Mokihinui Township flood mitigation advice

Prepared for West Coast Regional Council

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Cover photo: Looking southwest across the Mokihinui domain from the corner of Rawson and Batty Streets, July 2021 flood. [Photo provided by Bill Lynch]

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Executive summary

Mokihinui Township, comprising approximately 50 buildings, was flooded in July 2021 and February 2022, resulting in several properties being yellow-stickered. Following these floods, the West Coast Regional Council sought advice from NIWA on ways to mitigate impacts from both coastal and riverine flooding.

There are multiple sources of flooding which threaten Mokihinui township: coastal flooding, Mōkihinui River flooding, and flooding from small local catchments. The 2021 and 2022 flood events were caused by runoff from the local catchments overwhelming the capacity of culverts through the Mōkihinui River stopbank, causing ponding in the township. Flooding from the Mōkihinui River or sea due to failure of the defences has the potential to cause higher flow velocities and greater risk to life than flooding from the local catchments. In the event of stopbank overtopping or failure, deep and high velocity flood water could enter the township.

Flood risk from all sources is exacerbated by the location of the township on the most low-lying part of the floodplain. Any water entering the floodplain which cannot escape via the culverts or piped outfalls under the river stopbank will cause ponding in the area around the township.

Sea level rise poses a major threat to Mokihinui township by increasing the rate of coastal erosion, increasing the likelihood of the coastal bund or Mōkihinui River stopbank overtopping, and reducing the effectiveness of the culverts draining the township (due to increased sedimentation and more frequent closure of the flap valves).

To reduce the risk of flooding from local catchments, it is recommended to:

- Modify or remove the twin barrel farm culvert on Chatterbox Stream immediately downstream of the highway (as it is vulnerable to blockages that can divert floodwater toward the township).
- Upgrade the township stream culvert under the river stopbank to increase its capacity.
- Undertake frequent inspection and maintenance of the flapped culvert/outfall discharge points (particularly prior to forecast heavy rain and following Mōkihinui River floods).
- Survey stopbank crest levels (river and coastal) and top-up where necessary.

In the longer term (considering increasing risk due to climate change), consideration should be given to managing the exposure to flooding. It is recommended that:

- New development in the low-lying area of the township be restricted.
- Individual property owners consider raising floor levels as this is an effective way to reduce risk.
- Managed retreat be considered as a longer-term option. There are locations within a few hundred metres of existing properties which are at significantly lower risk.

1 Introduction

The Mokihinui Township (referred to as either Mokihinui or Waimarie in various maps and documents, and henceforth referred to as Mokihinui in this report) is located on the south bank of the Mōkihinui River mouth[1]. The township is protected from flooding by a range of flood defences funded by a local rating district and maintained by the West Coast Regional Council (WCRC).

Flooding in July 2021 and February 2022 inundated large areas of the township, resulting in several properties becoming yellow-stickered (e.g., property access became restricted due to potential health and/or safety risks). Following these floods, the West Coast Regional Council sought advice from NIWA for ways to mitigate impacts from both coastal and riverine flooding while working alongside river and coastal processes. This work was funded through MBIE Envirolink funding grant 2311-WCRC206.

To analyse flood risk and potential mitigation measures for Mokihinui Township we:

- reviewed relevant reports describing previous studies;
- conducted a field visit on 7 February 2023;
- analysed aerial imagery, LiDAR, river flow and rainfall data.

This report describes the sources of flooding (Section 2) and factors affecting the level of risk, including local topography (Section 3.1), existing defences (Section 3.2) and climate change impacts (Section 4). It then provides recommendations for risk mitigation over the short and long term (Section 5).

[1] Since 2019 the official name of the river has been spelled with a macron, although the name of the township has not been changed. This convention is followed throughout this report.

2 Sources of flood risk to Mokihinui Township

2.1 Coastal flooding and erosion

The coast adjacent to Mokihinui Township is identified as a coastal hazard area (CHA2) at risk to long term erosion and wave washover flooding (Measures et al. 2022).

2.1.1 Coastal defences

Coastal defences consist of two 800 m long parallel gravel bunds between the township and the sea. The outermost bund is a sacrificial bund while the inner bund is a secondary stopbank intended to contain coastal flooding when the outer bund is breached by the sea. In 2018, the rating district committee agreed to trial a series of short rock spur-groynes along the front face of the sacrificial bund. The spurs are intended only to provide some additional protection to the sacrificial bund and not to interrupt littoral drift.

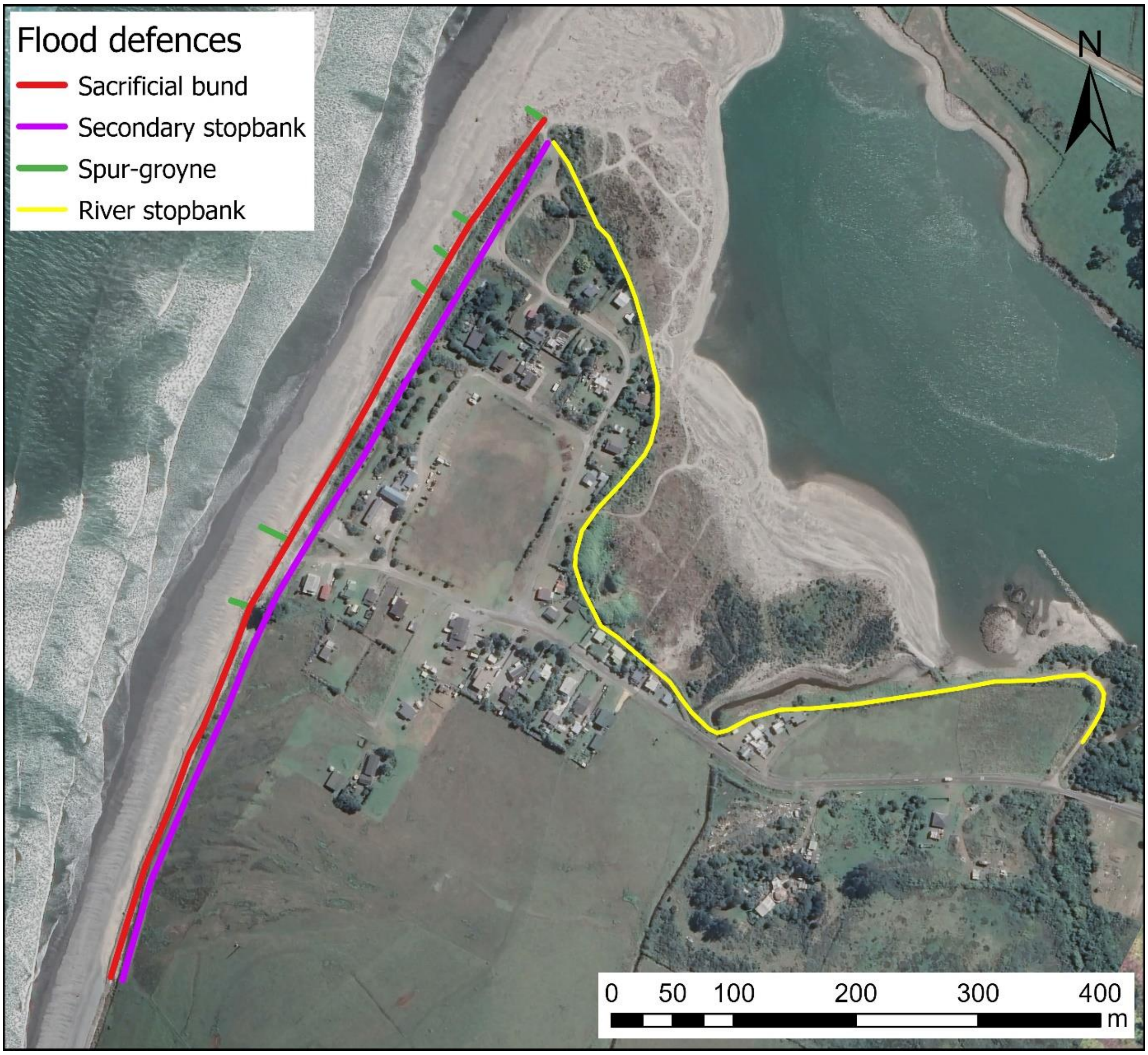

Figure 2-1: Map of existing flood defences.

The coastal defences have performed reasonably well at preventing flooding to the township, although the sacrificial bund is regularly damaged during large wave events. At times, the defences have come close to being overtopped. For example, the asset management plan (WCRC 2021) notes that:

> *"the seawall was severely damaged in February 1974 and in May 1977, the seawall was breached creating a large pond of seawater against the secondary coastal stopbank with a freeboard of only 150mm from the crest of that bank."*

The defences are regularly maintained following damage during coastal storms.

2.1.2 Long term erosion

Long term coastal erosion presents an ongoing risk to Mokihinui Township. Various studies have analysed long term erosion rates based on historic maps and imagery of the Mokihinui area. The most recent analysis was conducted in 2007 (Hicks et al. 2007a). This study found that the shoreline south of the Mokihinui River, adjacent to the township, has been continuously eroding since the earliest available survey in 1898. The study also found that the rate of shoreline retreat accelerated from approximately 0.5 m/yr to over 1 m/yr around 1955. This acceleration was likely due to a reduction in sediment delivery from the Mokihinui River to the coast following a large pulse of sediment generated during from the 1929 earthquake.

For this report, the analysis of historic shoreline change by Hicks et al. (2007a) has been updated for changes over the period 2007 to 2023 (Figure 2-2). The analysis shows little new erosion at the north end of the sacrificial bund near the river mouth (less than 1 m erosion), with erosion increasing further south. Opposite Lewis Street, there has been approximately 5 m of erosion since 2007, and approximately 10 m at the southern end of the sacrificial bund. The average rate of erosion is approximately 0.5 m/yr over the full length of the bund. This rate of erosion is consistent with Hicks et al. (2007a), who found that the sacrificial bund slowed, but did not prevent, long term erosion. It is likely that the lower erosion rate at the north end of the bund is due to greater maintenance effort in this area, as well a higher concentration of the rock spur-groynes.

The frequency and extent to which the sacrificial bund is eroded is likely to be influenced by the beach levels in front of the bund. The closer the bund is built to the sea, and the lower the beach levels are in front of the bund, the more vulnerable the bund is to wave attack.

Figure 2-2: 1955 aerial photo of Mokihinui Township, showing selected historical shorelines. Figure uses some data from Hicks et al. 2007a.

2.1.3 Coastal flood levels

Sea levels at the coast are caused by the combination of:

- Local mean sea level – the average level of the sea relative to a local datum, which changes over time as a result of sea level rise (see Section 4.1).
- Astronomic tide – the predictable twice-daily rise and fall of the tide.
- Storm surge – changes in sea level caused by air pressure and wind.
- Wave setup – as waves break on the coast, they cause an increase in mean water level (i.e., setup) between the breaker line and the shore.

These factors all control the "still" level of the sea, i.e., the sea level without the short-period oscillations caused by waves. Waves also cause "runup" when they hit the shore, which can elevate peak water levels even higher and cause spillover of defences.

Areas vulnerable to coastal flooding can be identified by comparing extreme sea levels to ground levels around Mokihinui Township. Estimated extreme sea levels are determined by combining local mean sea level, astronomic tide, storm surge, and wave setup data. This approach has been applied to map 1% annual exceedance probability extreme sea levels (i.e., the sea level which has a 1% chance of being exceeded in any year) for other coastal hazard areas in the West Coast Region (see Bosserelle and Allis 2022).

To estimate extreme sea levels, Bosserelle and Allis (2022) started from the national dataset calculated by Paulik et al. (2019, 2020) but updated the local mean sea level (based on new data collected since 2019 by LINZ) and wave setup components (based on local rather than national estimates). We can apply the same approach to calculate 100-year return period extreme sea level for Mokihinui.

Paulik et al. (2019, 2020) calculated the 100-year return period extreme sea level to be 4.05 m Lyttelton Vertical Datum (LVD37)[2]. Westport is the closest location with accurate mean sea level data, and has a similar wave climate to Mokihinui, so we can apply the adjustments Bosserelle and Allis calculated for Westport (wave setup adjusted from 1.5 m to 0.8 m; MSL offset updated with a 0.121 m increase). Applying these adjustments gives an updated estimate of 100-year return period extreme sea level of 3.47 m LVD37, or 3.11 m NZVD2016.

Figure 2-3 shows the land area vulnerable to coastal flooding under current sea levels. Flood levels with and without the influence of wave setup are shown. The open coast will experience the effect of wave setup, but there will be little wave setup within the Mokihinui River itself, so the river side of Mokihinui Township is exposed to slightly lower water levels during severe coastal flood events.

The map shows that almost all the buildings in Mokihinui Township are located on land below the 1% AEP coastal flood levels, indicating that they are at severe risk of flooding if there is a breach of the coastal bund.

[2] The conversion between Lyttelton Vertical Datum 1937 (LVD37) and New Zealand Vertical Datum 2016 (NZVD2016) varies spatially. Maps of the offset between the two datums are available from LINZ. For Mokihinui, the conversion is given by the equation: *Height in NZVD2016 = Height in LVD37 - 0.361m*.

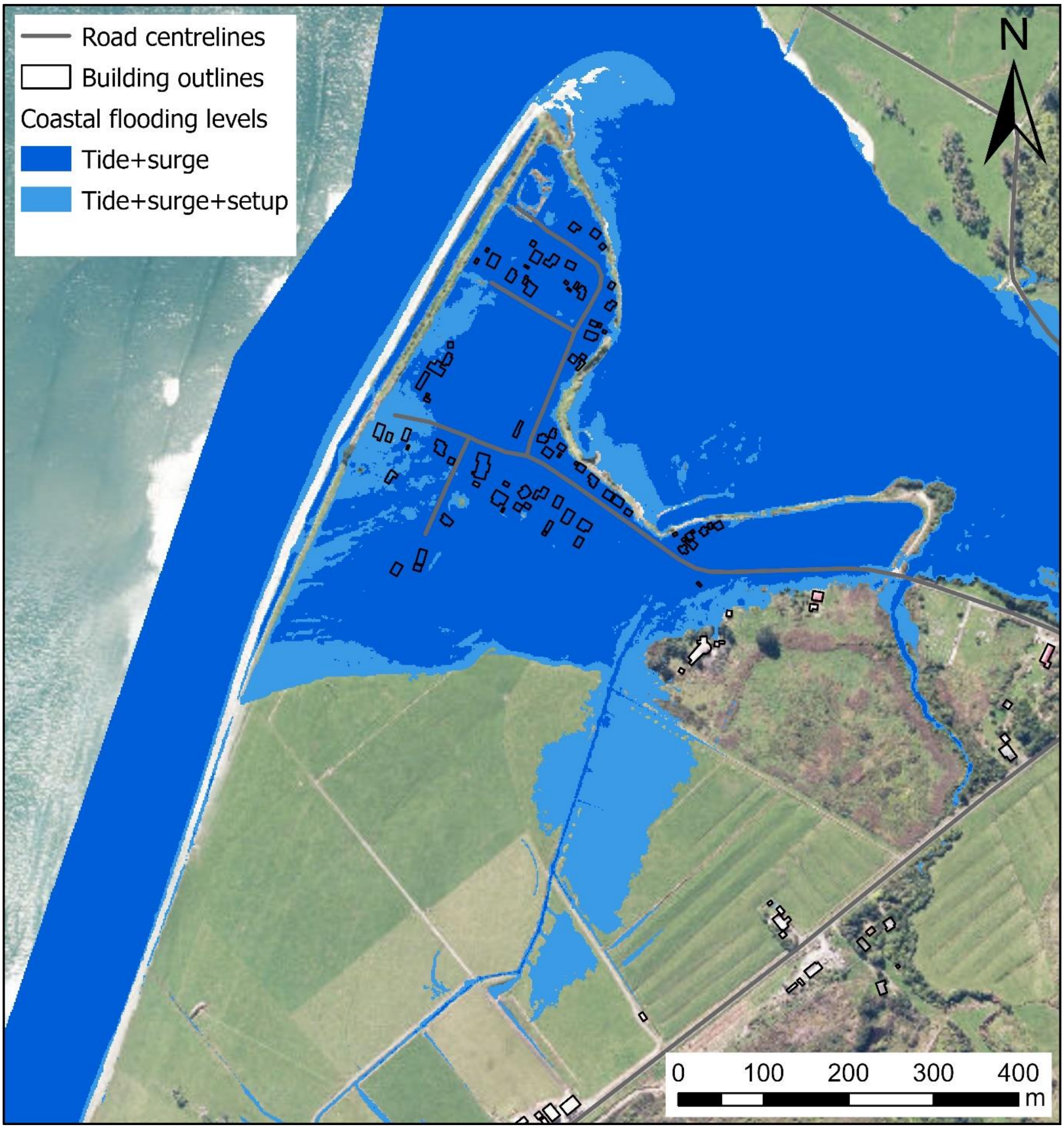

Figure 2-3: Land areas below the 1% annual exceedance probability extreme sea level. The flood extent is calculated using a simple "bathtub" approach, horizontally propagating water levels across the floodplain (land elevations from 2007 LiDAR survey). Two different extents are plotted, the dark blue indicates land below the level of the 1% AEP astronomic tide + storm surge (not including wave setup), and the light blue includes the effects of wave setup.

2.2 Mōkihinui River

The township has a long history of flooding from the Mōkihinui River. In his review of flooding on the West Coast, Benn (1990) identifies several river flood events which inundated properties in the township (Table 2-1).

Table 2-1: Records of historic river flooding affecting Mokihinui Township. Summarised from Benn (1990).

Date	Description of flooding (Benn 1990)
10–12 October 1936	"at lower Mokihinui all the Houses were flooded"
3 February 1945	"in the lower Mokihinui … flood waters entered some of the houses"
23 April 1948	"As a result of the heavy rain which fell for two days in the Buller district, the small township of Waimarie was almost submerged. The flooded Mokihinui River clashed with a rising tide and water backed up until the local hotel and nearby houses were inundated with 30 cm of water."
23 February 1949	"The most serious flooding was at Mokihinui, where the river swept through the township to enter nearly every house, farm, and building. There was 230 cm of water in the hotel."
21–27 November 1973	"Seddonville and Waimarie were also flooded, and floodwaters blocked the road at Mokihinui."

The first river defences at the township were constructed in 1952 and enhanced in 1968 and 1980-81 (WCRC 2014). The township is now protected from flooding from the Mōkihinui by a 960 m long, rock-armoured stopbank approximately 3 m high (Figure 2-1). Since 1973, there is no record of flooding from the Mōkihinui River. During field inspection, a low area was noticed in the crest of the river stopbank where it is crossed at an angle by a vehicle track.

It is recommended that the stopbank crest be surveyed to identify low spots and topped up where necessary.

Records of river flow in the Mōkihinui River are available from 1972 (with a gap in data from 1994 to 2007[3], see Figure 2-4). The 1973 flood was the largest Mōkihinui River flood flow on record (i.e., since 1972) and caused inundation of the township (Table 2-1). The second largest flood on record occurred in 2010, which caused extensive flooding upstream in Seddonville, but did not inundate Mokihinui Township (WCRC 2011).

[3] Flow data was initially funded by the public good science fund and measured at Burkes Creek (March 1972 to October 1980) and then Welcome Bay (September 1979 to March 1994). No flow data was then collected until May 2007 when the Welcome Bay site was reopened with funding from Meridian Energy Ltd until May 2012. Since May 2012 flow data collection has been funded by West Coast Regional Council.

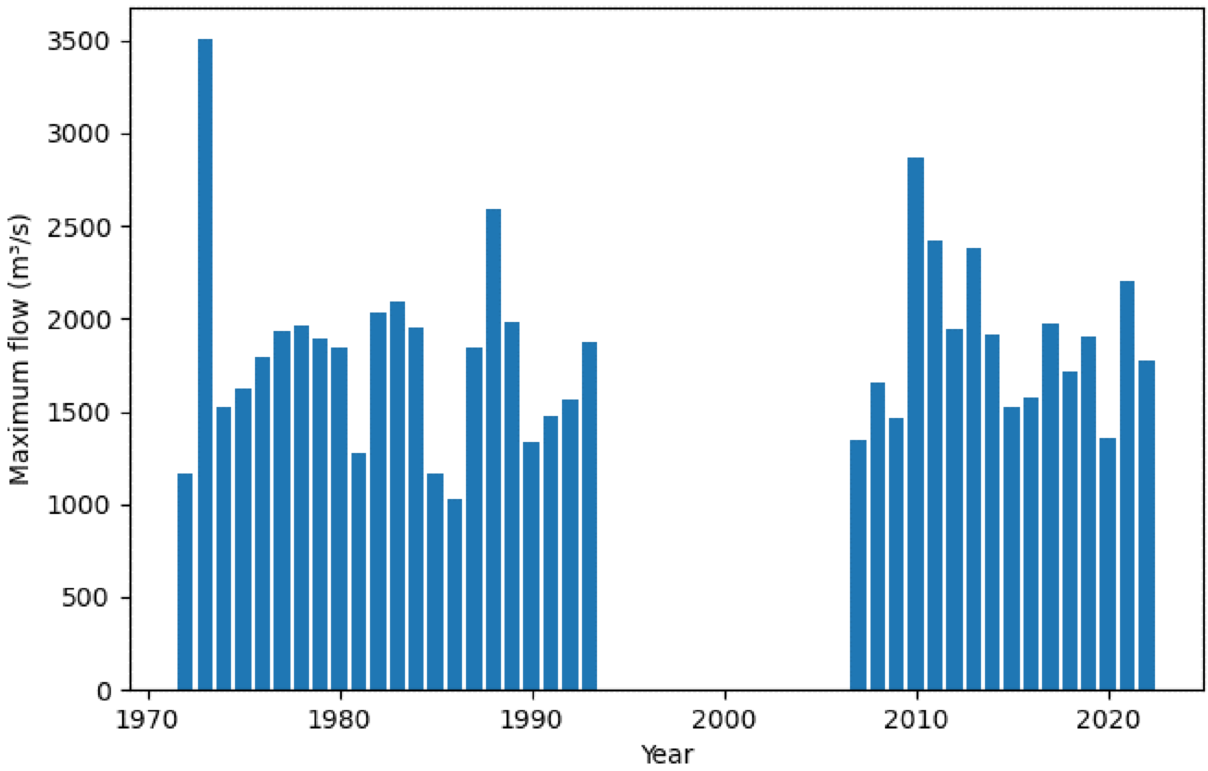

Figure 2-4: Annual maximum river flow recorded in the Mōkihinui River. Data available from 1972 to 1994 and 2007 to present.

Flood levels in the Mōkihinui River at the township occur due to a combination of river flow and tide/sea level, and are also influenced by the river mouth configuration. This differs from further upstream (e.g., in Seddonville) where there is no tidal influence and flooding is only dependent on river conditions. Figure 2-5 shows the timing of the flow peak relative to the tide for the 1973 and 2010 floods. It is notable that the timing of the flood peak for both the 1973 and 2010 events (at the flow recorder approximately 10 km upstream of the township) was around 1–3 hours before low tide, so the flood peak at the township likely coincided with relatively low sea levels. This suggests that flood levels during these events could have been 1–2 m higher if the timing had been different and the flow peak coincided with high tide.

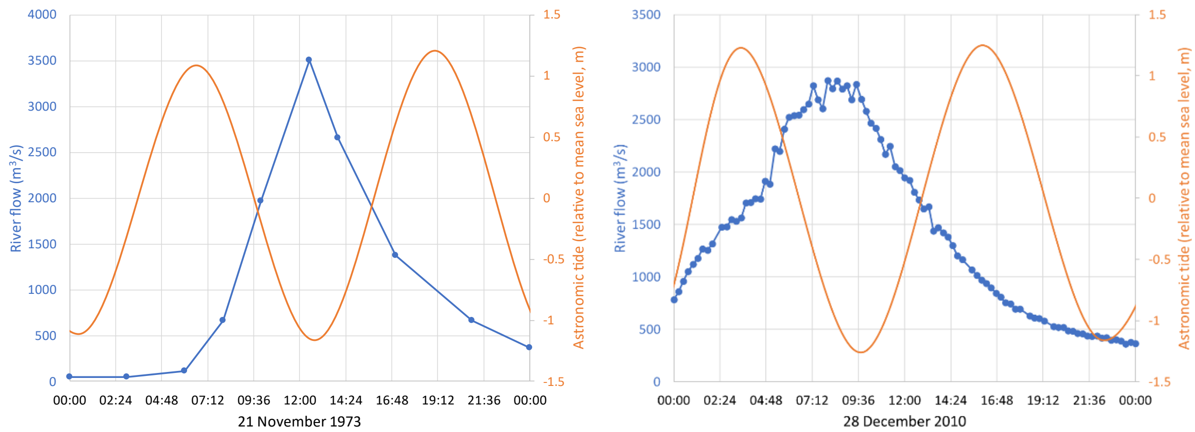

Figure 2-5: River flow hydrograph and tide level during the two largest Mokihinui River floods on record. Rivers flows recorded approximately 10 km upstream of Mokihinui Township, flood peak likely to reach township 1–2 hours after passing flow recorder. Astronomic tides from NIWA Tide Forecaster.

Two studies used the flow record to assess flood frequency (Henderson and McKerchar 2007, NIWA 2019; see Table 2-2). These assessments were reasonably consistent and indicate that the 1973 flood is representative of approximately a 1% annual exceedance probability river flow (100-year return period).

Table 2-2: Flood frequency estimates for the lower Mōkihinui River.

Average return period (years)	Annual exceedance probability	Henderson and McKerchar (2007)	NIWA (2019)
Mean Annual Flood	43%	1840 ±9%	1806 ±5%
5yr	20%	2170 ±11%	2191 ±6%
10yr	10%		2504 ±7%
20yr	5%	2700 ±15%	2605 ±8%
50yr	2%	3030 ±17%	3194 ±9%
100yr	1%	3280 ±19%	3486 ±9%
200yr	0.5%	3530 ±21%	
250yr	0.4%		3870 ±10%

2.3 Small local catchments

Both the July 2021 and February 2022 floods were the result of local drainage backing up behind the stopbank which protects the township from the Mōkihinui River.

There are three small catchments which have the potential to influence flooding in Mokihinui Township (Figure 2-6). An unnamed stream (labelled "Township Catchment" in Figure 2-6) drains the hills and farmland around and immediately behind the township. Either side of this catchment are the catchments of Brewery Stream (to the east) and Chatterbox Stream (to the south). Under normal conditions these streams do not affect the township, but during the February 2022 flood event a farm culvert on Chatterbox Stream blocked and caused water to spill into the Township Catchment, significantly increasing flooding in the township. Inspection of this twin barrel culvert showed that it had much smaller capacity, and greater likelihood of snagging debris, than the culvert immediately upstream under the state highway (Figure 2-7). Brewery Stream flows similarly close to the Township Catchment and any blockage could cause similar issues, although there are no records of this being an issue in past floods.

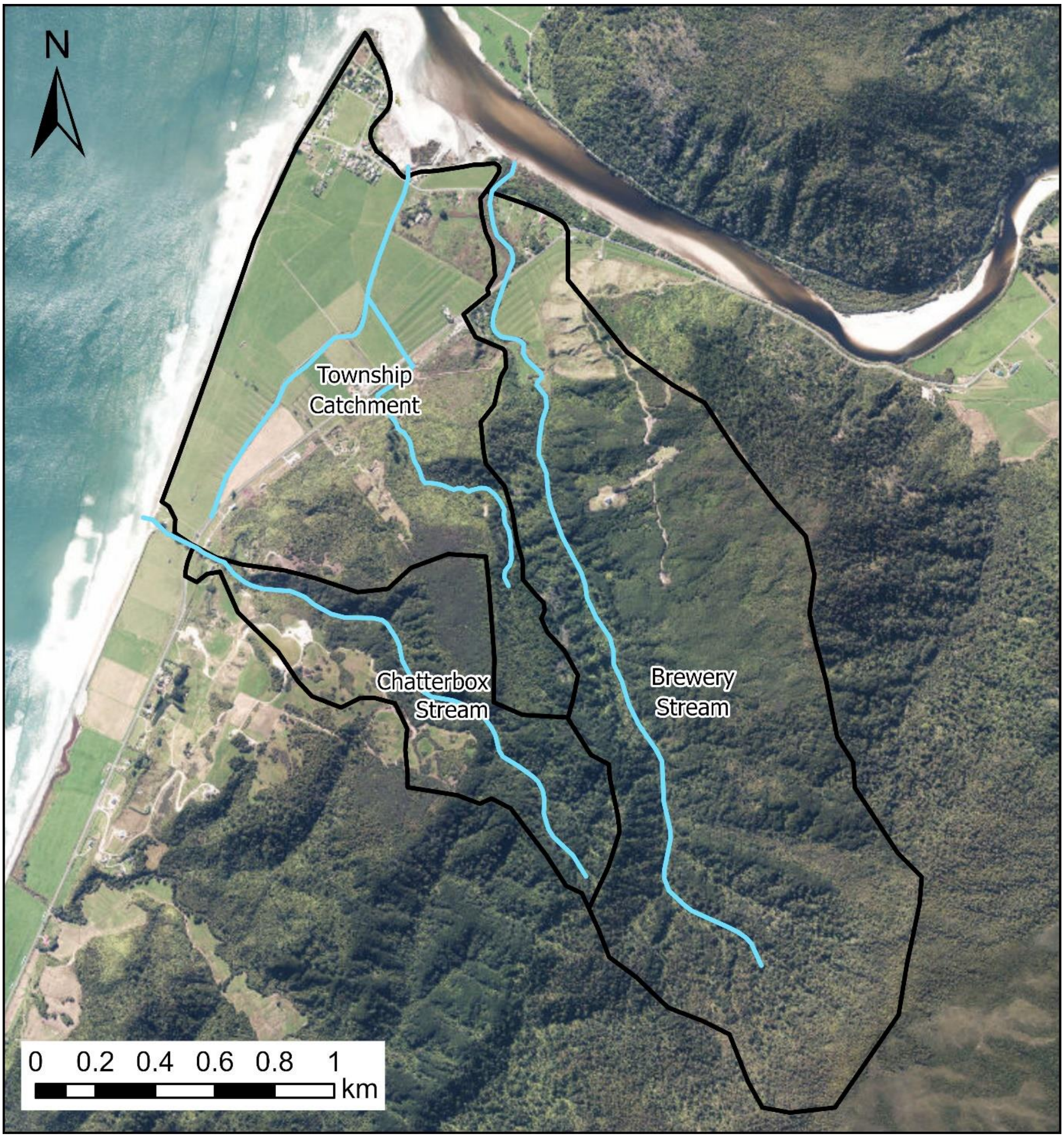

Figure 2-6: Map of local catchments and streams around Mokihinui Township. Catchment boundaries digitised from 2007 LiDAR. Stream centreline data from LINZ, with manual edits based on LiDAR.

Figure 2-7: Culverts on Chatterbox Stream. Left photo: State highway bridge/culvert. Right photo: twin barrel farm culvert immediately downstream of highway. During the February 2022 flood, the farm culvert blocked and caused water to spill into the Township Catchment.

None of the local catchments have any flow monitoring, so no flow data is available for the recent floods. Rainfall data is available from a raingauge at Ngakawau, approximately 10 km south of Mokihinui. Rainfall data for the July 2021 and February 2022 flood events is analysed in Figure 2-8.

Rainfall depths/intensities recorded at the Ngakawau gauge were greater during the February 2022 flood than the July 2021 flood. The February flood had particularly severe rainfall over durations of 12 to 24 hours, whereas the July event was most severe over longer durations. Due to the small size of the local catchments, it takes less time for rainfall to accumulate. This means that the most severe floods are generated by shorter duration, higher intensity rainfall events such as the February 2022 storm.

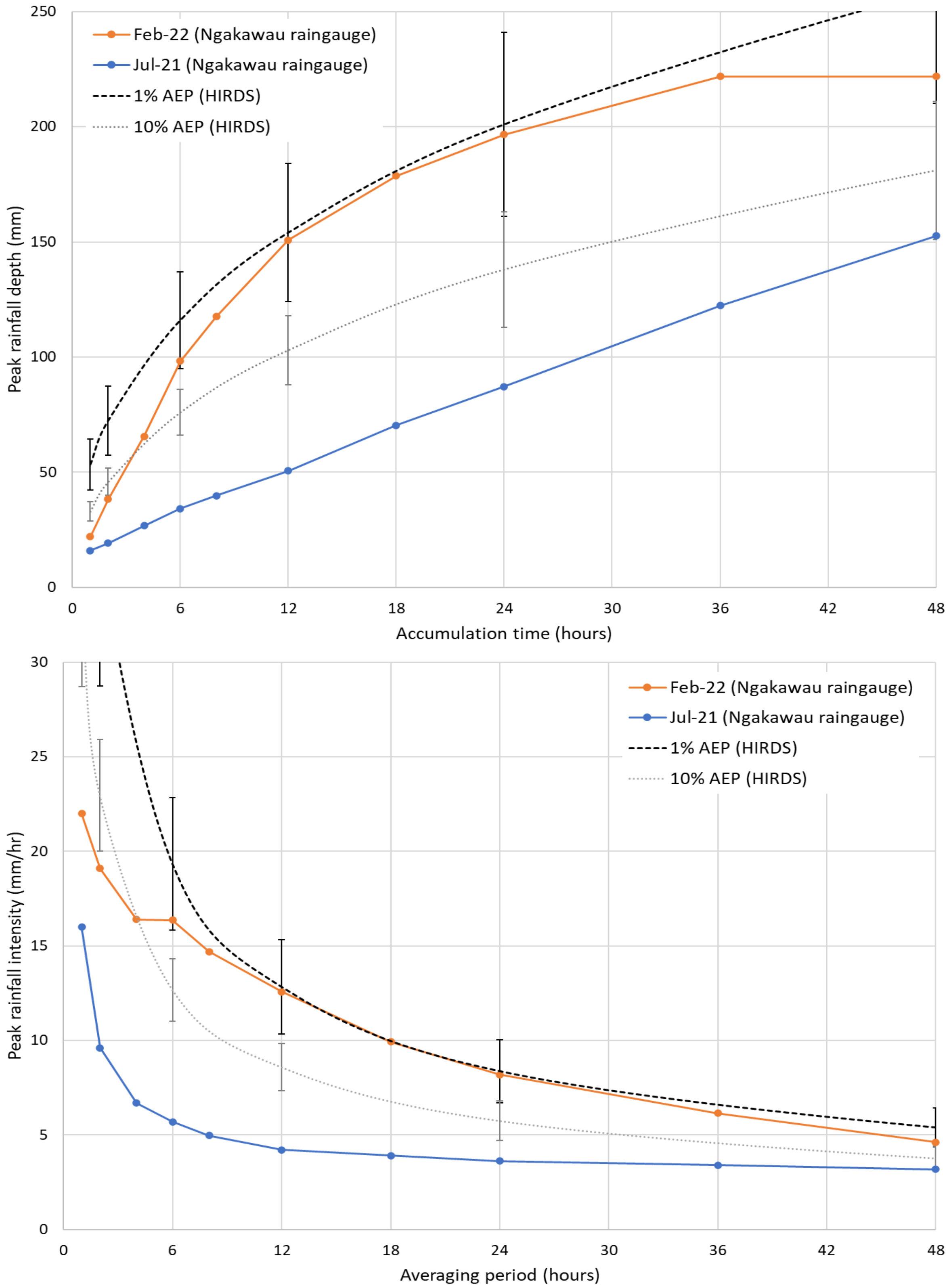

Figure 2-8: Peak rainfall depths and intensities recorded at Ngakawau raingauge during the July 2021 and February 2022 flood events. Maximum recorded rainfall accumulated over durations between 1 and 48 hours. Top plot shows total rainfall depth over accumulation period, bottom plot shows the same data but expressed in terms of average rainfall intensity over the accumulation period. Also shown are the 10% AEP (10-year return period) and 1% AEP (100-year return period) severe rainfall estimates for Mokihinui Township from the High Intensity Rainfall Design System, HIRDS (NIWA 2018).

Estimates of design flood flows for the local catchments are available from the NZ River Flood Statistics tool (NIWA 2019). The flood flow estimates highlight how the diversion of Chatterbox Stream flows into the Township Catchment during the February 2022 flood would have increased the flood flows affecting the township by approximately 50%.

We can convert the design flood flows into an equivalent average rainfall-runoff (by dividing flow rate by catchment area) to get an idea of how such flows compare to the rainfall depths measured during the July 2021 and February 2022 floods (remembering that a proportion of rainfall infiltrates into the ground). For the Township Catchment, the mean annual flood is equivalent to runoff of 17.1 mm/hr, the 10% AEP flood to 22.4 mm/hr, and the 1% AEP flood to 29.8 mm/hr.

Table 2-3: Flood flow estimates for small local catchments. Flood flow estimates taken from NZ River Flood Statistics tool (NIWA 2019) and adjusted based on updated estimates of catchment area (catchments as shown in Figure 2-6).

Catchment	Township Catchment	Chatterbox Stream	Brewery Stream
Area (ha)	144	61	224.1
Mean Annual Flood (m^3/s)	6.8	3.6	9.8
10% AEP flow (m^3/s)	9.0	4.8	12.8
1% AEP flow (m^3/s)	11.9	6.4	17.1

3 Other factors influencing flooding

3.1 Floodplain topography

The ground elevations around the Mokihinui Township control the spread of floodwater, irrespective of whether that water originates from coastal flooding, Mōkihinui River flooding, or flooding of the small local catchments. LiDAR data was analysed to investigate the topography of the Mokihinui Township floodplain (Figure 3-1). LiDAR of the area was flown in February-March 2007 by NZ Aerial Mapping Ltd for Meridian Energy (NZAM 2007). More recent LiDAR data collection has been funded by the Provincial Growth Fund but was not available at the time of this analysis.

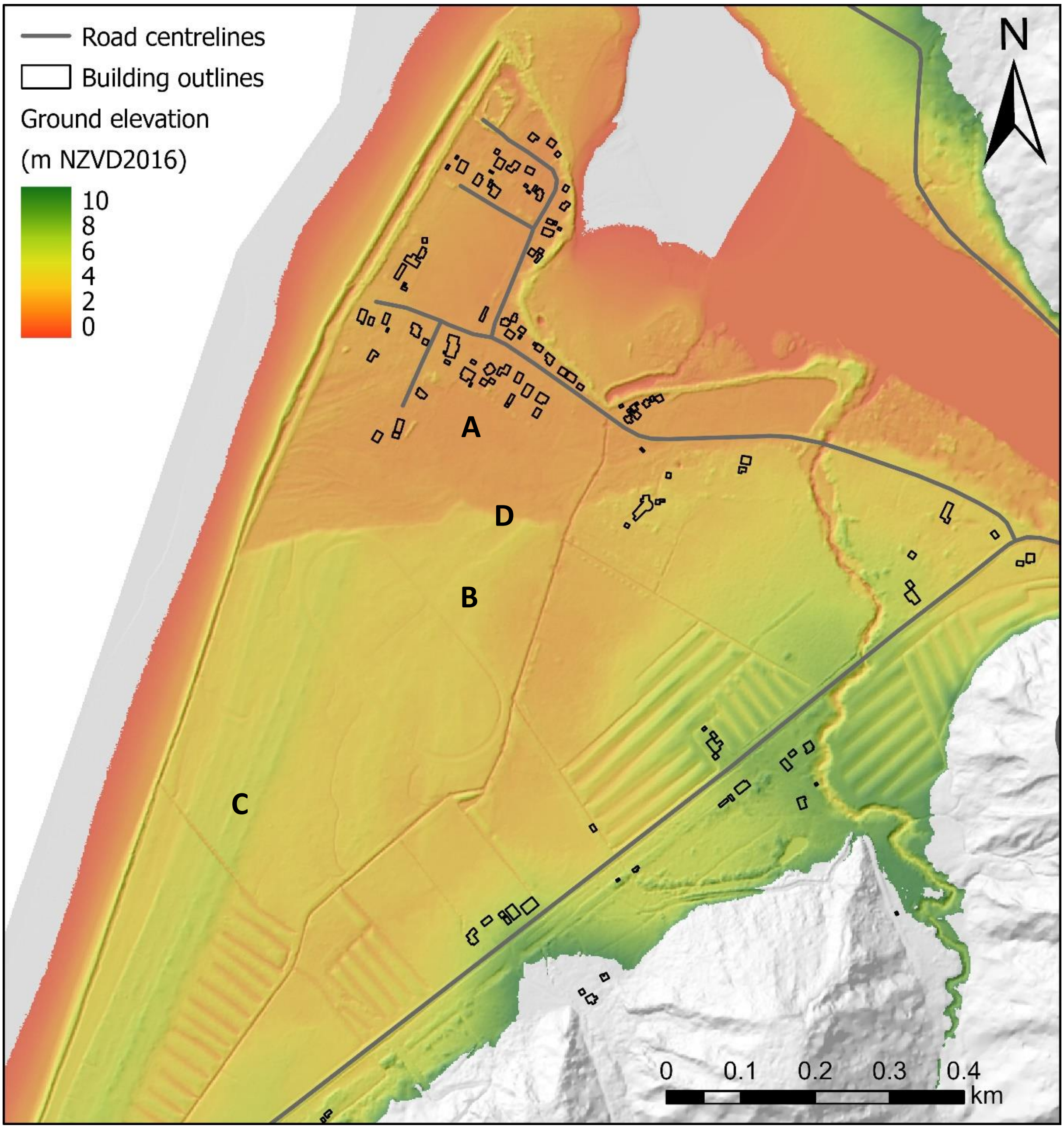

Figure 3-1: LiDAR data of the Mokihinui Township area. Elevations between 0 and 10 m are highlighted in colour. A greyscale 'hillshade' overlay covering the whole area allows visualisation of surface texture and slope. Letters refer to locations described in the text.

Figure 3-1 shows that the Mokihinui Township is built on a low-lying area (A) set below a higher terrace (B). Dune ridges are visible in the higher terrace (C), marking previous shoreline positions. The presence of the dune ridges indicates that the shoreline has previously eroded further inland than its current position and subsequently advanced, likely due to long term variability in sediment supply from the Mōkihinui River. The approximately 1.5 m elevation step (D) between the low-lying area and higher terrace shows the southernmost limit of where historic migration of the Mōkihinui River mouth has caused the river to erode the higher terrace. The river mouth has then migrated north, allowing deposition of river sediments forming the land upon which the township is constructed.

The LiDAR data provides information on the extent of land and buildings which would be flooded by different volumes of floodwater pooling behind the stopbanks (Figure 3-2). This plot shows that the land around buildings in the township starts to be flooded once water levels reach approximately 1.7 m NZVD2016, and land around the majority of the buildings in the township is flooded by floodwater levels of approximately 2.2 m. A flood level of 2.2 m corresponds to a total floodwater volume of 27,000 m^3 behind the stopbanks. This is equivalent to 19 mm of rain across the 144-ha Township Catchment, a volume of rain which fell in less than 1 hour during the February 2022 flood event (Figure 2-8).

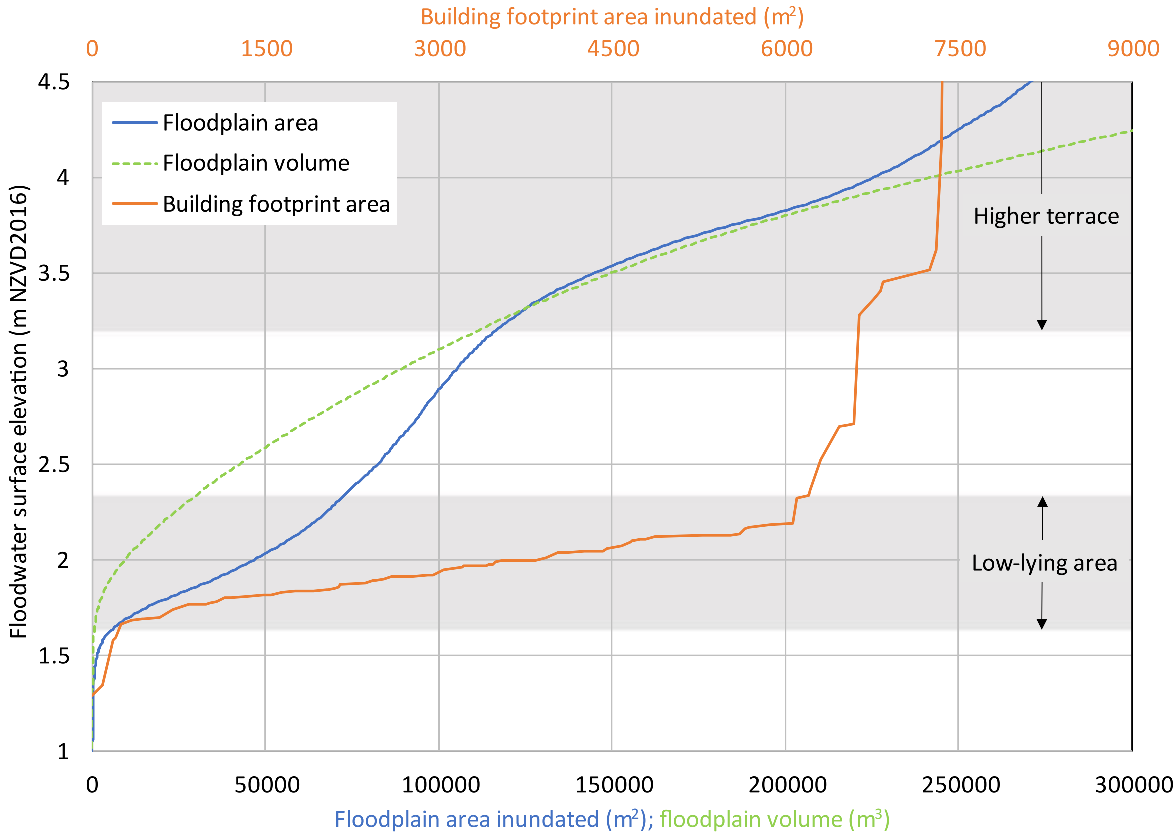

Figure 3-2: Relationship between flood volume, floodwater elevation, and building footprint area inundated. No data is available on building floor levels so building footprint elevations are simply taken from surrounding ground elevations.

3.2 Culverts under river stopbank

Three culverts/pipes pass under the river stopbank to allow drainage from the Township Catchment and the township itself. The largest culvert is on the Township Catchment stream (marked A in Figure 3-3) and is owned and maintained by Buller District Council. Two smaller piped outfalls (B) allow drainage from the township area and are maintained by West Coast Regional Council with funding from the flood defence rating district. All three of these culverts have flap valves on their downstream ends to prevent backflow during periods of high water levels in the Mōkihinui River.

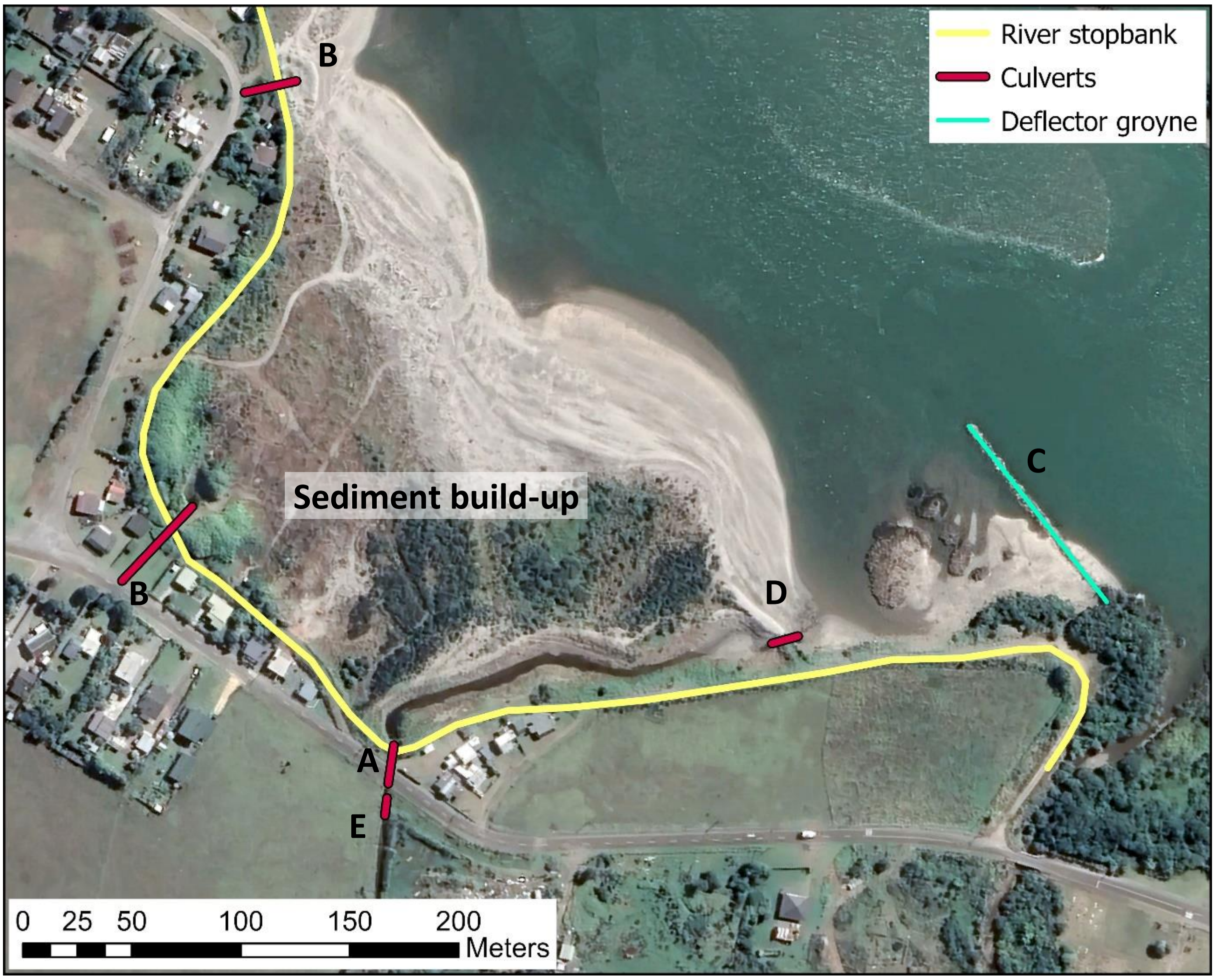

Figure 3-3: Map of river flood defences including stopbank, associated culverts and deflector groyne. Locations marked with letters are described in the report text.

The downstream end of all three culverts/outfalls under the river stopbank are affected by sediment build up. This build-up has been particularly noticeable since the rock deflector groyne (C in Figure 3-3, also referred to as a "training wall" in some reports) was constructed in 1978 to help protect the township stopbanks from river erosion and keep the river mouth aligned roughly perpendicular to the coast. The groyne has been effective at helping to manage the river dynamics and prevent erosion of the stopbank but has resulted in deposition of river sediment in front of the culverts.

Currently the only way available to maintain drainage is to clear the culvert outlets using heavy machinery. Low sumps have been excavated at the outlet of the two smaller pipes (B). These sumps allow the outfalls to flow freely with water that can then seep through (or spill over) the sediment deposits and into the river. In front of the main culvert (A), a channel to the river is maintained to allow the Township Catchment stream to drain freely. To help prevent this channel filling in, a secondary bund (with culvert) has been constructed at the downstream end of the channel (D) by Buller District Council (BDC). Anecdotally, this bund and culvert have been effective at reducing maintenance (dredging/excavation) requirements in the outlet channel.

Upstream of the main culvert under the stopbank (A) there is a farm culvert under an access track between paddocks (E). This culvert is in relatively poor condition but does not appear to overly restrict flow as it has similar capacity to the main culvert.

During the July 2021 and February 2022 flood events, the main culvert (A) was unable to discharge the full flow arriving from the Township Catchment (which in the case of the February event was increased by additional spill from Chatterbox Stream, see Section 2.3). Flows backed up inside the stopbank and spilt along Lewis Street towards the smaller piped outfalls (B). These outfalls were unable to convey the additional flow, and ponding occurred in the township causing property flooding. Sediment build-up in front of the piped outfalls was a factor which exacerbated flooding during the recent flood events. Emergency excavation in front of the outfalls was undertaken to help floodwater to drain from the township.

Regular maintenance of sediment at the culvert outfalls is recommended including inspection prior to forecast heavy rain (i.e., orange/red heavy rainfall warnings) and following Mōkihinui River floods (which could cause sedimentation) with urgent clearance if required.

4 Climate change impacts on flood risk

4.1 Sea level rise

Sea levels around New Zealand have increased by approximately 20 cm since 1900, and measured rates of sea level rise (SLR) are increasing (Stats NZ 2022).

In line with the approach taken for mapping coastal flood risk in other West Coast region coastal hazard areas (Bosserelle and Allis 2022), we have applied a series of SLR increments to forecast future coastal flood hazard which encompass a range of future sea level scenarios. This is the approach recommended in MfE (2017) as part of a Dynamic Adaptive Planning Pathways (DAPP) approach because there is deep uncertainty about the actual trajectory of SLR as it depends on political and public efforts to restrain emissions globally. We used the four SLR scenarios from MfE (2017), which are based on three greenhouse gas representative concentration pathways (RCP2.6, RCP4.5 and RCP8.5). The fourth, higher scenario is at the upper-end of the “likely range” (i.e., 83rd-percentile) of the wide ensemble of SLR projections based on emission scenario RCP8.5. This scenario is called ‘H+’. This higher H+ scenario reflects the possibility of future surprises (deep uncertainty) towards the upper range in SLR projections of an RCP8.5 scenario.

Table 4-1: Approximate years when specific sea level rise increments could be reached for various projected scenarios of sea level rise for wider New Zealand. SLR expressed in metres above 2020 mean sea level. Bold shows SLR increments mapped in this project. Reproduced from Bosserelle and Allis 2022).

SLR	NZ RCP2.6 *M* (median)	NZ RCP4.5 *M* (median)	NZ RCP8.5 *M* (median)	NZ *H*$^+$
0.0	**2020**	**2020**	**2020**	**2020**
0.1	2040	2038	2037	2033
0.2	2062	2057	2051	2044
0.3	2082	2073	2063	2054
0.4	2104	2089	2074	2062
0.5	**2126**	**2105**	**2083**	**2070**
0.6	2148	2121	2092	2077
0.7	>2150	2136	2100	2084
0.8		2150	2107	2091
0.9		>2150	2115	2097
1.0			**2123**	**2104**
1.1			2131	2111
1.2			2140	2117
1.3			2148	2123
1.4			>2150	2129
1.5				**2135**
1.6				2141
1.7				2146
1.8 – 2.0	**>2150**	**>2150**	**>2150**	**>2150**

For this analysis, we have mapped coastal flood levels including increments of sea level rise from 0 m to 2 m above present day mean sea levels in 0.5 m increments (Figure 4-1). This mapping uses the same bathtub mapping approach as applied in Section 2.1.3. The projected timing for sea level rise to reach these increments is uncertain and depends on future global emissions. The range of timings is presented in Table 4-1.

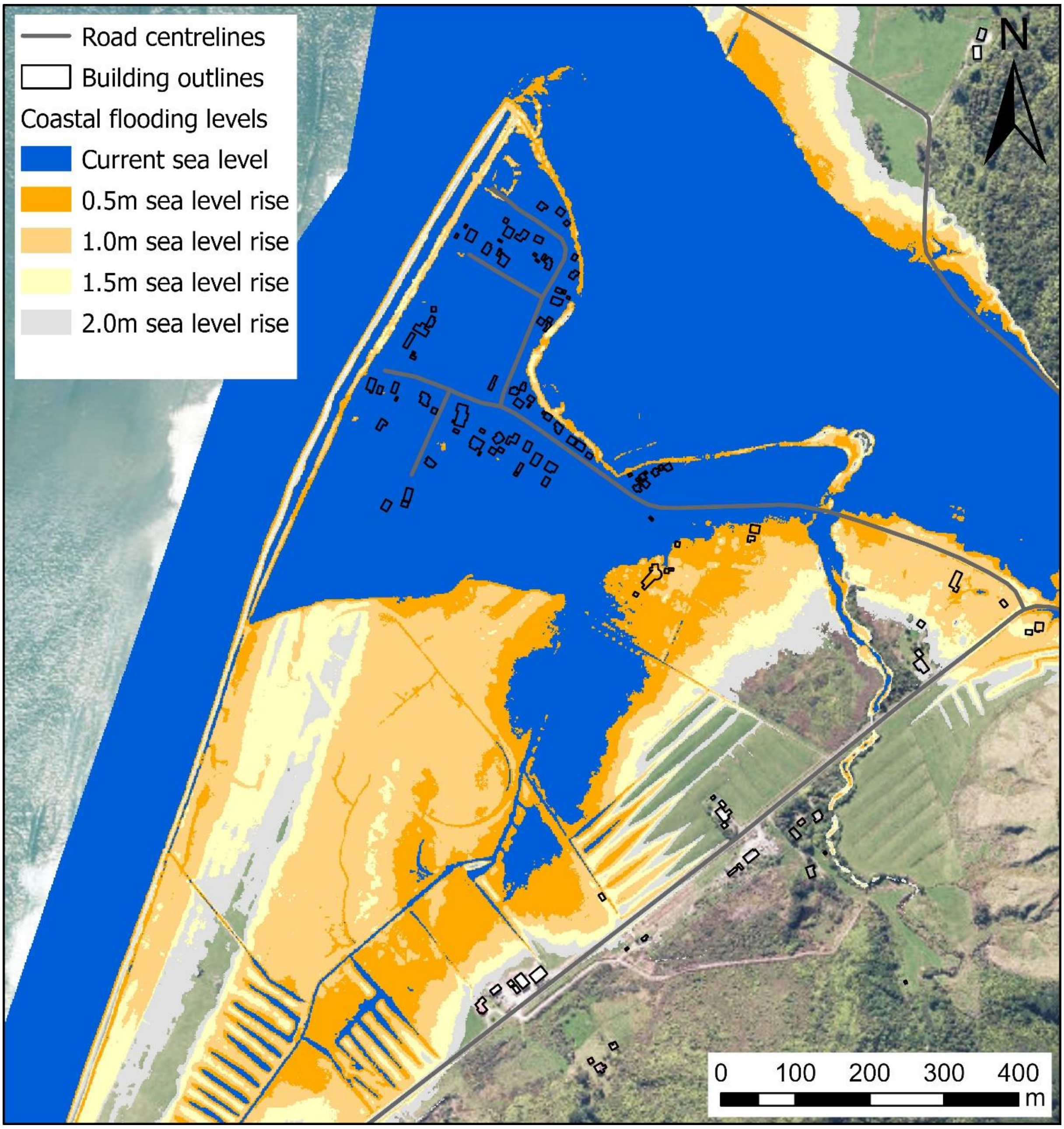

Figure 4-1: Land below the 1% AEP extreme sea level considering different amounts of sea level rise. The flood extent is calculated using a simple "bathtub" approach, horizontally propagating water levels across the floodplain (land elevations from 2007 LiDAR survey). Flood levels represent the 1% AEP flood + sea level rise. The 1% AEP flood level equals 3.11 m NZVD2016 for current sea level and includes astronomic tide, storm surge and wave setup (see Section 2.1.3).

As well as increasing flood risk, it is well established that sea level rise also accelerates coastal erosion. Hicks et al (2007a) investigated the potential impacts of sea level rise on coastal erosion at

Mokihinui settlement and concluded an acceleration of sea level rise to 5.5 mm/year would result in an additional 0.4–0.5 m/year of coastal erosion at Mokihinui Township.

Another impact of sea level rise is likely to be bed level increase (i.e., deposition) in the lower reaches of the Mōkihinui River. Sea level rise increases low and high tides equally, increasing water depth and reducing river velocities, which then promotes deposition. This deposition will occur in the main channel as well as in the already depositional areas in front of the outfall culverts under the river stopbank. Both increased river levels (causing more frequent and longer duration closure of the flap valves) and increased deposition (blocking drainage from the culvert outlets) will reduce the effectiveness of the culverts and increase flood risk behind the stopbanks.

4.2 Rainfall

Climate change is projected to increase the intensity of severe rainfall events. The high intensity rainfall design system (HIRDS, NIWA 2019) provides guidance on the expected changes to rainfall intensity because of climate change. As for sea level rise, the degree of change in rainfall intensity depends on future greenhouse gas emissions and has been assessed for a range of possible future scenarios.

For the period of 2031–2050, severe 1–6 hr duration rainfall intensities (likely to be the critical duration for causing flooding from the local catchments and land drainage) are projected to be approximately 5 to 10% heavier than historic rainfalls with the equivalent probability of occurrence. For the period of 2081–2100, severe rainfall intensities are projected to be 6 to 30% heavier than historic. This range reflects the different emissions scenarios.

4.3 Mōkihinui River flow

The effect of climate change on river flows is complex, but in general it is expected that climate change will increase the severity of floods. No modelling has simulated the impacts of climate change on flood flows in the Mōkihinui, but modelling has been conducted for the adjoining Buller River Catchment to the south (Zammit 2022). Predictions for the Buller River are that flood flows with a 1% annual exceedance probability (100-year return period) will increase by approximately 10 to 30% by 2100.

5 Options for improved flood mitigation

Various ideas have been suggested to help mitigate the impact of flooding on Mokihinui Township. In this section, we consider the feasibility of a range of options.

5.1 Pumps

Temporary pumps to discharge excess water from the township to the Mōkihinui River have been suggested as a method of maintaining drainage when the culverts are not draining freely due to high river levels, there is sediment build-up in front of the culverts, or flows are greater than the culvert capacities.

The main issue which affects the feasibility of using pumps to mitigate flooding is the capacity of pumping which would be required. Mean annual flood flows in the Township Catchment (moderate flood flows which are exceeded about once every 2.3 years) are estimated to be 6.8 m^3/s (Table 2-3). This flow is equivalent to 24,480 m^3/hour. The largest commercially available pumps for hire (150–200 mm diameter pipe) have a capacity on the order of 2,000 m^3/hour, so it would take 10 or more hours to discharge the volume of water which could accumulate in 1 hour (for example over the peak of the tide if river levels caused the flap valves to close). During more severe floods with higher flow rates, this imbalance between pump capacity and stream discharge is even greater.

There may still be some benefits to temporary pumps for facilitating rainfall drainage of the township area provided the Township Catchment stream does not spill into the township. For example, if one or both of the minor culverts (B in Figure 3-3) is blocked due to sediment build-up but the main BDC culvert (A in Figure 3-3) is able to convey flows from the Township Catchment stream then a pump would only need to cope with rainfall entering the small area of the township itself (approximately 10 ha). 2,000 m^3/hr pumping capacity for this 10 ha catchment is equivalent to 20 mm/hr runoff, indicating that commercially hired pumps could be effective for local drainage. However, local drainage is not the main cause of ponding behind the stopbanks, so having a pump only capable of managing this source of flooding has relatively small benefit.

Hired pumps are unlikely to be effective at mitigating flooding from the Township Catchment stream. Installing and maintaining larger capacity pumps is likely to be prohibitively expensive. As such, investment in pumps is not recommended.

5.2 Culvert improvements

The main culvert under the Mōkihinui River stopbank (A in Figure 3-3) was unable to convey the full flood flows from the Township Catchment during the flood events in July 2021 and February 2022. Increasing the capacity of this culvert could be an option to help mitigate flooding.

If upgrading the culvert, consideration should be given to:

- Sizing the culvert (or culverts, if additional culverts are constructed) such that it can pass the full estimated flood flows for the Township Catchment (Table 2-3), which is likely to require a significantly larger culvert than currently installed.
- Designing the culvert to minimise the risk of debris jamming in the flap valve and allowing backflow from the Mōkihinui River.

- Checking and potentially increasing the capacity of the farm culverts immediately upstream of the stopbank and the bund culvert on the channel downstream of the stopbank (D in Figure 3-3).

Increasing the capacity of the main culvert under the Mōkihinui River stopbank would reduce the likelihood of flooding from the Township Catchment (the cause of the two recent floods) and is recommended.

There is still a residual risk of flooding from the Township Catchment due to high stream flows coinciding with high Mōkihinui River water levels (due to a main river flood or high tide/storm surge). The frequency and duration with which the culvert flap valve is closed are likely to increase with sea level rise.

Another issue during the February 2022 flood was the farm culvert on Chatterbox Stream located downstream of the highway bridge (Figure 2-7). This culvert remains highly vulnerable to debris blockage which can then divert water from Chatterbox Stream towards the township. Modifying this culvert to mitigate this risk is recommended. Modifications could include one or more of:

- Replacement of the existing twin culvert with a larger single culvert more able to pass debris (similar to the highway culvert upstream).
- Replacement of the culvert with an appropriately designed ford.
- Removal of the culvert (i.e., no crossing point over the stream, alternative routes used to access land either side).
- Moving the culvert downstream to a location where blockage is less likely to divert water into the Township Catchment.
- Increasing bank height on the true right to prevent spill into the Township Catchment (blocking the low spot/drainage channel on the true right of Chatterbox Stream between the highway and farm culverts).

Modification of the Chatterbox Stream farm culvert would reduce the likelihood of Chatterbox Stream causing flooding of the township and is recommended.

5.3 Additional stopbanks

Constructing additional stopbanks/bunds to protect the properties from flooding of the Township Catchment was considered. A potential stopbank alignment is shown in Figure 5-1. Stopbanks would need to stretch from the high terrace downstream to the main Mōkihinui River stopbank, with the intention of preventing spillage from the stream into the township.

Issues or risks associated with additional stopbanks are:

- **Flood storage volume**
  There is relatively little storage volume inside the alignment of the new stopbanks. The alignment shown in Figure 5-1 encloses an area of approximately 12,000 m^2. Assuming a 1 to 1.5 m high stopbank (the terrace is only ~1.5 m high so a higher stopbank would need to be considerably longer), this could store a maximum flood volume of 12,000 to 18,000 m^3. During a mean annual flood (peak flow approximately 6.8 m^3/s, see Table

2-3) this area could fill and overtop if the culvert flap valve was closed for 30 to 45 minutes.

- **Drainage from behind stopbanks**
  The stopbanks would impede drainage from the township into the stream. For the area to the east of the stream, there would be no drainage unless a culvert (with flap valve) was provided. The main township to the west of the stream would become totally dependent on the two smaller piped outlets (B in Figure 3-3). In the event of coastal flooding (e.g., erosion of the sacrificial bund and waves spilling over the secondary stopbank), drainage of this floodwater into the stream would be prevented. In this situation, the smaller piped outlets would likely be insufficient, and the presence of additional embankments would increase flood depth and hazard.

- **Potential for spill into the township area from upstream of the stopbanks**
  Whilst the stopbanks would protect against the most common spill path from the Township Catchment stream, it is still possible for floodwater to spill out of the upstream reach, flowing across the high terrace and causing flooding in the township area.

Overall, there could be some benefits from construction of stopbanks. However, due to the issues and risks identified above, they are not recommended. Improvements to the existing culverts is the preferred method of mitigating risks from the stream.

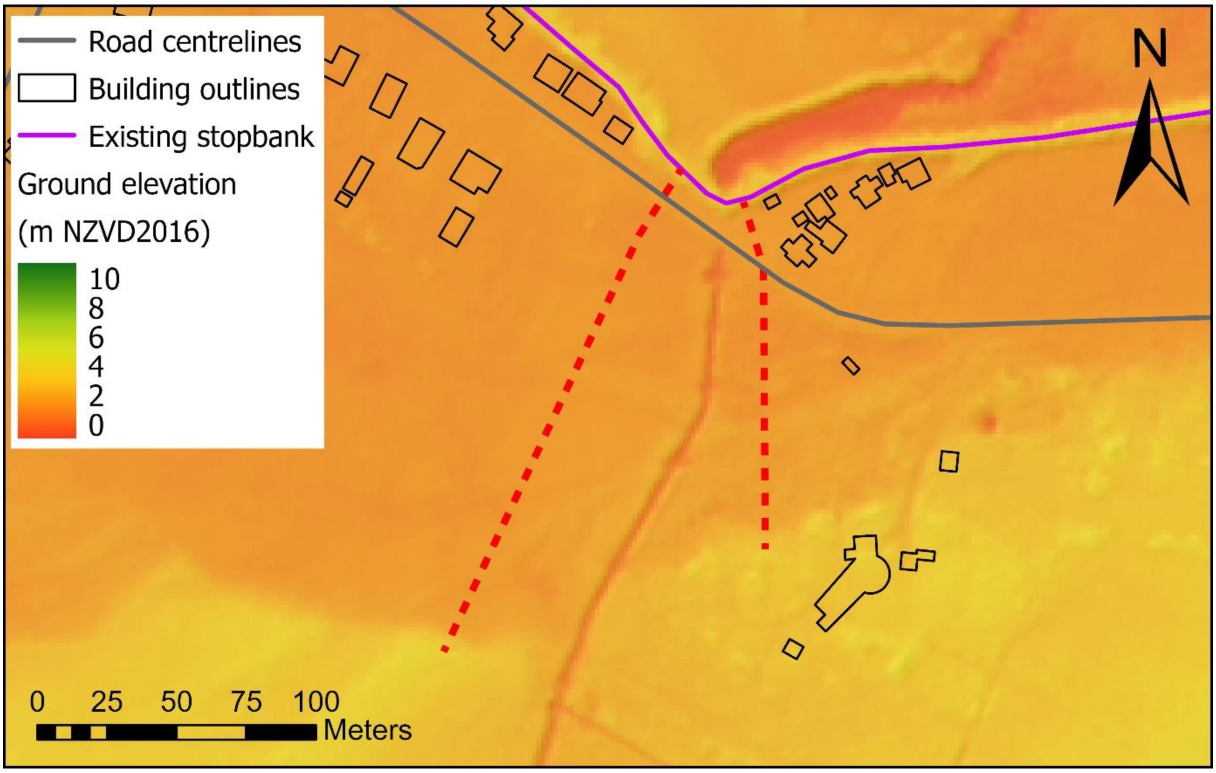

Figure 5-1: Hypothetical stopbank locations to provide additional protection from Township Catchment stream. Stopbank locations indicated by dashed red lines. Background imagery shows ground elevation (derived from LiDAR).

5.4 Modifications to reduce sediment deposition around outfalls

Sediment deposition around the outfalls requires continual maintenance and can cause blockages leading to flooding (Section 3.2). Removal or modification of the deflector groyne (C in Figure 3-3) has the potential to reduce deposition, however the deflector groyne has proven to be effective at maintaining the alignment of the river mouth and preventing erosion of the Mōkihinui River stopbank.

The construction of the bund and culvert across the channel leading to the main culvert on the Township Catchment stream appears to have been effective at helping reduce the rate of siltation in this channel.

Removing or modifying the deflector groyne is not recommended as this carries the risk of making the river stopbank vulnerable to erosion during river floods. I can think of no other modifications which will help reduce sediment build-up.

Ongoing maintenance of the culvert outlets is needed to maintain effective drainage from the township area. Sea level rise is likely to gradually increase the amount of deposition (and hence maintenance requirements).

5.5 Reduced exposure

As well as physical measures to prevent flooding, another method of reducing the impact of flooding is to reduce the exposure of buildings by increasing floor levels, or by relocating buildings to higher ground (managed retreat). One major advantage of reducing exposure is that, unlike other options, it can be effective at reducing or eliminating flood risk from all sources (e.g., coastal, Mōkihinui River and local catchments).

Restricting new development of the low-lying area is recommended to prevent new assets being constructed in such a high-risk location.

Raising floor levels is recommended as a method for individual property owners to reduce risk. The cost and feasibility of this approach is likely to be dependent on building design. Raising floor levels can be a very effective way to reduce the damages of flooding.

Managed retreat is much more expensive in the short term but is the most effective way of managing risk and has the benefit of reducing the requirement for costly ongoing maintenance of flood defences. It is notable that there are areas of land near Mokihinui Township which are significantly higher the current settlement and have much lower flood risk. The higher terrace (B in Figure 3-1) is 200–500 m from existing properties and approximately 1.5 m higher than the land around most of the existing buildings in the township. Some areas of the terrace still have some exposure to flood risk beyond 2100 under higher emissions climate change scenarios (see Section 4.1), but these risks are much lower than at the current township location (and parts of the terrace are above even the most extreme 2150 sea level rise projections).

Managed retreat should be considered as a long-term option for managing increasing flood and coastal erosion risk in the face of sea level rise. Planning ahead such that if or when properties require major renovation or repair (either because of a general need for maintenance, or because of flood damage), the option to move is available, would help minimise the costs associated with retreat. Undertaking the discussions and planning to identify a suitable location and consider the details of how retreat could take place (including consideration for timescales/triggers, and how it could be funded) is recommended. Managed retreat is also one of the best ways to reduce exposure to flood risk while working alongside river and coastal processes.

6 Conclusions and Recommendations

6.1 Flood risk

There are multiple sources of flooding which threaten Mokihinui Township: coastal flooding, Mōkihinui River flooding, and flooding from the small local catchments. The recent flood events of 2021 and 2022 were caused by runoff from the local catchments overwhelming the capacity of the culverts through the stopbank and causing ponding in the township area.

Flooding from the Mōkihinui River or sea has the potential to cause higher flow velocities and greater hazard than flooding from the local catchments. In the event of stopbank overtopping or failure, deep and high velocity flood water could enter the township. The township has been flooded numerous times from these sources, mostly prior to the construction of flood defences. The largest river floods since flow measurement commenced in 1972 were in 1973 and 2010. It is notable that these events both peaked close to low tide, indicating that flood levels could have been significantly higher if the timing of the tide relative to peak flow had been different.

Flood risk from all sources is exacerbated by the location of the township on the most low-lying part of the floodplain. Any water entering the floodplain which cannot escape via the culverts and piped outfalls under the river stopbank will cause ponding in the area around the township. The effectiveness of these outfalls is reduced by sedimentation on the river side of the stopbank and by high water levels in the river causing the culvert flap valves to close.

Sea level rise poses a major threat to Mokihinui Township by:

- Increasing the rate of coastal erosion, making it more difficult to maintain the sacrificial bund and secondary stopbank.
- Increasing the likelihood of the coastal bund overtopping during storms and increasing the potential damage if this does occur.
- Increasing the likelihood of the Mōkihinui River stopbank overtopping (as sea level risk will also lift river flood levels adjacent to the township).
- Reducing the effectiveness of the culverts draining the township due to increased sedimentation and more frequent closure of the flap valves.

6.2 Mitigation

To reduce the risk of flooding from local catchments, it is recommended to:

- **Modify or remove the twin barrel farm culvert on Chatterbox Stream immediately downstream of the highway.** These culverts are currently highly vulnerable to blockage and can cause Chatterbox Stream to spill toward the township (as happened in February 2022).
- **Upgrade the Township Catchment stream culvert under the river stopbank.** Upgrading this culvert to improve its capacity to pass the full flood flow of the Township Catchment will reduce the risk of floodwater spilling into the township.
- **Frequent inspection and maintenance of the flapped culvert/outfall discharge points.** The outfalls are vulnerable to sediment build-up which can impede drainage and

increase flood risk. Inspection prior to forecast heavy rain (i.e., orange/red heavy rainfall warnings) and following Mōkihinui River floods (which could cause sedimentation) is recommended, with urgent clearance when necessary.

- **Survey stopbank crest levels (river and coastal) and top-up where necessary.** There appears to be at least one low spot in the river stopbank where it is crossed by a vehicle track. Checking and rectifying any low spots will help reduce the risk of overtopping.

6.3 Longer-term planning

The location of Mokihinui Township is highly vulnerable to flooding and this risk is likely to increase in the future (due to climate change).

It is recommended that new development in the low-lying area of the township be restricted. There are locations nearby (within a few hundred metres) where land is 1.5 or more meters higher than the current township.

Raising floor levels is recommended as a method for individual property owners to reduce risk. The cost and feasibility of this is likely to be dependent on building design. Raising floor levels can be a very effective way to reduce the damages of flooding.

It is recommended that managed retreat be considered as a longer-term option to manage flood risk. Undertaking the discussions and planning to identify a suitable location and consider the details of how retreat could take place (including consideration for timescales and triggers, and how it could be funded) is recommended.

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