
<td>50 years</td>
</tr>
<tr>
<td>Net Present Value (NPV) of Damages - Existing Conditions</td>
<td>$153,614,495</td>
<td></td>
</tr>
<tr>
<td>Net Present Value (NPV) of Damages - Developed Conditions</td>
<td>$156,440,177</td>
<td></td>
</tr>
<tr>
<td>NPV of Reduction in Damages</td>
<td>-$2,825,683</td>
<td></td>
</tr>
<tr>
<td>Cost of Mitigation</td>
<td>$48,000,000</td>
<td></td>
</tr>
<tr>
<td>Benefit Cost Ratio</td>
<td>-0.06</td>
<td></td>
</tr>
</tbody>
</table>

Note: Negative values for reduction in damages indicates an increase in flood damage (i.e. the flood mitigation measure increases the damage caused by floods under existing conditions). This results in a negative benefit cost ratio.
8.4 Town reach dredging (option 23)

8.4.1 Project description

This option involves deepening the Burnett River through dredging activities in order to reduce future flood levels. Based on the preliminary hydraulic modelling and the MCA process, it was seen that dredging in targeted areas is more practical and effective than widespread dredging of the whole river. In this section, the potential for dredging the town reach is further explored.

The dredging activities would involve utilising a medium trailer suction hopper dredge (TSHD) similar to the Port of Brisbane’s dredge, the Brisbane, and a small Cutter Suction Dredger (CSD) to underwater excavate and dispose of a predicted total of between 1,733,000 m³ and 2,550,000 m³ of river bed spoil to -6 m AHD. As no geotechnical studies have yet been undertaken to determine stable angles of repose, this option has been assessed for both a 1 in 20 and 1 in 10 batter slope profile up to the mangroves within the intertidal zone of the Burnett River. These angles were chosen to be similar to the bank slopes observed under existing (pre-2013 flood) conditions, with the assumption that these bank slopes are generally stable. The intention would be to manage the extent and depth of dredging to preserve mangrove vegetation and bank stability as far as practical. A summary of the predicted volumes of dredge spoil is provided below in Table 8-5.

Table 8-5 Town reach dredging volumes

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Upstream of Burnett River Traffic Bridge (m³)</th>
<th>Downstream of Burnett River Traffic Bridge (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A¹</td>
<td>Capital dredging (1 in 20 batter slope)</td>
<td>1,700,000</td>
<td>33,000</td>
</tr>
<tr>
<td>B²</td>
<td>Capital dredging (1 in 10 batter slope)</td>
<td>2,350,000</td>
<td>200,000</td>
</tr>
</tbody>
</table>

Note:  
1 – 1 in 20 batter slope adopted  
2 – 1 in 10 batter slope adopted
### 8.4.2 Flood mitigation benefits

Based on the conceptual design of the works developed for this section, additional hydraulic modelling has been undertaken. The conceptual dredging profiles have been assessed in the hydraulic model for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events as well as the PMF. A summary of the reductions in flood levels is provided in Table 8-6 and Table 8-7 below, and the afflux plot for the 1% AEP event is included in Appendix F.

**Table 8-6 Flood level changes town reach dredging (option A – 1 in 20 slopes)**

<table>
<thead>
<tr>
<th>Flood Event</th>
<th>East Bundaberg</th>
<th>North Bundaberg</th>
<th>Avoca</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% AEP</td>
<td>&lt; -0.01 m</td>
<td>Nil</td>
<td>-0.15 m</td>
</tr>
<tr>
<td>10% AEP</td>
<td>&lt; -0.01 m</td>
<td>Nil</td>
<td>-0.15 m</td>
</tr>
<tr>
<td>5% AEP</td>
<td>&lt; -0.01 m</td>
<td>Nil</td>
<td>-0.14 m</td>
</tr>
<tr>
<td>2% AEP</td>
<td>&lt; -0.01 m</td>
<td>-0.03 m</td>
<td>-0.15 m</td>
</tr>
<tr>
<td>1% AEP</td>
<td>&lt; -0.01 m</td>
<td>-0.03 m</td>
<td>-0.14 m</td>
</tr>
<tr>
<td>0.5% AEP</td>
<td>&lt; -0.01 m</td>
<td>-0.02 m</td>
<td>-0.14 m</td>
</tr>
<tr>
<td>0.2% AEP</td>
<td>&lt; -0.01 m</td>
<td>-0.01 m</td>
<td>-0.14 m</td>
</tr>
<tr>
<td>PMF</td>
<td>0.02 m</td>
<td>-0.01 m</td>
<td>-0.13 m</td>
</tr>
</tbody>
</table>

**Table 8-7 Flood level changes town reach dredging (option B – 1 in 10 slopes)**

<table>
<thead>
<tr>
<th>Flood Event</th>
<th>East Bundaberg</th>
<th>North Bundaberg</th>
<th>Avoca</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% AEP</td>
<td>-0.02 m</td>
<td>Nil</td>
<td>-0.22 m</td>
</tr>
<tr>
<td>10% AEP</td>
<td>-0.03 m</td>
<td>Nil</td>
<td>-0.25 m</td>
</tr>
<tr>
<td>5% AEP</td>
<td>-0.03 m</td>
<td>Nil</td>
<td>-0.27 m</td>
</tr>
<tr>
<td>2% AEP</td>
<td>-0.02 m</td>
<td>-0.12 m</td>
<td>-0.24 m</td>
</tr>
<tr>
<td>1% AEP</td>
<td>-0.02 m</td>
<td>-0.09 m</td>
<td>-0.24 m</td>
</tr>
<tr>
<td>0.5% AEP</td>
<td>&lt; -0.01 m</td>
<td>-0.07 m</td>
<td>-0.23 m</td>
</tr>
<tr>
<td>0.2% AEP</td>
<td>&lt; -0.01 m</td>
<td>-0.04 m</td>
<td>-0.21 m</td>
</tr>
<tr>
<td>PMF</td>
<td>-0.02 m</td>
<td>&lt; -0.01 m</td>
<td>-0.18 m</td>
</tr>
</tbody>
</table>

Based on the above, it is seen that dredging based on 1 in 10 and 1 in 20 wherein a large quantity of material is removed upstream of the bridges in the vicinity of Harriet Island, provides negligible flood mitigation benefits to most heavily developed parts of Bundaberg. As this removal of material occurs upstream of critical constrictions in the river at the foundry and Millquin bend, the resulting reduction in flood levels in developed areas is severely limited. Some reduction in flood level is achieved upstream of Harriet Island, however there is limited development within the flood extent in those locations.
As demonstrated by the analysis of other options in the MCA, such as the river widening works (Options 31 and 35), the greatest benefit in terms of flood level reduction occurs when the river capacity can be increased through a section of river near Millaquin bend. The future viability of any dredging proposal will rely on geotechnical testing that indicates bank slopes steeper than 1 in 10 downstream of the Burnett River Traffic Bridge is achievable.

### 8.4.3 Design considerations

As shown in Table 8-5, the majority of the dredge spoil comes from dredging the river bed upstream of the Burnett River Traffic Bridge with only a small component of volume coming from dredging downstream of the Bridge. This is due to the section downstream of the bridges being generally deeper, narrower and having steeper bank slopes close to the assumed 1 in 10 and 1 in 20 dredge slopes.

If dredging is to be pursued as a flood mitigation option, a geotechnical study would have to be undertaken to determine practical angles of repose and river bed material properties. A refinement of the dredge extents and profiles is warranted following such a study. The most significant flood mitigation benefits come from dredging downstream of the Burnett River Traffic Bridge. However, natural bank angles in this region are in the order of 1 in 10 to 1 in 20, and the current assumed dredge concept removes only a small amount of material in this region. Steeper angles of repose would likely allow a smaller volume of material to be excavated within a smaller footprint to achieve the same or greater flood level reductions.

Due to the limit on vessel draft, restricted air draft at the existing bridges and inability to safely turn, the dredging works upstream of the bridge is expected to be conducted by a small Cutter Suction Dredger (CSD). A typical CSD is equipped with a rotating cutter head cutting hard soil into fragments. The cut soil is then sucked in by dredge pumps. Cutter suction dredgers are mostly stationary suction dredgers that cut the soil according to a pre-set profile. The CSD does not sail during dredging activities. It is proposed that the material is loaded into a split hopper barge moored alongside, which in turn would be sailed down the Burnett River for unloading and disposal.

For this conceptual option, it is estimated that a small CSD with a production capacity of 500 m$^3$/hour would be required, operating over a 24 hour day. Further consideration on the productive capacity of the CSD within the heavily constrained working environment upstream of the bridges is recommended if this option is to be developed further. For the dredging downstream of the bridges, the TSHD will be tidally restricted during the capital dredging campaign. It is predicted that the TSHD will steam up the river unloaded at low tide, turn safely and then depart loaded on a high tide.

### 8.4.4 Key project risks

The following are key risks associated with this conceptual dredging option:

- **Dredging and mangrove removal works are strongly regulated by State and Federal authorities and the current political and environmental climate is making increasingly difficult to undertake dredging works and secure spoil disposal and dredging permits.**

- **The assessment provided has not addressed spoil disposal constraints which will contribute significant cost, programming and permitting requirements. An assessment of availability, cost, program and permitting for spoil disposal should be undertaken to determine the viability of dredging works (not included within the provided cost estimate).**

- **Impact on the Burnett River geomorphology due to the dredging has not been considered.**
For dredge disposal, it has been assumed at this stage that current spoil disposal capacities at the Port of Bundaberg are limited.

This option predicts a large volume of dredge spoil. Further investigation is required on land disposal. There are a number of options which require further investigation if this option is to be developed further, including but not limited to:

- Split capital dredging campaign, leaving sufficient time for the first volume of material to be disposed, treated and recycled;
- An alternative spoil ground/s is found within close proximity to the dredging activities.

If any vegetation is impacted by the dredging works, it is anticipated there may be significant rates of siltation and erosion of the river banks leading to stability issues. An assessment of the siltation rate, erosion and bank stability post dredging and vegetation clearance should be undertaken to determine the viability and sustainability of the dredge options and the ongoing maintenance cost (not included within the provided cost estimate). Particular care should be taken to ensure that the final dredge angle of repose minimises any impacts on vegetation and bank stability.

Clean sediment has been considered and assumed within the Burnett River bed. Dredging costs and durations are expected to substantially increase through treatment of acid sulphate soils, nutrient load and any heavy metal contamination.

It has been assumed that the material in question is dredgeable and has a bulking factor of 1.3.

Deposition of siltation has been assumed to equally distribute between nominated boundaries.

For the dredging downstream of the bridges, the TSHD will be tidally restricted during the dredging campaign. It is predicted that the TSHD will steam up the river unladen at low tide, turn safely and then depart loaded during high tide.

The TSHD is not expected to be able to operate upstream of the Burnett River Traffic Bridge. This is due to insufficient available vessel draft at most tidal states, insufficient air draft to pass beneath the 3 bridges and insufficient depth and lateral distance to safely turn.

Survey downstream of the project area has not been thoroughly investigated, however it is expected that the TSHD will be tidally restricted over some part of the river from Millaquin bend to the mouth. It is expected that further maintenance dredging will need to be carried out in order to safely access the site. This aspect of additional dredging has not investigated and is excluded from the cost estimates provided below.

The current assumed dredge concept has not considered impacts to bridge foundations, as only small quantities of material are being removed from the proximity of the bridges based on the assumed 1 in 10 and 1 in 20 bank angles. Further studies are required to more accurately determine the limitations on dredging in the vicinity of the bridges.

Rates utilised within the cost estimates have been developed based on GHD's marine experience, particularly past experience with supervising past Weipa dredge campaigns. Dredging contractors have not been consulted for this particular project.

A 0.5 metre Under Keel Clearance (UKC) has been adopted for the TSHD.

As the capital and maintenance dredging will be undertaken outside Bundaberg Port limits, site superintendent role by a 3rd party consultant has been included in the cost estimates.
• Capital volumes will need to be delivered with appropriate pump out facilities including pipeline and tailwater sediment ponds. If this option were to be investigated through a feasibility stage, the following requires further investigation as it has not been currently considered:
  o Pump-out costs including pipeline and tailwater sediment ponds at the Port of Bundaberg's nominated site;
  o The optimal location for the dredge pump out location;
  o Associated maritime infrastructure required as part of pump-out operations;
  o Localised bathymetry, accessibility of the pump out during operation considering sea conditions and navigability.
• From the landside, the preferred pipeline route to the tailwater sediment ponds, size and location of the tailwater sediment ponds, land ownership, environmental values, efficiency/feasibility of pumping to the tailwater sediment ponds including ground conditions along the alignment, pump efficiencies, expected bend angles, changes in elevation and other aspects of the pipeline alignment have not been considered within this cost estimate.
• It is expected that the current maintenance campaign allowance for the Port of Brisbane will not be sufficient to cater for this additional work. Additional allocation under current environmental approvals will be required. Indicative costs for the approvals process has been provided in this estimate.

8.4.5 Key environmental issues

The town reach dredging will affect a large section of the Burnett River. This option is considered to have a number of associated risks, impacts and ecological constraints. Much of the footprint to be dredged falls within the wetland management areas along the Burnett River, including both the wetlands themselves, and their associated trigger zones (refer to the environmental overlay maps in Appendix F). Impacts to these wetland management areas and dredging within the river will need to be addressed under permitting. As stated elsewhere, the design of the dredging works must consider the existing geotechnical conditions and stable angles of repose. Dredging and removal/disturbance of vegetation will alter the riverine habitat in the reach. Likely impacts include (but are not limited to):

• Changes in water quality
• Increased sediment loads, both at the site, and downstream with potential flow on affects to the adjacent marine habitats
• Bankside de-stabilisation
• Loss of habitat important for aquatic communities, including protected species (e.g. mangroves)

The town reach dredging footprint also sits alongside mapped high value regrowth, endangered (dominant) regional ecosystems and areas of ecological significance. These impacts will need to be managed through the development of an environmental management plan, which will need to consider measures for water quality monitoring, erosion and sediment control, bank stabilisation, controls against release of contaminants or waste materials, and offsetting approaches. Further investigation will also need to be undertaken to determine the hydrological patterns of the site, and the suitability of dredged material for disposal.

If the dredging activities are predicted to impact on mangrove vegetation, offsetting strategies may need to be put in place for the loss of protected species habitat, and the removal of
mangroves and their habitat. Mangroves located along the banks of the Burnett River and dredging works to widen and deepen the river are likely to affect the distribution and prevalence of these species. Mangroves along the river provide significant environmental services benefit including acting as a nursery ground for fisheries species, as sediment (bank) stabilisers and provision of benefits for nutrient cycling among other roles (Blaber 2007; Aburto-Orbópeza et al. 2008; Hussain and Badola 2008). In addition, mangroves in this area will be used by crabs, fish, bird species and other biodiversity of importance to the ecosystem health of the river.

The mangroves along the banks of the Burnett River were, however, damaged during flooding from prolonged immersion and high velocity flows. The Council has selectively cleared and managed dead mangroves within the river for boating and community safety. Recovery of the mangroves is expected to occur over time, however, current habitat condition is less than that present before flooding.

Depending on the geotechnical conditions and the final design of the works, channel dredging works may require removal of some mangrove habitat and associated biodiversity. It may also indirectly affect persistence of mangroves if bank profiling affects the availability of intertidal mud flat habitat for mangroves.

Within Queensland, mangroves and other marine plants are protected under the Queensland Fisheries Act 1994. Permanent removal of mangroves requires offsetting to take account to loss of fisheries habitat values which would otherwise be provided by the impacted habitat. Offsetting must be achieved in accordance with the specific-issue offset policy for marine fish habitats under the Queensland Government Environmental Offsets Policy.

If impacts to mangroves are expected, works to identify the quantum and relevant offsets will need to be completed. This may require information to define the area and quality of mangrove habitat to be impacted and identify and secure offsets that provide equivalent environmental benefits.

Offsets that could be secured of relevance to proposed works include rehabilitation of local causeway crossings or culverts which may currently impede fisheries species movement. Planting or rehabilitating mangroves on banks that were degraded during floods or from other processes could also achieve offsetting requirements. These actions would reinstate habitat connectivity and values for fisheries dependent species. Identification of offsets of relevance would be achieved after quality and area of habitat needing offset is quantified and in consultation with Queensland Government.

A protected matters search for the area identifies that a number of shorebirds and other avifauna that are protected under state or Commonwealth legislation are also known to occur within the reaches of the Burnett River proposed for dredging. These bird species include whimbrels (*Numenius phaeopus*) and various species of sandpipers, plovers and tattlers among others. Removal of mangroves or bank re-profiling works has potential to affect nesting, breeding or feeding populations of protected birds. On site observations which will quantify and value habitats to be affected by dredging for mangrove permitting/offsetting should take account of use of these habitats and adjacent mud flats/banks by migratory and protected species. If birds and other species protected under the EPBC Act or international legislation have potential to be impacted an EPBC referral may be required for proposed works.

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An EPBC referral will be triggered if proposed works are likely to significantly impact upon a population of a protected species by altering the availability of habitat for feeding, breeding or resting. Measures to avoid and manage impacts will need to be considered. This could include completing works at a time when a migratory species is not present and re-establishing habitats of relevance for use by the migratory species.

Sediments to be dredged under this option from the river bed are likely to be potential acid sulfate soils or actual acid sulfate soils. They may also contain contaminants which could be released to the environment if the sediments are disturbed. Investigations to determine the quality of the materials and most appropriate management for material disposal will need to be undertaken. This will need to be completed to inform whether materials can be disposed of to land, are able to be beneficially reused, requires treatment for sulfidic material or contaminants or are suitable for ocean disposal. The procedures which should be followed for sampling, testing and assessing the suitability of material to be dredged, reused and disposed of are outlined within the National Assessment Guidelines for Dredging 2009. This guideline also provides information relevant to obtaining permits for dredged material management.

As per other options under consideration in this project, potential to release pollutants or contaminants during proposed works will need to be managed using activity prescriptive waste and pollution management plans. Water quality monitoring and management will also need to be completed to demonstrate that measures to mitigate impacts are effective. To establish relevant water quality management thresholds and criteria for effective dredge management will require baseline water quality data prior to dredging works commencing. Regulators can require up to 24 months sampling to establish baseline values and identify site specific thresholds for defining relevant dredge management actions. However, locations where seasonal differences are minimal and which have been subject to previous monitoring can utilise existing background data to supplement data requirements for establishing baseline values.

### 8.4.6 Cost estimate

The following table summarises the high level and indicative only cost estimates. Note that for both options, the proportion of total costs attributable to the small volume of dredging downstream of the Burnett River Traffic Bridge with the TSHD is less than 5% of the total cost. Therefore, approximately 95% of the below cost is associated with the removal of material from upstream of the bridges.

#### Table 8-8 Dredging cost estimates

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Preliminary Cost Estimate ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Capital dredging</td>
<td>43,200,000</td>
</tr>
<tr>
<td></td>
<td>Maintenance dredging (lower bound values)</td>
<td>2,500,000</td>
</tr>
<tr>
<td></td>
<td>Maintenance dredging (upper bound values)</td>
<td>3,000,000</td>
</tr>
<tr>
<td>B</td>
<td>Capital dredging</td>
<td>56,900,000</td>
</tr>
<tr>
<td></td>
<td>Maintenance dredging (lower bound values)</td>
<td>2,500,000</td>
</tr>
<tr>
<td></td>
<td>Maintenance dredging (upper bound values)</td>
<td>3,000,000</td>
</tr>
</tbody>
</table>

Note: 1 – 1 in 20 batter slope adopted
2 – 1 in 10 batter slope adopted

The major cost elements for both options include:

- $22.1 million and $35.3 million for the CSD upstream of the bridges for the 1 in 20 and 1 in 10 batter option, respectively. For this conceptual option, a small CSD with a production capacity of 500 m³/hour has been adopted for this stretch. Further consideration on the productive capacity of the CSD within the heavily constrained working environment is recommended if this option is to be developed further.
The following key assumptions have been made to derive the high level and indicative only cost estimates:

- Preliminary cost estimates are provided as indicative estimated costs only and must be relied upon at the risk of the reader.
- Please note that GHD has no control over the cost of labour, materials, equipment or services furnished by others, neither has it control over contractors methods for determining prices, competitive bidding or market conditions. The preliminary cost estimates produced by GHD will therefore be provided on the basis of its best judgement as experienced marine engineers, familiar with the construction industry. We can therefore not guarantee that any tenders or actual construction costs will not vary from the preliminary cost estimates provided.
- Preliminary cost estimates are likely to change once the appropriate approvals process and detailed design has been completed.
- Preliminary and indicative only cost estimates have been provided, based on conceptual dredge options, with predicted limits of accuracy 25% to 30%.
- It has been assumed that additional capital and maintenance dredging will be undertaken by a similar medium sized dredge to the Port of Brisbane's vessel called the Brisbane, under the current Queensland ports sharing agreement. Logistics of utilising the Brisbane with the Port of Brisbane, particularly for future maintenance dredge campaigns, has not been confirmed within the preliminary cost estimates. Due to this uncertainty, 50% uplift on the TSHD rates has been applied to better represent typical dredging contractor rates.
- For indicative estimating purposes, it has been assumed that the developed dredging rates for both maintenance and capital dredge activities are equal.
- Base case siltation rates (tidal regime) are based on the Burnett River Channel Depth Study Numerical Modelling Aspects (March 1994) by the Qld Government Hydraulics Laboratory. Siltation rates due to minor and/or major flooding has not been considered.
- Base case siltation rates are based on the Burnett River Channel Depth Study Numerical Modelling Aspects (March 1994) report by the Qld Government Hydraulics Laboratory under a tidal regime. Siltation rates due to minor and/or major flooding has not been considered.
- A lower and upper bound typical siltation rate of 0.001 and 0.002 m3/s along the town reach has been adopted based on the Burnett River Channel Depth Study Numerical Modelling Aspects (March 1994) report by the Qld Government Hydraulics Laboratory. For the -5m AHD and the -6m AHD dredging options, the predicted lower and upper siltation rates have been factored by 0.25, 50 and 100%, respectively.
- Dredge costs for the TSHD, MSQ survey, Bed Levelling and 3rd party site superintendent support have been based on actual costs for the 2012 Weipa dredge campaign.
- It also assumes that environmental impacts are permanent and occur as the result of a single dredging campaign. A provisional value has been provided for ASS/PASS treatment.
- For vegetation removal, it has been assumed a land disposal license to receive mangrove waste exists within 50km of site.
- All cost estimates exclude 10% GST
- 30% contingency allowed due to conceptual nature of design and works within a marine environment.
### 8.4.7 Benefit-cost assessment

Table 8-2 and Table 8-9 outline a benefit-cost assessment based on the existing case flood damages presented in Section 4 and developed conditions damage estimates derived from the results of hydraulic modelling discussed in Section 6.3.

#### Table 8-9 Benefit-cost assessment for the town reach dredging option A

<table>
<thead>
<tr>
<th>AEP (%)</th>
<th>Existing Conditions Damage ($)</th>
<th>Developed Conditions Town Reach Dredging A Damage ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>$748,079</td>
<td>$702,334</td>
</tr>
<tr>
<td>10%</td>
<td>$2,909,306</td>
<td>$2,909,001</td>
</tr>
<tr>
<td>5%</td>
<td>$21,785,701</td>
<td>$21,284,373</td>
</tr>
<tr>
<td>2%</td>
<td>$120,444,637</td>
<td>$118,973,468</td>
</tr>
<tr>
<td>1%</td>
<td>$234,366,265</td>
<td>$229,899,414</td>
</tr>
<tr>
<td>0.5%</td>
<td>$424,361,107</td>
<td>$417,948,605</td>
</tr>
<tr>
<td>0.2%</td>
<td>$620,779,274</td>
<td>$615,618,852</td>
</tr>
<tr>
<td>PMF (0.00001%)</td>
<td>$2,472,272,491</td>
<td>$2,468,984,346</td>
</tr>
</tbody>
</table>

**Average Annual Damage:**

- **Existing Conditions** $11,130,883
- **Developed Conditions** $10,987,986

**Discount Rate** 7%

**Evaluation Period** 50 years

**Net Present Value (NPV) of Damages - Existing Conditions** $153,614,495

**Net Present Value (NPV) of Damages - Developed Conditions** $151,642,406

**NPV of Reduction in Damages** $1,972,088

**Cost of Mitigation (NPV of capital and maintenance works)** $84,602,239

**Benefit Cost Ratio** 0.02
### Table 8-10  Benefit-cost assessment for the town reach dredging option B

<table>
<thead>
<tr>
<th>AEP (%)</th>
<th>Existing Conditions Damage ($)</th>
<th>Developed Conditions Town Reach Dredging B Damage ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>$748,079</td>
<td>$696,504</td>
</tr>
<tr>
<td>10%</td>
<td>$2,909,306</td>
<td>$2,854,753</td>
</tr>
<tr>
<td>5%</td>
<td>$21,785,701</td>
<td>$20,763,910</td>
</tr>
<tr>
<td>2%</td>
<td>$120,444,637</td>
<td>$113,310,439</td>
</tr>
<tr>
<td>1%</td>
<td>$234,366,265</td>
<td>$224,145,137</td>
</tr>
<tr>
<td>0%</td>
<td>$424,361,107</td>
<td>$411,295,014</td>
</tr>
<tr>
<td>0.2%</td>
<td>$620,779,274</td>
<td>$608,872,229</td>
</tr>
<tr>
<td>PMF (0.00001%)</td>
<td>$2,472,272,491</td>
<td>$2,467,344,965</td>
</tr>
</tbody>
</table>

**Average Annual Damage:**

- **Existing Conditions**: $11,130,883
- **Developed Conditions**: $10,764,684

**Discount Rate**: 7%

**Evaluation Period**: 50 years

**Net Present Value (NPV) of Damages - Existing Conditions**: $153,614,495

**Net Present Value (NPV) of Damages - Developed Conditions**: $148,560,671

**NPV of Reduction in Damages**: $5,053,823

**Cost of Mitigation (NPV of capital and maintenance works)**: $98,302,239

**Benefit Cost Ratio**: **0.05**
8.4.8 Construction duration

Estimate duration for the construction activities associated with this conceptual options are summarised below in Table 8-11.

Table 8-11 Dredging construction duration estimates

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Activity</th>
<th>Preliminary Duration Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A¹</td>
<td>Capital dredging</td>
<td>TSHD</td>
<td>3 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSD</td>
<td>21 weeks</td>
</tr>
<tr>
<td>B²</td>
<td>Capital dredging</td>
<td>TSHD</td>
<td>17 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSD</td>
<td>28 weeks</td>
</tr>
<tr>
<td>Both Options</td>
<td>Maintenance dredging (yearly)</td>
<td>Lower bound values</td>
<td>9 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upper bound values</td>
<td>11 days</td>
</tr>
</tbody>
</table>

Note: 1 – 1 in 20 batter slope adopted
2 – 1 in 10 batter slope adopted

8.4.9 Implementation advice

If this option were taken forward, studies should be immediately commenced to address the key risks identified herein. The focus should be on optimising the design of the works as informed by the results of geotechnical and environmental surveys. It is likely that without favourable geotechnical conditions that support steeper dredge bank slopes through the critical section at Millaquin bend, dredging will not be a viable flood mitigation strategy compared to the other options available.

Dredging works would disturb marine sediments affecting local water quality and remove mangroves, potentially affecting intertidal mud flat environments. Shorebirds, fishery species and other fauna (including the protected water mouse) are likely to use the impacted mangrove and mud flat environments and some of these species that are likely to inhabit the project area may be protected under international treaties. Environmental assessments will, therefore, be required to support dredge permit applications to confirm appropriate environmental controls for project delivery. Studies would include, at a minimum, seabed habitat studies, shorebird studies and baseline water quality studies to inform project controls. Study data would need to characterise wet and dry season conditions and include shorebird migratory periods.

Marine plants provide fisheries habitat and are protected under the Queensland Fisheries Act 1994. Any plants disturbed or removed from the project area will need to be offset under the Marine Fish Habitat Offset Policy under the Queensland Government Offsets Policy. Direct offsets are preferred under the policy where spatial areas of fish habitat are used as a surrogate for loss or gain of the fisheries productivity provided by the affected habitat.

As the anticipated spoil ground is located within the port precinct the project it is not predicted to require a detailed Environmental Impact Assessment Statement under either the Queensland or Commonwealth assessment processes. It is expected that no cultural heritage matters will be affected by the project. Works would be achieved through submission of dredging permit applications. Permits that may be required depending on project footprint include:

- Sea dumping permit;
- Material change of use – environmentally relevant activities (ERA 16);
- Operational tidal works within a coastal management district;
- Removal of marine plants;
• Operational works clearing of native vegetation if any is considered watercourse regrowth.

• Additional permits would be required if the areas to be dredged are found to:
  o Support protected shorebirds or other fauna;
  o Include sediment contaminants;
  o Affect remaining bank stability.

Permit applications will need to be supported by a dredge environmental management plan, evidence of resource entitlement or land ownership consent, a description of the proposed works, a description of the plants of fauna to be impacted and measures taken to reduce or avoid impacts, a description of offsets to be applied to any residual impacts.
8.5  Millaquin bend widening works (option 31)

8.5.1  Project description

This project involves the deepening and widening of the Burnett River through excavation and dredging activities and the construction of engineered revetment wall in order to mitigate flooding effects. The material would be removed from the northern bank of the river at Millaquin Bend, and would involve works within (and likely resumption of) parts of the properties along the eastern side of Mariner’s Way. The project would also involve the removal of an area of mangrove vegetation. Plans showing the footprint of works, depths of excavation, and typical cross-sections of the dredging profile are included in Appendix F.

This option involves utilising a medium trailer suction hopper dredge similar to the Port of Brisbane’s dredge, the Brisbane, and conventional terrestrial earth moving equipment to excavate and dispose of a predicted 900,000 m³ of cut and river bed spoil to -5 m AHD and the construction of approximately 1.4 kilometres of rock revetment wall. The rock revetment wall has a typical 1 in 2 batter, with the crest formed at insitu property ground level (generally between 2 m and 4 m AHD) down to a toe level of 0 m AHD. At 0m AHD, there would be a 10 m wide level terrace for bank stability. At the edge of the terrace, a 1 in 20 batter slope is proposed down to -5m AHD.

8.5.2  Flood mitigation benefits

Based on the conceptual design of the works developed for this section, additional hydraulic modelling has been undertaken. The conceptual dredging and excavation profile has been assessed in the hydraulic model for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events as well as the PMF. A summary of the reductions in flood levels is provided in Table 8-12 below, and the afflux plot for the 1% AEP event is included in Appendix F.

<table>
<thead>
<tr>
<th>Flood Event</th>
<th>Approximate Reduction in Flood Level (East Bundaberg)</th>
<th>Approximate Reduction in Flood Level (North Bundaberg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% AEP</td>
<td>-0.14 m</td>
<td>N/A (not flooded under existing conditions)</td>
</tr>
<tr>
<td>10% AEP</td>
<td>-0.25 m</td>
<td>N/A (not flooded under existing conditions)</td>
</tr>
<tr>
<td>5% AEP</td>
<td>-0.44 m</td>
<td>N/A (not flooded under existing conditions)</td>
</tr>
<tr>
<td>2% AEP</td>
<td>-0.57 m</td>
<td>-0.11 to -0.37 m</td>
</tr>
<tr>
<td>1% AEP</td>
<td>-0.58 m</td>
<td>-0.2 to -0.31 m</td>
</tr>
<tr>
<td>0.5% AEP</td>
<td>-0.50 m</td>
<td>-0.24 to -0.28 m</td>
</tr>
<tr>
<td>0.2% AEP</td>
<td>-0.47 m</td>
<td>-0.15 to -0.23 m</td>
</tr>
<tr>
<td>PMF</td>
<td>-0.14 m</td>
<td>-0.07 to -0.1 m</td>
</tr>
</tbody>
</table>
A summary of the approximate number of properties (residential, commercial and industrial) that would have a greatly reduced risk of above floor flooding if the works were constructed is provided in Table 8-13.

<table>
<thead>
<tr>
<th>AEP (%)</th>
<th>Base case</th>
<th>Mitigated case</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>19</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>133</td>
<td>93</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>879</td>
<td>576</td>
<td>303</td>
</tr>
<tr>
<td>1</td>
<td>1726</td>
<td>1290</td>
<td>436</td>
</tr>
<tr>
<td>0.5</td>
<td>3097</td>
<td>2618</td>
<td>479</td>
</tr>
<tr>
<td>0.2</td>
<td>4132</td>
<td>3813</td>
<td>319</td>
</tr>
<tr>
<td>PMF</td>
<td>13113</td>
<td>13015</td>
<td>98</td>
</tr>
</tbody>
</table>

The flood mitigation benefits of this proposal throughout the Bundaberg city area are substantial, considering the relatively small footprint of works compared to other options under consideration. A description of the cost-benefit ratio of the works is provided below in Section 8.5.7.

8.5.3 Design considerations

Both capital and maintenance dredge activities have been considered. The capital excavation and dredge campaign is a ‘once-off’ activity where a predicted 900,000 m$^3$ is excavated. The maintenance dredge campaign is predicted to occur on a yearly basis with approximately 100,000 m$^3$ (lower bound) to 130,000 m$^3$ (upper bound) of river bed material to be excavated and disposed. Further studies are required to accurately determine the rates of sedimentation and therefore dredge maintenance.

8.5.4 Key project risks

The following are the key risks and assumptions identified at this stage for this conceptual option. Each of these risks will need to be further investigated and managed if this project is taken forward.

- Dredging and mangrove removal works are strongly regulated by State and Federal authorities and the current political and environmental climate is making increasingly difficult to undertake dredging works and secure spoil disposal and dredging permits.
- At this stage, no geotechnical investigations have been undertaken. All wall heights, batter slopes and terrace widths therefore need to be reviewed on the basis of detailed geotechnical investigations that should be undertaken as a matter of priority if this option were to be taken forward.
- The assessment provided has not addressed spoil disposal constraints which will contribute significant cost, programming and permitting requirements. An assessment of availability, cost, program and permitting for spoil disposal should be undertaken to determine the viability of dredging works (not included within the provided cost estimate).
- Impact on the Burnett River geomorphology due to the dredging has not been considered.
- For dredge disposal, it has been assumed at this stage that current spoil disposal capacities at the Port of Bundaberg are limited.
- This option predicts a large volume of dredge spoil. Further investigation is required on appropriate and available land disposal sites. There are a number of options which
require further investigation if this option is to be developed further, including but not limited to:

- Split capital dredging campaign, leaving sufficient time for the first volume of material to be disposed, treated and recycled;
- An alternative spoil ground/s is found within close proximity to the dredging activities.

- Due to vegetation removal, it is anticipated there may be significant rates of siltation and erosion of the river banks leading to stability issues, unless appropriately managed. An assessment of the siltation rate, erosion and bank stability post dredging and vegetation clearance should be undertaken to determine the viability and sustainability of the dredge options and the ongoing maintenance cost (not included within the provided cost estimate).

- Clean sediment has been considered and assumed within the Burnett River bed. Dredging costs and duration are expected to substantially increase as a result of treatment of acid sulphate soils, nutrient load and any heavy metal contamination.

- It has been assumed that the material in question is dredgeable and has a bulking factor of 1.3.

- Deposition of siltation has been assumed to equally distribute between nominated boundaries.

- The TSHD will be tidally restricted during the dredging campaign. It is predicted that the TSHD will steam up the river unladen at low tide, turn safely and then depart loaded during high tide.

- Survey downstream of the project area has not been thoroughly investigated, however it is expected that the TSHD will be tidally restricted over some part of the river from the project area to the mouth. It is expected that further maintenance dredging will need to be carried out in order to safely access the site. This aspect of additional dredging has not been investigated and is excluded from the cost estimates provided below. It is noted that DTMR is currently preparing for dredging activities to restore a navigable channel along the reach of the river adjacent to Kirby’s Wall, although the suitability of this channel for the TSHD has not been investigated.

- Rates utilised within the cost estimates have been developed based on GHD's marine experience, particularly past experience with supervising Weipa dredge campaigns. Dredging contractors have not been consulted for this particular project.

- A 0.5 metre Under Keel Clearance (UKC) has been adopted for the TSHD.

- As the capital and maintenance dredging will be undertaken outside Bundaberg Port limits, site superintendent role by a 3rd party consultant has been included in the cost estimates.

- Capital volumes will need to be delivered with appropriate pump out facilities including pipeline and tailwater sediment ponds. If this option were to be further investigated through a feasibility stage, the following requires further investigation as it has not been currently considered:
  - Pump-out costs including pipeline and tailwater sediment ponds at the nominated spoil disposal site;
  - The optimal location for the dredge pump out location;
  - Associated maritime infrastructure required as part of pump-out operations;
- Localised bathymetry, accessibility of the pump out during operation considering sea conditions and navigability.

- From the landside, the preferred pipeline route to the tailwater sediment ponds, size and location of the tailwater sediment ponds, land ownership, environmental values, efficiency/feasibility of pumping to the tailwater sediment ponds including ground conditions along the alignment, pump efficiencies, expected bend angles, changes in elevation and other aspects of the pipeline alignment have not been considered within this cost estimate.

- It is expected that the current maintenance campaign allowance for the Port of Brisbane will not be sufficient to cater for this additional work. Additional allocation under current environmental approvals will be required. Indicative costs for the approvals process has been provided in this estimate.

### 8.5.5 Key environmental issues

Bank accretion at Millaquin Bend within the Burnett River has occurred over time. Aerial photographs from the 1940’s indicate this bank of the river was not as substantial in form as today. The proposed option of widening the river by re-engineering the bank profile at this river section will need to consider how frequently this maintenance will need to occur. Once off impacts from bank works are considered less impactful than chronic ongoing impacts from repeated maintenance works. Therefore, further studies to quantify sedimentation and maintenance rates are considered of vital importance.

Millaquin Bend supports significant mangroves, is an area of ecological significance, and a wetland management area (refer to the environmental overlay maps in Appendix F). This designation reflects the ecological value this area provides to the river ecosystem health and, downstream of the river, to coastal waters.

Mangroves located along the banks of the river at this location provide significant environmental services benefit. They are a nursery ground for fisheries species, they act as sediment stabilisers and provide benefits for nutrient cycling among other roles (Blaber 2007; Aburto-Oropeza et al. 2008; Hussain and Badola 2008). Water quality, nutrient cycling, biogeochemical processes and sediment bank stabilisation are benefits which mangroves will provide to the Burnett River at this location. In addition, mangroves in this area will be used by crabs, fish, bird species and other biodiversity of importance to the ecosystem health of the river.

The mangroves on the eastern bank of the Burnett River at Millaquin Bend were, however, damaged during flooding from prolonged immersion and high velocity flows. The Council has selectively cleared and managed dead mangroves within the river for boating and community safety. Recovery of the mangroves is expected to occur over time, however, current habitat condition is less than that present before flooding.

Widening of the Burnett River at Millaquin Bend will require removal of mangrove habitat and associated biodiversity. Within Queensland mangroves and other marine plants are protected under the Queensland Fisheries Act 1994. Permanent removal of mangroves requires offsetting to take account to loss of fisheries habitat values which would otherwise be provided by the impacted habitat. Offsetting must be achieved in accordance with the specific-issue offset policy for marine fish habitats under the Queensland Government Environmental Offsets Policy.

If impacts to mangroves are expected, works to identify the quantum and relevant offsets will need to be completed. This may require information to define the area and quality of mangrove habitat to be impacted and identify and secure offsets that provide equivalent environmental benefits.
Offsets that could be secured of relevance to proposed works include rehabilitation of local causeway crossings or culverts which may currently impede fisheries species movement. Planting or rehabilitating mangroves on banks that were degraded during floods or from other processes could also achieve offsetting requirements. These actions would reinstate habitat connectivity and values for fisheries dependent species. Identification of offsets of relevance would be achieved after quality and area of habitat needing offset is quantified and in consultation with Queensland Government.

The impacts to mangrove and mud flat habitats also have potential to realise flow on impacts to protected species such as shorebirds and may require water quality management triggers to be established through baseline water quality monitoring. Widening and affecting the bank environment at Millaquin Bend also has potential to impact upon species protected under the EPBC Act and may require an EPBC referral.

This reach of the Burnett River is upstream of a wetland that is classified as having High Ecological Significance and within a wetland management area (refer Figure 2 in Appendix F). Works to widen the river at this bend will, therefore, need to comply with regulations governing the risk of impacting upon the presence and value of protected wetland habitat.

Sediments to be removed from the bank at Millaquin Bend to facilitate widening and re-profiling of the river are likely to be potential acid sulfate soils or actual acid sulfate soils. They may also contain contaminants which could be released to the environment if the sediments are disturbed. Soil investigations to determine the quality of the materials and most appropriate management for material disposal will need to be undertaken. This will need to be completed to inform whether materials can be disposed of to land, are able to be beneficially reused, requires treatment for sulfidic material or contaminants or are suitable for ocean disposal.

### 8.5.6 Cost estimate

The following Table 8-14 summarises the high level and indicative only cost estimate for this option.

<table>
<thead>
<tr>
<th>Description</th>
<th>Preliminary Cost Estimate ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital works</td>
<td>32,100,000</td>
</tr>
<tr>
<td>Maintenance dredging (lower bound values)</td>
<td>1,800,000</td>
</tr>
<tr>
<td>Maintenance dredging (upper bound values)</td>
<td>2,100,000</td>
</tr>
</tbody>
</table>

The following key assumptions have been made to derive high level and indicative cost estimates:

- Preliminary cost estimates are provided as indicative estimated costs only and must be relied upon at the risk of the reader.
- Note that GHD has no control over the cost of labour, materials, equipment or services furnished by others, neither has it control over contractors methods for determining prices, competitive bidding or market conditions. The preliminary cost estimates produced by GHD will therefore be provided on the basis of its best judgement as experienced marine engineers, familiar with the construction industry. We can therefore not guarantee that any tenders or actual construction costs will not vary from the preliminary cost estimates provided.
- Preliminary cost estimates are likely to change once the appropriate approvals process and detailed design has been completed.
- A major component of the costs of this option is involved with the engineered revetment wall. An indicative per metre rate based on past experience has been used, by the actual
costs will depend on the required rock size and geotechnical conditions, both of which have not been determined.

- Preliminary and indicative only cost estimates have been provided, based on conceptual dredge options, with predicted limits of accuracy 25% to 30%.
- It has been assumed that additional capital and maintenance dredging will be undertaken by a similar medium sized dredge to the Port of Brisbane’s vessel called the Brisbane, under the current Queensland ports sharing agreement. Logistics of utilising the Brisbane with the Port of Brisbane, particularly for future maintenance dredge campaigns, has not been confirmed within the preliminary cost estimates. Due to this uncertainty, 50% uplift on the TSHD rates has been applied to better represent typical dredging contractor rates.
- For indicative estimating purposes, it has been assumed that the developed dredging rates for both maintenance and capital dredge activities are equal.
- Base case siltation rates (tidal regime) are based on the Burnett River Channel Depth Study Numerical Modelling Aspects (March 1994) by the Qld Government Hydraulics Laboratory. Siltation rates due to minor and/or major flooding has not been considered.
- A lower and upper bound typical siltation rate of 0.001 and 0.002 m³/s has been adopted based on the Burnett River Channel Depth Study Numerical Modelling Aspects (March 1994) report by the Qld Government Hydraulics Laboratory. For all dredging options, the predicted lower and upper siltation rates have been factored by 0, 25, 50 and 100%, respectively.
- Dredge costs for the TSHD, MSQ survey, Bed Levelling and 3rd party site superintendent support have been based on actual costs for the 2012 Weipa dredge campaign. Mobilisation and Demobilisation of the TSHD to Bundaberg reflect the 2012 cost sharing agreement between relevant Queensland Port Authorities and Port of Brisbane.
- It also assumes that environmental impacts are permanent and occur as the result of a single dredging campaign. A provisional value has been provided for ASS/PASS treatment.
- For vegetation removal, it has been assumed a land disposal licensed to receive mangrove waste exists within 50 km of site.
- All cost estimates exclude 10% GST
- 30% contingency allowed due to conceptual nature of design and works within a marine environment.
8.5.7 Benefit-cost assessment

Table 8-15 outlines a benefit-cost assessment based on the existing case flood damages presented in Section 4 and developed conditions damage estimates derived from the results of hydraulic modelling discussed in Section 8.5.2.

### Table 8-15 Benefit-cost assessment for Millaquin bend widening works

<table>
<thead>
<tr>
<th>AEP (%)</th>
<th>Existing Conditions Damage ($)</th>
<th>Developed Conditions Millaquin Bend Widening Damage ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18%</td>
<td>$748,079</td>
<td>$702,334</td>
</tr>
<tr>
<td>10%</td>
<td>$2,909,306</td>
<td>$2,909,001</td>
</tr>
<tr>
<td>5%</td>
<td>$21,785,701</td>
<td>$21,284,373</td>
</tr>
<tr>
<td>2%</td>
<td>$120,444,637</td>
<td>$118,973,468</td>
</tr>
<tr>
<td>1%</td>
<td>$234,366,265</td>
<td>$229,899,414</td>
</tr>
<tr>
<td>0%</td>
<td>$424,361,107</td>
<td>$417,948,605</td>
</tr>
<tr>
<td>0.2%</td>
<td>$620,779,274</td>
<td>$615,618,852</td>
</tr>
<tr>
<td>PMF (0.00001%)</td>
<td>$2,472,272,491</td>
<td>$2,468,984,346</td>
</tr>
</tbody>
</table>

**Average Annual Damage:**

- $11,130,883
- $10,987,986

**Discount Rate**

7%

**Evaluation Period**

50 years

**Net Present Value (NPV) of Damages - Existing Conditions**: $153,614,495

**Net Present Value (NPV) of Damages - Developed Conditions**: $123,285,077

**NPV of Reduction in Damages**: $30,329,417

**Cost of Mitigation (NPV of capital and maintenance works)**: $61,081,567

**Benefit Cost Ratio**: 0.50

8.5.8 Construction duration

Estimate duration for the construction activities associated with this conceptual options are summarised below in Table 8-17.

### Table 8-16 Millaquin bend widening construction duration estimates

<table>
<thead>
<tr>
<th>Description</th>
<th>Activity</th>
<th>Preliminary Duration Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital works</td>
<td>Site establishment and vegetation clearing</td>
<td>12 weeks</td>
</tr>
<tr>
<td></td>
<td>Engineered revetment wall</td>
<td>13 weeks</td>
</tr>
<tr>
<td></td>
<td>TSHD</td>
<td>11 weeks</td>
</tr>
<tr>
<td>Maintenance dredging</td>
<td>Maintenance dredging (lower bound values)</td>
<td>6 days</td>
</tr>
<tr>
<td></td>
<td>Maintenance dredging (upper bound values)</td>
<td>7 days</td>
</tr>
</tbody>
</table>
8.5.9 Implementation advice

If this option were taken forward, studies should be immediately commenced to address the key risks identified herein. The focus should be on optimising the design of the works as informed by the results of geotechnical and environmental surveys.

Dredging works would disturb marine sediments affecting local water quality and remove mangroves, potentially affecting intertidal mud flat environments. Shorebirds, fishery species and other fauna (including the protected water mouse) are likely to use the impacted mangrove and mud flat environments and some of these species that are likely to inhabit the project area may be protected under international treaties. Environmental assessments will, therefore, be required to support dredge permit applications to confirm appropriate environmental controls for project delivery. Studies would include, at a minimum, include seabed habitat studies, shorebird studies and baseline water quality studies to inform project controls. Study data would need to characterise wet and dry season conditions and include shorebird migratory periods.

Marine plants provide fisheries habitat and are protected under the Queensland Fisheries Act 1994. Any plants disturbed or removed from the project area will need to be offset under the Marine Fish Habitat Offset Policy under the Queensland Government Offsets Policy. Direct offsets are preferred under the policy where spatial areas of fish habitat are used as a surrogate for loss or gain of the fisheries productivity provided by the affected habitat.

As the anticipated spoil ground is located within the port precinct the project it is not predicted to require a detailed Environmental Impact Assessment Statement under either the Queensland or Commonwealth assessment processes. It is expected that no cultural heritage matters will be affected by the project. Works would be achieved through submission of dredging permit applications. Permits that may be required depending on project footprint include:

- Sea dumping permit;
- Material change of use – environmentally relevant activities (ERA 16);
- Operational tidal works within a coastal management district;
- Removal of marine plants;
- Operational works clearing of native vegetation if any is considered watercourse regrowth.
- Additional permits would be required if the areas to be dredged are found to:
  - Support protected shorebirds or other fauna;
  - Include sediment contaminants;
  - Affect remaining bank stability.

Permit applications will need to be supported by a dredge environmental management plan, evidence of resource entitlement or land ownership consent, a description of the proposed works, a description of the plants of fauna to be impacted and measures taken to reduce or avoid impacts, a description of offsets to be applied to any residual impacts.
8.6 Regional bridge upgrades (option 38)

8.6.1 Existing flood immunity & affected communities

As part of this option, a total of five bridge crossing were identified for potential upgrade. Those five bridges were further investigated to determine the existing immunity of the crossings and the communities affected by bridge closure (Table 8-17). The viability of upgrading each crossing was then assessed.

**Table 8-17 Regional bridge immunity to Burnett River flooding**

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Road</th>
<th>Affected communities</th>
<th>Current flood immunity (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perry River Bridge</td>
<td>Mingo Rd</td>
<td>Good Night, Morganville</td>
<td>&lt; 20% AEP</td>
</tr>
<tr>
<td>St Agnes Creek Bridge</td>
<td>Walla Rd</td>
<td>Good Night, Morganville</td>
<td>10% AEP</td>
</tr>
<tr>
<td>Booyal Crossing</td>
<td>Causeway Rd</td>
<td>Good Night, Morganville</td>
<td>Frequently cut each year</td>
</tr>
<tr>
<td>Pine Creek Bridge</td>
<td>Pine Creek Rd</td>
<td>Givelda, Electra, Pine Creek</td>
<td>&lt; 20% AEP</td>
</tr>
<tr>
<td>Cherry Creek Bridge</td>
<td>Pine Creek Rd</td>
<td>Givelda, Electra, Pine Creek</td>
<td>&lt; 20% AEP</td>
</tr>
</tbody>
</table>

The Perry River and St Agnes Creek bridges are both located on the same critical evacuation route for the Good Night and Morganville areas. Those communities gain access to the Bruce Highway near Wallaville by taking a northerly route along Mingo Rd and Walla Rd and must pass both crossings. Booyal Crossing is on an alternative route that gives more direct access to Booyal on the eastern side of the river.

The viability of upgrading Booyal Crossing has been previously investigated by Bundaberg Regional Council. As the crossing is currently a low level causeway across the Burnett River, the existing flood immunity is negligible, with the route being regularly cut by natural annual flows and dam environmental releases. The prospects for upgrading the crossing to provide a flood evacuation route are therefore limited, as a full replacement with a high-level bridge structure would be required. Other improvements (such as raising the structure by a small amount, or providing additional through-drainage) would only improve the general trafficability and amenity of the route, and therefore fall outside the scope of this flood risk management study.

For the remaining four crossings, the current bridge level and Burnett River flood levels are summarised below:
## Table 8-18 Regional bridge crossing flood levels

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Existing deck level (approximate)</th>
<th>20% AEP flood level</th>
<th>10% AEP flood level</th>
<th>5% AEP flood level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perry River Bridge</td>
<td>24.5 m AHD</td>
<td>28.6 m AHD</td>
<td>32.3 m AHD</td>
<td>36.1 m AHD</td>
</tr>
<tr>
<td>St Agnes Creek Bridge</td>
<td>31.6 m AHD</td>
<td>Nil</td>
<td>31.3 m AHD</td>
<td>35.0 m AHD</td>
</tr>
<tr>
<td>Pine Creek Bridge</td>
<td>10.1 m AHD</td>
<td>13.2 m AHD</td>
<td>16.9 m AHD</td>
<td>20.5 m AHD</td>
</tr>
<tr>
<td>Cherry Creek Bridge</td>
<td>11.1 m AHD</td>
<td>13.2m AHD</td>
<td>16.9 m AHD</td>
<td>20.5 m AHD</td>
</tr>
</tbody>
</table>

To achieve a nominal 10% AEP flood immunity for Burnett River backwater flooding, the Perry River, Pine Creek and Cherry Creek bridges would have to be raised by approximately 8 m, 7 m and 6 m respectively. To span across the 10% AEP flood extent, a 140 m long bridge is required at Cherry Creek and a 100 m long bridge would be sufficient at the Perry River.

However, due to the local topography at Pine Creek, a bridge spanning the 10% AEP flood extent would exceed 500 m in length. To achieve immunity to the 20% AEP flood event, a more reasonable bridge length of 160 m would be required.

In light of the difficulty in achieving reasonable flood immunity along Pine Creek Road, and due to the requirement for two separate and substantial bridge upgrades, it is likely the more viable solution for the Givelda, Pine Creek and Electra communities is the alternative evacuation route through private property and state forest to the south.

### 8.6.2 Viable upgrades

Based on the information presented in Section 8.6.1, the most viable upgrades for improving the access to isolated regional communities during and after a flood event are as follows:

a. Upgrading the Perry River crossing to achieve a nominal 10% AEP flood immunity to Burnett River backwater flooding (equivalent to the existing immunity of the St Agnes Creek bridge), subject to further investigation of local Perry River flooding. On initial review, the most appropriate location for the new bridge crossing would be approximately 260 m downstream of the current crossing, as the approaches to the current bridge are in cut. A new 100 m long bridge and approach roads would need to be constructed, and the current bridge could remain open during and after construction. The new roadway and bridge is assumed to have a carriageway width of 12 m (giving a total bridge deck width of 13 m including traffic barriers). This upgrade would benefit approximately 400 – 600 residents in the Goodnight Scrub and Morganville areas.

b. As an alternative to the Perry River Bridge upgrade, an evacuation route may be available through the Goodnight Scrub National Park and along Kalliwa Road to Gayndah-Mount Perry Road. This option would require additional investigation to determine the existing flood immunity to the Perry River and other creek flood sources, but at a minimum would require raising of the earth embankment over Mingham Creek to above Paradise Dam backwater levels. Based on further investigations, this option may prove to be a more cost effective solution than the Perry River Bridge upgrade. Again, this
upgrade would benefit approximately 400 – 600 residents in the Goodnight Scrub and Morganville areas.

c. Formalising and maintaining the alternative 4WD evacuation route for the Pine Creek, Givelda and Electra communities. These works would involve an initial review of the condition of the route, following by minor rectification works where the road surface is found to be degraded. It is expected that any works would be limited to re-dressing of isolated sections of the road that have been eroded and possibly the installation of minor cross-drainage culverts to prevent further excessive erosion and damage. Some additional survey and property boundary modifications would be required to re-align the road reserve so that it fully covers the existing road formation. The proposed alternate evacuation routes are shown in Appendix H.

8.6.3 Key project risks

The key risks associated with these projects are similar to those typically expected for bridge and road construction. For the Perry River bridge, the key risks are:

- The design, construction methodology and costs associated with the bridge construction and approach roads are dependent on the local geotechnical conditions, which are currently unknown. As is standard practice with bridge construction, a geotechnical investigation would need to be undertaken to underpin the design of the structure and the design of the earthworks on the approach roads.

- At this stage, there has been no investigation of local Perry River flooding. As the new Perry River Bridge would be constructed at a much higher level than the current bridge, concerns over bridge afflux are minimal. However, the design of bridge foundations and abutments will need to consider the expected velocities during major flooding in the Perry River itself.

- The initial concept for the new Perry River Bridge is located on an alternate alignment to the current bridge, and resumption of some currently undeveloped private property would be required for both the bridge and the new approach roads. Access to this property and appropriate compensation would have to be negotiated with the affected land owner/s.

8.6.4 Key environmental issues

The proposed bridge upgrade is likely to have a number of impacts for freshwater and terrestrial taxa. Construction is likely to generate lighting, noise and vibration which may impact the natural behaviour of fauna. The bridge upgrade is also likely to require the diversion or temporary bunding of the waterway. This activity will create a temporary barrier to dispersal of aquatic flora and fauna.

A long term barrier to dispersal may also be imposed by the bridge itself. Possible impacts of bridge structure include:

- Large scale turbulence resulting from bridge piers;
- Increased flood flow velocities;
- Changes to in-stream and bank vegetation affecting water shading, habitat values and water velocities;
- Limited light penetration under the bridge deck creating a nonphysical barrier for some fish species that may avoid dark areas during daylight hours; and
- Restrictions to dispersal and/or migration leading to the loss or decline of populations upstream and/or downstream, and the loss of gene flow and genetic diversity contained within those populations.
A permit under the Fisheries Act will be required for construction of the new bridge. An appropriate design should also be developed to comply with the recommendations and guidelines presented in:

- Culvert Fishway Planning and Design Guidelines (Kapitzke 2010)
- Waterway barrier works development approvals (Peterken et al. 2009)
- Fisheries Guidelines for Fish-Friendly Structures (Derbyshire 2006)
- Why do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings (Fairfull and Witheridge 2003)
- Fisheries guidelines for design of stream crossings (Cotterell 1998).

Riparian vegetation will also be disturbed and/or removed during the upgrade. Riparian vegetation has an important role for aquatic habitats in providing protection from the sun, heat and wind, and in protecting aquatic taxa from predators (e.g. raptors). The organic material produced by riparian vegetation also provides an important basis for foodwebs, and provides habitat for aquatic fauna. In addition, riparian vegetation buffers aquatic ecosystems against the impacts from the terrestrial landscape.

The removal and/or disturbance of riparian vegetation may also result in the increase of sediment and nutrient loads in waterways, as nutrient cycling patterns may be disrupted and bank stabilisation is compromised. In addition, there is the potential for a chemical spill to occur or other wastes/pollutants to be released, as construction machinery will be operating within and adjacent to the waterway. Consequently, a number of environmental controls will need to be implemented to mitigate and manage potential impacts. These management plans may include (but are not limited to) a pollution and waste management plan, an erosion and sediment control plan, a dust management plan, weed and pest management during works and a revegetation/rehabilitation plan. These management plans will form part of planning development documents for permit application.

8.6.5 Cost estimate

The estimated costs of the new Perry River Bridge structure, based on an assumed per m² rate for high-level planning purposes, is $14.3M inclusive of planning, design and permitting. Estimated costs for the approach roads, based on estimated earthworks volumes and road pavement areas is $3M, inclusive of planning, design, permitting, drainage and an allowance for private landowner compensation. The total estimated cost of the new Perry River Bridge upgrade is therefore $17.3M. The assumptions and limitations set out elsewhere in this report apply to this cost estimate.

Based on initial assumptions about the minimum amount of drainage required to facilitate general trafficability, both alternative 4WD evacuation routes for the Givelda, Pine Creek and Electra areas could be formalised for approximately $1M.
8.7  Bundaberg North evacuation route upgrades (option 39)

8.7.1  Existing flood immunity & affected communities

As part of this option, a total of five road segments were identified for potential upgrade. Table 8-19 outlines the existing flood immunity of each road segment and the role the road segment plays in evacuation and access during a flooding. The viability of upgrading each segment was then assessed.

Table 8-19  North Bundaberg evacuation route summary

<table>
<thead>
<tr>
<th>Segment</th>
<th>Location</th>
<th>Nature &amp; purpose</th>
<th>Current flood immunity (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hinkler Avenue</td>
<td>Between Tallon Bridge and North School Hill roundabout</td>
<td>A raised section of viaduct would provide vital connectivity between the north and south sides of the river during a flood event.</td>
<td>10% AEP</td>
</tr>
<tr>
<td>Mount Perry Rd (west)</td>
<td>Between Moore Park Rd and Christen St</td>
<td>Forms part of the key evacuation route allowing communities in parts of North Bundaberg, Fairymead and Gooburrum to escape from the floodplain.</td>
<td>1% AEP (assuming the Cummins St levee project proceeds – 2% AEP otherwise)</td>
</tr>
<tr>
<td>Mount Perry Rd (east)</td>
<td>Between Walters St and North School Hill roundabout</td>
<td>As above.</td>
<td>2% AEP</td>
</tr>
<tr>
<td>Fairymead Rd</td>
<td>Queen St to McKenzies Rd</td>
<td>As above.</td>
<td>2% AEP</td>
</tr>
<tr>
<td>Batchler’s Rd</td>
<td>Near Faggs Rd to Loeskow St</td>
<td>Alternative to the Mount Perry Rd routes.</td>
<td>5% AEP</td>
</tr>
</tbody>
</table>

Hinkler Avenue currently represents the critical link between the north and south sides of the river during a flood event. Under existing conditions, the Hinkler Avenue is cut in the 5% AEP flood event and the alternative Mount Perry Road / Queen Street route is cut shortly thereafter, meaning that no emergency services can access North Bundaberg from the south side of the river.

Mount Perry Rd west of the North School Hill roundabout is cut in two locations as set out in Table 8-19. The eastern most section of road is cut during the 1% AEP flood event which means that, in conjunction with the closure of Hinkler Avenue at an earlier stage, no evacuation along established routes is possible for the communities in parts of North Bundaberg, Fairymead and Gooburrum. The highlighted section of Fairymead Rd performs the same function, and both sections would need to be upgraded to provide a continuous evacuation
route. The western section of Mount Perry Rd remains open until the between the 1% and 0.5% AEP event assuming the Cummins Street levee project proceeds. Otherwise, this section is also cut in the 1% AEP event.

Batchler’s Rd, which is currently cut during the 2% AEP flood event, presents an alternative route to Mount Perry Road.

The works associated with raising the highlighted sections of road to a nominal 0.5% AEP standard are outlined below in Table 8-20:

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Existing minimum road level (approximate)</th>
<th>0.5% AEP flood level</th>
<th>Construction type</th>
<th>Length of works</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hinkler Avenue</td>
<td>5.0 m AHD</td>
<td>9.6 – 10.6 m AHD</td>
<td>Raised viaduct / bridge structure with partial earth embankment</td>
<td>0.8 km (assumed)</td>
</tr>
<tr>
<td>Mount Perry Rd (west)</td>
<td>8.0 m AHD</td>
<td>8.25 m AHD</td>
<td>Earth fill with cross-drainage</td>
<td>0.7 km</td>
</tr>
<tr>
<td>Mount Perry Rd (east)</td>
<td>8.5 m AHD</td>
<td>9.6 – 10.0 m AHD</td>
<td>Earth fill with cross-drainage</td>
<td>1.0 km</td>
</tr>
<tr>
<td>Fairymead Rd</td>
<td>7.2 m AHD</td>
<td>8.2 – 8.7 m AHD</td>
<td>Earth fill</td>
<td>1.3 km</td>
</tr>
<tr>
<td>Batchler’s Rd</td>
<td>6.0 m AHD</td>
<td>8.2 m AHD</td>
<td>Earth fill with cross-drainage</td>
<td>1.7 km</td>
</tr>
</tbody>
</table>

8.7.2 Preliminary design

To facilitate the high-level estimation of costs for the above options, a basic geometric design of the five identified road segment upgrades was undertaken. The concept designs are included in Appendix I.

For the basis of this high-level assessment, it has been assumed that the entire Hinkler Avenue viaduct would be constructed as a raised bridge structure, while the other roads would be raised earth fill embankments with traditional cross-drainage. Further hydraulic modelling to investigate allowable local afflux may allow some part of the raised Hinkler Avenue to be constructed on earth fill.

8.7.3 Viable upgrades

Based on the above concept designs, it is seen that the Batchler’s Rd option involves a substantially larger amount of earthworks compared to the Mount Perry Rd upgrades. As these options serve the same function, it is considered that the Mount Perry Rd upgrades should be preference due to cost. Mount Perry Rd is also the most obvious choice for an evacuation route, having better connectivity with the surrounding road network.

8.7.4 Key project risks

As the road upgrades occur in existing road corridors, the risk of adverse geotechnical conditions is lower than for a greenfield development. If any issues exist with the current roads
in these areas, the road upgrades should seek to rectify those issues and bring the new works up to accepted standards.

The design of local cross-drainage has not been investigated at this stage. It is likely that additional drainage will be required to offset the potential local flood level impacts of the raised road embankments. An indicative allowance has been made in the cost estimates.

### 8.7.5 Key environmental issues

While the upgrades to the evacuation routes are for an existing developed footprint, the size (width) of these corridors may need to be increased to allow for expansion. In addition, the actual construction activities will generate a number of impacts through the construction phase. Such impacts are likely to include noise, vibration and lighting disturbance, sediment runoff and vegetation clearing. Activities may also have potential to release waste materials or pollutants into the environment or introduce or spread weeds or pest species. In order to effectively manage these impacts, a number of management plans will need to be developed. These management plans may include (but are not limited to) a pollution and waste management plan, an erosion and sediment control plan, a dust management plan, weed and pest management during works and a revegetation/rehabilitation plan. These management plans will form part of planning development documents for permit application.

### 8.7.6 Cost estimate

The following high-level cost estimates have been prepared for the road upgrade options.

**Table 8-21 North Bundaberg evacuation route upgrade cost estimates**

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Cost estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hinkler Avenue</td>
<td>$104M</td>
</tr>
<tr>
<td>Mount Perry Rd (west)</td>
<td>$1.8M</td>
</tr>
<tr>
<td>Mount Perry Rd (east)</td>
<td>$2.5M</td>
</tr>
<tr>
<td>Fairymead Rd</td>
<td>$3.1M</td>
</tr>
</tbody>
</table>
8.8 **Funding for house raising (option 40)**

The raising of residential dwellings that experience above floor flooding is a viable flood mitigation options that has been identified through the MCA process.

8.8.1 **Past examples**

House raising has been used effectively in a number of flood affected regions of NSW (e.g. Lismore, Maclean, Fairfield) and Queensland (e.g. Brisbane).

8.8.2 **Advantages & disadvantages**

The advantages and disadvantages of housing raising are summarised in Table 8-22.

<table>
<thead>
<tr>
<th>Table 8-22</th>
<th>Advantages and disadvantages of housing raising</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td>House Raising</td>
<td>-Reduction in tangible and intangible costs;</td>
</tr>
<tr>
<td></td>
<td>-Reduced risk to personal safety;</td>
</tr>
<tr>
<td></td>
<td>-Potential reduction in insurance premiums;</td>
</tr>
<tr>
<td></td>
<td>-Improved re-sale value of property;</td>
</tr>
<tr>
<td></td>
<td>-Isolation of house during a flood;</td>
</tr>
<tr>
<td></td>
<td>-Resistance of owners to evacuate;</td>
</tr>
<tr>
<td></td>
<td>-Occupation of the space beneath a raised house and associated increase in damage cost potential.</td>
</tr>
</tbody>
</table>

8.8.3 **Number of properties inundated**

Table 8-23 indicates the number of buildings inundated for a range of floods with different frequencies of occurrence.

<table>
<thead>
<tr>
<th>Table 8-23</th>
<th>Number of buildings inundated above floor level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency of Flood Event</strong></td>
<td><strong>Number of Slab on Ground Buildings</strong></td>
</tr>
<tr>
<td>20 year ARI flood or more frequent</td>
<td>157</td>
</tr>
<tr>
<td>Between 20 year ARI and 50 year ARI flood</td>
<td>643</td>
</tr>
<tr>
<td>Between 50 year ARI and 100 year ARI flood</td>
<td>725</td>
</tr>
</tbody>
</table>
8.8.4 Costs

The cost associated with raising a house depends on the type of dwelling and construction material. The cost of raising a typical highset ‘Queenslander’ style of dwelling is in the order of $60,000 while the cost of raising a fully brick slab on ground dwelling is significantly greater.

Table 8-24 provides an estimate of the cost to raise all of the high-set (“Queenslander”) residential buildings that experience above floor flooding for a range of flood events.

**Table 8-24 Indicative cost of house raising**

<table>
<thead>
<tr>
<th>Frequency of Flood Event</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 year ARI flood or more frequent</td>
<td>$62,940,000</td>
</tr>
<tr>
<td>50 year ARI flood or more frequent</td>
<td>$89,100,000</td>
</tr>
<tr>
<td>100 year ARI flood or more frequent</td>
<td>$183,060,000</td>
</tr>
</tbody>
</table>

8.8.5 Eligibility criteria

Due to the large number of properties that experience above floor flooding during large flood events, it is may not be economically viable to implement a house raising scheme for all affected dwellings. As a result, a set of eligibility criteria is required to identify dwellings most suited to house raising. It is recommended that this criteria be developed by Council if this scheme is taken forward. The eligibility criteria might include, for example:

- Probability of flooding (i.e. provide housing raising assistance to more frequently flooded dwellings);
- Depth of above floor flooding in a given flood event;
- Severity of flood hazard (i.e. provide housing raising assistance to properties located in higher hazard areas);
- Type of property (e.g. slab on ground or highset); and
- Type of construction material (e.g. wood or brick).
8.9 Bartholdt Drive alternative evacuation route

As discussed in Section 6.4.4, BRC requested that GHD include an additional evacuation route option. This project was developed independently by BRC and has been included in this report for consideration by decision makers.

8.9.1 Existing flood immunity & affected communities

The existing immunity of the Branyan Drive crossing of McCoys Creek and the communities affected by road closure are summarised below (Table 8-25 and Table 8-26).

Table 8-25 McCoys Creek crossing immunity to Burnett River flooding

<table>
<thead>
<tr>
<th>Crossing</th>
<th>Affected communities</th>
<th>Estimated population</th>
<th>Current flood immunity (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Branyan Drive at McCoys Creek</td>
<td>Residents in Branyan off Branyan Drive, Barthold Drive, Arcadia Drive and surrounding local roads</td>
<td>460 houses &amp; 1150 people</td>
<td>5% AEP</td>
</tr>
</tbody>
</table>

Table 8-26 McCoys Creek crossing flood levels

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Existing deck level (approximate)</th>
<th>10% AEP flood level</th>
<th>5% AEP flood level</th>
<th>2% AEP flood level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Branyan Drive at McCoys Creek</td>
<td>9.8 m AHD</td>
<td>7.3 m AHD</td>
<td>9.4 m AHD</td>
<td>11.5 m AHD</td>
</tr>
</tbody>
</table>

8.9.2 Project description and cost estimate

BRC developed a conceptual design and cost estimate for the project. The works involve the construction of approximately 630 m of a new 7 m wide road within an existing unformed road reserve, along with associated earthworks and drainage. BRC estimates the total cost of the project to be approximately $1.4M.

The new route via Bartholdt Drive would remain flood-free in the PMF event. This project would provide a substantial benefit to a relatively large population.
9. Conclusion and Recommendations

BRC and GHD are currently undertaking a comprehensive Floodplain Risk Management Study to assess the nature of flood risk across the lower Burnett River catchment, and identify a wide range of potential flood management measures. This Flood Mitigation Options Assessment report forms part of the overall study, and focuses on large-scale flood mitigation projects.

This report has provided an overview of the process undertaken to engage with the community, identify a wide range of potential large-scale flood mitigation options, filter those options through a multi-criteria analysis and then undertake further investigations on a number of selected options that appeared most favourable on initial review.

The detailed assessment of the set of selected conceptual flood mitigation options as presented in Section 8 provides a sound basis for decision making. The options presented in Section 9.1 represent large-scale flood mitigation strategies that, subject to further investigation, consultation and design, could be implemented to help reduce the impact of large floods on communities along the Burnett River.

Several of the options that appeared viable following the initial MCA process (based on high-level assumptions about the nature and extent of works) proved to be problematic or ineffective following detailed assessment. A discussion of these options is provided in Section 9.3.

9.1 Recommended large-scale flood mitigation options

9.1.1 East levee and floodgate

The east levee and floodgate proposal has emerged from detailed assessment as the most viable levee project for the Bundaberg area. While the estimated outright costs of this option ($71M capital works) are substantial, a preliminary assessment of the benefits (reduction in tangible flood damage) is favourable. An estimated total of 741 properties would have a greatly reduced risk of experiencing above floor flooding in a 1% AEP event if the levee were constructed. With a benefit-cost ratio of 0.77, this option warrants further consideration. If this option is to be taken forward, a geotechnical assessment and a local flood assessment should be undertaken to underpin the preliminary design.

9.1.2 Millaquin bend widening works

Widening the river at Millaquin bend appears favourable following detailed assessment despite the substantial estimated costs ($32.1M capital works and $2.1M/yr on-going maintenance). Benefits in terms of reduced flood levels are experienced across Bundaberg, including areas on both the south and north sides of the river. An estimated total of 436 properties would have a greatly reduced risk of experiencing above floor flooding in a 1% AEP event if the works were constructed. The overall benefit-cost ratio of 0.50 justifies further consideration of this proposal. Further detailed design iteration and optimisation would follow the completion of geotechnical and environmental surveys.

9.1.3 Funding for house raising

This proposal is a potentially beneficial flood mitigation scheme. BRC should consider the selection of eligibility criteria so that any funds made available for this scheme maximise the benefit to the community in terms of both equity and flood damage reductions.

9.1.4 Perry River Bridge upgrade

The construction of a new Perry River Bridge 8 m higher than the existing bridge would bring this crossing up to an equivalent flood immunity standard to the St Agnes Creek Bridge. The
upgrading of this crossing at an estimated cost of $17.3M would be the most effective means of improving the evacuation capabilities and general access to the Good Night and Morganville communities in the event of a flood.

As an alternative to the Perry River Bridge upgrade, an evacuation route may be available through the Goodnight Scrub National Park and along Kalliwa Road to Gayndah-Mount Perry Road. This option would require additional investigation to determine the existing flood immunity to the Perry River and other creek flood sources, but at a minimum would require raising of the earth embankment over Mingham Creek to above Paradise Dam backwater levels. Based on further investigations, this option may prove to be a more cost effective solution than the Perry River Bridge upgrade. Either the bridge upgrade or the alternative evacuation route would service an estimated population of 400 – 600.

9.1.5 Pine Creek, Givelda and Electra alternate evacuation routes

For a total estimated cost of approximately $1M plus on-going yearly maintenance, an alternate 4WD evacuation route could be secured for the Pine Creek, Givelda and Electra communities.

9.1.6 Hinkler Avenue upgrade

While the estimated costs of this upgraded are substantial ($104M capital works), the establishment of a reliable connection between the north and south sides of the Burnett River at Bundaberg warrants further consideration as part of strategic emergency management planning activities. The benefits of this route are substantial and include improved evacuation access to established recovery facilities on the south side of the river and improved emergency access to the north side of the river.

9.1.7 Mount Perry Rd & Fairymead Rd upgrades

The raising of Mount Perry Rd & Fairymead Rd to provide more reliable flood evacuation routes at an estimated upfront cost of $7.4M would also deliver substantial benefits to the community.

9.1.8 Bartholdt Drive alternative evacuation route

Upgrading Bartholdt Drive would provide a high immunity (i.e. above the PMF level) evacuation route servicing an approximate population of 1150 for an estimated cost of $1.4M.

9.1.9 Combined flood mitigation schemes

The scope and timeframe of this current study has limited the assessment of the ways in which individual flood mitigation strategies could be beneficially combined. On the basis of limited information, it is recommended that the potential benefits of the following combined mitigation strategies be investigated further:

- East levee and Millaquin bend works – These two projects could be combined to provide flood mitigation benefits to communities on both the north and south sides of the river. The lowering of river flood levels afforded by the bend widening works could either reduce the height and expense of the East levee or reduce the frequency of the East levee overtopping event.

- Low level North levee or North levee and Millaquin bend works – Further investigations may reveal that the Millaquin bend works may help to alleviate some of the adverse impacts associated with the construction of levees on the north side of the river.

- Low level North levee or North levee and Gardens channel works – Further investigations may reveal that the Gardens channel works may help to alleviate some of the adverse impacts associated with the construction of levees on the north side of the river.
9.2 Other recommendations for flood management measures

As part of the continuing work on the FRMS over the coming months, BRC and GHD will examine a wide range of flood management measures in addition to the large-scale mitigation options considered in this preliminary report. These other measures will nonetheless require a commitment of funds. The below list of flood management measures is provided for the purposes of flagging the possible recommendations of the FRMS. These initiatives have been developed based on community consultation and feedback, and are currently being explored by BRC and GHD. If implemented, these measures would form part of a comprehensive flood risk management strategy and provide substantial value to the community. As a guide, it is anticipated that all of the below measures could be implemented for less than $2.5M.

- Ongoing funding for Flood Resilience Officers over the next 5 years. BRC currently has two officers temporarily funded who network amongst community groups and could educate the community on flood risk once the FRMS is complete.
- Implementation of physical flood markers as public art. These could function as meeting points during disasters for disseminating information, evacuation points and could help educate the community on probable and historical flood risk;
- Flood Education / Notice Boards with electronic message boards for direct communications to at risk communities during event. These boards could also be a designated place for BRC’s “meeting trees”, provide central points for community members to source direct and dedicated information regarding flood risk and could be placed close to the flood markers for community education in non-flood times. Display messages might include current or predicted upstream gauge readings and inundation alerts for local communities. These sites could also be meeting places for emergency radio networks (UHF/VHF) that Council has established with SES groups;
- Improve the understanding of storm surge, tsunami and coincident flood events with the Burnett River;
- Implement a Disaster Management Portal making flood risk data easy to interpret and practical for use during events by disaster management personnel.
- Include evacuation routes into Council’s flood gauge mapping system with “time to closure”;
- Direct mail outs for community education campaigns based on flood risk, including detailed flood information for their property and Get Ready campaign material;
- Physically marking evacuation route zones for each property. This could include a colour coding system for wheelie bin lids, electricity poles, street signs and road pavement/footpath markings. Develop public signage at key locations on evacuation routes at locations which aren’t alarming or threatening to the community;
- Implement CCTV cameras at key points on river for boats coming and going to improve situational awareness and allow commercial and recreational boat users to better understand conditions;
- Additional rain gauges on tributaries of the Lower Burnett;
- Mapping of overland flow paths for tributaries leading to the Burnett River to assist refinement of evacuation routes;
- Work with the Bureau of Meteorology to integrate flood warnings to flood gauge mapping and improve early warning predictions for Paradise Dam;
- Further improve the BoM Enviromon base station to improve data interpretation (i.e. assess IFD curves against actual rainfall to better quantify risks).
9.3 Options not currently considered viable

In addition to the projects not considered viable upon initial consideration (refer to Section 6.5) and following the MCA process (refer to Section 7.6), several of the options taken forward for detailed assessment proved to be problematic or ineffective as flood mitigation measures. Based on the assessment undertaken to date, these options are not recommended.

9.3.1 Other levees

Both the North levee (option 1) and the low levee North levees (option 10) were selected for detailed assessment based on their potential to protect parts of the severely flood affected North Bundaberg area. Of all the various levees considered for the North Bundaberg area, these two proposals were considered the most viable. Following conceptual design and further hydraulic assessment across the full range of design flood events, it is seen that the downsides to these options outweigh any potential benefits. Adverse flood level impacts outside of the levees, as well as the potential for increased flood levels behind the levees when they are overtopped, means that on balance they do not represent viable flood mitigation schemes.

9.3.2 Dredging

An initial assessment of dredging the Burnett River was undertaken for the following scenarios:

- Dredging the river from the Burnett River mouth to Ben Anderson Barrage; and
- Dredging targeted sections of the Burnett River only.

Based on an assessment of hydraulic, social, environmental and economic factors, dredging the river from the mouth to the Ben Anderson Barrage was found by GHD, Council and the CRG to not be a viable flood mitigation option. The potential benefits of such a proposal in terms of flood level reduction was not compatible with the extremely high costs and volumes of spoil, especially when compared to other selective dredging options.

A hydraulic assessment of selective dredging of certain sections of the river indicated that this option could effectively reduce nearby flood levels. However, based on further detailed assessment, it is seen that the ability to dredge the river in critical locations is severely limited by the depth, width and steepness of the existing river banks. In the absence of detailed geotechnical information, assumptions on maximum stable dredge batter slopes restrict the amount of material that could be dredged from critical locations such as Millaquin bend. While it is possible to dredge the wider, shallower sections of the river upstream of the town reach bridges, the hydraulic assessment has shown that such works do not result in substantial flood level reductions.

Any further consideration of dredging as a flood mitigation measure would have to be based on a favourable geotechnical assessment that supports steep dredge batter slopes while not impacting on bank stability.

9.3.3 Other bridge upgrades

Of the various bridges upgrades initially considered, the Pine Creek Bridge and the Cherry Creek Bridge upgrades are not considered viable in light of the available alternate evacuation route.

The St Agnes Creek Bridge already has a higher degree of flood immunity than other bridges in the area, and raising the bridge further would be considered impractical. The Perry River Bridge upgrade discussed in Section 9.1.3 would nonetheless significantly improve evacuation and access capabilities for the Good Night and Morganville communities.
9.3.4 Other road upgrades

Of the various North Bundaberg evacuation route upgrades taken forward for detailed consideration, the Batchler’s Rd option is not considered a viable option unless problems emerge for the Mount Perry Rd route.