PREVENTING FLOOD DISASTERS – A BETTER OPTION THAN CREATING THEM

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ABSTRACT

Christchurch desperately needs new affordable housing for families displaced by the 2010 and 2011 earthquakes. Gravel deposits on the alluvial fans of the large north Canterbury rivers provide attractive building sites in terms of foundation conditions with a low risk of liquefaction. However, the fact they are alluvial fans means that a river has flowed there at some stage in the past. We will present a case study of the flood hazard assessment that was undertaken for an 80 hectare residential development in close proximity to the Cust Main Drain, which in name might sound rather innocuous but in fact has flood flows in excess of 200 m^3/s.

The Cust Main Drain has stopbanks on both sides that are built to a height in excess of a 2% annual exceedance probability flood event. So sounds like it's already protected? Go ahead and start building? NO!! It was exactly this type of thinking that Neil Ericksen highlighted as flawed in his 1986 report "Creating Flood Disasters?" The "protection" provided by stopbanks encourages intensification of development on floodplains due to the perceived protection which they provide and the risk actually increases. Our assessment of flood risk at the proposed development site was based on considering two key questions - What would happen if the stopbanks failed? What would happen if a flood larger than expected occurred?

KEYWORDS

2D hydraulic modelling, stopbank failure, flood hazard, residual risk, floodplain management.

PRESENTER PROFILE

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1 INTRODUCTION

The development of new housing in Christchurch has been a priority for district, regional and central government since the September 2010 and February 2011 earthquakes. A number of subdivisions have had consents fast tracked and there is a particular urgency to provide housing for those living in red zoned areas.

Pattle Delamore Partners Ltd (PDP) has recently assessed the flood hazard for a proposed subdivision located to the north west of Kaiapoi Township (Silverstream Estates). The site is located on alluvial material and therefore has a very low liquefaction risk, no doubt an attractive proposition to prospective buyers from red zone areas.

To ensure residents relocating to these new subdivisions are not simply swapping an earthquake hazard for a flood hazard, we assessed two key questions:

- what happens if the stopbank fails? and,
- what happens if the design flood is exceeded?

The Silverstream Estates site was historically (pre 1868) an island in the Waimakariri River channel. Currently the Waimakariri River is bounded by stopbanks to prevent overland flooding. Secondary stopbanks are located on the Eyre River, and also serve to direct any floodwater that does breakout from the Waimakariri River, back into it. The Kaiapoi River flows longitudinally through Silverstream Estates whilst the confluence of the Kaiapoi River, Ohoka Stream and Cust Main Drain is located on the north-west corner of the site. Of the three waterways, the Cust Main Drain is the largest, draining a catchment area of around 200 km^2 (Figure 1). The lower reaches of the Cust Main Drain include stopbanks which are designed to contain the 2% AEP event

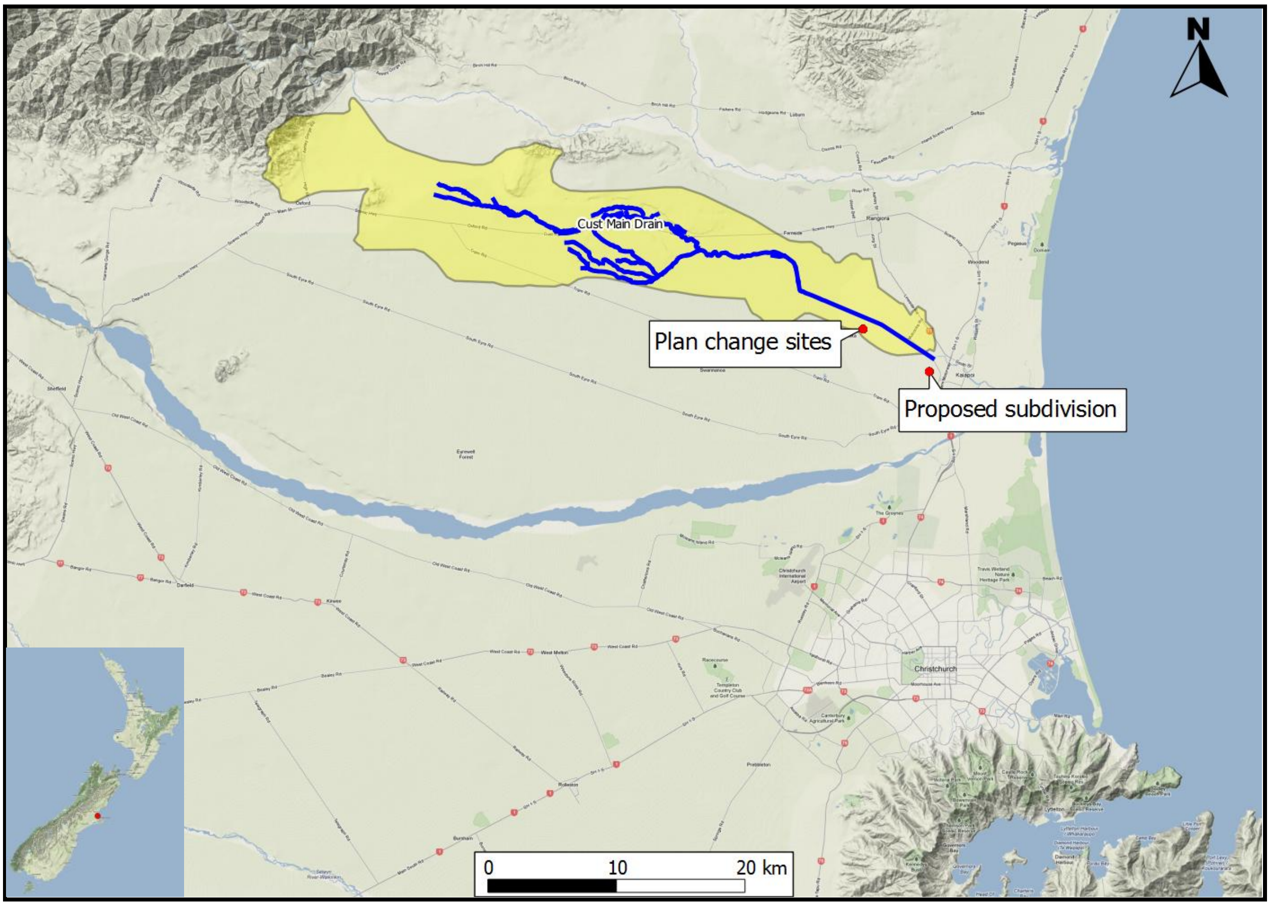

Figure 1: Location of plan change sites and proposed subdivision, with the Cust Main Drain catchment highlighted in yellow.

2 THE PROBLEM

PDP's role was to determine minimum floor levels and ensure that any recommendations to mitigate flood risk (such as raising ground levels) had minimal offsite impacts.

"Flood risk" is a product of probability of occurrence and consequence. Ericksen (1986) demonstrated that a reduction in the probability of flood occurrence, through the use of structures such as stopbanks, leads to a perception of safety. This in turn increases the desirability of an area for development, and the resulting intensification then increases the flood risk, given that the consequences of a flood would be greater. The post stopbank flood risk will return to, or exceed, the pre stopbank risk.

Waimakariri District Council (WDC) is the local authority responsible for considering building consent applications. WDC indicated a willingness to accept ground levels set at the 2% AEP flood event with suitable freeboard for the floor levels. This is consistent with clause E1.3.2 of the Building Code, which all new building work must comply with:

> *"Surface water, resulting from an event having a 2% probability of occurring annually, shall not enter buildings."*

2.1 THE EASY SOLUTION

The minimum floor levels must be above the 2% AEP flood event, with an allowance for freeboard. Figure 2. shows the LiDAR imagery for the northern half of the site (shaded), and the stopbanks which protect the Silverstream Estates from Cust Main Drain flood flows.

Environment Canterbury (ECan) confirmed that the stopbanks are designed to contain the Cust Main Drain 2% AEP flood event.

However, it should not be assumed that the stopbanks will perform to their design capacity; the risk of the stopbanks failing also needed to be considered. Failure mechanisms could include:

- the channel becoming blocked, causing the stopbanks to overtop;
- an increase in river flow as a result of climate change, leading to a reduced channel capacity; and,
- piping failure instigated by rabbit warrens, stock damage, vegetation or inadequate design/construction.

Other factors to consider include that:

- intensification behind the stopbanks will increase the flood risk given the greater consequences of flooding. Where there used to be rural land (low flooding consequence) there will be residential housing (high flooding consequence);
- There is a residual risk associated with failure of the stopbanks;
- There are two other streams (the Ohoka Stream and the Kaiapoi River) that are both constricted by bridges. If the bridges have insufficient capacity, then the

water level will increase to the elevation of the stopbanks before it can spill over. In this instance, the stopbanks would act as a dam, preventing water from leaving the subdivision area; and,

- The Eyre River is located about 10 km to the southwest of Silverstream Estate, and has stopbanks which could potentially fail. Given that Silverstream Estates is an old island of the Waimakariri River, it is likely that any stopbank failure would lead to flow traversing through the subdivision, putting further strain on the conveyance of the two bridges.

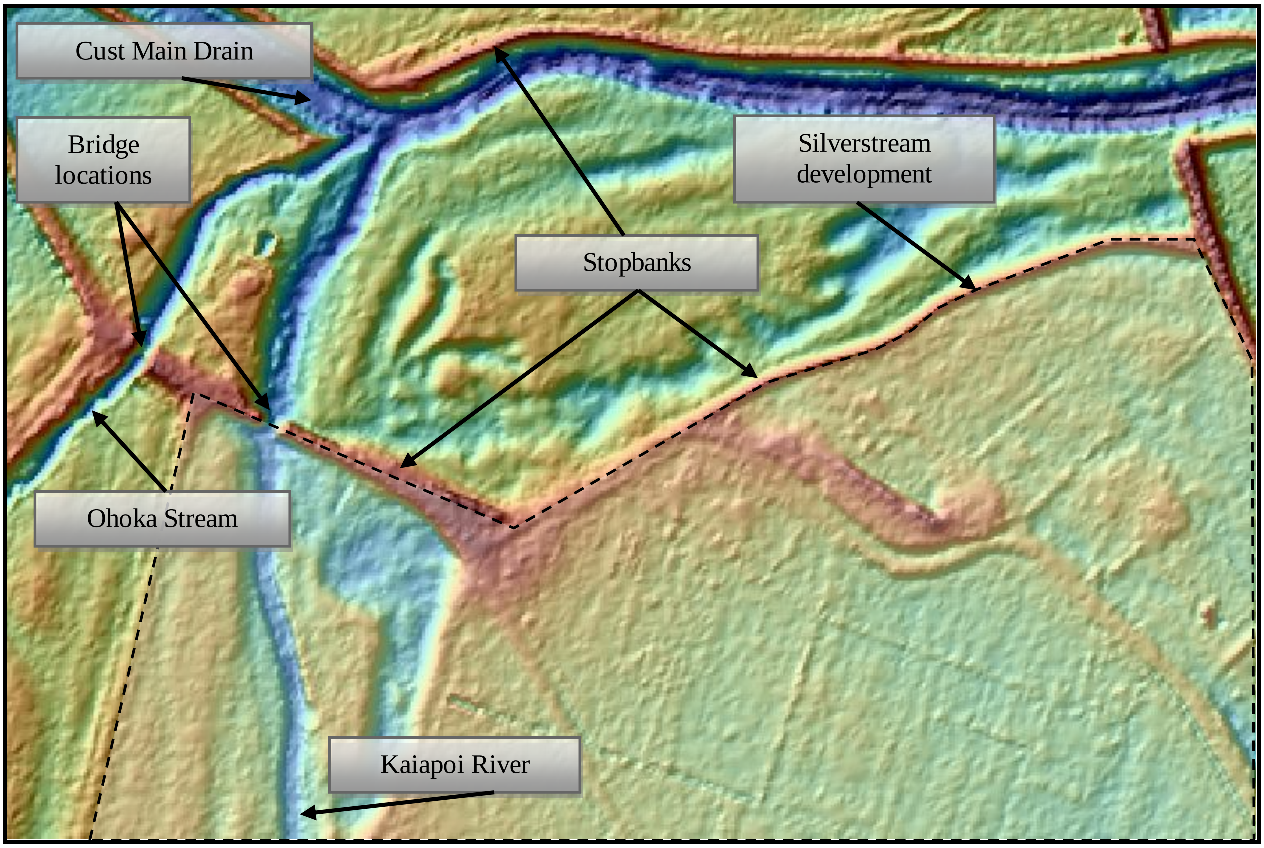

Figure 2: LiDAR imagery for Northern Area of Silverstream Estates, red is land with a high elevation and blue is land with a low elevation

2.2 THE ROBUST SOLUTION

To analyse how WDC requirements could be met, PDP built an integrated 1D-2D model of Silverstream Estates and the contributing catchments. This model was used to identify the water elevations caused by various flooding scenarios and so assist in setting recommended minimum floor levels.

2.2.1 PREVIOUS FLOOD STUDIES

Prior to undertaking any modelling, we first sought to understand the hydrology and hydraulics of the area. Numerous flood studies within the area had been completed which contributed to the understanding of the flood mechanics. This included a study by ECan on the potential effects of a breakout from either the Ashley River or the Waimakariri River, a rapid flood hazard assessment by DHI Water and Environment Ltd (DHI) and a 1D model of the Cust Main Drain by ECan.

Previous work completed by ECan (Oliver, 2008) considered the breakout of the Ashley River. Approximately 25% of the total flow was assumed to break out of the Ashley River during the 0.5% AEP flood event. This was tested for different locations with the most adverse flooding effects resulting in a floodwater level of 3.6 mRL on the Silverstream Estates site. A similar breakout scenario was assessed for the Waimakariri River but was shown not to impact on the Silverstream Estates site. This highlighted the need to consider a breakout event from the Eyre River.

DHI undertook a rapid flood hazard assessment of the area between the Ashley and Waimakariri Rivers to produce approximate flood hazard maps for use by WDC for strategic planning purposes. The considerable area to be analysed was divided into manageable catchments. One of these catchment boundaries runs through the Silverstream Estates site, along the eastern boundary of the Kaiapoi River. For the purposes of the Rapid Flood Hazard Assessment, the catchments were assumed to not be hydrologically connected. The model predicted 1% AEP flood levels of between 4 mRL and 4.5 mRL across the western catchment, which Silverstream Estates is within. The catchment to the east did not show any significant flooding onsite. Given that the elevation of the boundary between these two catchments is as low as 3.6 mRL, it is likely that the two catchments are hydrologically connected. This was taken into consideration when delineating catchment boundaries and identifying flood flow contributions from catchments.

ECan (Boyle, 2009) completed hydraulic analysis of the Cust Main Drain in September 2009. The purpose of this study was to investigate why the Cust Main Drain was so close to capacity from a flood peak (94 m^3/s) that was well below its design discharge (184 m^3/s). The study found that vegetation growth, which led to increased channel roughness was responsible for the higher than expected water levels.

The existing information indicated that the minimum floor level would be at least 3.6 mRL (based on the Ashley breakout) and based on the Rapid Flood Hazard Assessment, potentially as high as 4.5 mRL. The mean reduced elevation of the site prior to any earthworks was 3.06 mRL so the volume of fill required to ensure that minimum floor levels were acceptable was likely to be significant.

The MIKE11 model (Boyle, 2009) demonstrated that the capacity of the Cust Main Drain to convey the 2% AEP flood event cannot be taken as guaranteed, and the possibility of banks overtopping should be considered.

2.2.2 HYDROLOGY

The flat nature of the catchments makes separating them difficult, particularly for large flood events, where flood flows could be expected to flow across these boundaries. The largest catchment is Cust Main Drain (identified in Figure 3) which is close to four times the combined catchment size of the Ohoka Stream and the Kaiapoi River (200 km^2 vs 55 km^2). At this stage it seemed reasonable to assume that majority of the floodwater will travel within the stopbanks of the Cust Main Drain, leaving Silverstream Estates largely unaffected.

Figure 3 shows catchments as identified by ECan's online GIS database. There are two other catchments between the Ashley River and the Waimakariri River that may also contribute floodwater to Silverstream Estates, the Eyre River Catchment and the Waimakariri Water Race Catchment. Closer inspection shows that the Eyre River is a tributary of the Waimakariri River and therefore does not generally contribute to flooding on Silverstream Estates. The Waimakariri Water Race does not drain directly to a permanent watercourse. Rather, it consists predominantly of a large network of stockwater, irrigation races and drains, a number of which terminate at the Old Burrows Pit. The flood hazard assessment performed by DHI (Anese & Whyte, 2010) showed floodwater flowing from the Waimakariri Water Race catchment traversing predominantly into the Ohoka and Kaiapoi catchments. The catchment size of the Waimakariri Water Race is approximately 82 km^2, bringing the catchment area upstream of the two bridges (Figure 2) on the Kaiapoi River and Ohoka Stream to a total of 137 km^2, similar to that of Cust Main Drain.

Whilst the Cust Main Drain stopbanks provide protection against floodwaters within the Cust Main Drain, they also act as a dam, effectively preventing any water that accumulates, from leaving the Silverstream Estates area. Given that the only outlet for floodwater is via either one of the bridges on the Ohoka Stream or Kaiapoi River, there is a risk that the capacity of these bridges will be exceeded and water will begin to pond behind the stopbanks. Excess floodwater will not be able to escape until the floodwater elevation exceeds that of the stopbanks.

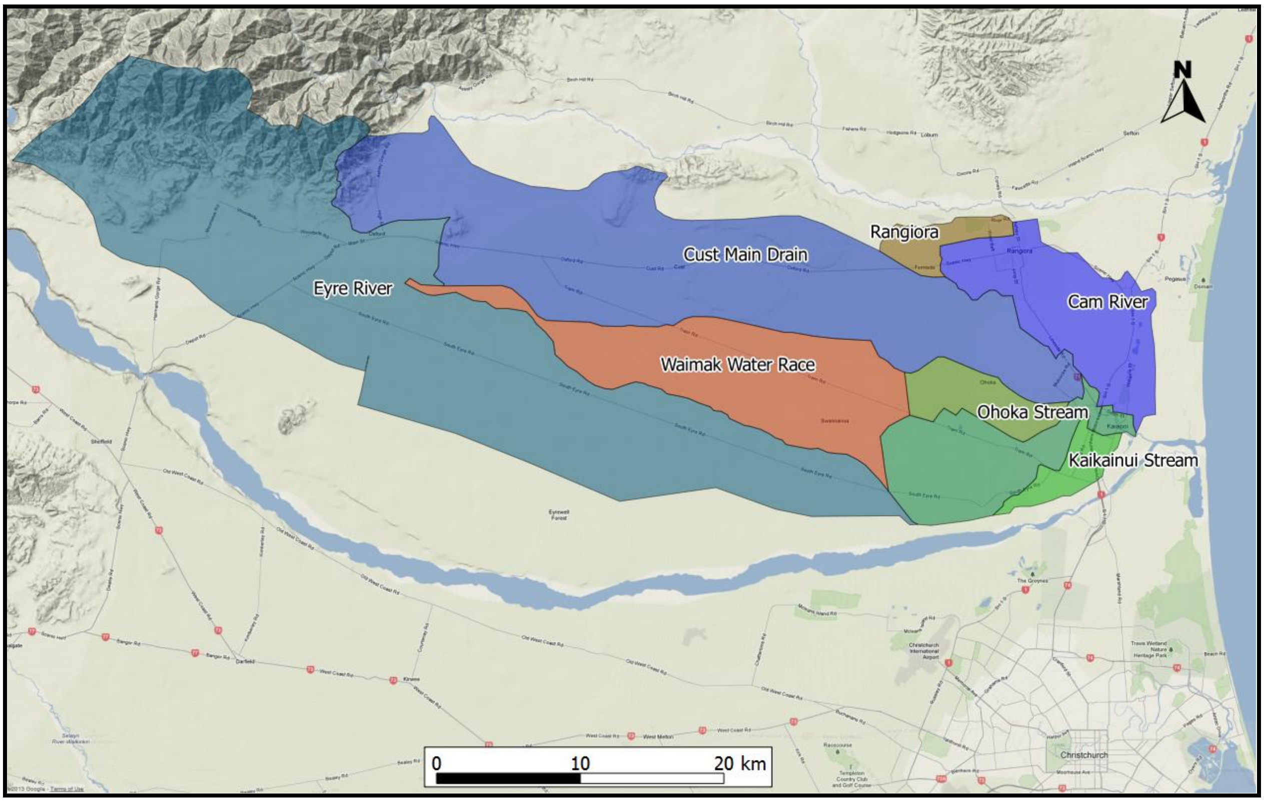

Figure 3: Potential catchments delivering floodwater to Silverstream Estates

2.2.3 MODEL BUILD

Due to the flat nature of the site and the complexity of the overland flow paths it was decided that a linked 1-D/2-D hydraulic model would provide the most accurate information for estimating flood levels on the site.

To ensure an acceptable flood risk, whilst also ensuring that the flood risk to surrounding properties is not increased, a number of pre and post-development events and scenarios were modelled, including:

- 2% AEP flood event with varying contributions from the Waimakariri Water Race Catchment, used to set the minimum ground level; and,
- 0.5% AEP flood event with and without a stopbank failure on the Eyre River, this was used to gain an indication as to what a suitable freeboard might be.

The 1-D/2-D model combines the land surface, river channels, surface and vegetation roughness, river inflows and downstream boundary conditions to estimate the depth of flooding for various scenarios. The 2-D software package used was Tuflow, which solves the free surface flow using two-dimensional shallow water equations.

The land surface was represented by a 5 m x 5 m grid developed from LiDAR data supplied by WDC. The river channels were included as dynamically linked 1-D elements represented by typical cross sections. This included the Cust Main Drain and Kaiapoi River downstream of the Kaiapoi River and Cust Main Drain Confluence.

The roughness characteristics for the 2-D domain were obtained from ECan. They were supplied as a 10 m x 10 m grid with each cell having a unique roughness value.

The downstream boundary of the model was located at the confluence of the Kaiapoi River and Waimakariri River. This was represented by a sinusoidal wave representing a typical tidal cycle. The peak (high tide) was set at 2.3 m, which represents coincidence of a spring tide, a mean annual flood in the Waimakariri River plus a 0.5 m increase in sea level to allow for the effects of climate change.

The river inflows were represented by hydrographs. Long term hydrological information was available for the Cust Main Drain at the Threlkelds Road water level recorder (Ref. 66417). At the time of analysis, the site had 26 years of data (1980 to 1986 and 1991 to 2011).

A regional flood frequency method was then employed to estimate peak flows for the other catchments. The flow record for the Cust Main Drain was analysed to obtain a typical flood hydrograph; this was then scaled by the peak flow of the respective catchment to obtain a representative hydrograph.

2.2.4 RESULTS AND DISCUSSION

Figure 4 shows the locations where floodwater elevations were extracted from the model results. Table 1 shows the peak floodwater elevations at three locations on the perimeter of the development site. The 2% AEP flood event results in water elevations of 4.0 mRL at the northern end of the site, and 4.1 mRL at the southern end of the site (recall that the elevation of the embankment at the southern end of the site is approximately 4.0 mRL). Depending on the coincidence timings between the Cust Main Drain and the Ohoka and Kaiapoi Rivers, the flood water elevation on the Silverstream side of the stopbanks could be up to 0.5 m higher than the flood water elevation on the Cust Main Drain side. This occurs because the stopbanks effectively act as a dam embankment, preventing the escape of any flood water except via either the Kaiapoi Bridge or the Ohoka Bridge. The lowest elevation of the stopbanks is approximately 4.2 mRL but generally the elevation is closer to 4.4 – 4.5 mRL.

Depending on hydrograph timings, the stopbanks were found to be counterproductive, preventing the dispersal of floodwaters, and increasing water elevations on the development side of the stopbanks by up to 0.5 m. Given that the site lies on an island that was once the watercourse of the Waimakariri River, there is a strong possibility that if a stopbank failure occurred on the Eyre River, the floodwaters would flow into the

Kaiapoi River, across the Silverstream Estates site. In this scenario, the stopbanks would be a hindrance, and cause a buildup of flood waters. Modelling of this scenario shows that water elevation builds up to 4.4 mRL, at which point the elevation of the majority of the stopbanks is exceeded.

Given the above, PDP recommended a minimum floor level of 4.4 to 4.5 mRL. This floor level is generally greater than the elevation of the stopbanks, so protecting houses not just in the event of a stopbank failure, also when the stopbanks prevent the escape of floodwater.

Figure 4: Aerial view of the proposed development site and locations where water elevations were extracted from the model results.

Table 1: Summary of peak flood elevations			
AEP Flood Event	Ohoka Bridge (on Island Rd)	Kaiapoi Bridge (on Island Rd)	Ford crossing between Island Rd and Giles Rd
2%	4.0 mRL	4.0 mRL	4.1 mRL
1%	4.1 mRL	4.1 mRL	4.2 mRL
0.5%	4.2 mRL	4.2 mRL	4.3 mRL
0.5% + Eyre River Breakout	4.4 mRL	4.4 mRL	4.4 mRL

3 CONCLUSIONS

Stopbanks cannot be guaranteed to perform as per their intended design; there are numerous failure mechanisms that can occur. In particular, stopbank failure should always be considered where the consequences of failure are particularly high. The construction of a stopbank does not ensure protection for buildings on the other side. Furthermore, in some instances, stopbanks may prevent flood water from dispersing and act as a dam.

It is good practice to base freeboard on a larger than expected flood event, rather than just choosing a number such as 300 mm. In this instance, we considered the 0.5% AEP flood event, which coincidentally, produced a freeboard of 300 mm. It is useful to check the model performance for an event that exceeds the design capacity. Whilst some failure is permitted and even expected for such an extreme event, it is important to ensure that such failure is not likely to lead to catastrophic consequences, such as loss of life.

ACKNOWLEDGEMENTS

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