Cobden Lagoon and Range Creek flood management review

Prepared for West Coast Regional Council

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Executive summary

The Grey River stopbanks have been effective at protecting Cobden from direct flooding by the Grey River, resulting in significant reductions in flood frequency and depth. However, Range Creek and Cobden Lagoon cause regular flooding to the low-lying parts of Cobden on the north side of the Grey stopbanks. This report assesses the causes of flood risk and potential management options for this area. To inform this assessment various data were analysed including LiDAR-derived topography, aerial imagery and stormwater network GIS data, and water level records. A site visit was undertaken on 2 May 2017, and previous relevant studies were reviewed.

Flooding from Cobden Lagoon occurs when lagoon inflows exceed outflows, particularly when the lagoon level is already high. The inflows come from Range Creek and, at times, from storm water overflow/backflow. Outflows from the lagoon are via a culvert to the Grey River or a channel cut to the beach. The outflow to the Grey River gets shut off when the river is in flood, while the cut to the beach must be opened manually which is problematic at high tide and high waves.

Given the modest number of properties at risk, that raised floor levels already provide an effective means of minimising the impacts of flooding, and the need to fund any flood risk management activities through local rates, there is a need to identify cost effective solutions. Bearing this in mind, the following actions are recommended:

- Optimised operation of the culvert flood gate enabled by improvements to the gate flap valve and/or telemetry of downstream water level.
- Strict use of planning controls to minimise exposure to flooding.
- Continued maintenance of the cut from Cobden Lagoon to the beach to allow it to be opened to alleviate severe flooding (even though it is ineffective for frequent smaller events).
- Installing a bund between the lagoon and the most vulnerable houses to mitigate small frequent floods.

Sea level rise will increase flood frequency and severity in the future by increasing the frequency and duration with which the flood gate on the Cobden Lagoon outlet culvert needs to be closed, increasing the frequency with which lagoon ponding flooding occurs. All flood mitigation and planning should consider this changing risk.

1 Introduction

1.1 Background

Range Creek drains into Cobden Lagoon, a small low-lying coastal lagoon behind the Grey River stopbanks on the north side of the Grey River (Figure 1-1). The Grey River stopbanks, which were installed following major flooding in 1988, have been very effective at mitigating flooding in Cobden from the Grey River. However, Range Creek and Cobden Lagoon cause regular flooding to the lowest-lying parts of Cobden behind the stopbanks.

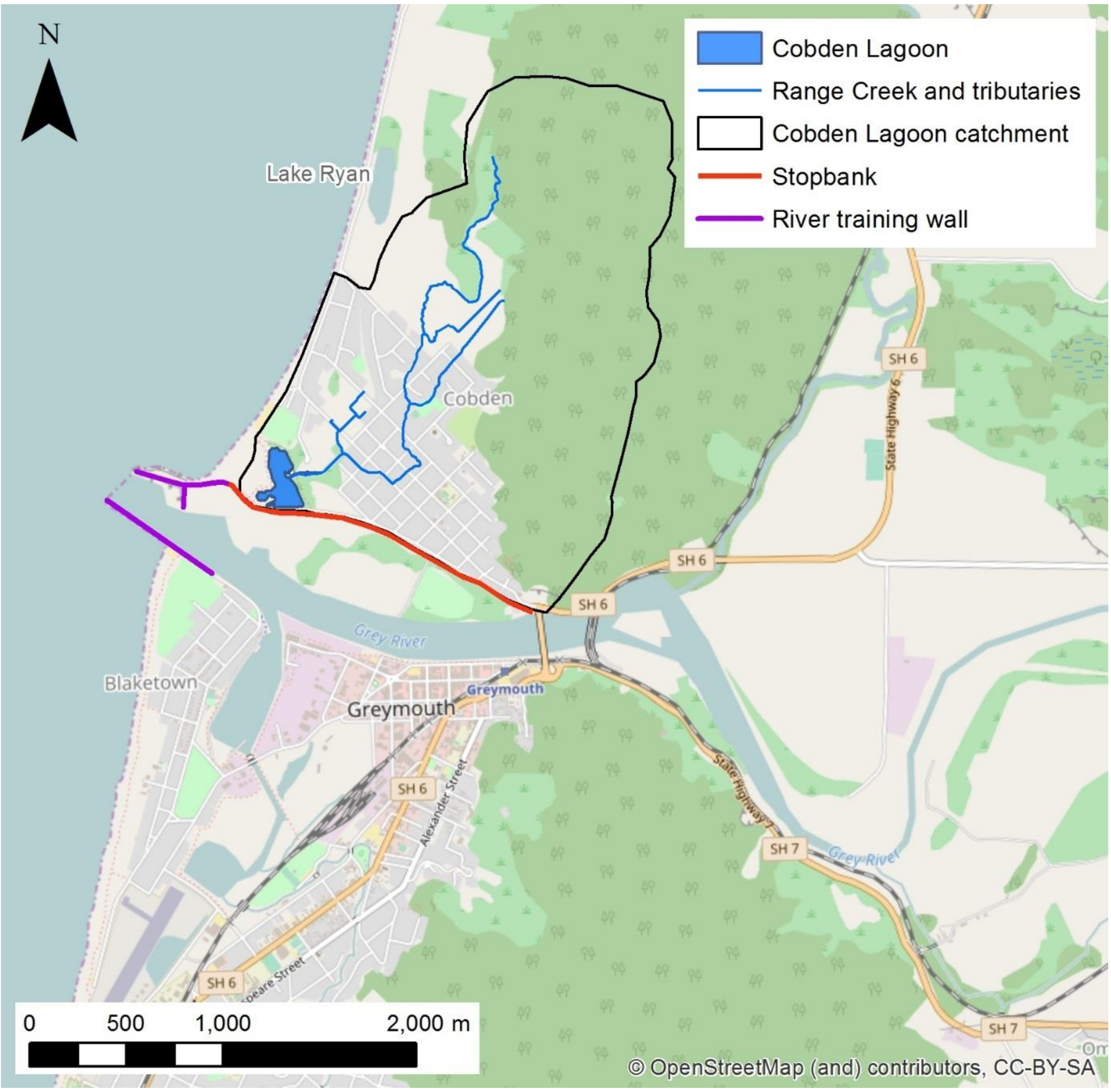

Figure 1-1: Overview map showing locations of key features described in the text. Note that only the stopbanks relevant to Cobden have been marked, other stopbanks are excluded for clarity.

West Coast Regional Council requested advice from NIWA regarding flood risk from Cobden Lagoon and Range Creek, and options for management.

1.2 Previous studies

There are several existing reports relevant to understanding flooding from Cobden Lagoon and Range Creek:

- **Cobden Lagoon / Range Creek Flood Mitigation Investigations** (Gardner 2013) – This report is very valuable to understanding flood risk from Cobden Lagoon and Range Creek. It describes a modelling study to investigate flood risk and potential mitigation options. The creek and lagoon are modelled downstream of Bright Street. An update to this report (Gardner 2016) was carried out to include LiDAR data in the analysis.

- **Cobden Lagoon – Range Creek Flood Protection** (Hall 2012) – This report describes an earlier investigation into flood management which included 1D modelling of Range Creek.

- **Changes to Tidal (Range) Creek, Cobden Domain, 1928 – '29** (Trayes 2014) – This report describes the history of Range Creek and Cobden Lagoon.

- **Tidal and flood influence on water level in Grey Lagoon** (Plew 2011) – This report describes an analysis of different factors affecting water level on the downstream side of the lagoon outlet culvert. It is relevant as these water level conditions have a controlling influence on the lagoon and are important to consider for operation of the culvert floodgate.

- **Grey River flood modelling** (CHFM 2002) – This report describes modelling of flood levels in the Grey River outside the Cobden stopbanks.

1.3 Scope of this investigation

This investigation has intentionally avoided re-visiting the analyses described in these previous studies; instead, it focusses on additional analysis to better understand the flooding mechanisms and inform low cost, practical solutions for flood mitigation.

To assess flooding mechanisms and the options for mitigation, the following activities have been undertaken:

- Review of previous studies.

- Site inspection of the Grey River stopbank, Cobden Lagoon, Range Creek and the areas of Cobden at risk of flooding (inspection undertaken on 2 May 2017).

- Analysis of LiDAR topographic data, other GIS data including aerial imagery and stormwater network data, and water level records.

Rather than describe these activities separately, this report presents the finding as they relate to flooding mechanisms and factors affecting flooding (Section 2) and potential mitigation (Section 3), before summarising recommendations and conclusions (Section 4).

All elevation data used in this report is reduced to Lyttelton Vertical Datum 1937 (LVD). A description of datum conversions applied is given in Appendix A.

2 Flooding mechanisms and factors affecting flooding

2.1 Flooding from Cobden Lagoon

There appear to be two main flooding mechanisms: ponding from Cobden Lagoon and overflow from Range Creek. Ponding flooding from Cobden Lagoon is the most frequent cause of flooding. Ponding flooding occurs when high levels in the lagoon inundate the lowest lying land adjacent to the lagoon.

Flooding by ponding occurs when lagoon inflows exceed outflows, particularly when the lagoon level is already high. The inflows come from Range Creek and, at times, from storm water overflow/backflow. Outflows from the lagoon are via a culvert to the Grey River or a channel cut to the beach (Figure 2-1). The outflow to the Grey River gets shut off when the river is in flood, while the cut to the beach must be opened manually which is problematic at high tide and high waves. Operation of the culvert and cut is discussed further in Section 2.4.

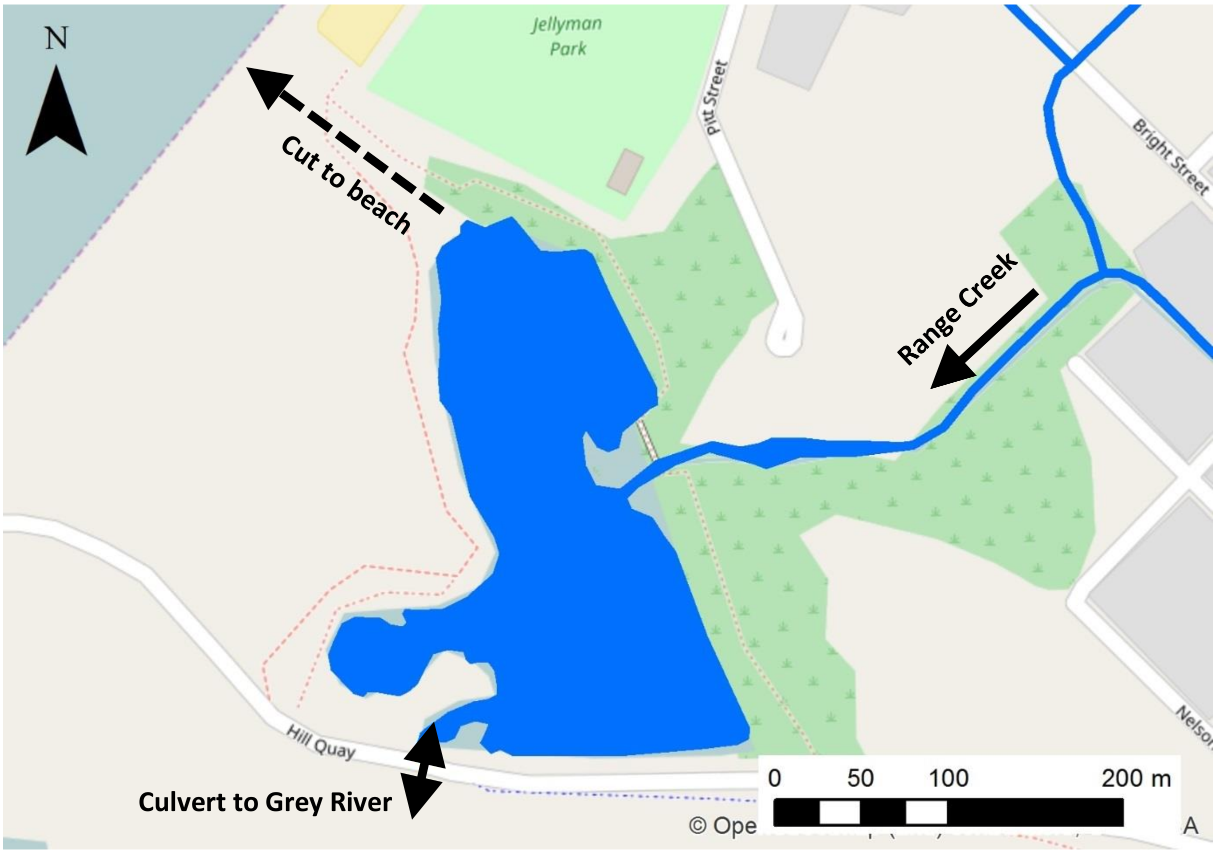

Figure 2-1: Schematic of Cobden Lagoon inflows and outflows.

Using the LiDAR data, we can calculate the relationship between water level and volume as shown in Figure 2-2. Mapping the LiDAR data for elevations likely to be affected by flooding from the lagoon clearly identifies the areas at risk (Figure 2-3).

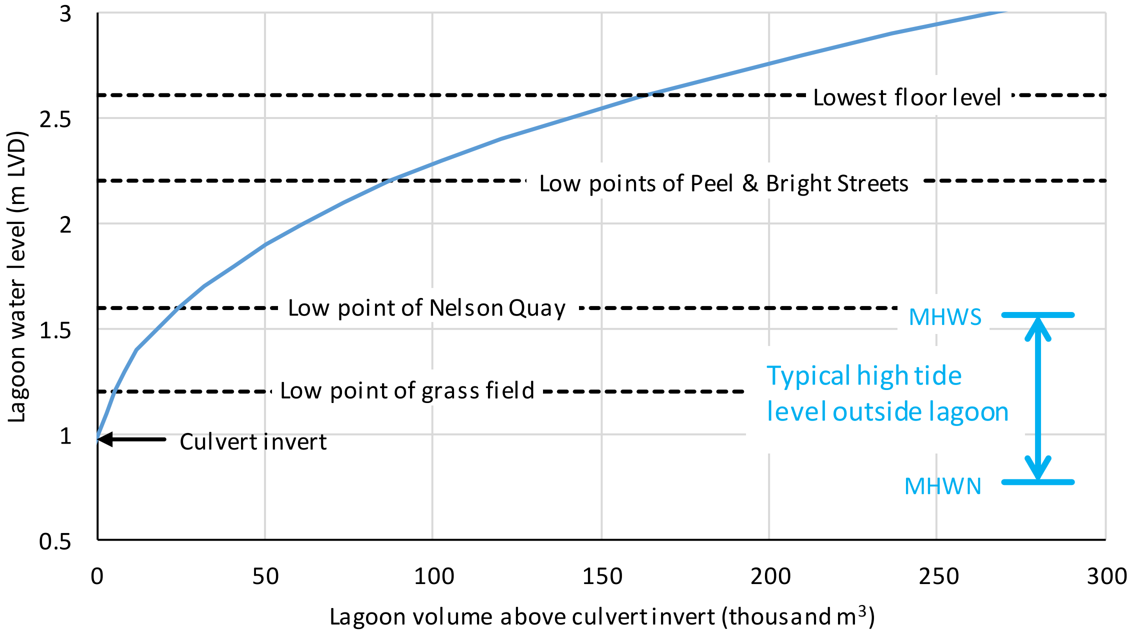

Figure 2-2: Cobden Lagoon water level - volume relationship with key levels marked. Level-volume relationship and marked street levels as calculated from LiDAR data; floor level data is from property surveys. Culvert elevation and tidal range are less certain due to difficulties obtaining accurate datum offsets. The LiDAR data only provides the above-water topography so the level/volume relationship shown in the figure is based on assumed bathymetry below 1.3 m LVD (lagoon water level at the time of LiDAR data collection).

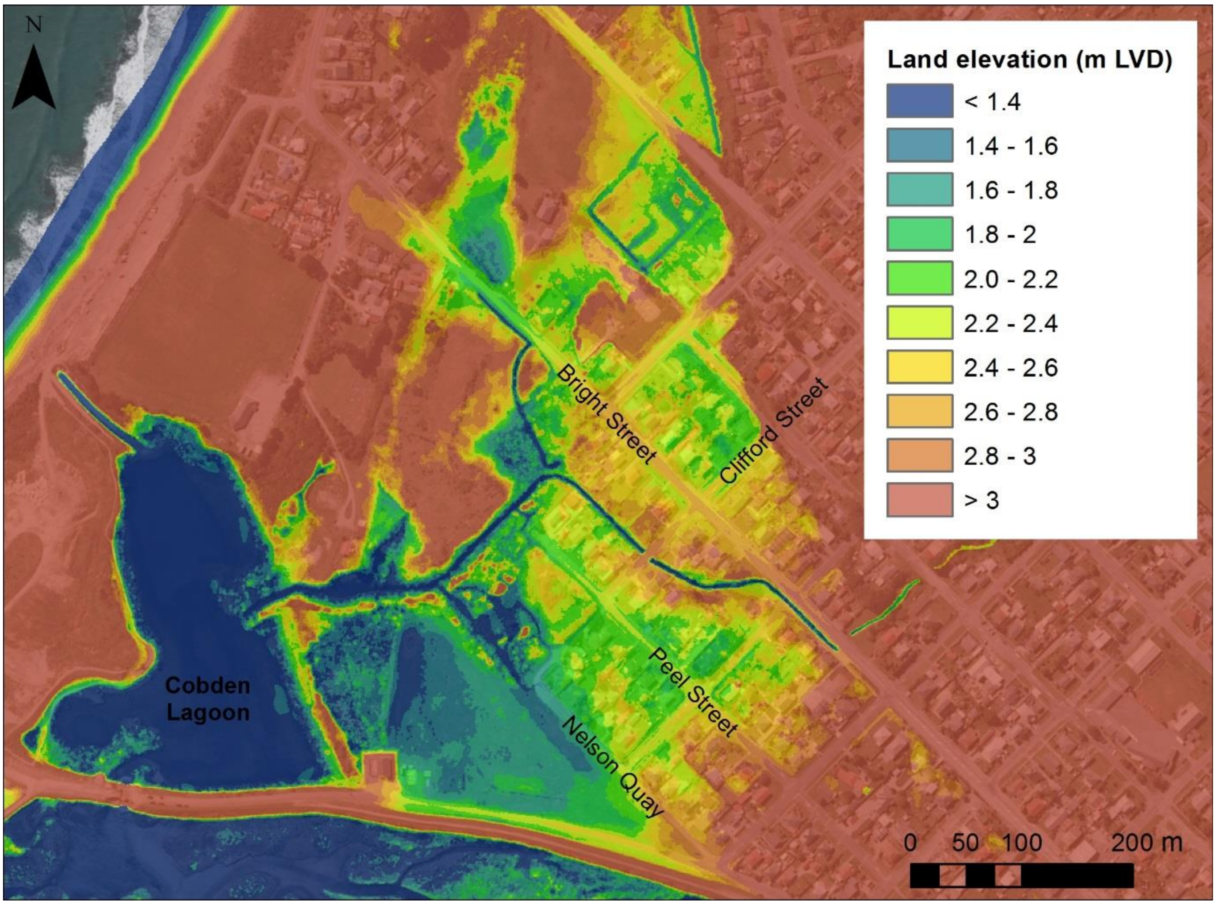

Figure 2-3: Map of ground elevation for low lying areas around Cobden Lagoon. Map shows LiDAR derived bare earth digital elevation model (vegetation and buildings removed) with aerial imagery in background.

Floor level information for some properties is available from a 2009 survey (supplied by WCRC for this analysis, original source unknown). This information shows the lowest house floor level to be 2.61 m LVD and the lowest garage floor level to be 2.08 m LVD. In general, floor levels are raised 0.5 m to 1.0 m above surrounding ground levels (e.g., Figure 2-4). Raised floor levels are a very effective means of mitigating the impacts of flooding. Due to the extent of flat low-lying ground a much greater volume of water is required to cause flooding of buildings than to inundate the land around the lowest lying buildings. Flooding of Nelson Quay road surface and the surrounding sections requires a lagoon volume (above the culvert invert) of 24,000 m^3, but 71,000 m^3 is required to cause flooding of garages, and 163,000 m^3 to cause flooding of houses (Figure 2-2). Whilst the frequent flooding of the lowest lying areas likely causes significant inconvenience and stress to residents whose land and access is impacted, raised floor levels mean damage to buildings and their contents is much less frequent.

The volume of water in the lagoon is influenced by inflows to the lagoon and outflows from the lagoon. Lagoon inflow hydrographs from Range Creek for different return period storms were estimated by Gardner (2013). Based on these hydrographs it is possible to calculate inflow volumes as shown in Figure 2-5. During a mean annual flood in Range Creek the volume of water delivered in six hours is ~88,000 m^3. This is sufficient to fill the lagoon from the level of the culvert invert to 2.2 m LVD (Figure 2-2), high enough to submerge Nelson Quay 0.6 m deep (Figure 2-4).

Figure 2-4: View eastwards from the north-western end of Nelson Quay. Raised floor levels and low level of road marked (from LiDAR) in red..

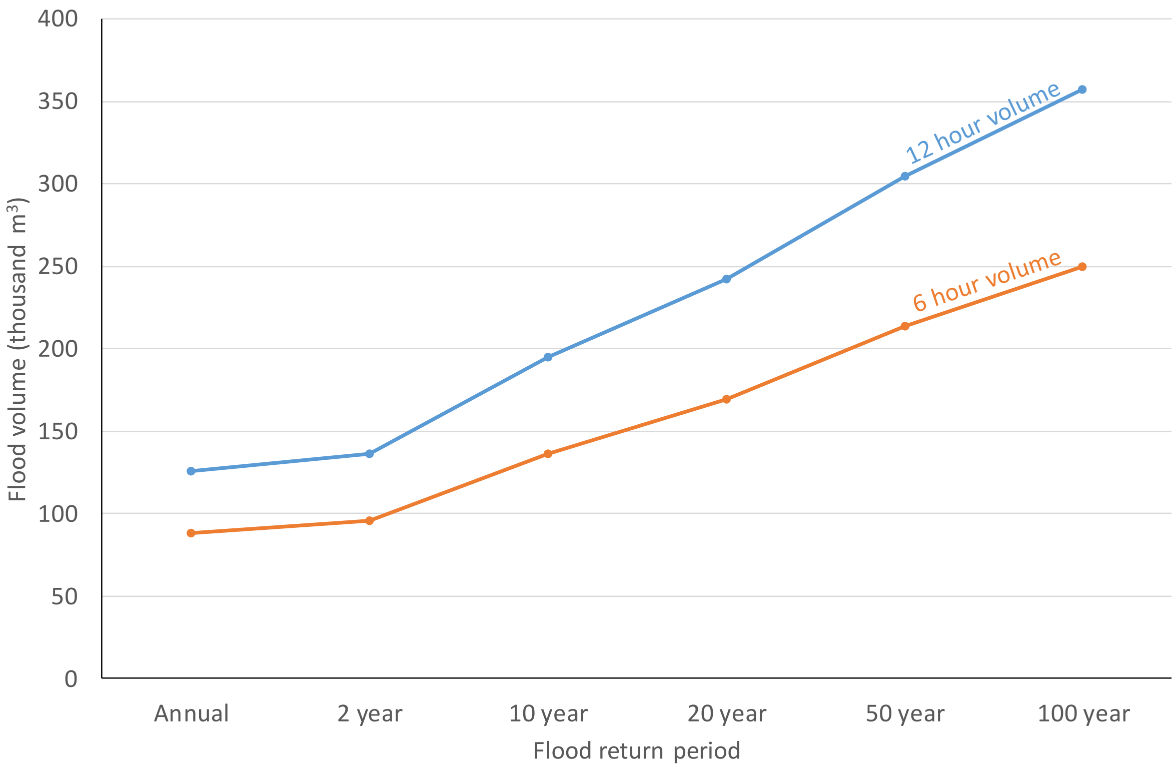

Figure 2-5: Range Creek flood return period vs flood volume. Calculated from flood hydrographs developed by Gardner (2013).

West Coast Regional Council has operated a water level recorder in Cobden Lagoon since January 2012. This provides a valuable record of lagoon behaviour enabling us to better measure the frequency of ponding flooding and understand its causes. During the five years of lagoon level data which was examined for this study (January 2012 to May 2017 with some missing data), there were 15 events with water levels exceeding 1.8 m LVD, 2 events exceeding 2.0 m LVD and the largest event peaked at 2.28 m LVD (Figure 2-6 shows events per year for the 5-year period).

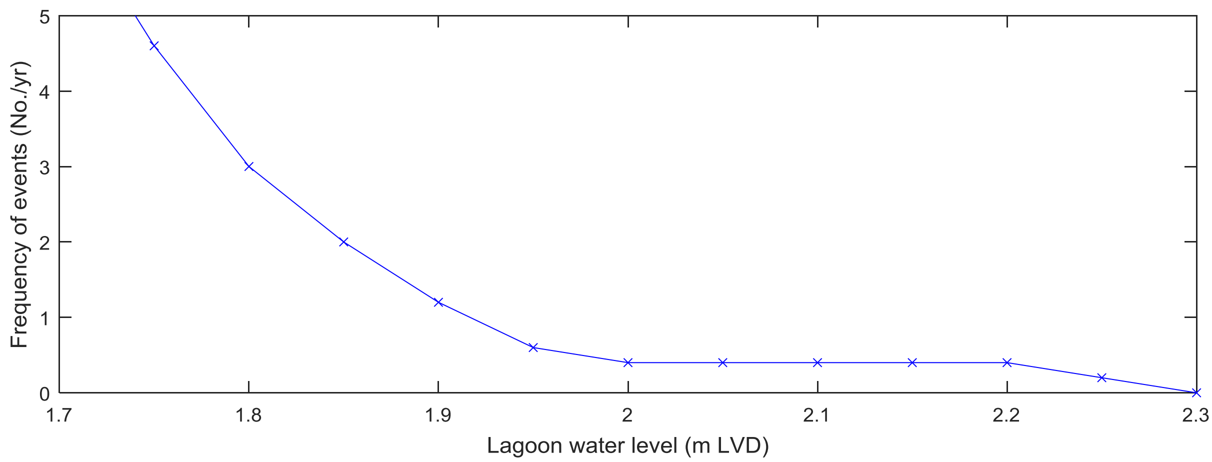

Figure 2-6: Cumulative frequency of high water level events in Cobden Lagoon. Observed frequency of events exceeding each level calculated from water level monitoring data (January 2012 to May 2017).

2.2 Flooding from Range Creek

Modelling the lower reaches of Range Creek downstream of Bridge Street identified that flooding directly from the creek was also possible (Gardner 2013). A profile of Range Creek is shown in Figure

2-7. At the base of the hills is an elevated terrace, approximately 5 m higher than the lower reaches of the catchment (e.g., seaward from Bright Street). The creek initially flows in a shallow channel across grassy paddocks on the upper part of the terrace but then in its middle reaches the channel becomes much larger as it cuts down into the upper terrace and drops towards the low-lying land near the lagoon. There are two significant tributaries which join the main stem in the middle, incised reaches of the creek. After the creek emerges from the terrace, between Fox Street and Bright Street, it flows in a shallow, low gradient channel for a further 700 m to Cobden Lagoon.

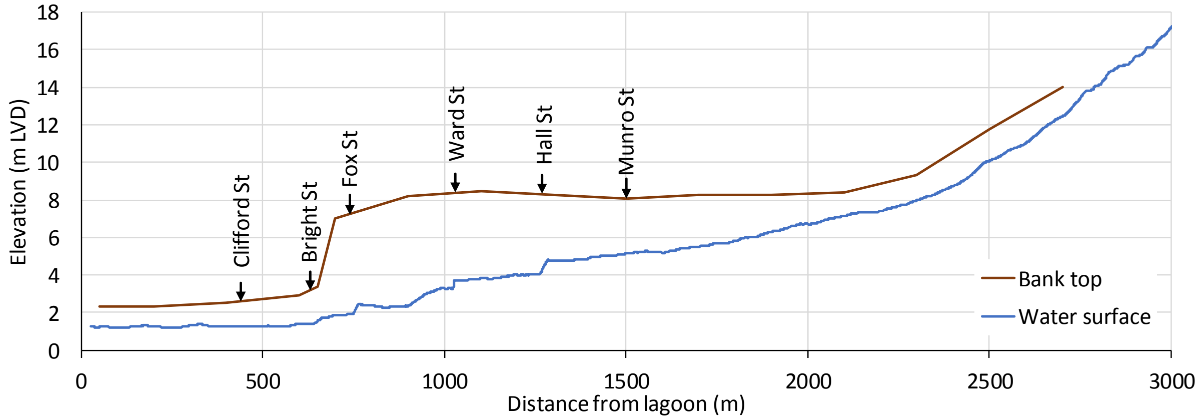

Figure 2-7: Profile of Range Creek. Water surface and bank top elevation derived from LiDAR.

The middle reaches of Range Creek have very low flood risk due to the oversized, incised channel. The incised channel also provides very little storage so it rapidly conveys all flood flows to the lower terrace. Once on the lower terrace the creek gradient is much lower and modelling showed that during flood events the creek can overtop and flow overland towards the lagoon (Gardner 2013). However, the modelling also showed that this flooding mechanism generally resulted in shallower flooding than that caused by ponding of Cobden Lagoon. Any flooding from Range Creek is not likely to be deep enough to cause flooding of buildings (due to raised floor levels) and is likely to be of relatively short duration, so any impacts associated with flooding of roads or sections is likely to be minimised.

2.3 Stormwater drainage

Figure 2-8 shows land used in the Cobden Lagoon catchment. The upper part of Cobden Lagoon's catchment rises to 300 m in the steep, bush-clad hills of the Rapahoe Range. At the base of the hills there is some grassland around the upper part of Range Creek but the rest of the basin between the hills and the lagoon is urbanised with an engineered stormwater drainage network of pipes and channels (catchment land use shown in Figure 2-8). The catchment draining directly to the lagoon has an area of 271 ha. However, much of the urban area, as well as the whole of the south-east part of Cobden (an additional 109 ha), drains into a piped networks.

Cobden has a combined sewer system for urban areas that drains both stormwater and wastewater. This system has overflows so that during rain events when the treatment system and pipe network would be overloaded the system discharges directly to the Grey River (through flap valves to prevent reverse flow). Grey District Council (GDC) have recently installed a separate foul sewer system and homeowners are in the process switching over to the new system. Once this is complete the old system will be for stormwater only. During periods of high river levels in the Grey River flap valves on the downstream end of the stormwater network close to prevent backflow. Once this happens the stormwater pipe network backs up. GDC operates pumping stations when this happens to allow the continued discharge of water from the system. However, overland flow to Cobden Lagoon is likely during high intensity rainfall that exceeds the design capacity for the stormwater pipes or the stormwater pumps if the flap valves are closed.

The small natural channels which drain the hill slopes above the south-eastern part of Cobden run into pipes (separate from the stormwater and foul sewer systems) which take them directly to the Grey River. Although there are flap valves on the end of these pipes they are understood to drain relatively freely even when Grey River levels are high. This can happen because the pipes are sealed and their entrances are higher than the river water level.

Overall it is unclear exactly how much flow the stormwater network contributes to Cobden Lagoon under different conditions of rain intensity and Grey River level. It is likely that the contribution is small under normal conditions but during high intensity rainfall over Cobden it may be quite significant.

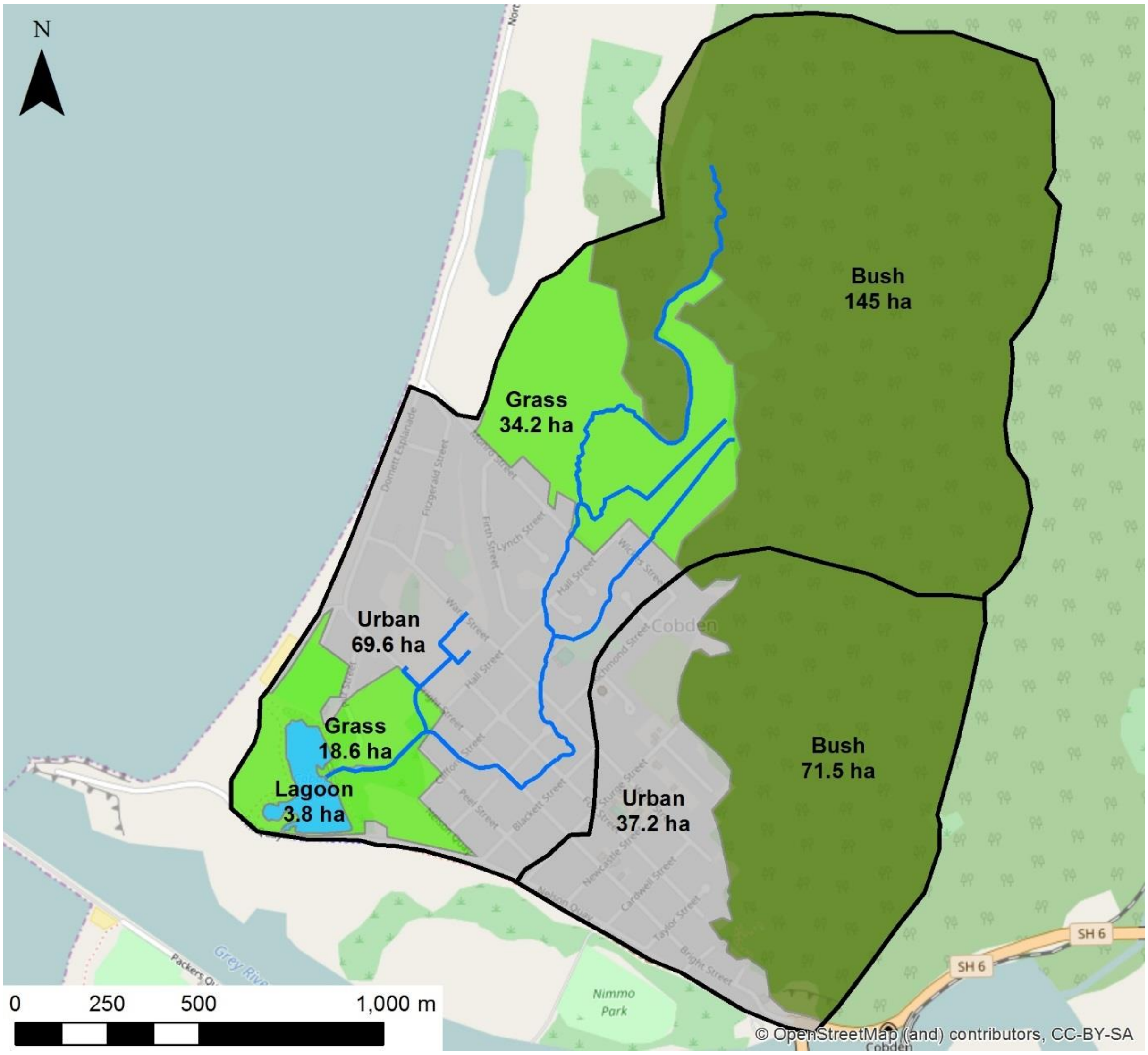

Figure 2-8: Cobden Lagoon catchment and land use. The main catchment, outlined in black with river channels marked in blue, drains via Range Creek or directly to the lagoon. The south-eastern part of the catchment, in separate black outline, does not connect directly to Range Creek but likely connects indirectly

if/when the pipe network is overwhelmed (the position of the divide between the Range Creek and south eastern catchments is approximate).

2.4 Lagoon outlets and Grey River floods

Stopbanks provide effective protection to Cobden from Grey River floods, which otherwise could cause flooding up to levels exceeding 4 m LVD (CHFM 2002). The only permanent outlet from Cobden Lagoon is through a 2 m by 1 m rectangular box culvert under the stopbanks to the tidal reach of the Grey River near its mouth. The invert of the culvert is at 0.97 m LVD (see Appendix A). During spring-tides, flow through the culvert reverses at high tide when tidal levels in the Grey River rise above the culvert invert. This allows salt water into the lagoon on these occasions, maintaining a brackish environment. During extremely high tides this reverse flow can be sufficient to raise the lagoon to the level where flooding occurs (Figure 2-9).

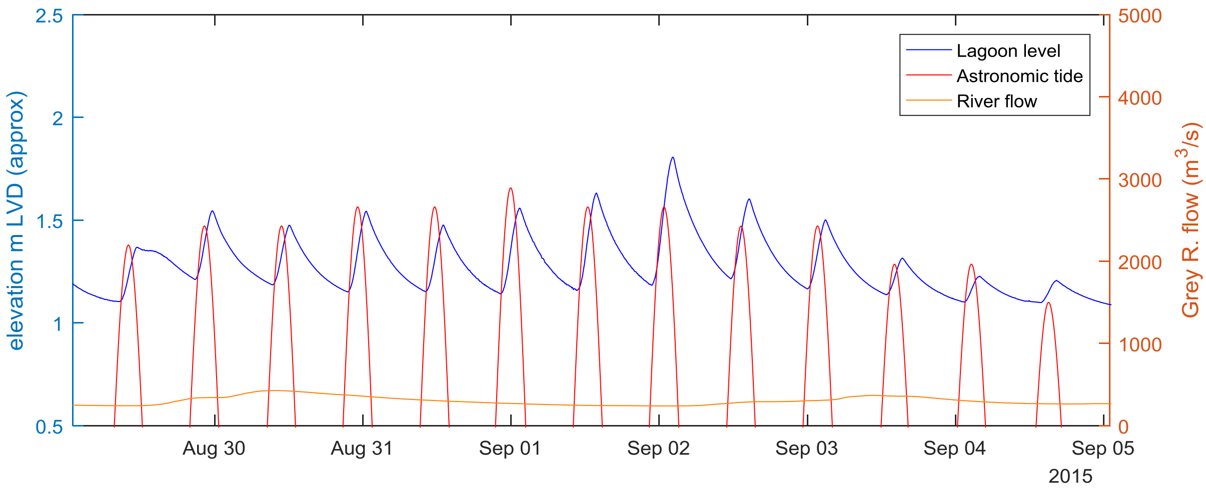

Figure 2-9: Lagoon level, tide level and river flow for 29 August to 5 September 2015, a period of high lagoon levels peaking at 1.8 m LVD on 2 September 2015. Plots show lagoon level from WCRC level recorder (blue, left axis), tide from LINZ tide table (red, left axis), and river flow from NIWA Grey River at Dobson flow recorder (orange, right axis). The Grey River flow data has been time lagged by 90 mins to account for travel time from flow recorder to lagoon (Plew 2011). It should be remembered that the tide level shown only includes astronomic tides (i.e., no storm surge or river effect). Peak levels on 2 September are likely due to storm surge on top of the spring high tide.

As the culvert flows underneath the Grey River stopbanks it has a flood gate to prevent backflow during river floods (Figure 2-10). The flood gate is a manually-operated vertical-sliding gate (knife gate) on the downstream (Grey River) side of the culvert. The flood gate has a small inset flap valve to allow discharge if the river level drops below the lagoon level.

GDC are responsible for flood gate operation. During river flood events GDC manually monitor flow through the culvert and as soon as flow starts to reverse (i.e., to flow from the river to the lagoon) they shut the gate. GDC continue to monitor the water level on either side of the gate (manually, using the staff gauges), and once the river level falls below the lagoon level they re-open the gate. The flap valve in the gate is too small to effectively drain the lagoon during significant rainfall, which is why GDC leave the gate open as long as possible before a river flood and re-open it as soon as possible after the river flood.

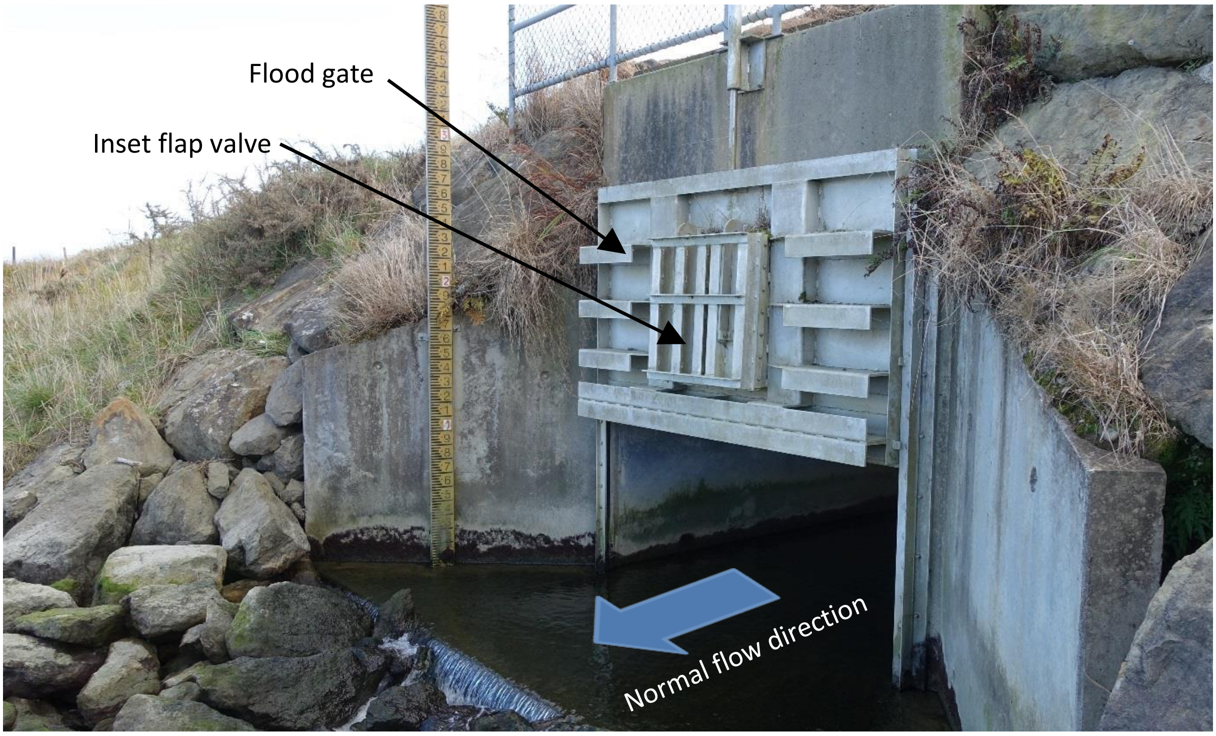

Figure 2-10: Downstream end of Cobden Lagoon outlet culvert. 2 m by 1 m rectangular culvert through Grey River stopbank with vertical sliding flood gate which is manually closed during Grey River floods. Note smaller flap gate inset into flood gate.

Figure 2-11: Aerial photo showing location of lagoon outlets. Imagery from Google Earth.

As well as the culvert, there is also a prepared cut from the lagoon directly to the open coast (Figure 2-11). This channel is designed to be opened during floods using an excavator to allow emergency drainage of the lagoon. Previous attempts to use the cut have found that it is very difficult to open the cut during high tide because waves and high sea levels hinder work and tend to fill in the channel mouth. It is also logistically challenging to organise the heavy machinery necessary to open the cut at short notice. The cut was enlarged in 2013 to make its operation more effective but it was observed during the site visit that the channel is gradually filling up, especially at its seaward end where wave and wind action tends to deposit material into the channel.

Figure 2-12 shows lagoon level, tide level, and river flow data for the two highest lagoon level events since the lagoon level recorder was installed in 2012. During both events the Grey River was in flood (peak flows of 2,500 and 4,900 m^3/s for the two events respectively).

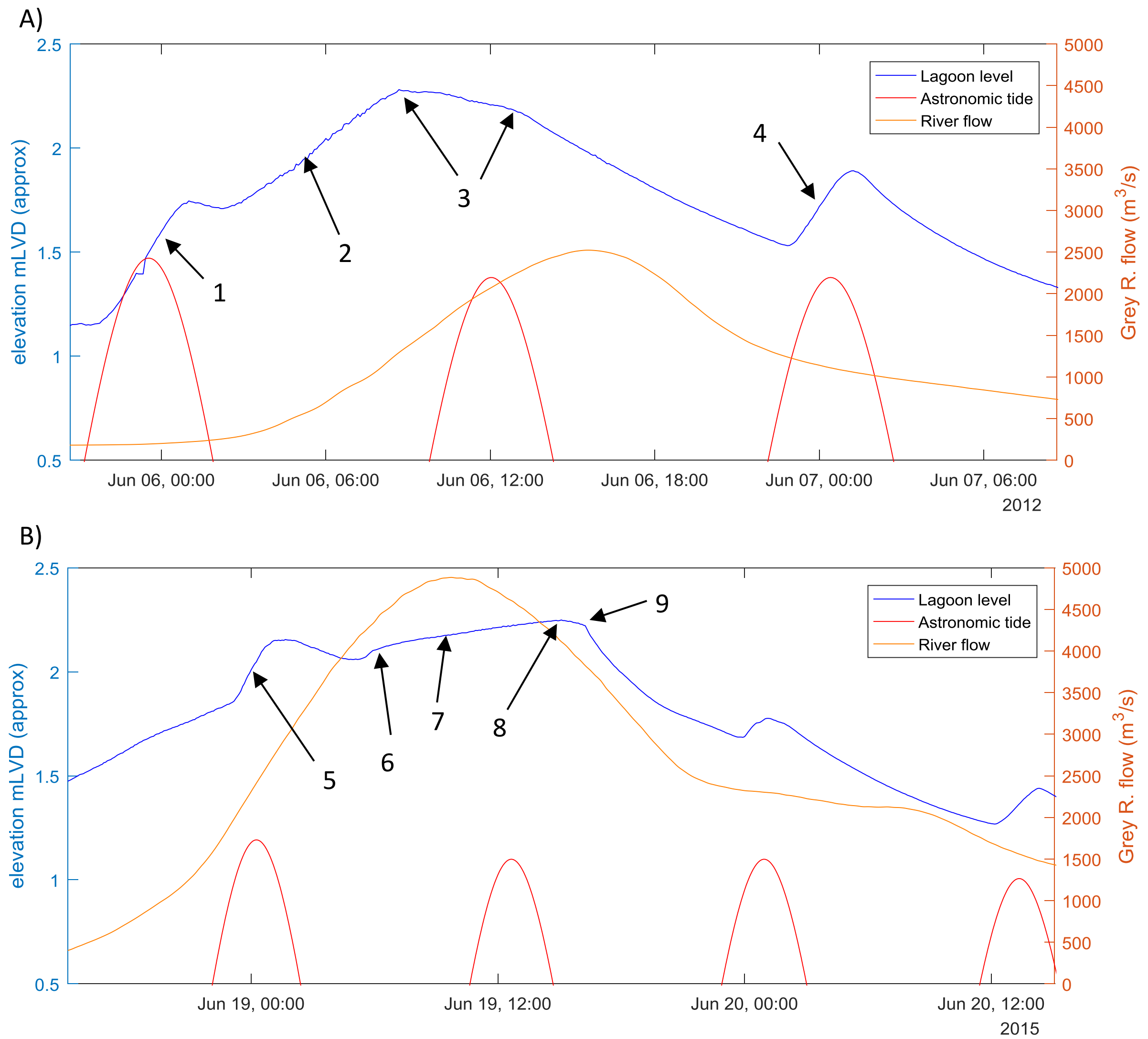

Figure 2-12: Lagoon level, tide and river flow during the two highest lagoon levels recorded between 2012 and 2017. A) Flooding reaches 2.28 m LVD on 6 June 2012; B) Flooding reaches 2.25 m LVD on 19 June 2015. Plots show lagoon level from WCRC level recorder (blue, left axis), tide from LINZ tide table (red, left axis), and river flow from NIWA Grey River at Dobson flow recorder (orange, right axis). The Grey River flow data has been time lagged by 90 mins to account for travel time from flow recorder to lagoon (Plew 2011). It should be remembered that the tide level shown only includes astronomic tides (i.e., no storm surge or river effect). Numbered features are described in the text.

No data were formally recorded regarding lagoon flood gate operation but sharp ‘unnatural’ changes in lagoon level trends provide a good indication of when manual interventions occurred. Several notable features are numbered in the plots:

1. Sharply rising levels coinciding with high tide indicate that flood gate was still open at this time. Lagoon levels rise to ~1.7 m LVD in advance of the flood.
2. Likely that flood gates were shut by this point so rising level in the lagoon is likely due to Range Creek inflows.
3. Lagoon starts to drain as (presumably) river levels drop, possibly through flap valve initially but at some time over this period flood gate is likely opened.
4. High tide, elevated by flood recession causes inflows to the lagoon, flood gate remains open and this allows backflow into the lagoon to raise levels back up to 1.9 m LVD.
5. Flood gate still open as rising tide coupled with river flood causes rapid increase in lagoon levels which then subside slightly after high tide.
6. Levels begin to rise rapidly suggesting reverse flow from the river has re-started, immediately after this the flood gate is likely closed as the rate of level increase reduces suddenly.
7. Increasing levels in the lagoon are likely due to inflows from Range Creek (GDC report rainfall of “130-200mm in 24 hours” affecting coastal areas – GDC 2015).
8. Lagoon levels peak and start to slowly drop, likely draining through flap valve inset into flood gate.
9. Lagoon levels start to recede rapidly, likely due to flood gate being opened as river levels drop.

2.5 Sea level rise

Sea level rise will have a major impact on flood risk in Cobden as it will impact on the ability to drain Cobden Lagoon. Rising sea level will increase the frequency and duration with which the flood gate on the Cobden Lagoon outlet culvert needs to be closed, increasing the frequency with which lagoon ponding flooding occurs.

3 Potential mitigation

The most frequent and deep flooding is caused by ponding on the low-lying land adjacent to Cobden Lagoon so any mitigation should target this. There are three potential approaches to reducing the extent and frequency of flooding from Cobden Lagoon:

1. Reducing inflows to the lagoon.
2. Improving drainage out of the lagoon.
3. Containing the spread of water such that inundation of roads, sections and buildings is minimised.

In addition to reducing the flood frequency and extent it is also possible to minimise the impacts of flooding by increasing resilience.

3.1 Reducing inflows

Previous studies have considered the possibility of diverting upper Range Creek into Lake Ryan (location marked in Figure 1-1) as a means of reducing flows into Cobden Lagoon (Hall 2012, Gardner 2013). This could be effective at reducing inflows but would require significant earthworks. Problems with this option are that Lake Ryan only drains via seepage through the gravel barrier, and high levels in Lake Ryan already cause flooding of the access road to the farm adjacent to the lagoon. This option is not preferred as it is costly, is unlikely to fully alleviate flooding from Cobden Lagoon, and may simply move the flood risk to a different location.

Another option which has not been considered previously is the possibility of creating flood storage in the upper catchment. To be effective a significant volume of water would have to be stored and then released once the flood gate was opened and lagoon levels had started dropping. The topography in upper Range Creek is such that a flood storage area could be created sufficient to contain flood water from approximately one quarter of the total lagoon catchment. This would provide significant flood risk reduction but would be costly as it would require construction of an approximately 180 m long embankment and a suitable control structure, as well as compensation to the landowner whose land would suffer increased flooding.

3.2 Improving drainage of the lagoon

The inability to drain the lagoon during times of high river/tide levels is one of the major causes of flooding, and reverse flow into the lagoon can be a cause of flooding if the flood gate is not closed at the right time.

Pumping has been identified previously as a potential solution to flooding from the lagoon. Pumping is already used to manage the stormwater/combined sewer system, but the benefits this pumping has by reducing inflows to Cobden Lagoon have not been fully quantified. A range of pumping options were investigated by Gardner (2013, 2016). Pumps of 5 m^3/s capacity were found to be very effective for alleviating flooding but were very expensive (Gardner 2013). Before discarding pumping as on option for flood management it would be worth considering the costs and benefits of a more moderately sized pumping option, although it is recognised that any pumping option is likely to be expensive, both for capital costs and for operation/maintenance.

The existing cut from the lagoon to the sea is ineffective for managing smaller/frequent flooding due to the logistics and physical difficulty associated with opening the cut effectively. The difficulty of opening the cut at high tide, which is when flooding is most likely to occur, is a major barrier to its effectiveness. It has been suggested that closing the culvert and making the cut a permanent outlet could be a potential solution, but due to the exposed coastline and the small size of the lagoon and Range Creek it is very likely the outlet would be closed regularly by wave action, which would then result in flooding. Despite the difficulties in opening the cut it is likely that the cut could provide a valuable means of alleviating severe flooding. At times of extreme lagoon level opening the cut is likely to be easier due to the water level difference between the lagoon and the sea. As such the cut complements any other mitigation which is targeted at smaller/more frequent flooding.

One achievable means of making some improvement in the frequency and severity of flooding seems to be improvements to the outlet culvert flood gate and its operation. During both of the flood events shown in Figure 2-12 the flood gate was used effectively to reduce flooding; however, it would likely have been possible to further reduce flood levels and duration by making some alterations to its operation. For example, during the high tide prior to each event significant tidal inflow entered the lagoon which did not fully drain prior to the main flood event arriving. If the gate could have been used to exclude this tide then more storage would potentially have been available to contain the flood.

Operation of the flood gate is challenging, relying on very frequent or even continuous on-site monitoring by GDC staff from prior to a flood arriving until after the flood has fully subsided, a period which can take 48 hours or more. Replacement or modification of the flood gate so that it incorporates a large flap valve, preferably with its invert at the base of the culvert and constructed of a lightweight design to allow unimpeded flow when levels are favourable, would greatly assist in achieving optimal gate operation. If a well-designed flap valve were included the gate could be closed in advance of a flood, ensuring that as much of the lagoon's volume as possible was preserved to store Range Creek inflows during the event before the flap would be closed automatically once Grey River levels exceeded lagoon levels. The gate would then continue to function optimally during the event, opening and closing as necessary, until after the event. Another method of enabling improved gate operation would be to install telemetered water level recorders on the Grey River side of the gate to allow remote monitoring of level differential across the gate, with appropriate alarms at times of reverse flow. Telemetered gate operation could also be beneficial. Improvements to the gate by improving the flap valve and telemetry would have the twin benefits of helping to minimise flooding as well as freeing up GDC staff to undertake other flood management and monitoring tasks.

3.3 Containing flooding

Containing the spread of flooding by using a bund to protect the lowest lying areas was investigated by Gardner (2013, 2015) and identified as part of the preferred option. Modelling suggested that a bund could provide effective protection during frequent smaller floods but would be much less effective during larger floods (greater than 2-year return period) when flood water was likely to outflank the structure (but it still offered some reduction in flood levels). Additionally, it was found that a bund was a relatively low cost solution compared to many other options.

Whilst the construction of a bund does appear to be an effective and relatively low cost option, it should be noted that its effectiveness relies on its ability to prevent water pooling in the area behind it. If this option is pursued, then attention needs to be given to preventing backflow through pipe networks or overland flow pooling in the area behind the bund.

Another option considered by Gardner (2013) as a means of helping to contain the spread of flooding was lowering the grass area adjacent to the lagoon to provide greater flood storage (i.e., modifying the level vs volume relationship shown in Figure 2-2). However, modelling showed this to have only minor benefits (only 2 to 3 cm reduction in flood levels), and it was subsequently discarded.

3.4 Planning and resilience

Methods such as raising floor levels and designing flood resilient houses such that damage from flooding is limited (e.g., water resistant floor and wall construction, raised electrical sockets) is widely recognised as being an important aspect of flood risk management internationally (e.g., Bowker et al. 2007). The impacts of flooding in Cobden are vastly reduced by the raised floor levels which are present in all houses in the most at risk area.

Strict planning control on new development and floor levels, as well as support for residents to implement measures to enhance flood resilience, could be a very cost-effective way to limit the damage from flooding, particularly given the relatively small number of properties involved.

4 Conclusions and recommendations

The Grey River stopbanks are effective at protecting Cobden from direct flooding by the Grey River, resulting in significant reductions in flood frequency and depth. Despite this protection the land surrounding Cobden Lagoon is very low lying and floods frequently from the lagoon. The flooding mechanisms are complex and are influenced by Grey River flows and tides (which cause reverse flow into the lagoon or require the flood gate to be closed), design and operation of the lagoon outlets, local rainfall in the Range Creek catchment, and design issues with the stormwater system draining the urban area.

Given the modest number of properties at risk, that raised floor levels already provide an effective means of minimising the impacts of flooding, and the need to fund any flood risk management activities through local rates, there is a need to identify cost effective solutions. Bearing this in mind, the following actions are recommended:

Improved operation of the culvert floodgate enabled by improvements to the gate – Modifying the flood gate to include a more effective flap valve would allow simplified and more effective operation during events. Installing a telemetered water level recorder downstream of the gate, and potentially telemetered gate operation, would allow improved operation as well as providing better monitoring data. These changes would also facilitate increased use of the gate during higher than normal tides (e.g., red alert tide days, NIWA 2017).

Strict usage of planning controls to minimise exposure – i.e., strict enforcement of minimum floor levels for any new/replacement buildings. A suggested minimum floor level of at least 3.3 m LVD (300 mm above the level corresponding to a 100-year return period 6-hour inflow) or 0.5 m above surrounding ground level (whichever is higher) is recommended and would appear to be in line with many existing buildings. Development of any new sections on the low-lying land around the lagoon should be prohibited.

Continued use and maintenance of the cut – The cut is ineffective for managing minor, frequent flooding due to the challenges of opening it during high tide or high wave conditions. However, during severe flooding elevated lagoon levels will make opening easier and the cut has the potential to mitigate severe floods.

Installing a bund as investigated by Gardner (2013, 2016) – Modelling showed that this could be effective for Range Creek events up to a 2-year return period and offered some residual benefits during more severe events. If this is pursued, it is recommended that an assessment be conducted of how drainage in the area behind the bund will function during periods of elevated lagoon level. There seems to be a possible risk that the area could still flood due to either overland flow pooling behind the bund (i.e., if flap valves through the bund are closed due to high lagoon levels) or backflow through storm drains allowing flood water to make its way behind the bund.

Sea level rise will increase flood frequency and severity in the future. Any management and planning activities should consider this changing risk.

5 Acknowledgements

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Appendix A Vertical datums

To compare LiDAR, water level and culvert invert elevations it is necessary that they are all reduced to the same datum. The LiDAR data was supplied in Lyttelton Vertical Datum (LVD), but the gauge datum for the lagoon water level recorder was unknown. The elevation of the culvert invert (and gauge board zero) is variously reported as either 0.97 m below LVD or 0.97 m above LVD. Based on an examination of the data it is clear the true level is 0.97 m above LVD. Based on the observed level during the site visit it is then possible to resolve levels as follows:

- **Culvert invert = 0.97 m LVD**
- 0 mark on gauge board on upstream side of culvert is level with invert, i.e., **Culvert gauge board datum = 0.97 m LVD**
- Lagoon water level 10:20 am on 2 May 2017 (during site visit) was 0.13 m on the culvert gauge board (= 1.10 m LVD)
- The lagoon water level recorder showed 0.55 m at 10:20 am on 2 May 2017, therefore: **Cobden lagoon water level recorder datum = 0.55 m LVD** (i.e., 1.10 m LVD – 0.55 m)

The following plots (all using the datum offsets calculated above) confirm that this assumption appears reasonably accurate (i.e., to ±0.05 m):

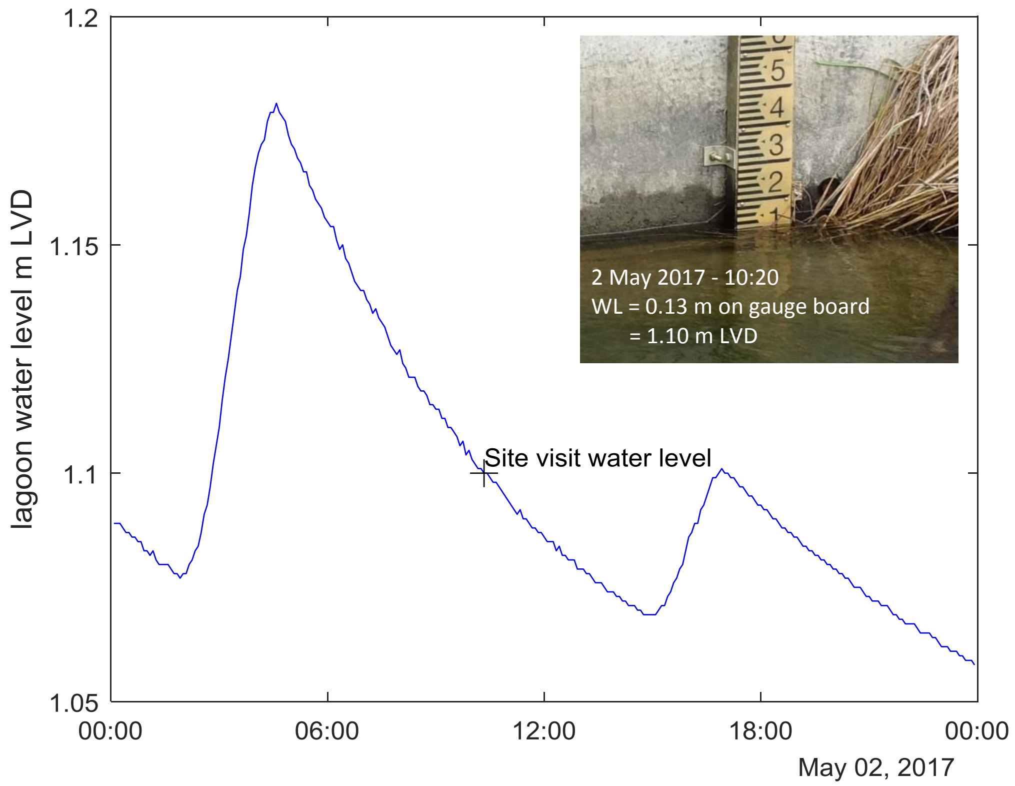

Figure A-1: Lagoon level on day of site visit.

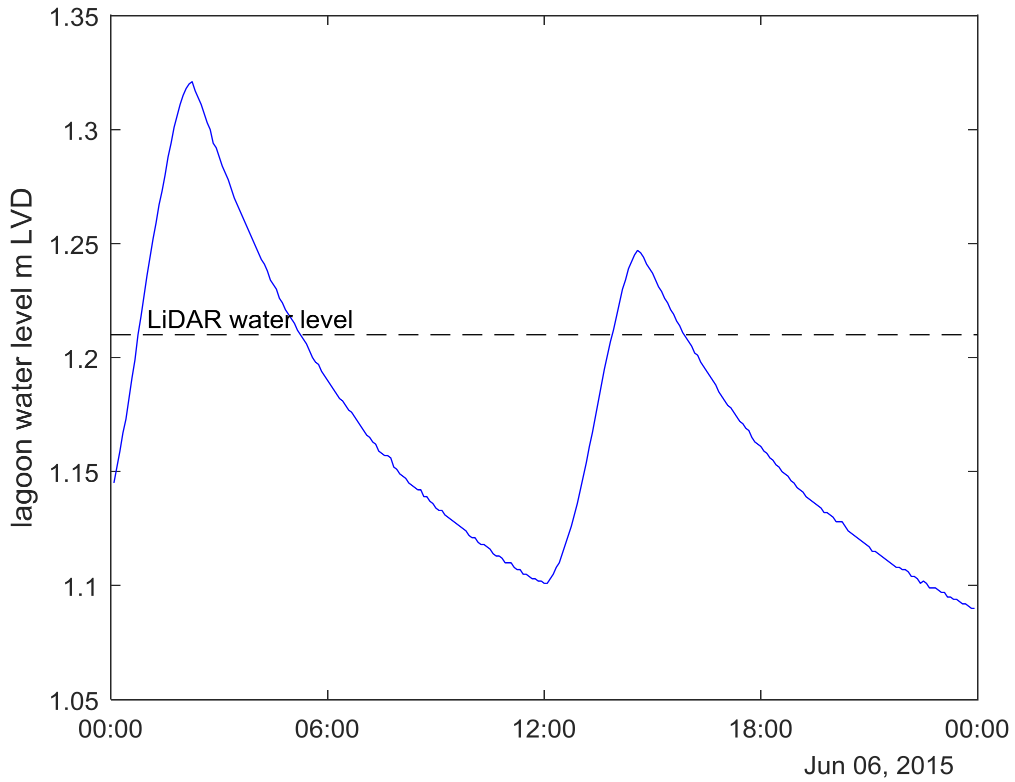

Figure A-2: Cobden lagoon level on day of LiDAR flight. Time of LiDAR data collection over lagoon unknown. Water level calculated as average of LiDAR point data returned from lagoon surface.

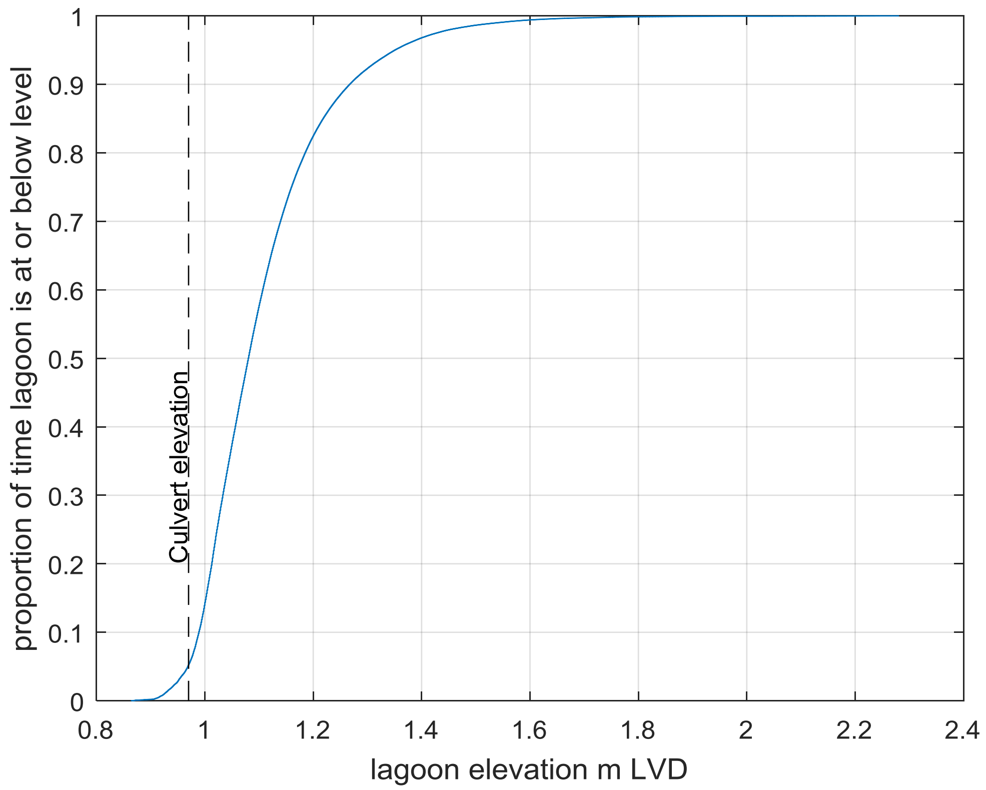

Figure A-3: Cobden lagoon level duration curve (2012-2017).

For consideration of tidal levels, I have converted between local chart datum (as used for LINZ tidal predictions) based on information reported in Gardner 2013, that:

- **Grey chart datum = -1.831 m LVD**

This offset seems reasonably consistent with LINZ data regarding chart datum offset at Westport (the closest port where LINZ specify this data) where chart datum = -1.779 m LVD (Westport chart datum is 7.327m below benchmark "DJMC" which has an elevation of 5.548 m LVD in the LINZ geodetic database).