Addendum to Avon River Temporary Stopbanks Risk Assessment

22 March 2016

To	Peter Christensen - Christchurch City Council		
Copy to			
From	Petros Armenis, Malcolm Barker	Tel	(07) 33163149
Subject	Avon River Stopbanks - Updated Risk Assessment Considering Hydrological Flood Loading Events up to the 1 in 50 yr AEP and the 1 in 100 yer AEP	Job no.	41/29027

1 General and Scope

This memorandum summarises an update to the Risk Assessment of the Avon River Stopbanks that was carried out and reported by GHD (Oct, 2015). The initial risk assessment was carried out considering combined seismic, tidal and flood hazard loading acting on the existing stopbanks with flood and tidal loads up to the 1 in 200 AEP event.

The Christchurch City Council requested additional analyses to investigate the risk considering flood events up to the 1 in 100 and 1 in 50 AEP.

This involved modifying the hydrological flood loading to include events up to the 1 in 100 or 1 in 50 AEP events only to assess the resulting societal and individual risk. The following scenarios were analysed:

- Hydrological flood loading up to and including the 1 in 100 AEP flood event using the following stopbank bank heights
  - Existing Level
  - Raised stopbank bank to prevent overtopping up to the 1 in 100 AEP flood level
- Hydrological flood loading up to and including the 1 in 50 AEP flood event using the following levee bank heights
  - Existing Level
  - Raised stopbank bank to prevent overtopping up to the 1 in 100 AEP flood level

2 Assumptions and Limitations

The same assumptions and limitations made in the Avon River Stopbanks Risk Assessment undertaken by GHD (Oct 2015) have also been made in this assessment.

3 Results for the Flood Loading Up to and Including the 1 in 100 AEP Event

The existing risk model was modified to analyse hydrological flood loading up to and including the 1 in 100 AEP. The risk analysis was undertaken using the existing stopbank geometry and the geometry of stopbank section raised to an elevation in which the design flood overtopping should not occur.

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3.1 Existing Stopbank Levee Geometry

The resulting societal risk using the existing stopbank geometry is presented in Figure 3-1 below. The contribution of risk by the failure events that were considered in the risk analysis are summarised in Figure 3-2 and Table 3-1 below.

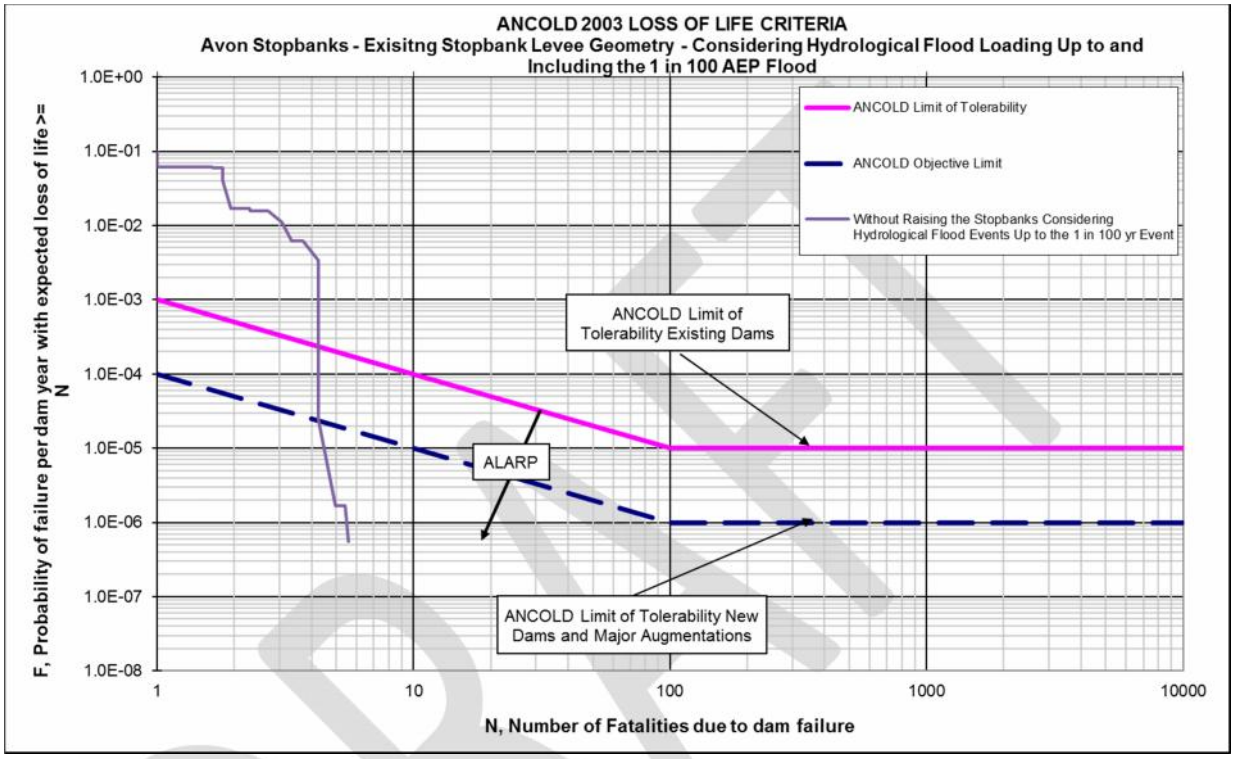

Figure 3-1 Societal Risk for Existing Stopbank Geometry for Seismic Events with Tides and Hydrological Flood Events Up to and Including the 1 in 100 AEP Flood

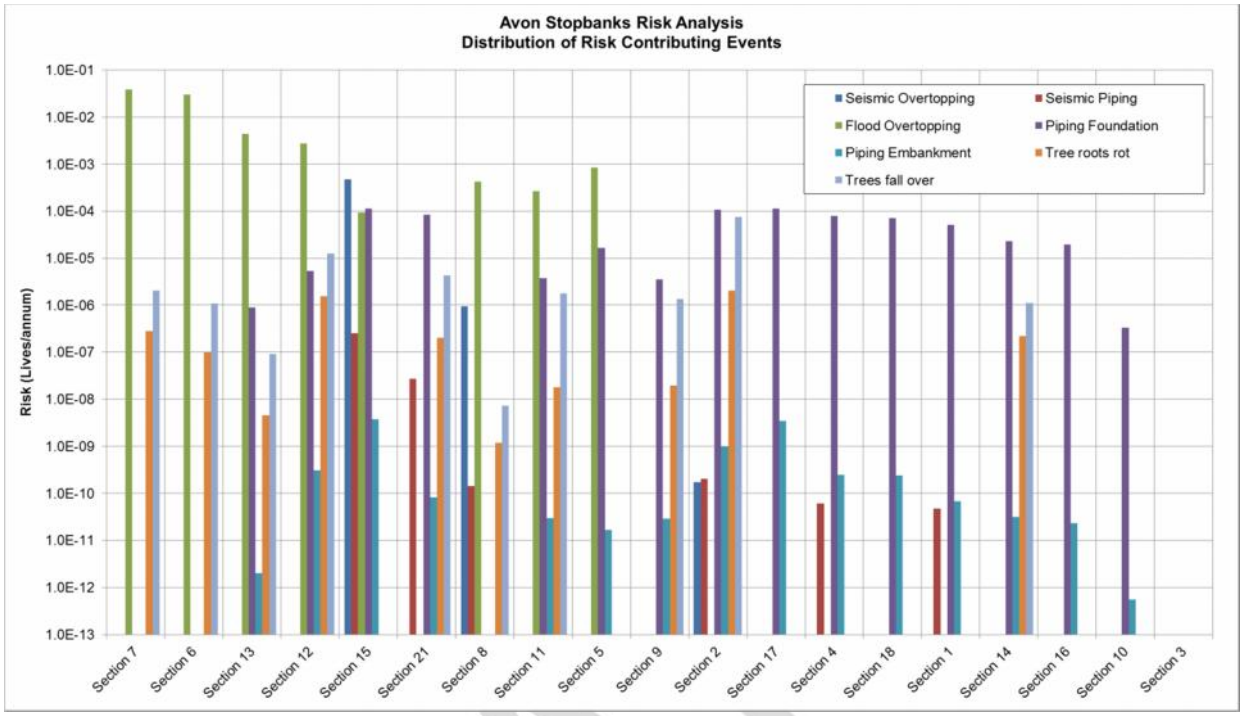

Figure 3-2 Failure Mode Contribution to Risk for the existing stopbank geometry considering hydrological flood loading up to and including the 1 in 100 AEP event

Table 3-1 Tabulation of Data Presented on Figure 3-2 above

Section Number	Seismic Overtopping	Seismic Piping	Flood Overtopping	Piping Foundation	Piping Embankment	Tree roots rot	Trees fall over	Total	Percentage Total Risk	Individual Risk
Section 7	0.00E+00	0.00E+00	3.81E-02	0.00E+00	0.00E+00	2.82E-07	2.06E-06	3.81E-02	48.52%	1.95E-04
Section 6	0.00E+00	0.00E+00	3.04E-02	0.00E+00	0.00E+00	9.81E-08	1.10E-06	3.04E-02	38.73%	3.15E-04
Section 13	0.00E+00	0.00E+00	4.34E-03	8.93E-07	2.02E-12	4.60E-09	9.16E-08	4.34E-03	5.53%	2.70E-05
Section 12	0.00E+00	0.00E+00	2.78E-03	5.34E-06	3.09E-10	1.54E-06	1.27E-05	2.80E-03	3.57%	7.13E-05
Section 15	4.68E-04	2.49E-07	9.46E-05	1.12E-04	3.80E-09	0.00E+00	0.00E+00	6.75E-04	0.86%	8.04E-06
Section 21	0.00E+00	2.70E-08	0.00E+00	8.44E-05	8.26E-11	2.03E-07	4.24E-06	8.89E-05	0.11%	2.55E-07
Section 8	9.38E-07	1.43E-10	4.26E-04	0.00E+00	0.00E+00	1.18E-09	7.28E-09	4.27E-04	0.54%	9.63E-05
Section 11	0.00E+00	0.00E+00	2.66E-04	3.72E-06	3.00E-11	1.81E-08	1.78E-06	2.72E-04	0.35%	3.14E-06
Section 5	0.00E+00	0.00E+00	8.37E-04	1.66E-05	1.69E-11	0.00E+00	0.00E+00	8.53E-04	1.09%	2.22E-06
Section 9	0.00E+00	0.00E+00	0.00E+00	3.51E-06	2.86E-11	1.95E-08	1.34E-06	4.87E-06	0.01%	4.69E-07
Section 2	1.71E-10	2.03E-10	0.00E+00	1.07E-04	1.01E-09	2.04E-06	7.47E-05	1.84E-04	0.23%	3.70E-07
Section 17	0.00E+00	0.00E+00	0.00E+00	1.14E-04	3.42E-09	0.00E+00	0.00E+00	1.14E-04	0.15%	5.64E-07
Section 4	0.00E+00	6.14E-11	0.00E+00	7.81E-05	2.49E-10	0.00E+00	0.00E+00	7.81E-05	0.10%	2.50E-07
Section 18	0.00E+00	0.00E+00	0.00E+00	7.02E-05	2.40E-10	0.00E+00	0.00E+00	7.02E-05	0.09%	6.67E-07
Section 1	0.00E+00	4.73E-11	0.00E+00	5.09E-05	6.77E-11	0.00E+00	0.00E+00	5.09E-05	0.06%	1.74E-07
Section 14	0.00E+00	0.00E+00	0.00E+00	2.30E-05	3.10E-11	2.21E-07	1.11E-06	2.44E-05	0.03%	2.99E-08
Section 16	0.00E+00	0.00E+00	0.00E+00	1.97E-05	2.35E-11	0.00E+00	0.00E+00	1.97E-05	0.03%	8.82E-08
Section 10	0.00E+00	0.00E+00	0.00E+00	3.35E-07	5.45E-13	0.00E+00	0.00E+00	3.35E-07	0.00%	1.01E-08
Section 3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00E+00
Totals	4.69E-04	2.77E-07	7.72E-02	6.90E-04	9.31E-09	4.43E-06	9.91E-05	7.84E-02	100.00%	
	0.5978%	0.0004%	98.3901%	0.8798%	0.0000%	0.0056%	0.1264%			

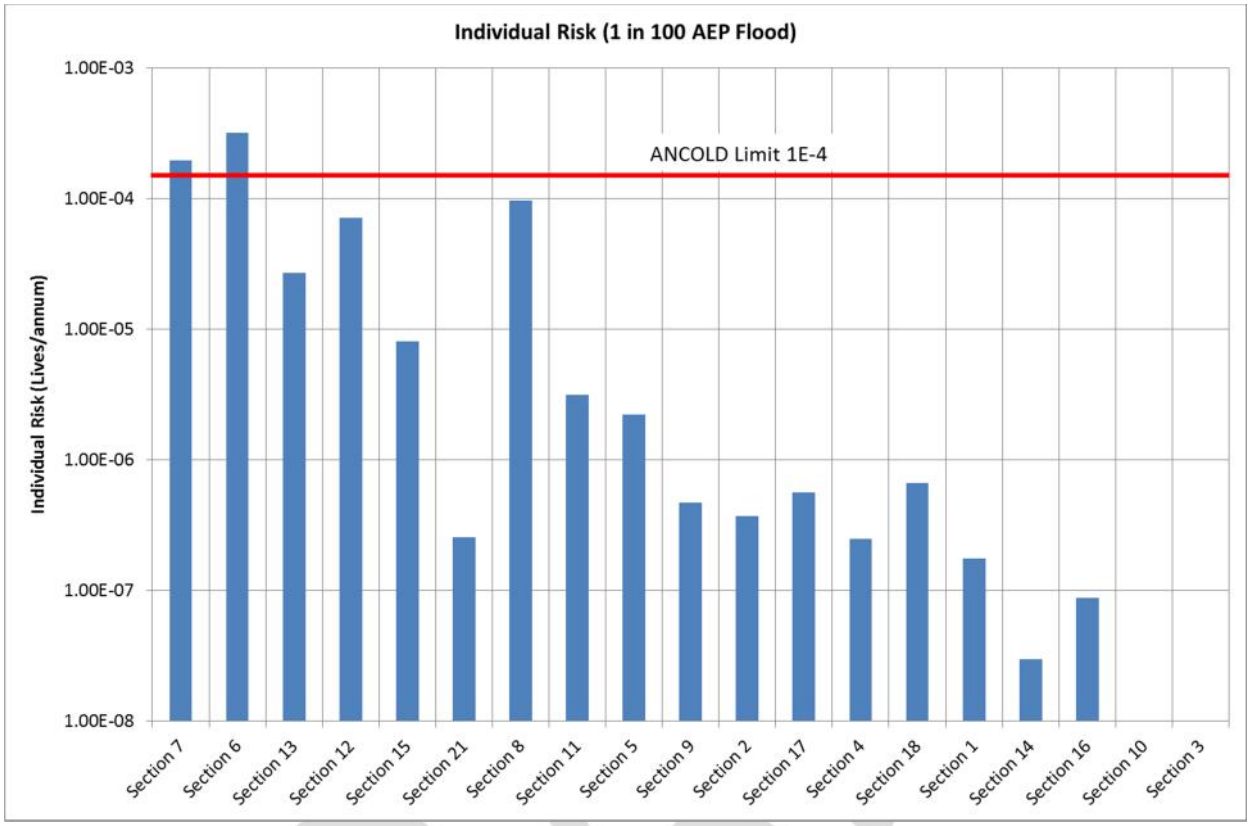

Figure 3-3 Individual Risk for existing stopbanks considering hydrological flood loading up to and including the 1 in 100 AEP event

Table 3-2 Individual Risk above the ANCOLD Limit of Tolerability for existing stopbanks considering hydrological flood loading up to and including the 1 in 100 AEP event

Section	Individual Risk
6	3.15 E-04
7	1.95 E-04

It can be seen that the resulting societal risk is well in excess of the ANCOLD Tolerable limit. The individual risk for this scenario was also above the ANCOLD tolerable limit of 1.0E-4 lives/annum as shown in Figure 3-3 and Table 3-2 above. The dominating risk contributor for this scenario was flood overtopping of Sections 6 and 7. It should be noted that the crest of both Sections 6 and 7 contain deteriorated sandbags which resulted in a high probability of overtopping due to a high probability of sandbag erosion.

3.2 Raised Stopbanks

The analysis summarised in Section 3.1 above was repeated using stopbanks raised to prevent overtopping with the 1 in 100 AEP flood. It should be noted that no additional allowance was made for crest settlement induced by seismic loading or otherwise that may exceed the flood levels. The raised sections and their geometry are summarised in Table 3-3 below. The resulting societal risk is presented in Figure 3-4 below. The contribution of risk by the failure events that were considered in the risk analysis are summarised in Figure 3-5 and Table 3-4 below.

Table 3-3 Raised Section to Prevent Overtopping for the 1 in 100 AEP Flood Event

Section	Centreline Chainage (m)	Raised Stopbank Crest Level (mRL)	Required Embankment raise to prevent overtopping for the 1 in 100 flood event (mm)*	Suggested Raise Type
Left Bank				
5	16,468	11.17	160	Fill material raise
6	15,504	11.08	200	Replace sandbags with embankment
7	14,952	11.10	205	Replace sandbags with embankment
8	14,314	11.12	110	Replace sandbags with embankment and use Concrete section on road side to limit encroachment on the road
11	12,048	11.18	75	Raise Embankment and flatten land side slope
12	11,520	11.25	235	Replace land side sandbags with embankment
13	10,587	11.38	290	Raise embankment and use Concrete section on road side to limit encroachment on the road if necessary
Right Bank				
15	15,179	11.10	15	Raise Embankment and flatten land side slope

** No additional allowance was made for crest settlement induced by seismic loading or otherwise that may exceed the flood levels*

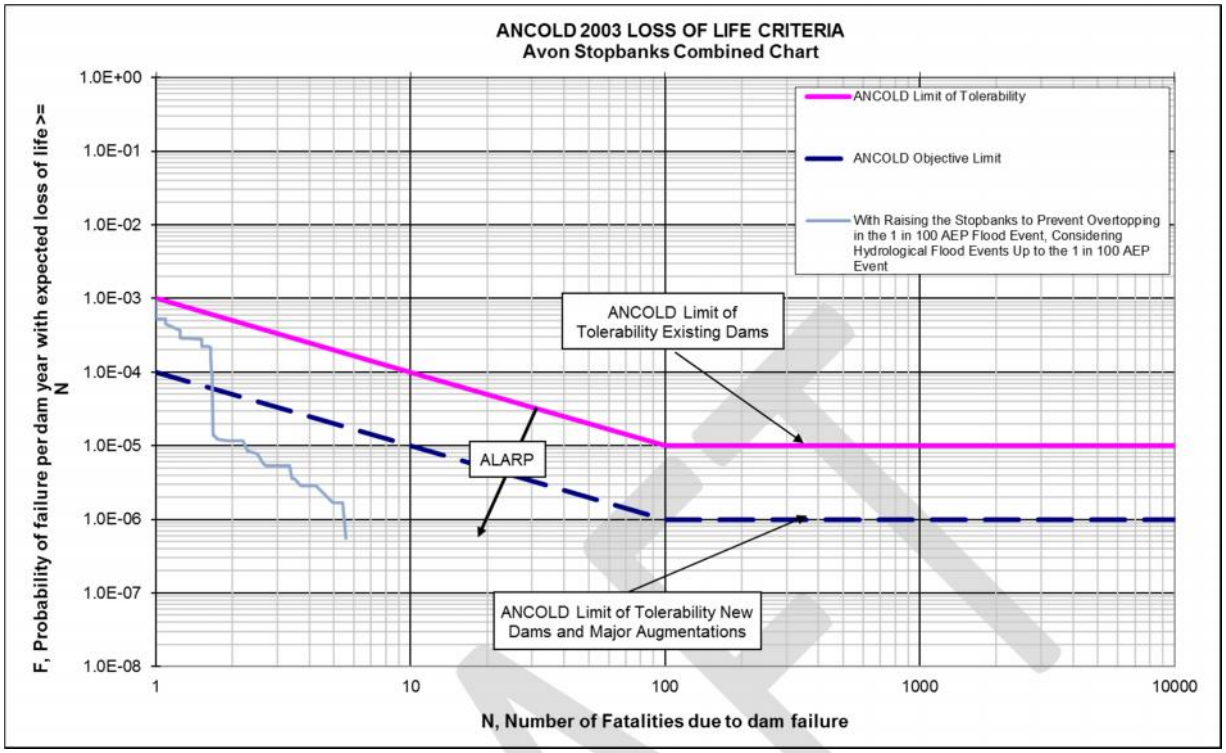

Figure 3-4 Societal Risk for Raised Stopbanks for Seismic Events with Tides and Hydrological Flood Events Up to and Including the 1 in 100 AEP Flood

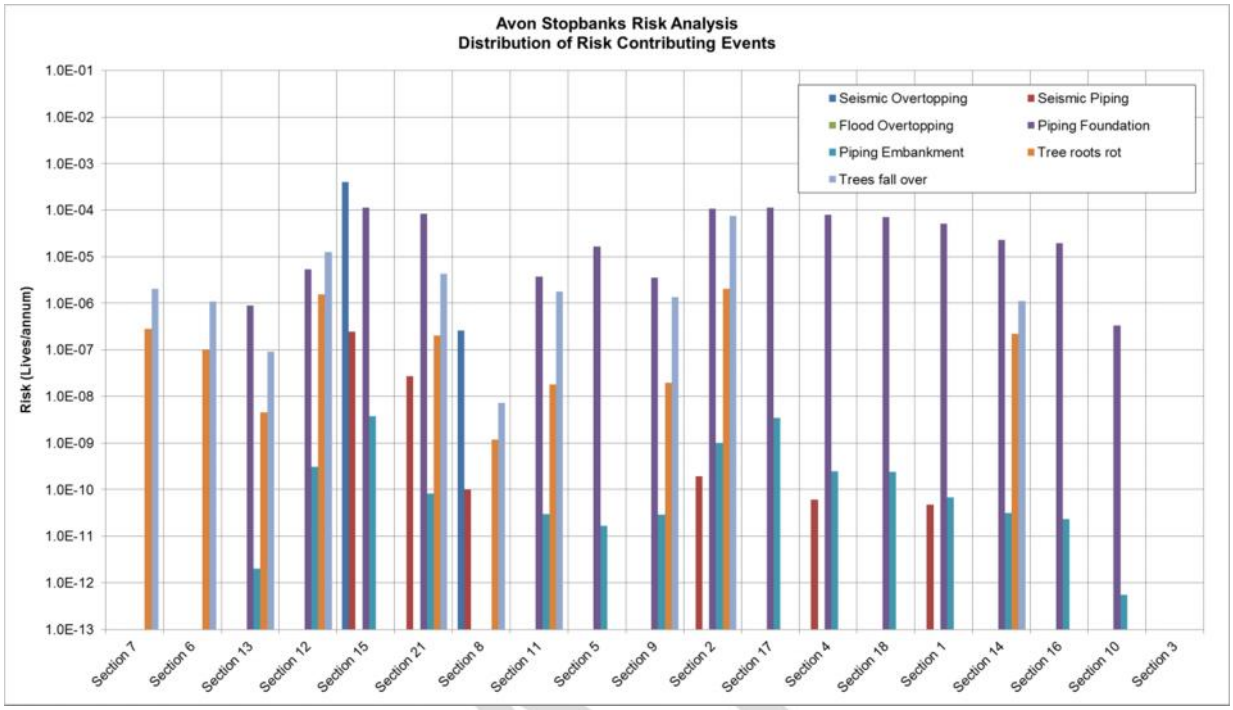

Figure 3-5 Failure Mode Contribution to Risk for the raised stopbank geometry considering hydrological flood loading up to and including the 1 in 100 AEP event

Table 3-4 Tabulation of Data Presented in Figure 3-5 above

Section Number	Seismic Overtopping	Seismic Piping	Flood Overtopping	Piping Foundation	Piping Embankment	Tree roots rot	Trees fall over	Total	Percentage Total Risk	Individual Risk
Section 7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.82E-07	2.06E-06	2.34E-06	0.20%	3.73E-07
Section 6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.81E-08	1.10E-06	1.19E-06	0.10%	1.06E-05
Section 13	0.00E+00	0.00E+00	0.00E+00	8.93E-07	2.02E-12	4.60E-09	9.16E-08	9.90E-07	0.08%	6.67E-09
Section 12	0.00E+00	0.00E+00	0.00E+00	5.34E-06	3.09E-10	1.54E-06	1.27E-05	1.96E-05	1.64%	1.14E-06
Section 15	3.99E-04	2.44E-07	0.00E+00	1.12E-04	3.80E-09	0.00E+00	0.00E+00	5.12E-04	42.86%	6.66E-06
Section 21	0.00E+00	2.70E-08	0.00E+00	8.44E-05	8.26E-11	2.03E-07	4.24E-06	8.89E-05	7.45%	2.55E-07
Section 8	2.62E-07	9.97E-11	0.00E+00	0.00E+00	0.00E+00	1.18E-09	7.28E-09	2.70E-07	0.02%	1.09E-05
Section 11	0.00E+00	0.00E+00	0.00E+00	3.72E-06	3.00E-11	1.81E-08	1.78E-06	5.51E-06	0.46%	4.97E-07
Section 5	0.00E+00	0.00E+00	0.00E+00	1.66E-05	1.69E-11	0.00E+00	0.00E+00	1.66E-05	1.39%	4.38E-08
Section 9	0.00E+00	0.00E+00	0.00E+00	3.51E-06	2.86E-11	1.95E-08	1.34E-06	4.87E-06	0.41%	4.69E-07
Section 2	0.00E+00	1.95E-10	0.00E+00	1.07E-04	1.01E-09	2.04E-06	7.47E-05	1.84E-04	15.40%	3.69E-07
Section 17	0.00E+00	0.00E+00	0.00E+00	1.14E-04	3.42E-09	0.00E+00	0.00E+00	1.14E-04	9.56%	5.64E-07
Section 4	0.00E+00	6.14E-11	0.00E+00	7.81E-05	2.49E-10	0.00E+00	0.00E+00	7.81E-05	6.55%	2.50E-07
Section 18	0.00E+00	0.00E+00	0.00E+00	7.02E-05	2.40E-10	0.00E+00	0.00E+00	7.02E-05	5.88%	6.67E-07
Section 1	0.00E+00	4.73E-11	0.00E+00	5.09E-05	6.77E-11	0.00E+00	0.00E+00	5.09E-05	4.27%	1.74E-07
Section 14	0.00E+00	0.00E+00	0.00E+00	2.30E-05	3.10E-11	2.21E-07	1.11E-06	2.44E-05	2.04%	2.99E-08
Section 16	0.00E+00	0.00E+00	0.00E+00	1.97E-05	2.35E-11	0.00E+00	0.00E+00	1.97E-05	1.65%	8.82E-08
Section 10	0.00E+00	0.00E+00	0.00E+00	3.35E-07	5.45E-13	0.00E+00	0.00E+00	3.35E-07	0.03%	1.01E-08
Section 3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00E+00
Totals	4.00E-04	2.71E-07	0.00E+00	6.90E-04	9.31E-09	4.43E-06	9.91E-05	1.19E-03	100.00%	
	33.4801%	0.0227%	0.0000%	57.8214%	0.0008%	0.3708%	8.3042%			

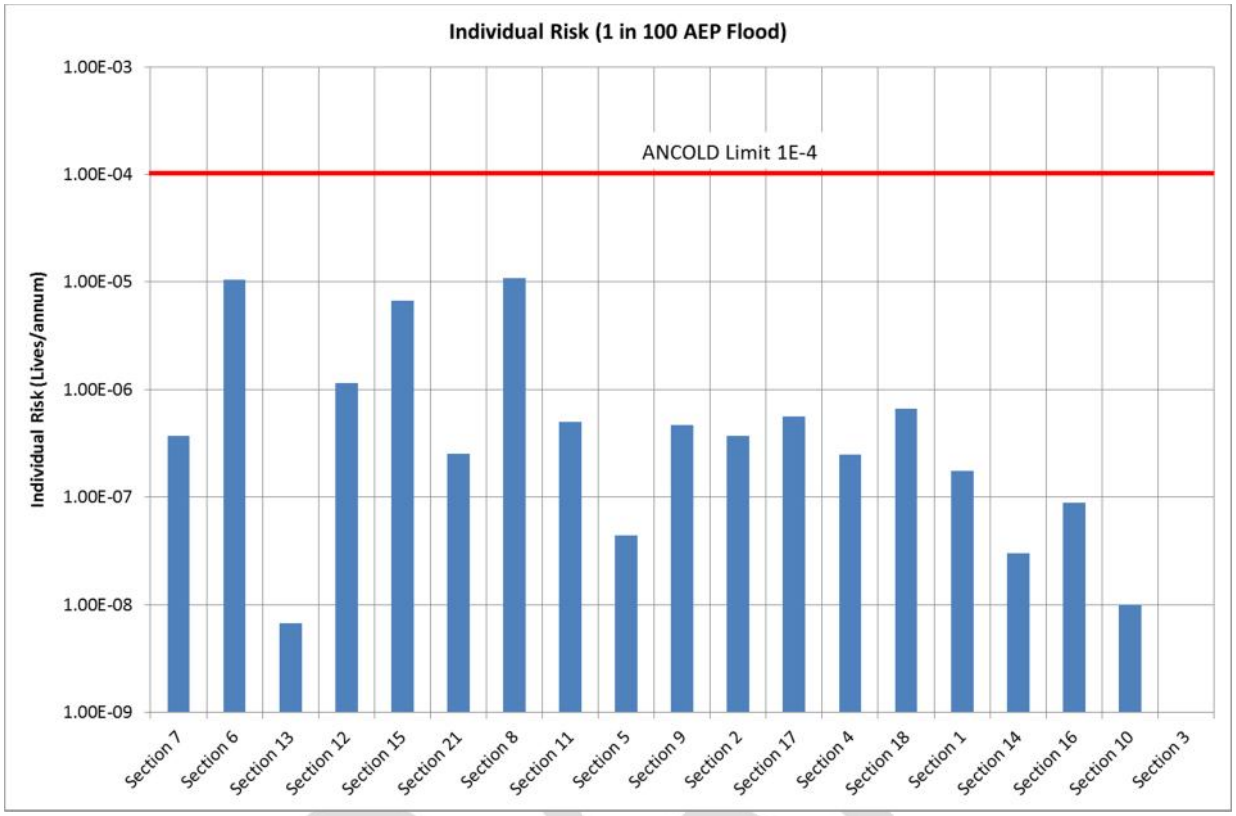

Figure 3-6 Individual Risk for raised stopbanks considering hydrological flood loading up to and including the 1 in 100 AEP event

It can be seen that both the societal and individual risk are below the ANCOLD Limit of Tolerability for existing dams. The decrease in risk from the existing stopbank geometry evidently resulted in removing the risk of flood overtopping. It can be seen that the dominating risk contributor for this scenario was seismic overtopping of the Section 15 levee followed by piping through the foundations of Sections 15, 21, 2, 17, 4, 18, 1, 14 and 16. This suggests that replacing the deteriorated sandbags and topping up the stopbank levees in accordance with the suggested raises made in Table 3-3 above, are effective remedial actions to reduce the risk to tolerable limits for flood events up to the 1 in 100 AEP event only.

4 Risk Analysis for Flood Loading Up to and Including the 1 in 50 AEP Event

The existing risk model was modified to analyse hydrological flood loading up to and including the 1 in 50 AEP. The risk analysis was undertaken using the existing stopbank geometry and the geometry of stopbank section raised to an elevation in which the design flood overtopping should not occur.

4.1 Existing Stopbank Geometry

The resulting societal and individual risks for the stopbank with the flood events up to the 1 in 50 AEP event with the existing stopbank geometry are presented in Figure 4-1 and Figure 4-3 below respectively.

The contribution of risk by the failure events that were considered in the risk analysis are summarised in Figure 4-2 and Table 4-1 below.

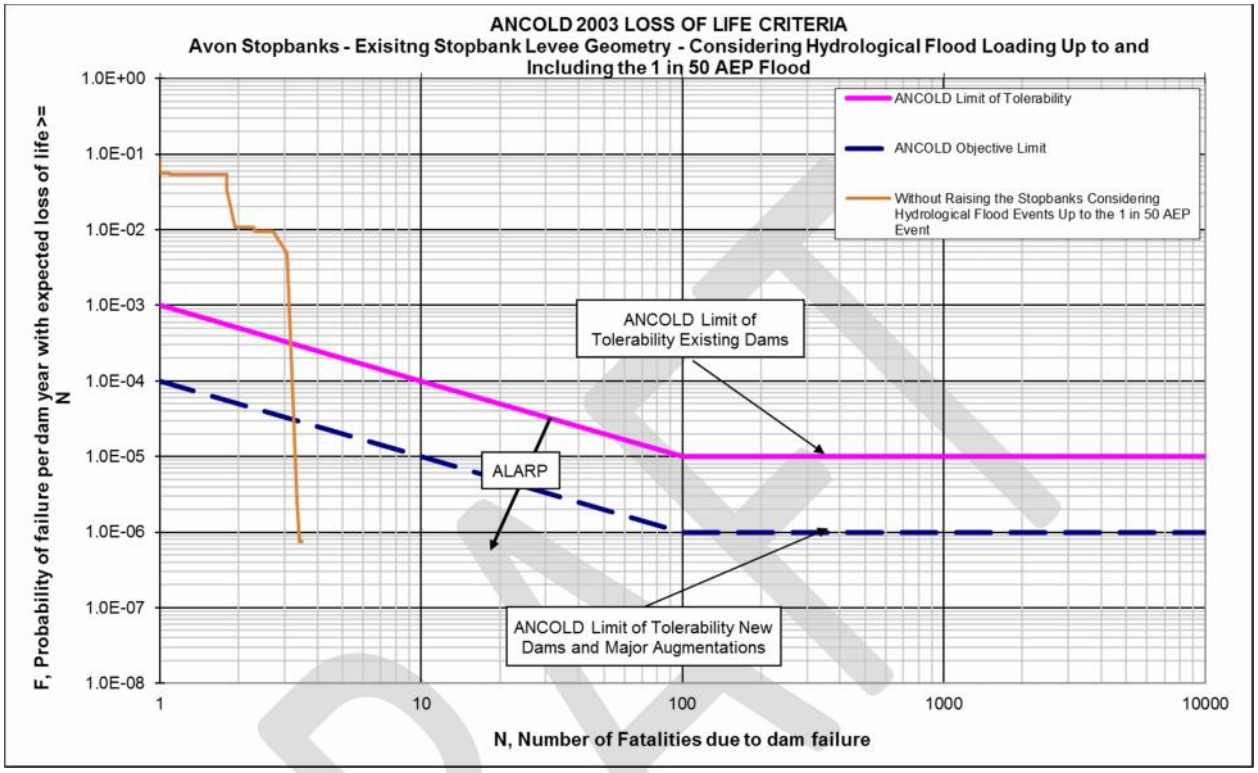

Figure 4-1 Societal Risk for Existing Stopbank Geometry for Seismic Events with Tides and Hydrological Flood Events Up to and Including the 1 in 50 AEP Flood

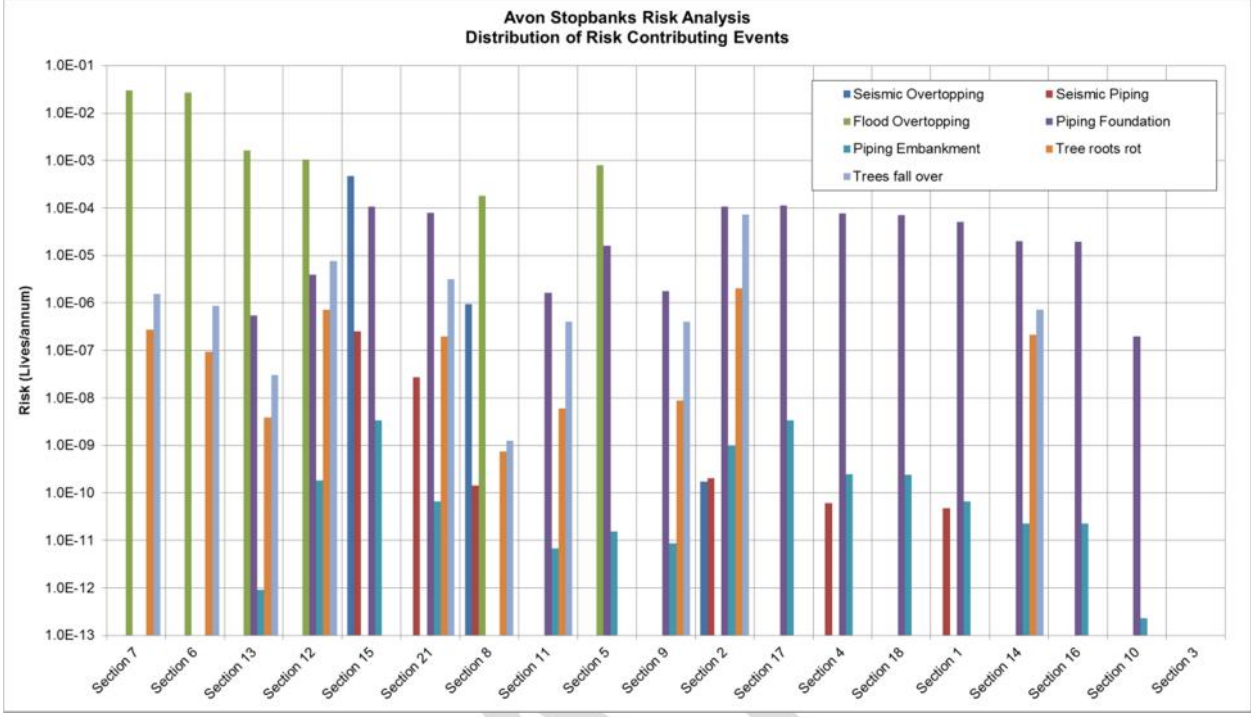

Figure 4-2 Failure Mode Contribution to Risk for the existing stopbank geometry considering hydrological flood loading up to and including the 1 in 50 AEP event

Table 4-1 Tabulation of data presented in Figure 4-2 below

Section Number	Seismic Overtopping	Seismic Piping	Flood Overtopping	Piping Foundation	Piping Embankment	Tree roots rot	Trees fall over	Total	Percentage Total Risk	Individual Risk
Section 7	0.00E+00	0.00E+00	3.03E-02	0.00E+00	0.00E+00	2.76E-07	1.56E-06	3.03E-02	48.88%	1.85E-04
Section 6	0.00E+00	0.00E+00	2.68E-02	0.00E+00	0.00E+00	9.35E-08	8.71E-07	2.68E-02	43.23%	3.07E-04
Section 13	0.00E+00	0.00E+00	1.64E-03	5.44E-07	8.99E-13	3.85E-09	3.06E-08	1.64E-03	2.64%	1.16E-05
Section 12	0.00E+00	0.00E+00	1.04E-03	3.91E-06	1.81E-10	7.25E-07	7.56E-06	1.05E-03	1.70%	5.78E-05
Section 15	4.68E-04	2.49E-07	0.00E+00	1.08E-04	3.35E-09	0.00E+00	0.00E+00	5.76E-04	0.93%	7.97E-06
Section 21	0.00E+00	2.70E-08	0.00E+00	7.83E-05	6.61E-11	1.96E-07	3.21E-06	8.18E-05	0.13%	2.51E-07
Section 8	9.38E-07	1.43E-10	1.79E-04	0.00E+00	0.00E+00	7.36E-10	1.25E-09	1.80E-04	0.29%	8.87E-05
Section 11	0.00E+00	0.00E+00	0.00E+00	1.65E-06	6.81E-12	6.02E-09	4.08E-07	2.06E-06	0.00%	1.42E-06
Section 5	0.00E+00	0.00E+00	8.07E-04	1.61E-05	1.56E-11	0.00E+00	0.00E+00	8.23E-04	1.33%	2.19E-06
Section 9	0.00E+00	0.00E+00	0.00E+00	1.77E-06	8.58E-12	8.94E-09	4.02E-07	2.18E-06	0.00%	4.53E-07
Section 2	1.71E-10	2.03E-10	0.00E+00	1.06E-04	9.99E-10	2.03E-06	7.37E-05	1.82E-04	0.29%	3.69E-07
Section 17	0.00E+00	0.00E+00	0.00E+00	1.13E-04	3.37E-09	0.00E+00	0.00E+00	1.13E-04	0.18%	5.61E-07
Section 4	0.00E+00	6.14E-11	0.00E+00	7.77E-05	2.45E-10	0.00E+00	0.00E+00	7.77E-05	0.13%	2.48E-07
Section 18	0.00E+00	0.00E+00	0.00E+00	7.02E-05	2.40E-10	0.00E+00	0.00E+00	7.02E-05	0.11%	6.64E-07
Section 1	0.00E+00	4.73E-11	0.00E+00	5.07E-05	6.69E-11	0.00E+00	0.00E+00	5.07E-05	0.08%	1.73E-07
Section 14	0.00E+00	0.00E+00	0.00E+00	2.00E-05	2.26E-11	2.13E-07	7.23E-07	2.09E-05	0.03%	2.82E-08
Section 16	0.00E+00	0.00E+00	0.00E+00	1.95E-05	2.28E-11	0.00E+00	0.00E+00	1.95E-05	0.03%	8.73E-08
Section 10	0.00E+00	0.00E+00	0.00E+00	1.96E-07	2.27E-13	0.00E+00	0.00E+00	1.96E-07	0.00%	8.88E-09
Section 3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00E+00
Totals	4.69E-04	2.77E-07	6.07E-02	6.68E-04	8.59E-09	3.55E-06	8.84E-05	6.20E-02	100.00%	
	0.7566%	0.0004%	98.0163%	1.0782%	0.0000%	0.0057%	0.1427%			

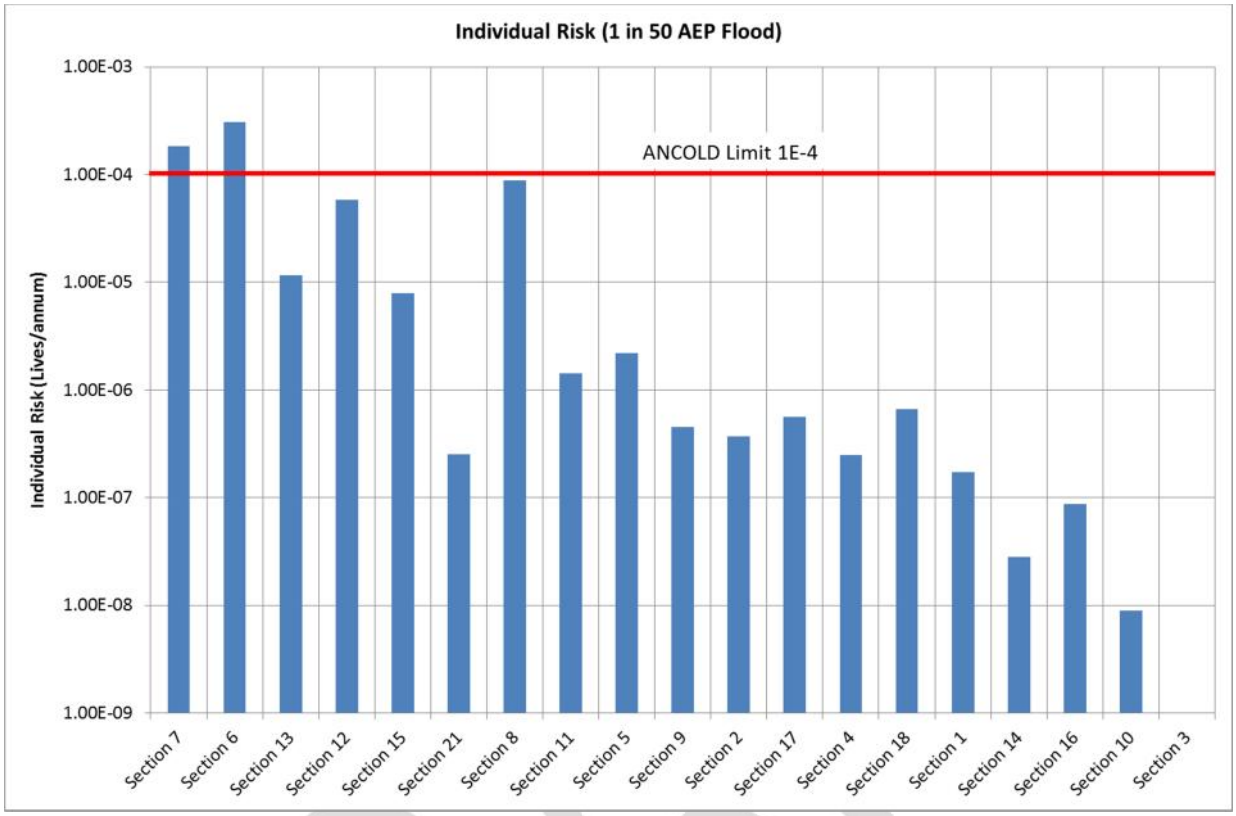

Figure 4-3 Individual Risk for existing stopbank considering hydrological flood loading up to and including the 1 in 50 AEP event

Table 4-2 Individual Risk above the ANCOLD Limit of Tolerability for existing stopbank levees considering hydrological flood loading up to and including the 1 in 50 AEP event

Section	Individual Risk
6	3.07 E-04
7	1.85 E-04

Similarly to the analysis outcomes described in Section 3.1 above, it can be seen that the resulting societal risk is well in excess of the ANCOLD Limit of Tolerability for existing dams. The individual risk for this scenario was also above the ANCOLD tolerable limit of 1.0E-4 lives/annum as shown in Figure 4-3 and Table 4-2 below The dominating risk contributor for this scenario was also flood overtopping of Sections 6 and 7.

4.2 Raised Stopbank Levees

The analysis summarised in Section 4.1 above was repeated using stopbanks raised to prevent overtopping with the 1 in 50 AEP flood event. It should be noted that no allowance was made for crest settlement induced by seismic loading or otherwise. The raised sections and their geometry are summarised in Table 4-3 below. The resulting societal risk is presented in Figure 4-4 below and the contribution of risk by the failure events that were considered in the risk analysis are summarised in Figure 4-5 and Table 4-4 below:

Table 4-3 Raised Section to Prevent Overtopping for the 1 in 50 AEP Flood Event

Section	Centreline Chainage (m)	Raised Stopbank Crest Level (mRL)	Required Embankment raise to prevent overtopping for the 1 in 50 flood event (mm)*	Suggested Raise Type
Left Bank				
5	16,468	11.02	10	Fill material raise
6	15,504	11.04	155	Replace sandbags with embankment
7	14,952	11.05	150	Replace sandbags with embankment
8	14,314	11.06	50	Replace sandbags with embankment and use Concrete section on road side to limit encroachment on the road
12	11,520	11.114	125	Replace land side sandbags with embankment
13	10,587	11.25	160	Raise embankment and use Concrete section on road side to limit encroachment on the road if necessary
Right Bank				
15	15,179	11.10	15	Raise Embankment and flatten land side slope

** No additional allowance was made for crest settlement induced by seismic loading or otherwise that may exceed the flood levels*

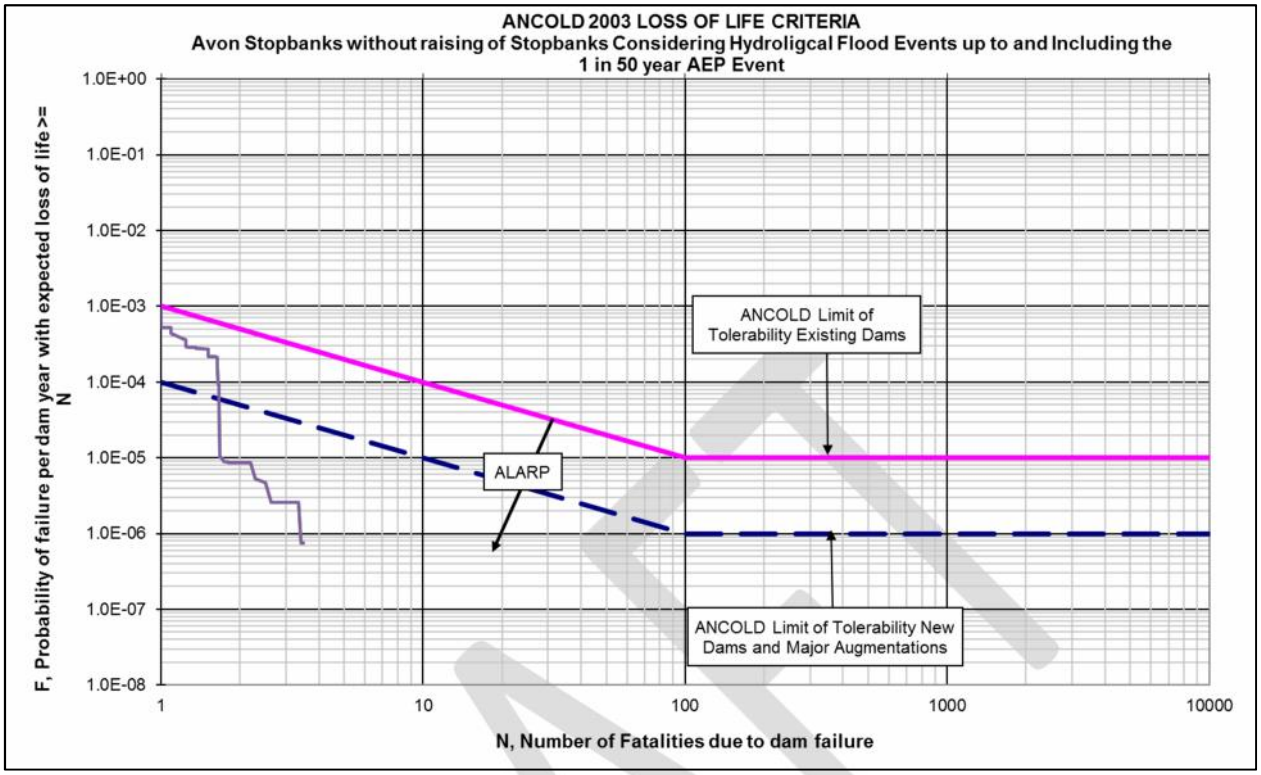

Figure 4-4 Societal Risk for Raised Stopbanks for Seismic Events with Tides and Hydrological Flood Events Up to and Including the 1 in 50 AEP Flood

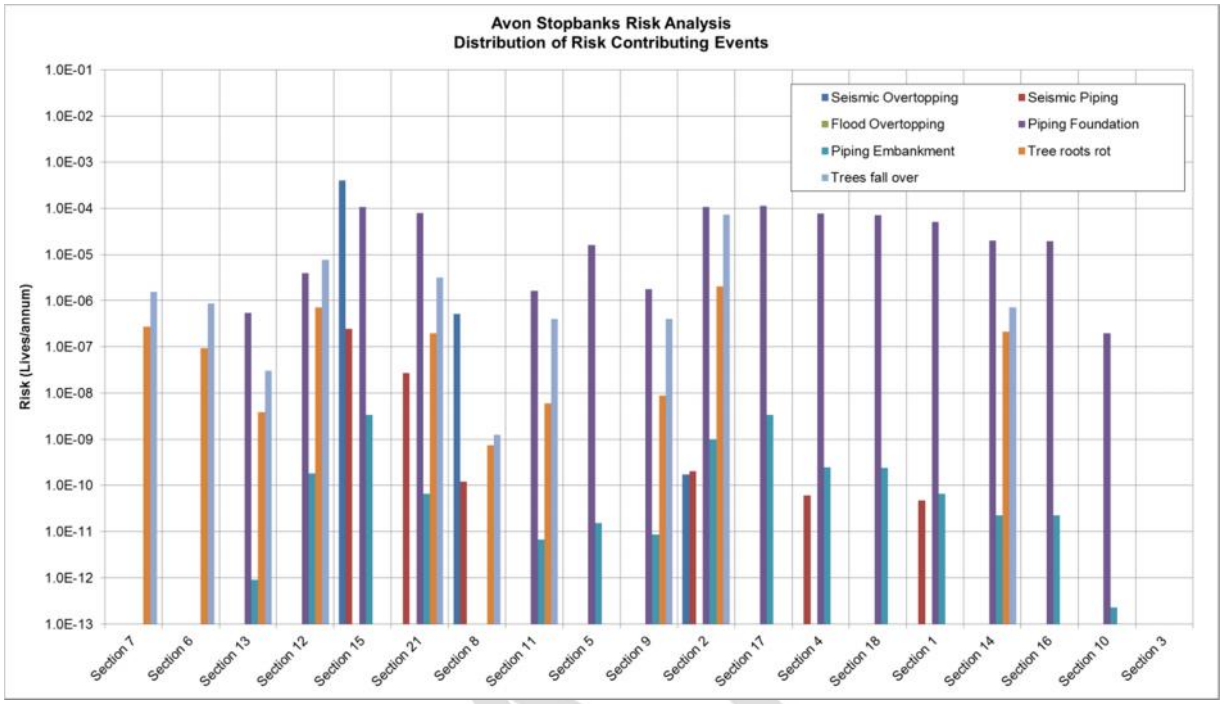

Figure 4-5 Failure Mode Contribution to Risk for the raised stopbank geometry considering hydrological flood loading up to and including the 1 in 50 AEP event

Table 4-4 Tabulation of data presented in Figure 4-5

Section Number	Seismic Overtopping	Seismic Piping	Flood Overtopping	Piping Foundation	Piping Embankment	Tree roots rot	Trees fall over	Total	Percentage Total Risk	Individual Risk
Section 7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.76E-07	1.56E-06	1.83E-06	0.16%	1.93E-06
Section 6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.35E-08	8.71E-07	9.64E-07	0.08%	2.30E-05
Section 13	0.00E+00	0.00E+00	0.00E+00	5.44E-07	8.99E-13	3.85E-09	3.06E-08	5.78E-07	0.05%	4.77E-09
Section 12	0.00E+00	0.00E+00	0.00E+00	3.91E-06	1.81E-10	7.25E-07	7.56E-06	1.22E-05	1.05%	1.60E-06
Section 15	3.99E-04	2.44E-07	0.00E+00	1.08E-04	3.35E-09	0.00E+00	0.00E+00	5.07E-04	43.71%	6.65E-06
Section 21	0.00E+00	2.70E-08	0.00E+00	7.83E-05	6.61E-11	1.96E-07	3.21E-06	8.18E-05	7.05%	2.51E-07
Section 8	5.19E-07	1.22E-10	0.00E+00	0.00E+00	0.00E+00	7.36E-10	1.25E-09	5.21E-07	0.04%	2.58E-05
Section 11	0.00E+00	0.00E+00	0.00E+00	1.65E-06	6.81E-12	6.02E-09	4.08E-07	2.06E-06	0.18%	1.42E-06
Section 5	0.00E+00	0.00E+00	0.00E+00	1.61E-05	1.56E-11	0.00E+00	0.00E+00	1.61E-05	1.39%	1.15E-06
Section 9	0.00E+00	0.00E+00	0.00E+00	1.77E-06	8.58E-12	8.94E-09	4.02E-07	2.18E-06	0.19%	4.53E-07
Section 2	1.71E-10	2.03E-10	0.00E+00	1.06E-04	9.99E-10	2.03E-06	7.37E-05	1.82E-04	15.70%	3.69E-07
Section 17	0.00E+00	0.00E+00	0.00E+00	1.13E-04	3.37E-09	0.00E+00	0.00E+00	1.13E-04	9.78%	5.61E-07
Section 4	0.00E+00	6.14E-11	0.00E+00	7.77E-05	2.45E-10	0.00E+00	0.00E+00	7.77E-05	6.70%	2.48E-07
Section 18	0.00E+00	0.00E+00	0.00E+00	7.02E-05	2.40E-10	0.00E+00	0.00E+00	7.02E-05	6.05%	6.64E-07
Section 1	0.00E+00	4.73E-11	0.00E+00	5.07E-05	6.69E-11	0.00E+00	0.00E+00	5.07E-05	4.37%	1.73E-07
Section 14	0.00E+00	0.00E+00	0.00E+00	2.00E-05	2.26E-11	2.13E-07	7.23E-07	2.09E-05	1.80%	2.82E-08
Section 16	0.00E+00	0.00E+00	0.00E+00	1.95E-05	2.28E-11	0.00E+00	0.00E+00	1.95E-05	1.68%	8.73E-08
Section 10	0.00E+00	0.00E+00	0.00E+00	1.96E-07	2.27E-13	0.00E+00	0.00E+00	1.96E-07	0.02%	8.88E-09
Section 3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00E+00
Totals	4.00E-04	2.71E-07	0.00E+00	6.68E-04	8.59E-09	3.55E-06	8.84E-05	1.16E-03	100.00%	
	34.4610%	0.0234%	0.0000%	57.5854%	0.0007%	0.3058%	7.6237%			

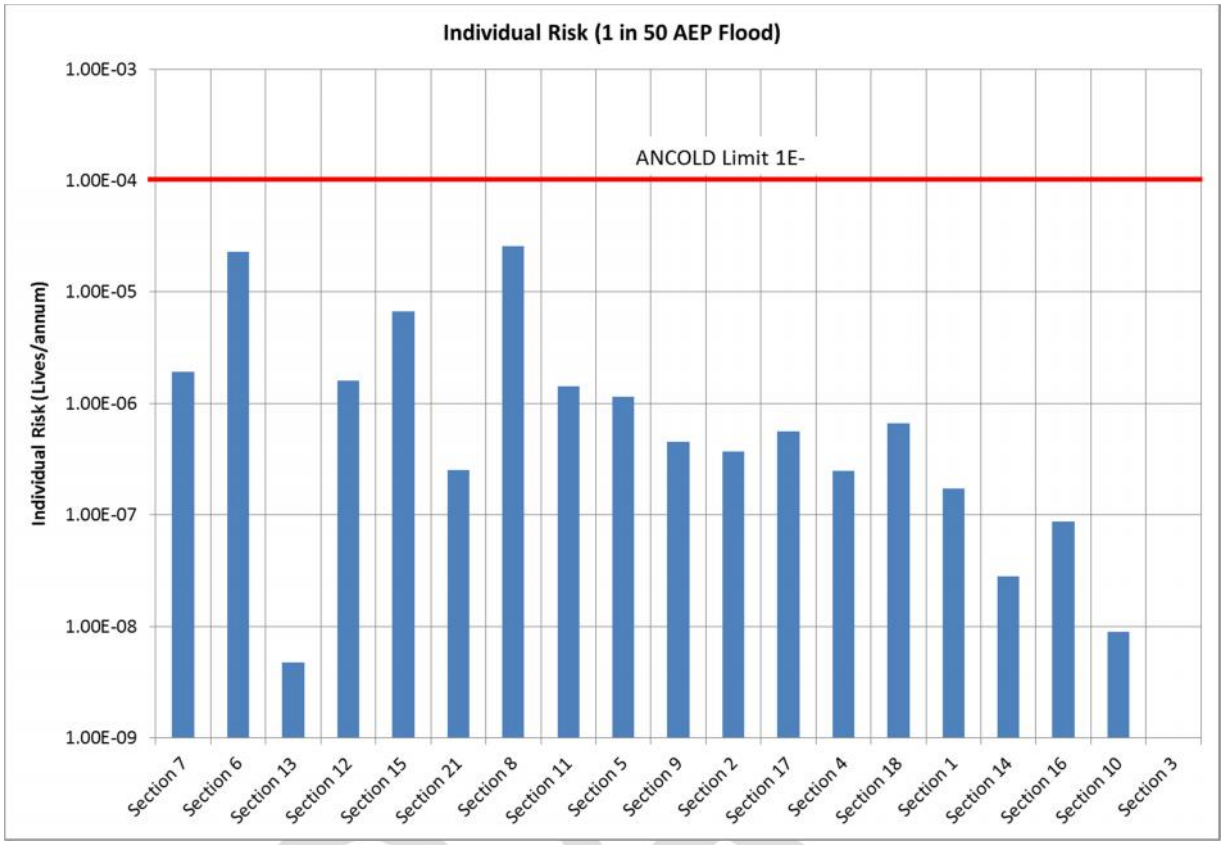

Figure 4-6 Individual Risk for raised stopbanks considering hydrological flood loading up to and including the 1 in 50 AEP event

Similarly to the analysis described in Section 3.2 above, it can be seen that both the societal risk and the individual risk are below the ANCOLD Limit of Tolerability for existing dams. The decrease in risk from the existing stopbank geometry evidently resulted in removing the risk of flood overtopping by raising the stopbanks. This suggests that replacing the deteriorated sandbags and topping up the stopbanks in accordance with the suggested raise types made in Table 3-3 above are effective remedial actions to reduce the risk to tolerable limits for flood events up to the 1 in 50 AEP event only. It can be seen that the dominating risk contributor for this scenario was seismic overtopping of the Section 15 levee followed by piping through the foundations of Sections 15, 21, 2, 17, 4, 18, 1, 14 and 16.

5 Summary and Conclusions

The societal and individual risk of the Avon River Stopbank Levees were assessed for reduced flood events, up to and including the 1 in 100 AEP flood event and up to and including the 1 in 50 AEP flood event using the original risk model. The analyses were undertaken using the existing stopbank geometry and raised stopbank geometry. It was found that the societal and individual risk for the existing stopbank geometry was above the ANCOLD Limit of Tolerability for existing dams for both scenarios considered. It was also found that the risk was dominated by flood overtopping of section 6 and 7, which contained deteriorated sandbags on the crest of the stopbanks.

Raising the stopbanks susceptible to the considered flood overtopping events was found to significantly reduce the societal and individual risk to below the ANCOLD Limit of Tolerability for existing dams. The required raise heights to achieve this and the suggested raise mechanisms are summarised in Table 3-3 and Table 4-3 for the 1 in 100 AEP flood scenario and 1 in 50 AEP Flood scenario considered respectively. A combined chart of the societal risk plots for each of the scenarios analysed in this memorandum is presented in Figure 5-1 below.

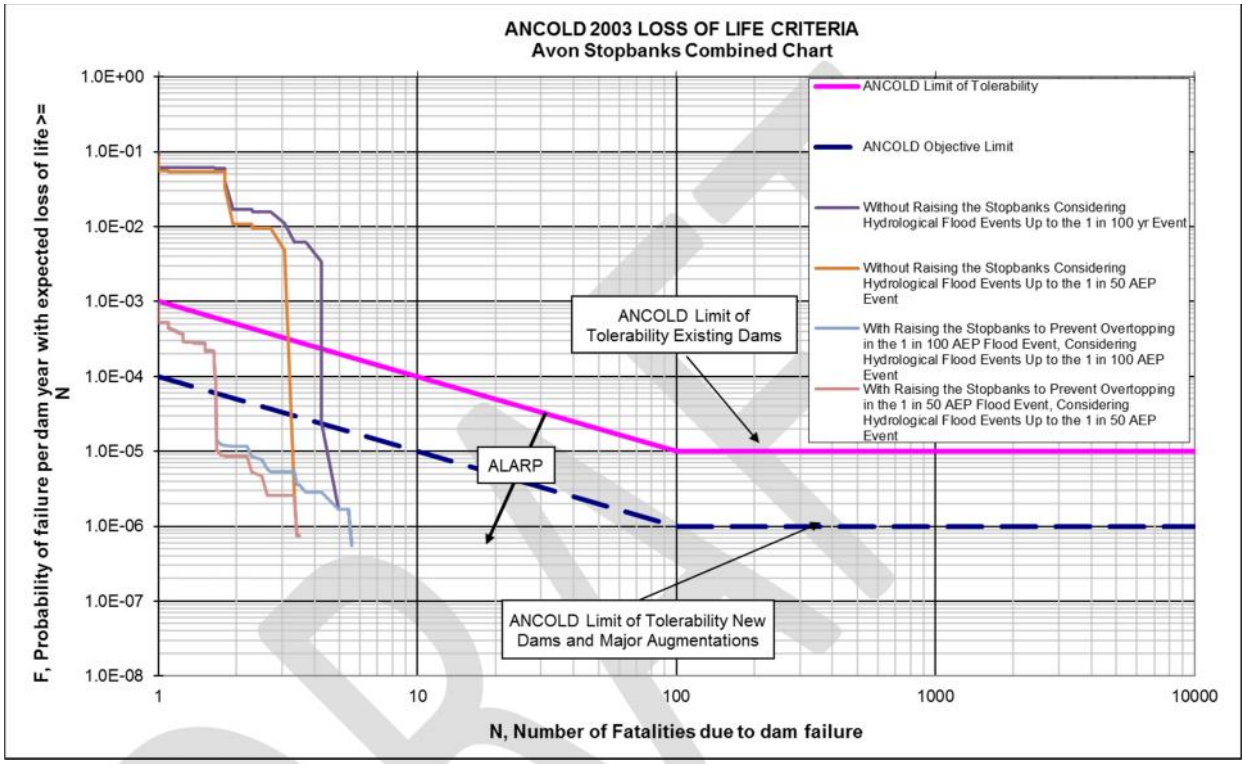

Figure 5-1 Combined Societal Risk for the Scenarios Analysed Summarised in this Memorandum

6 References

GHD (Oct 2015), “Christchurch City Council – Stopbank – Risk Assessment”

Regards

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