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MEMORANDUM

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Copied recipients	Gary Williams (Waterscape), Brendan Russ (WCRC)	**Memo date**	10 November 2021
Author	Dr. Dai Thomas		
Project reference	773-AKLWT290497 Franz Josef Stopbanks		
Memo subject	Franz Josef Stopbanks – Scour and riprap calculations, and stopbank design.		

Background

The West Coast Regional Council (WCRC) are proposing to raise the elevation of the Church, Helipad and Havill Wall stopbanks and construct the new NZTA stopbank that extends from the end of the Helipad stopbank to the Havill Wall stopbank (**Figure 1**). The WCRC requested a stopbank design with a 20-year design life. As discussed later in this memorandum, the stopbank was designed to convey the design discharge of 2,500 m^3/s and assuming 20-years of channel aggradation.

On Figure 1, the Church and Helipad stopbanks are shown as red circles and extend from chainage 0 to 750. The NZTA and Havill Wall stopbanks are shown as crimson squares and extend from chainage 0 to 1650

The existing stopbanks will be raised by an average of 2m and the new NZTA stopbank will be about 5m high. The Church, Helipad and Havill Wall stopbanks will be raised by placing bulkfill on top of, and on the landward side of the existing stopbanks, and extending the rock (riprap) up the face on the riverward side. The WCRC specified a batter of 3H:1V for the bulkfill on the landward side (Error! Reference source not found.). On the riverward side, the batter of the raised section will match the existing batter with a maximum of 2H:1V (personal communication, Brendan Russ, WCRC, September 2021). The batter along the existing stopbanks varies from 1.9H:1V to 3.1H:1V. The bulkfill portion of the stopbank will be 6m wide at the crest.

The WCRC specified a rock gradation with a median weight (W_{50}) of 5.3 tonnes which is equivalent to a median size (D_{50}) of about 1.3m (**Table 1**). The rock gradation is the same as used for the raising of the Church and Helipad Stopbanks in 2016 (Gardner, 2016). The WCRC specified a toe down depth of 4m to account for scour along the toe (**Error! Reference source not found.**).

Table 1 Approximate Quarried Rock Size Specification[1]

Percent Passing	Weight range (tonnes)	Approximate Size of b-axis (m)
50	4.5 – 6	1.3 – 1.4
35	3 – 4.5	1.1 – 1.3
1.5 - 3	1.5 - 3	0.9 – 1.1

[1]Provided by Land River Sea Consulting from 2016 Franz Josef stopbank design (Gardner, 2016)

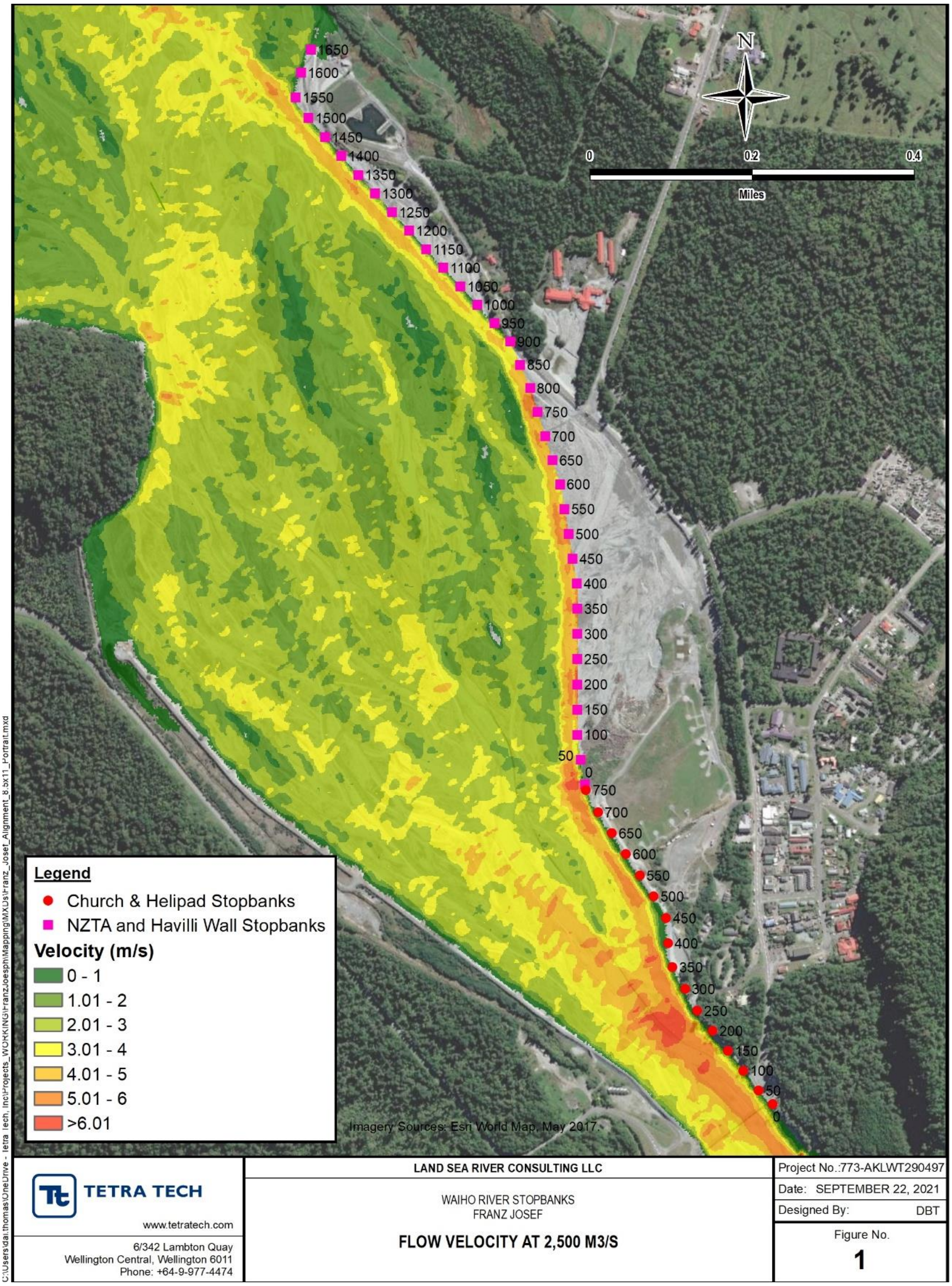

Figure 1 Stopbank alignment and predicted velocity at 2,500 m^3/s.

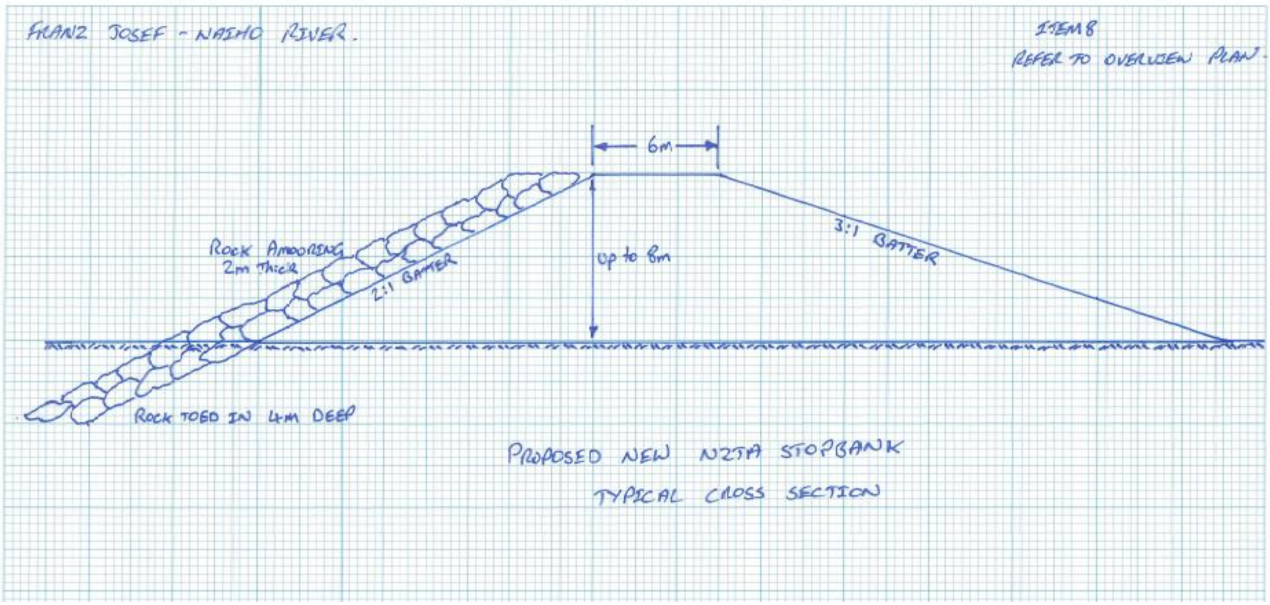

Figure 2. Typical cross-section geometry for the proposed stopbank upgrade (Figure provided by the WCRC)

The WCRC indicated that the rock along the existing stopbanks was toed down between 4 and 6m (personal communication, Brendan Russ of the WCRC and Mathew Garner from Land River Sea Consulting, September 2021). The toe down depth will be investigated by WCRC during the raising of the stopbanks scheduled for 2022.

The proposed alignment of the NZTA stopbank was selected by Matthew Gardner, Dai Thomas and Gary Williams in consultation with the WCRC. The alignment was also confirmed with Mark Healy from WSP who consulted with Waka Kotahi (N.Z. Transportation Authority) (personal communication, July 2021). Gardner (2021) performed an analysis of the historic aggradation rates along the Waiho River from the base of the Franz Josef Glacier to the Waiho Loop. The aggradation rates were determined based on repeat cross-section (CS) surveys at CS13 through 22 for the period from 1998-2021. The aggradation rate varied from 0.2 m at CS20 to 2.0 m at CS17,18 and 19, with an average rate of 1.5 m over the 20-year period. A representative aggradation rate of 0.2m/year was selected.

Tetra Tech-Coffey, under contract to Matthew Gardner from Land River Sea Consulting, performed a rock sizing analysis and scour calculations to verify the WCRC specifications. Gary Williams provided review of the scour and rock sizing analyses. Tetra Tech-Coffey also developed the design for the stopbank.

Hydraulic Analysis

Gardner (2021) performed hydraulic modelling of the Waiho River from upstream of the State Highway 6 bridge to downstream of the Waiho Loop. The model output was used to perform the rock sizing and scour analyses and to design the stopbank.

The hydraulic model geometry was based on the 2021 survey data and the proposed NZTA stopbank alignment. The model geometry was further modified to include a 2m deep by 30m wide channel along the toe of the right bank. A Manning's n-value of 0.05 was applied to the channel bed and the model was run for a series of flows from 500 to 3,500 m^3/s in 500 m^3/s increments. The design discharge is 2,500 m^3/s. A sensitivity analysis was performed by varying the Manning's n-value to 0.04 and 0.06 and comparing the predicted hydraulic conditions (depth, velocity and water-surface elevation) with the baseline conditions. As expected, the predicted velocities for the n=0.04 run are higher compared to the n=0.05 and 0.06 runs. The predicted velocities for the n=0.04 run were used in the scour and riprap calculations since they provide slightly more conservative results.

The hydraulic model was further modified to represent the aggradation over the 20-year period. The model was re-run at the design discharge and the predicted water-surface elevation was used, in part, to develop the top of stopbank profile.

Rock (Rock) Sizing

The riprap equations were developed for rivers and hydraulic structures that cover a range of hydraulic conditions (slope, velocity, depth). The rock sizing analysis was performed based on 8 riprap equations which include:

- Wallingford
- California Highways
- U.S. Army Corps of Engineers
- Jansen et al (low and high turbulence
- Isbash (fitted and loose)
- USACE (1994)
- Aust Roads (2013)

Gary Williams provided a spreadsheet that included the first five methods shown above. The spreadsheet was modified to include the USACE (1994) and the Aust Roads (2013) methods.

The riprap equations predict the rock sizing as either the D30 (30-percent of the rocks in the gradation are equal or smaller than the size), the D50 (median rock size), or the W33 (by weight). For comparison purposes, the D50 was calculated as 20% larger than the D30 size. For the W33, the D33 was computed as follows: D33 =W33 / $(0.85*\rho_S)^{0.33}$, where ρ_S = density of rock (2,650 kg/m^3). Note that the D33 size is approximately the same as the D30 size.

The parameters applied to the rock equations vary, but most include a combination of depth and/or velocity. The USACE (1994) method is more detailed and includes the ratio of curvature of the bend to the channel width, safety factor, stability factor and thickness coefficient.

The depth and velocity values were obtained from the hydraulic model developed by Gardner (2021) at the design discharge and the median bed material size (D_{50}) was 163mm based on the field sampling using the pebble count method (Wolman, 1954). Representative depth and velocity values were selected at 50m intervals in the artificial scour section near the base of the stopbank (Figure 1). The selected velocities typically represent the highest values along the stopbank, and therefore are the most conservative.

For the riprap equations, a velocity factor (usually about 1.5) is typically applied for velocities obtained from 1-D hydraulic model. Since the velocities were obtained from a 2-D model, and in the braid channel near the stopbanks, no velocity scaling factor was applied.

For the Wallingford, US. Army, Jansen and Isbash methods, the riprap was computed applying a batter of 1.5H:1V, and therefore, the results are conservative.

The predicted riprap sizes were evaluated for each equation and a representative size was selected for the Church and Helipad stopbanks, and the NZTA and Havilli Wall stopbanks. In general, the riprap sizes are reasonably consistent within each section with one or two outliers. The representative size was selected by excluding the outliers and choosing a size near the upper end of the predicted sizes (**Table 2** and **Table 3**). The representative values are summarized in **Table 4**.

Table 2 Comparison of the computed riprap sizes and representative sizes based for the Church (Distance 0 to 500m) and Helipad Reaches (Distance 500-750m).

Distance	VELOCITY	DEPTH	WAL/FORD (1.5H:1V)	CALIFORNIA HIGHWAYS		US ARMY (1.5H:1V)	JANSEN et al. (1.5H:1V)		ISBASH (1.5H:1V)		USACE (1994)	Aust. Roads
(m)	V (m/s)	D (m)	D50 (m)	W33 (kg)	D33 (m)	D30 (m)	D50 (m) Low Turb.	D50 (m) High Turb	D30 (m) Fitted	D30 (m) Loose	D30 (m)	D50 (m)
0	4.70	4.06	0.59	346	0.54	0.47	0.66	1.75	0.47	0.92	0.6	0.77
50	5.44	3.88	0.93	831	0.72	0.69	0.88	2.34	0.63	1.23	2.7	1.04
100	3.89	3.18	0.38	110	0.37	0.31	0.45	1.20	0.32	0.63	1.2	0.53
150	4.29	4.39	0.43	199	0.45	0.37	0.55	1.46	0.39	0.77	1.4	0.64
200	5.39	2.93	1.04	781	0.70	0.72	0.86	2.30	0.62	1.21	2.9	1.02
250	6.49	4.67	1.44	2,385	1.02	1.02	1.25	3.33	0.90	1.75	4.0	1.47
300	5.87	5.55	0.98	1,309	0.83	0.76	1.02	2.73	0.73	1.44	3.0	1.21
350	5.73	4.83	0.98	1,137	0.80	0.75	0.98	2.60	0.70	1.37	2.9	1.15
400	5.44	4.26	0.89	829	0.72	0.67	0.88	2.34	0.63	1.23	2.7	1.04
450	4.67	4.63	0.54	333	0.53	0.45	0.65	1.73	0.47	0.91	1.8	0.76
500	5.65	4.41	0.98	1,046	0.77	0.74	0.95	2.53	0.68	1.33	2.9	1.12
550	6.19	4.58	1.26	1,802	0.93	0.92	1.14	3.03	0.82	1.60	3.6	1.34
600	5.78	5.01	0.98	1,199	0.81	0.76	0.99	2.65	0.71	1.40	3.0	1.17
650	5.29	5.43	0.72	698	0.68	0.59	0.83	2.21	0.60	1.17	2.3	0.98
700	5.79	5.27	0.96	1,205	0.81	0.75	0.99	2.65	0.71	1.40	2.9	1.17
750	5.91	4.92	1.06	1,358	0.84	0.80	1.04	2.76	0.74	1.45	3.1	1.22
		Minimum	0.43	199	0.45	0.37	0.55	1.46	0.39	0.77	1.43	0.64
		Average	0.94	1,098	0.76	0.72	0.93	2.49	0.67	1.31	2.81	1.10
		Maximum	1.44	2,385	1.02	1.02	1.25	3.33	0.90	1.75	4.02	1.47
		Representative Values										
		D30 (m)	0.92		0.90	0.80	0.83	1.67	0.80	1.17	3.00	1.00
		D50 (m)	1.10		1.08	0.96	1.00	2.00	0.96	1.40	3.60	1.20

Table 3 Comparison of the computed riprap sizes and representative sizes based for the NZTA (Distance 0 to 900m) and the Havilli Wall Reaches (Distance 900 to 1650m).

Distance	VELOCITY	DEPTH	WAL/FORD (1.5H:1V)	CALIFORNIA HIGHWAYS		US ARMY (1.5H:1V)	JANSEN et al. (1.5H:1V)		ISBASH (1.5H:1V)		USACE (1994)	Aust. Roads
(m)	V (m/s)	D (m)	D50 (m)	W33 (kg)	D33 (m)	D30 (m)	D50 (m) Low Turb.	D50 (m) High Turb	D30 (m) Fitted	D30 (m) Loose	D30 (m)	D50 (m)
0	6.66	4.55	1.58	2,798	1.07	1.10	1.32	3.51	0.95	1.85	3.63	1.55
50	4.73	5.55	0.51	361	0.54	0.45	0.67	1.77	0.48	0.93	1.41	0.78
100	4.33	5.62	0.39	210	0.45	0.36	0.56	1.48	0.40	0.78	1.12	0.66
150	4.47	5.04	0.45	256	0.48	0.40	0.59	1.58	0.43	0.83	1.25	0.70
200	5.03	4.51	0.68	519	0.61	0.55	0.75	2.00	0.54	1.06	1.72	0.89
250	4.49	4.14	0.51	263	0.49	0.42	0.60	1.60	0.43	0.84	1.32	0.71
300	4.53	4.18	0.52	276	0.50	0.43	0.61	1.62	0.44	0.86	1.35	0.72
350	5.48	3.41	1.01	864	0.73	0.73	0.89	2.37	0.64	1.25	2.28	1.05
400	4.01	3.99	0.37	133	0.39	0.32	0.48	1.27	0.34	0.67	1.01	0.56
450	4.82	3.05	0.73	404	0.56	0.54	0.69	1.84	0.50	0.97	1.71	0.81
500	5.55	2.18	1.32	937	0.75	0.84	0.91	2.44	0.66	1.29	2.64	1.08
550	3.77	2.55	0.38	92	0.35	0.31	0.42	1.13	0.30	0.59	0.97	0.50
600	3.28	3.42	0.22	40	0.26	0.20	0.32	0.85	0.23	0.45	0.63	0.38
650	4.14	3.81	0.41	160	0.41	0.35	0.51	1.35	0.36	0.71	1.10	0.60
700	4.78	3.47	0.67	380	0.55	0.51	0.68	1.81	0.49	0.95	1.62	0.80
750	5.07	3.18	0.83	546	0.62	0.61	0.76	2.04	0.55	1.07	1.92	0.90
800	4.29	4.03	0.45	198	0.45	0.38	0.55	1.45	0.39	0.77	1.19	0.64
850	4.06	4.40	0.36	143	0.40	0.32	0.49	1.30	0.35	0.69	1.01	0.58
900	3.62	4.19	0.26	72	0.32	0.24	0.39	1.04	0.28	0.55	0.77	0.46
950	3.81	4.86	0.29	98	0.35	0.27	0.43	1.15	0.31	0.61	0.85	0.51
1000	3.86	5.38	0.28	106	0.36	0.27	0.44	1.18	0.32	0.62	0.85	0.52
1050	3.76	5.11	0.27	91	0.34	0.26	0.42	1.12	0.30	0.59	0.81	0.50
1100	3.87	5.60	0.28	108	0.36	0.27	0.44	1.19	0.32	0.62	0.85	0.52
1150	3.47	6.09	0.19	56	0.29	0.20	0.36	0.96	0.26	0.50	0.63	0.42
1200	3.65	4.79	0.25	76	0.32	0.24	0.40	1.06	0.28	0.56	0.76	0.47
1250	3.57	4.79	0.24	66	0.31	0.23	0.38	1.01	0.27	0.53	0.72	0.45
1300	3.71	4.97	0.26	83	0.33	0.25	0.41	1.09	0.29	0.57	0.78	0.48
1350	3.54	4.43	0.24	63	0.30	0.23	0.37	0.99	0.27	0.52	0.72	0.44
1400	3.98	4.33	0.35	128	0.38	0.31	0.47	1.26	0.34	0.66	0.97	0.56
1450	3.90	4.27	0.33	113	0.37	0.29	0.45	1.20	0.32	0.63	0.92	0.53
1500	4.28	4.54	0.42	196	0.44	0.36	0.54	1.45	0.39	0.76	1.15	0.64
1550	4.41	3.32	0.54	235	0.47	0.42	0.58	1.54	0.41	0.81	1.34	0.68
1600	2.86	4.32	0.13	17	0.20	0.13	0.24	0.65	0.17	0.34	0.64	0.29
1650	2.41	5.32	0.07	6	0.14	0.08	0.17	0.46	0.12	0.24	0.41	0.20
		Min	0.07	6	0.14	0.08	0.17	0.46	0.12	0.24	0.41	0.20
		Ave	0.46	297	0.44	0.38	0.54	1.43	0.39	0.76	1.21	0.63
		Max	1.58	2,798	1.07	1.10	1.32	3.51	0.95	1.85	3.63	1.55
		Representative Values										
		D30 (m)	0.58		0.70	0.70	0.75	1.67	0.50	1.10	2.30	0.92
		D50 (m)	0.70		0.84	0.84	0.90	2.00	0.60	1.32	2.76	1.10

Table 4 Comparison of the representative riprap sizes for each method with the average size and the specified riprap size.

Method	Church & Helipad Stopbanks		NZTA and Havilli Wall Stopbanks	
	D30 (m)	**D50 (m)**	**D30 (m)**	**D50 (m)**
WALLINGFORD	0.92	1.10	0.6	0.70
CALIFORNIA HIGHWAYS	0.90	1.08	0.7	0.84
US ARMY	0.80	0.96	0.7	0.84
JANSEN et al (Low Turbulence)	0.83	1.00	0.80	0.90
JANSEN et al (High Turbulence)	1.67	2.00	1.67	2.00
ISBASH (Fitted)	0.80	0.96	0.50	0.60
ISBASH (loose)	1.17	1.40	1.10	1.32
USACE	3.00	3.60	2.30	2.76
Aust Roads	1.00	1.20	0.9	1.10
Average (excl. USACE)	1.01	1.21	0.86	1.04
WCRC - Specified	1.30	1.33	1.30	1.33

Comparison of the representative sizes indicates that the USACE and the Jansen et al (High Turbulence) methods predict riprap sizes that are about three times and two times larger, respectively, than the other methods. The USACE method scales the velocity by a factor that is based on the channel width and radius of curvature. The equation was developed for conditions where the flow is around the outside of a meander bend, and not where flow is expanding such as along the stopbanks. The USACE method is sensitive to the velocity due scaling by the bend radius factor; as a result, it predicts very large rock. Removing the velocity scaling factor results in similar rock sizes predicted by the other equations.

Comparison of the average riprap sizes (excluding the USACE method) indicates the median size (D50) is about 1.2 m along the Church and Helipad stopbanks, which is very similar to the specified rock size of 1.3m. All the methods, except for the USACE, Jansen et al (High Turbulence) and Isbash (loose fitted) predict smaller rock sizes compared to the specified rock size. The Isbash (loose fitted) method predicts a rock size of 1.4m, which is close to the specified size of 1.3m. The Jansen et al method was sized for a batter of 1.5H:1V, which is steeper than the site conditions, and therefore, the result is conservative.

Along the NZTA and Havilli Wall stopbanks, the average predicted rock size is 1.0m. Similar to the upper section, all the methods, except for the USACE and Jansen et al (High Turbulence) predict smaller rock sizes compared to the specified rock size.

In summary, the rock sizes specified by the WCRC are larger than predicted by the riprap equations (except for the USACE and the Jansen et al. High Turbulence equations), and therefore, it is expected the specified rock will be stable up to the design discharge of 2,500 m^3/s.

Scour Analysis

The scour calculations were performed based on the following three methods:

- N.Z. Railways
- Maza and Echavaria
- Blench

Gary Williams provided a spreadsheet that included the scour equations. Similar to the riprap equations, the hydraulic values were obtained at 50m intervals near the stopbank from the existing conditions hydraulic model at the design discharge of 2,500 m^3/s (Gardner, 2021) (**Table 5**).

The following assumptions were made for the scour calculations:

- Since the hydraulic values were obtained from a 2-D model, a unit width (1 meter) was applied.
- The "rise" is the difference in depth between the low-water and flood conditions. A depth of 0.5m was assumed for the low-water conditions.
- The median (D_{50}) bed material size of 163 mm was applied based on the field measurement.

The scour formula predicts the total flow depth (D) which includes the scour depth (Ds). The predicted scour is shown for each method in the column labelled (Ds-D). The scour depths are separated into the two sections: (1) Helipad and Church stopbanks, and (2) proposed NZTA and Havill Wall Stopbanks.

For the Helipad and Church stopbank, the N.Z. Railways method predicts negative scour depths, which indicates that the predicted scour depths are less than the modelled conditions. It is important to note that the modelled conditions include a 2m deep channel along base of the stopbank. Therefore, the NZ Railways method predicts no additional scour. The NZR formula is based around asymmetry, and for the braid in a wide channel is likely to under-estimate the scour.

The Maza and Echavaria method predicts scour depths ranging from 1.5 to 2.4 with an average of 1.5m. The Blench method predicts scour depths ranging from 0.4 to 1.9m with and average of 1.2 m. Therefore, the predicted scour depths are less than the rock toe-down depth of 6m.

For proposed NZTA stopbanks (chainage 0 to 900m), the N.Z. Railways method predicts negative scour depths indicating that the predicted scour depths are less than the modelled conditions. The Maza and Echavaria method predicts scour depths ranging from -0.2 to 2.5 with an average of 0.8, and the Blench method predicts scour depths ranging from -0.1 to 1.9m to 2.2m with an average of 0.7 m.

For proposed Havill Wall stopbanks (chainage 900 to 1650m), the N.Z. Railways method predicts negative scour depths indicating that the predicted scour depths are less than the modelled conditions. The Maza and Echavaria method predicts scour depths ranging from 0.0 to 0.8 with an average of 0.3, and the Blench method predicts scour depths ranging from -0.3 to 0.7m with an average of 0.2 m.

In summary, the total scour depth (which includes the predicted scour depths and the 2m scour depth represented in the model) is less than the 4m toe down depth, and therefore, the WCRC toe down depth is appropriate. Since the channel is aggradational, the toe down depth will become more conservative over time.

Table 5 Summary of the scour calculations for the helipad and church stopbanks, and the proposed NZTA and Havill Wall stopbanks.

Chainage	FLOW	VELOCITY	WIDTH	AREA	MAX. DEPTH	MEAN DEPTH	RISE	MATERIAL	N.Z. RAILWAYS		MAZA & ECHAV.		BLENCH	
(m)	Q (m^3/s)	V (m/s)	W (m)	A (m^2)	D (m)	Dm (m)	R (m)	d50 (mm)	Ds	Ds-D	Ds	Ds-D	Ds	Ds-D
Helipad and Church Stopbanks														
0.0	19.1	4.7	1.0	4.1	4.1	4.1	3.6	0.2	1.8	-2.3	4.9	0.9	4.8	0.8
50.0	21.1	5.4	1.0	3.9	3.9	3.9	3.4	0.2	2.0	-1.9	5.3	1.4	5.2	1.3
100.0	12.3	3.9	1.0	3.2	3.2	3.2	2.7	0.2	1.4	-1.8	3.5	0.3	3.6	0.4
150.0	18.8	4.3	1.0	4.4	4.4	4.4	3.9	0.2	1.7	-2.6	4.9	0.5	4.8	0.4
200.0	15.8	5.4	1.0	2.9	2.9	2.9	2.4	0.2	1.7	-1.2	4.2	1.3	4.3	1.3
250.0	30.3	6.5	1.0	4.7	4.7	4.7	4.2	0.2	2.4	-2.2	7.1	2.4	6.6	1.9
300.0	32.6	5.9	1.0	5.6	5.6	5.6	5.1	0.2	2.4	-3.2	7.5	1.9	6.9	1.4
350.0	27.7	5.7	1.0	4.8	4.8	4.8	4.3	0.2	2.2	-2.6	6.6	1.7	6.2	1.4
400.0	23.2	5.4	1.0	4.3	4.3	4.3	3.8	0.2	2.1	-2.2	5.7	1.5	5.5	1.2
450.0	21.6	4.7	1.0	4.6	4.6	4.6	4.1	0.2	1.9	-2.7	5.4	0.8	5.3	0.6
500.0	24.9	5.7	1.0	4.4	4.4	4.4	3.9	0.2	2.1	-2.3	6.1	1.6	5.8	1.4
550.0	28.4	6.2	1.0	4.6	4.6	4.6	4.1	0.2	2.3	-2.3	6.7	2.1	6.3	1.7
600.0	29.0	5.8	1.0	5.0	5.0	5.0	4.5	0.2	2.3	-2.7	6.8	1.8	6.4	1.4
650.0	28.7	5.3	1.0	5.4	5.4	5.4	4.9	0.2	2.2	-3.2	6.8	1.3	6.4	0.9
700.0	30.5	5.8	1.0	5.3	5.3	5.3	4.8	0.2	2.3	-2.9	7.1	1.8	6.6	1.3
750.0	29.0	5.9	1.0	4.9	4.9	4.9	4.4	0.2	2.3	-2.6	6.8	1.9	6.4	1.5
Proposed NZTA and Havill Wall Stopbanks														
0.0	26.1	6.9	1.0	3.8	3.8	3.8	3.3	0.2	2.3	-1.4	6.3	2.5	6.0	2.2
50.0	26.3	4.7	1.0	5.5	5.5	5.5	5.0	0.2	2.0	-3.5	6.3	0.8	6.0	0.4
100.0	24.3	4.3	1.0	5.6	5.6	5.6	5.1	0.2	1.9	-3.7	5.9	0.3	5.7	0.1
150.0	22.5	4.5	1.0	5.0	5.0	5.0	4.5	0.2	1.9	-3.1	5.6	0.6	5.4	0.4
200.0	22.7	5.0	1.0	4.5	4.5	4.5	4.0	0.2	2.0	-2.5	5.6	1.1	5.4	0.9
250.0	18.6	4.5	1.0	4.1	4.1	4.1	3.6	0.2	1.8	-2.4	4.8	0.7	4.8	0.6
300.0	19.8	4.7	1.0	4.2	4.2	4.2	3.7	0.2	1.8	-2.3	5.1	0.9	5.0	0.8
350.0	18.1	5.3	1.0	3.4	3.4	3.4	2.9	0.2	1.8	-1.6	4.7	1.3	4.7	1.3
400.0	16.0	4.0	1.0	4.0	4.0	4.0	3.5	0.2	1.6	-2.4	4.3	0.3	4.3	0.3
450.0	14.7	4.8	1.0	3.0	3.0	3.0	2.5	0.2	1.6	-1.4	4.0	1.0	4.1	1.0
500.0	12.1	5.6	1.0	2.2	2.2	2.2	1.7	0.2	1.5	-0.6	3.4	1.3	3.6	1.4
550.0	10.2	4.0	1.0	2.5	2.5	2.5	2.0	0.2	1.3	-1.2	3.0	0.5	3.2	0.6
600.0	11.2	3.3	1.0	3.4	3.4	3.4	2.9	0.2	1.3	-2.1	3.2	-0.2	3.4	0.0
650.0	17.4	4.6	1.0	3.8	3.8	3.8	3.3	0.2	1.7	-2.1	4.6	0.8	4.5	0.7
700.0	16.7	4.8	1.0	3.5	3.5	3.5	3.0	0.2	1.7	-1.7	4.4	1.0	4.4	1.0
750.0	16.1	5.1	1.0	3.2	3.2	3.2	2.7	0.2	1.7	-1.4	4.3	1.1	4.3	1.1
800.0	18.7	4.6	1.0	4.0	4.0	4.0	3.5	0.2	1.8	-2.2	4.8	0.8	4.8	0.7
850.0	18.2	4.1	1.0	4.4	4.4	4.4	3.9	0.2	1.7	-2.7	4.7	0.3	4.7	0.3
900.0	15.0	3.6	1.0	4.2	4.2	4.2	3.7	0.2	1.5	-2.7	4.1	-0.1	4.1	-0.1
950.0	19.6	4.0	1.0	4.9	4.9	4.9	4.4	0.2	1.7	-3.1	5.0	0.2	4.9	0.1
1000.0	21.8	4.0	1.0	5.4	5.4	5.4	4.9	0.2	1.8	-3.6	5.5	0.1	5.3	-0.1
1050.0	21.2	4.2	1.0	5.1	5.1	5.1	4.6	0.2	1.8	-3.3	5.3	0.2	5.2	0.1
1100.0	24.3	4.3	1.0	5.6	5.6	5.6	5.1	0.2	1.9	-3.7	5.9	0.3	5.7	0.1
1150.0	24.9	4.1	1.0	6.1	6.1	6.1	5.6	0.2	1.9	-4.2	6.1	0.0	5.8	-0.3
1200.0	20.2	4.2	1.0	4.8	4.8	4.8	4.3	0.2	1.8	-3.0	5.1	0.3	5.0	0.2
1250.0	19.7	4.1	1.0	4.8	4.8	4.8	4.3	0.2	1.7	-3.1	5.0	0.2	4.9	0.1
1300.0	20.8	4.2	1.0	5.0	5.0	5.0	4.5	0.2	1.8	-3.2	5.3	0.3	5.1	0.2
1350.0	19.6	4.4	1.0	4.4	4.4	4.4	3.9	0.2	1.8	-2.6	5.0	0.6	4.9	0.5
1400.0	20.2	4.7	1.0	4.3	4.3	4.3	3.8	0.2	1.8	-2.5	5.1	0.8	5.0	0.7
1450.0	16.7	3.9	1.0	4.3	4.3	4.3	3.8	0.2	1.6	-2.7	4.4	0.1	4.4	0.1
1500.0	19.4	4.3	1.0	4.5	4.5	4.5	4.0	0.2	1.8	-2.8	5.0	0.4	4.9	0.4
1550.0	14.7	4.4	1.0	3.3	3.3	3.3	2.8	0.2	1.6	-1.7	4.0	0.7	4.1	0.7
1600.0	2.4	2.9	1.0	0.8	0.8	0.8	0.3	0.2	0.4	-0.5	1.0	0.1	1.2	0.4
1650.0	2.0	2.4	1.0	0.8	0.8	0.8	0.3	0.2	0.3	-0.5	0.8	0.0	1.1	0.2

Stopbank Design

To simplify the stopbank design, a continuous chainage was developed that extends from 0 to 2,358m. Note, that the chainage for the design is different than the chainage shown in Figure 1. Chainage 0 starts at the downstream end of the Havill Wall and chainage 2,358m is located at the upstream end of the Church stopbank.

The stopbank design was developed using the following method.

1. The hydraulic model was run for the 20-year aggradation conditions at the design discharge of 2,500 m^3/s.
2. Stopbank design profiles were developed for 3 scenarios which included raising the stopbank by 2, 2.5 and 3m.
3. The stopbank profiles were developed by selecting a profile with a minimum number of slope changes to match the predicted aggradation conditions and water-surface elevations.
4. Cross-sections were developed at approximately 50m intervals that included the bulkfill, toedown rock and facing rock.
5. The volume of rock was computed for each scenario using the end-area method and the resulting volumes were compared with the available rock. Planform mapping was developed to show the extents (particularly the bulkfill on the landward side) of the stopbank.
6. Following discussion with the WCRC, the 2m raise was selected for the following reasons:
    - The rock quantity for the 3m raise exceeded the available rock and therefore was not considered.
    - Both the 2 and 2.5m raise encroach onto private land and the church near the Church stopbank, with the 2m raise having less encroachment.
    - The WCRC are also planning to raise the stopbanks along the left side of the Waiho River. It is likely that the stopbanks along the left side will be raised to similar elevations as the right side. The amount of funding (and the quantity of available bulkfill and rock) is unknown, and correspondingly, it is not known how high the left stopbanks can be raised. The WCRC decided not to overbuild the right side without confidence knowing that the left side will be built to match, and therefore, the WCRC selected a 2m raise.

The proposed design profile is shown in **Figure 3** and **Appendix A.1**. The design planform and representative cross-sections are shown in **Appendix A.2 to A.4**.

Following are comments on the design.

- The freeboard varies along the length of stopbanks.
    - The average freeboard along the stopbank is 1.1m at the design discharge. There are two areas with freeboard less than 0.5m, which occur near the up- and downstream ends of the stopbank.
    - The WCRC requested that the stopbank crest near the upstream end (from about chainage 2,207 to 2,358m) be raised by about 1m to prevent the bulkfill on the landward side encroaching on to private property and the church property. The private property is located between Chainage 1,908 and 1,959m and the church between 2,257 and 2,308m (Appendix A.1). As a result, there is no freeboard at the upstream end under the predicted aggradation conditions at the design discharge..
    - Bulkfill will not be placed on the private property. As a result, the batter in this area will be about 2.3H:1V (or 23 degrees) compared to the design specification of 3H:1V. The angle of repose for cobbles is about 40 degrees and therefore, the 2.3H:1V batter is expected to be stable.
    - The freeboard near Chainage 2109m is about 4m. This area has experienced significant aggradation. Initially, the aggradation is expected to be greater at the upstream end compared to downstream. Therefore, the larger freeboard will provide an additional factor of safety.
    - The freeboard along the proposed NZTA stopbank is about 4m. The channel bed is relatively low in this area. It is anticipated that the channel will quickly aggrade, and as a result, the freeboard will be reduced to similar values as the Havill Wall.
- The calculated bulkfill and rock quantities are shown in **Table 6.**
- The bulkfill material will be sourced from the river bed.
- Typically, a filter layer is constructed between the bulkfill and the rock. The filter layer is intended to create a layer for placement of the rock and to prevent fines washing out of the bulkfill layer. Because

the bulkfill contains a large range of particle sizes including sands and gravels, it was determined that a filter layer was not necessary.

- Construction of the NZTA stopbank will create a low elevation area that will be bounded by the NZTA stopbank to the west and stopbank along state highway 6 to the east. At present, there is a stormwater drain that flows into this area that has the potential to cause ponding. The WCRC has indicated that the drain will be moved to prevent flows into the low elevation area.
- It is important to recognize that the aggradation patterns will vary with each flood, and future aggradation cannot be accurately predicted. Significant effort has been made to evaluate historic deposition patterns in order to predict future aggradation.
- The 20-year design life is intended to be an interim measure while the long-term plan is put in place. This assumes that the aggradation rates and locations are similar to the past 20 years, however there is no freeboard at the up- and downstream ends of the stopbank at the design discharge.

Table 6 Calculated rock and bulkfill quantities for the 2m stopbank raise.

Item	Quantity
Bulkfill (m^3)	208,420
Rock (tonne)	89,678
Rock[1] (m^3)	45,989

[1]Rock volume was calculated at 1.95 tonnes/m^3 as specified by WCRC.

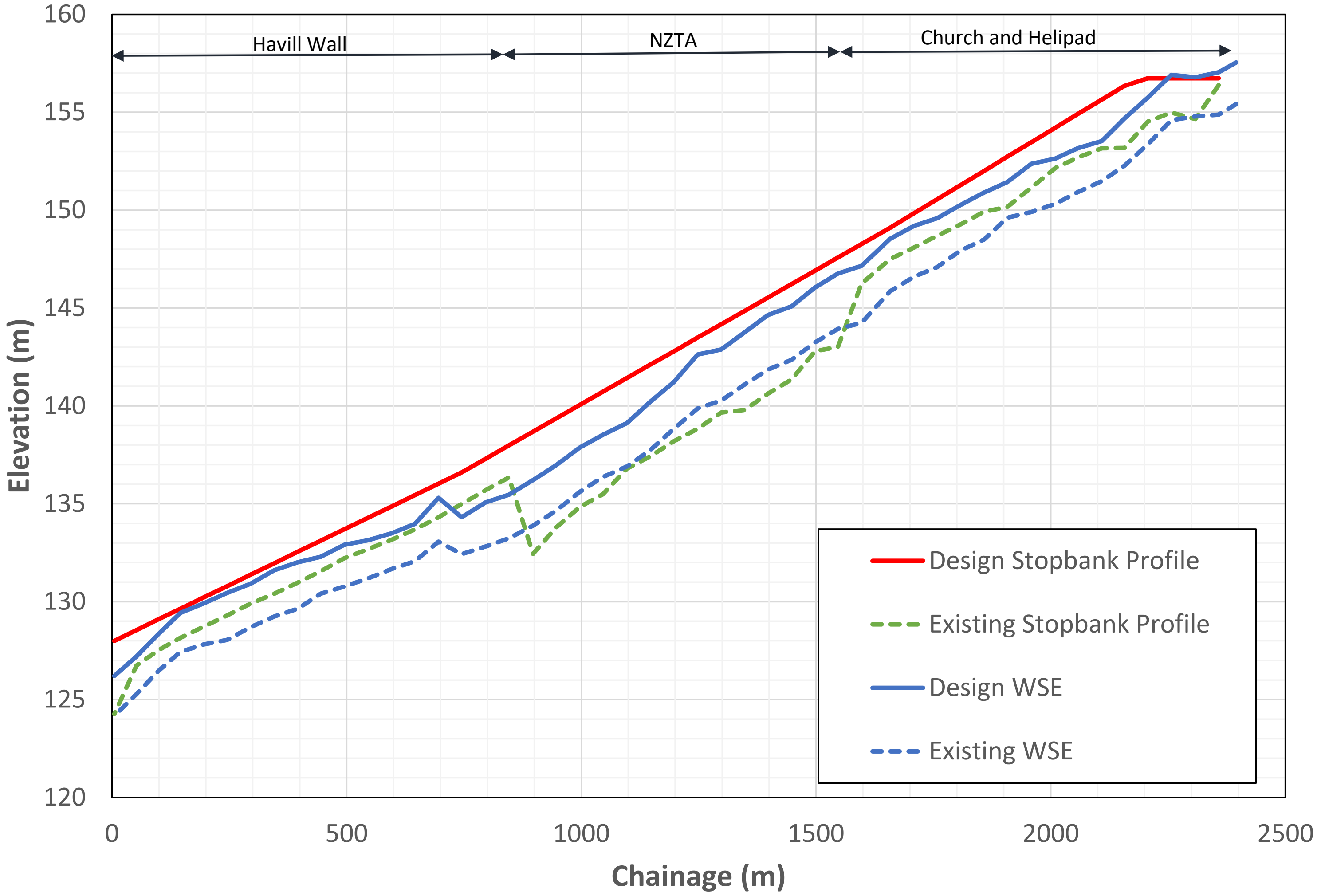

Figure 3 Comparison of existing and proposed stopbank profile for the 2m raise, and the existing and design water-surface profiles.

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