Memorandum: Achievement of NPS-FM 2020 suspended sediment attribute bands for the Otago stream network

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1 Background

Neverman and Smith (2022a, 2022b) modelled mean annual suspended sediment loads for baseline and future land cover scenarios (GMP and GMP+) across the Otago region, and assessed the improvement in NPS-FM 2020 suspended fine sediment attribute bands at 34 State of the Environment (SoE) water quality monitoring sites.

Otago Regional Council (ORC) requested Manaaki Whenua – Landcare Research (MWLR) assess the achievement of suspended fine sediment attribute bands across the REC2 stream network using modelled baseline visual clarity provided by ORC and the mean annual suspended sediment loads from Neverman and Smith (2022a, 2022b).

2 Methods

For a description of the SedNetNZ model and the baseline, GMP, and GMP+ land cover scenarios used to model mean annual sediment loads please see Neverman and Smith (2022a, 2022b).

To assess the improvement in visual clarity under the GMP and GMP+ scenarios we use the approach developed by Hicks et al. (2019), consistent with Neverman and Smith (2022a, 2022b). This approach is recommended by the Ministry for the Environment in their guidance for implementing the NPS-FM 2020 sediment requirements (Ministry for the Environment 2022), and directly informed development of the suspended fine sediment attribute for the NPS-FM 2020 (see Hicks and Shankar 2020).

Following Hicks et al. (2019) and Ministry for the Environment (2022), the proportional reduction in mean annual suspended sediment load required to achieve the target attribute bands is calculated for each segment of the River Environment Classification v2.4 (REC2) digital stream network. The proportional reduction is a function of the ratio between the current state visual clarity and the minimum visual clarity for the target attribute band using Equation 1:

$$PR_v = 1 - (V_o/V_b)^{1/a} \tag{1}$$

where PR_v is the minimum proportional reduction in mean annual suspended sediment load required to achieve the target attribute band, V_o is the minimum median visual clarity for the target band (Table 1), and V_b is the current state median visual clarity. We follow the recommendation of Ministry for the Environment (2022) and assume a in equation 1 takes the national average reported by Hicks et al. (2019) of -0.76. This is consistent with Neverman and Smith (2022a, 2022b).

Unlike other contaminants, the attribute band thresholds for suspended fine sediment are determined by the "sediment class" associated with each REC2 segment (Table 1), as defined in Appendix 2C of the NPS-FM (2020). The sediment class of a given segment is determined by the climate, topography, and geology classification (as defined in the REC2) of upstream segments predominately contributing flow to a given segment. This can produce abrupt changes in sediment class between adjoining REC2 segments. We use the layer denoting suspended sediment class for the REC2 digital stream network produced by Hicks and Shankar (2020)[1] to identify the sediment class of each segment in Otago (Figure 1).

Due to the size of the many lakes in the Otago region the REC2 network often contains multiple parallel segments within the body of a lake. As the NPS-FM (2020) sediment regulations would not apply to these segments we exclude them from the summaries in this report by excluding segments with ≥70% of their length intersecting lakes (~2% of the REC2 network).

[1] Available from the MfE data portal at https://data.mfe.govt.nz/layer/103687-hydrological-modelling-to-support-proposed-sediment-attribute-impact-testing-2020/

Table 1. Attribute bands and associated numeric attribute states for suspended fine sediment, reproduced from the NPS-FM (2020). Note the use of visual clarity (m) as the attribute unit.

Value (and component)	Ecosystem health (Water quality)			
Freshwater body type	Rivers			
Attribute unit	Visual clarity (metres)			
Attribute band and description	**Numeric attribute state by suspended sediment class**			
	1	2	3	4
A Minimal impact of suspended sediment on instream biota. Ecological communities are similar to those observed in natural reference conditions.	≥1.78	≥0.93	≥2.95	≥1.38
B Low to moderate impact of suspended sediment on instream biota. Abundance of sensitive fish species may be reduced.	<1.78 and ≥1.55	<0.93 and ≥0.76	<2.95 and ≥2.57	<1.38 and ≥1.17
C Moderate to high impact of suspended sediment on instream biota. Sensitive fish species may be lost.	<1.55 and >1.34	<0.76 and >0.61	<2.57 and >2.22	<1.17 and >0.98
National bottom line	**1.34**	**0.61**	**2.22**	**0.98**
D High impact of suspended sediment on instream biota. Ecological communities are significantly altered and sensitive fish and macroinvertebrate species are lost or at high risk of being lost.	<1.34	<0.61	<2.22	<0.98

The minimum record length for grading a site is the median of 5 years of at least monthly samples (at least 60 samples).

Councils may monitor turbidity and convert the measures to visual clarity.

See Appendix 2C Tables 23 and 26 for the definition of suspended sediment classes and their composition.

The following are examples of **naturally occurring processes** relevant for suspended sediment:

- naturally highly coloured brown-water streams
- glacial flour affected streams and rivers
- selected lake-fed REC classes (particularly warm climate classes) where low visual clarity may reflect autochthonous phytoplankton production.

3 Results

3.1 Baseline compliance

The dominant suspended sediment class in Otago is class 1, spanning 47% of the stream network (Table 2, Figure 1). Class 1 has a national bottom line (NBL) of 1.34 m median visual clarity and band A minimum threshold of 1.78 m (Table 1). Class 3 is also predominant across the region, spanning 42% of the stream network, and tends to be the class of the main stem of the major rivers (Figure 1). Class 3 has an NBL of 2.22 m median visual clarity and band A minimum threshold of 2.95 m.

Table 2. Length (km and %) of the FMU and regional stream network in each suspended sediment class.

	Stream length by suspended sediment class (km)			
FMU	**1**	**2**	**3**	**4**
Catlins	457 (25%)	347 (19%)	4 (<1%)	1,050 (57%)
Clutha Mata-Au	16,742 (55%)	1,223 (4%)	12,391 (40%)	242 (<1%)
Dunedin & Coast	964 (59%)	620 (38%)	59 (4%)	2 (<1%)
North Otago	1,427 (33%)	1,341 (31%)	1,549 (36%)	–
Taieri	2,974 (32%)	176 (2%)	6,179 (66%)	8 (<1%)
Otago	**22,565 (47%)**	**3,706 (8%)**	**20,182 (42%)**	**1,302 (3%)**

The baseline median visual clarity of each REC2 segment was modelled by Ton Snelder (LandWaterPeople – LWP) and provided to MWLR by ORC. These modelled baseline visual clarity data are independent of suspended sediment loads modelled by SedNetNZ (Neverman & Smith, 2022a; 2022b). Model performance statistics from cross-validation were supplied with the visual clarity data and are reproduced in Table 3. Differences occur between the baseline states in this modelled dataset and the measured data previously provided by ORC at the 34 monitoring sites assessed in Neverman and Smith (2022a, 2022b). Modelled median visual clarity is higher than measured at 24 monitoring sites, lower at 8, and equal at 2 (Table 4). The modelled data places 20 of the 34 monitoring sites in the same band as the measured data, 2 in a lower band, and 12 in a higher band. Two monitoring sites (Kawarau at Chards Road and Taieri at Outram) are band C in the measured data, but below NBL in the modelled data. Eight sites are below the NBL in the measured data and above NBL in the modelled data, including Lovells Creek at Station Road, Pomahaka at Burkes Ford, Pomahaka at Glenken, Waitahuna at Tweeds Bridge, Tokomairiro at Lisnatunny, Sutton Stream at SH87, which are band C in the modelled data, and the Owhiro Stream at Riverside Road which is band B in the modelled data. The location of monitoring sites is displayed in Figure 4 in the Appendix.

Table 3. Reported statistics for modelled median visual clarity, provided by ORC. Definitions of the statistics are provided in the Appendix.

Statistic	Value
n	109
R^2	0.39
NSE	0.38
RMSD	0.23
Bias	0.003

Table 4. Comparison of median visual clarity and associated attribute band using measured data from SoE monitoring sites as used in Neverman and Smith (2022a, 2022b) with modelled median visual clarity supplied by ORC from LWP (rounded to 2 d.p.). Monitoring site locations are presented in Figure 4. "Difference" signifies the direction of change in attribute band for the modelled data relative to the measured data at each site.

				Measured		Modelled		
FMU	**Site ID**	**Site No.**	**Suspended sediment class**	**Visual clarity (m)**	**Attribute band**	**Visual clarity (m)**	**Attribute band**	**Difference**
Catlins	Catlins at Houipapa	2	4	1.33	B	1.67	A	Higher
Clutha Mata-Au	Benger burn at SH8	1	3	1.90	D	2.071	D	
	Clutha @ Balclutha	3	3	1.51	D	1.60	D	
	Clutha @ Millers Flat	4	3	2.15	D	1.84	D	
	Crookston Burn at Kelso Road	5	1	1.20	D	1.20	D	
	Heriot Burn at Park Hill Road	6	1	0.93	D	1.23	D	
	Kawarau @ Chards Rd	7	3	2.52	C	1.78	D	Lower
	Lindis at Ardgour Road	9	3	2.70	B	2.66	B	
	Lindis at Lindis Peak	10	3	2.46	C	2.50	C	
	Lovells Creek at Station Road	12	1	1.14	D	1.52	C	Higher
	Manuherikia at Blackstone Hill	13	3	2.04	D	1.90	D	
	Manuherikia at Galloway	14	3	1.69	D	1.63	D	
	Manuherikia at Ophir	15	3	1.60	D	1.63	D	
	Mill Creek at Fish Trap	16	3	1.39	D	1.51	D	
	Pomahaka at Burkes Ford	18	1	1.29	D	1.37	C	Higher
	Pomahaka at Glenken	19	3	1.76	D	2.27	C	Higher
	Thomsons Creek at SH85	29	3	1.22	D	1.40	D	
	Wairuna at Millar Road	33	1	0.66	D	1.02	D	
	Waitahuna at Tweeds Bridge	34	1	1.14	D	1.41	C	Higher
Dunedin & Coast	Lindsays Creek at North Road Bridge	11	1	1.50	C	2.00	A	Higher
	Tokomairiro at Lisnatunny	30	1	1.24	D	1.50	C	Higher
	Tokomairiro at West Branch Bridge	31	1	1.62	B	1.62	B	

Table 4 (cont.)

FMU	Site ID	Site No.	Suspended sediment class	Measured		Modelled		
				Visual clarity (m)	Attribute band	Visual clarity (m)	Attribute band	Difference
Taieri	Kye Burn at SH85 Bridge	8	3	2.35	C	2.80	B	Higher
	Owhiro Stream at Riverside Rd	17	1	0.40	D	1.56	B	Higher
	Sutton Stream at SH87	20	3	1.50	D	2.46	C	Higher
	Taieri at Allanton Bridge	21	3	1.12	D	1.32	D	
	Taieri at Creamery Road bridge	22	3	1.69	D	1.92	D	
	Taieri at Linnburn Runs Road	23	3	2.50	C	2.90	B	Higher
	Taieri at Outram	24	3	2.34	C	1.43	D	Lower
	Taieri at Stonehenge	25	3	2.50	C	2.65	B	Higher
	Taieri at Sutton	26	3	1.21	D	1.33	D	
	Taieri at Tiroiti	27	3	0.73	D	1.11	D	
	Taieri at Waipiata	28	3	1.52	D	1.53	D	
	Waipori at Waipori Falls Reserve	32	3	2.20	D	2.09	D	

In the present work, the modelled visual clarity data determines the baseline state of each REC2 segment (Figure 1). There is a high level of compliance with the NPS-FM (2020) across the stream network for the baseline state, with 96% of the network by length above the national bottom line (Table 5). 78% of the network is in band A, a further 9% is in band B, and 9% is in band C. 4% of the network by length is below the NBL (band D). 22% of the stream network therefore has potential to improve in attribute band.

Table 5. Length (km and %) of the Otago stream network in each attribute band by suspended sediment class. Note segments are only counted in the highest band with which they comply.

	Total stream length by suspended sediment class (km)				
Attribute band	**1**	**2**	**3**	**4**	**Total length by band**
A	18,937 (40%)	3,706 (8%)	13,446 (28%)	1,302 (3%)	**37,391 (78%)**
B	1,471 (3%)	–	2,718 (6%)	–	**4,189 (9%)**
C	1,977 (4%)	–	2,226 (5%)	–	**4,202 (9%)**
D	180 (<1%)	–	1,791 (4%)	–	**1,971 (4%)**
Total length by sediment class	**22,565 (47%)**	**3,706 (8%)**	**20,182 (42%)**	**1,302 (3%)**	**47,754 (100%)**

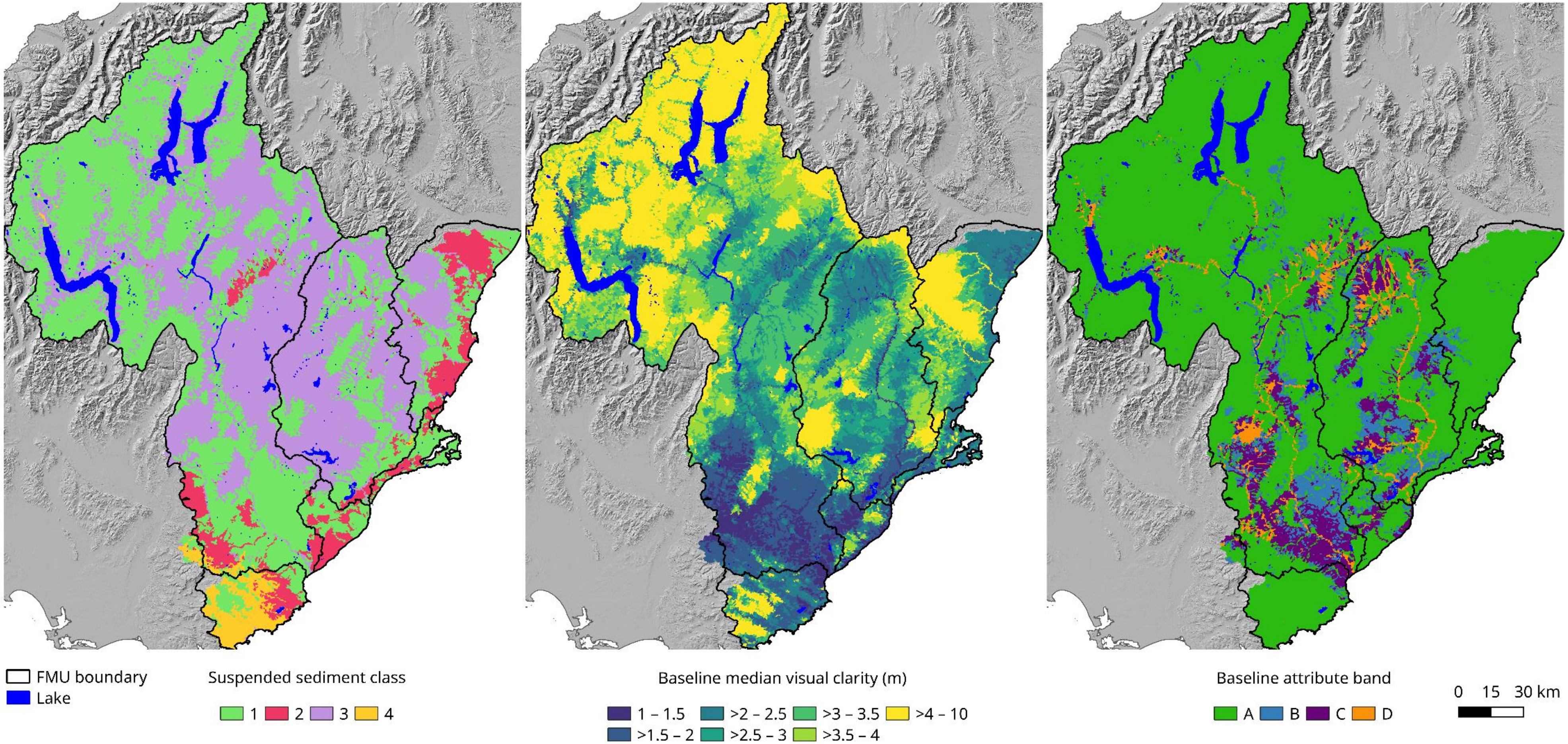

Figure 1. Suspended sediment class (left), modelled baseline median visual clarity provided by ORC (centre), and corresponding current state attribute band (right) for Otago.

Figure 2 shows the spatial distribution of segments requiring a reduction in baseline suspended sediment load to achieve each attribute band. Table 6 summarises the required reductions within each FMU and across Otago. The majority of segments across the region and FMUs require a ≤30% reduction in load to improve their attribute band (Table 6). The North Otago FMU has a high baseline compliance, with no segments below the NBL, <1% by length requires a load reduction to achieve band B, and 4% requires a reduction to achieve band A. The Catlins and Dunedin FMUs also have a high compliance with the NBL with <1% of segments by length below the NBL. The Taieri has the lowest compliance, with 8% of the stream network below the NBL, 22% requiring a reduction to achieve band B, and 37% requiring a reduction to achieve band A.

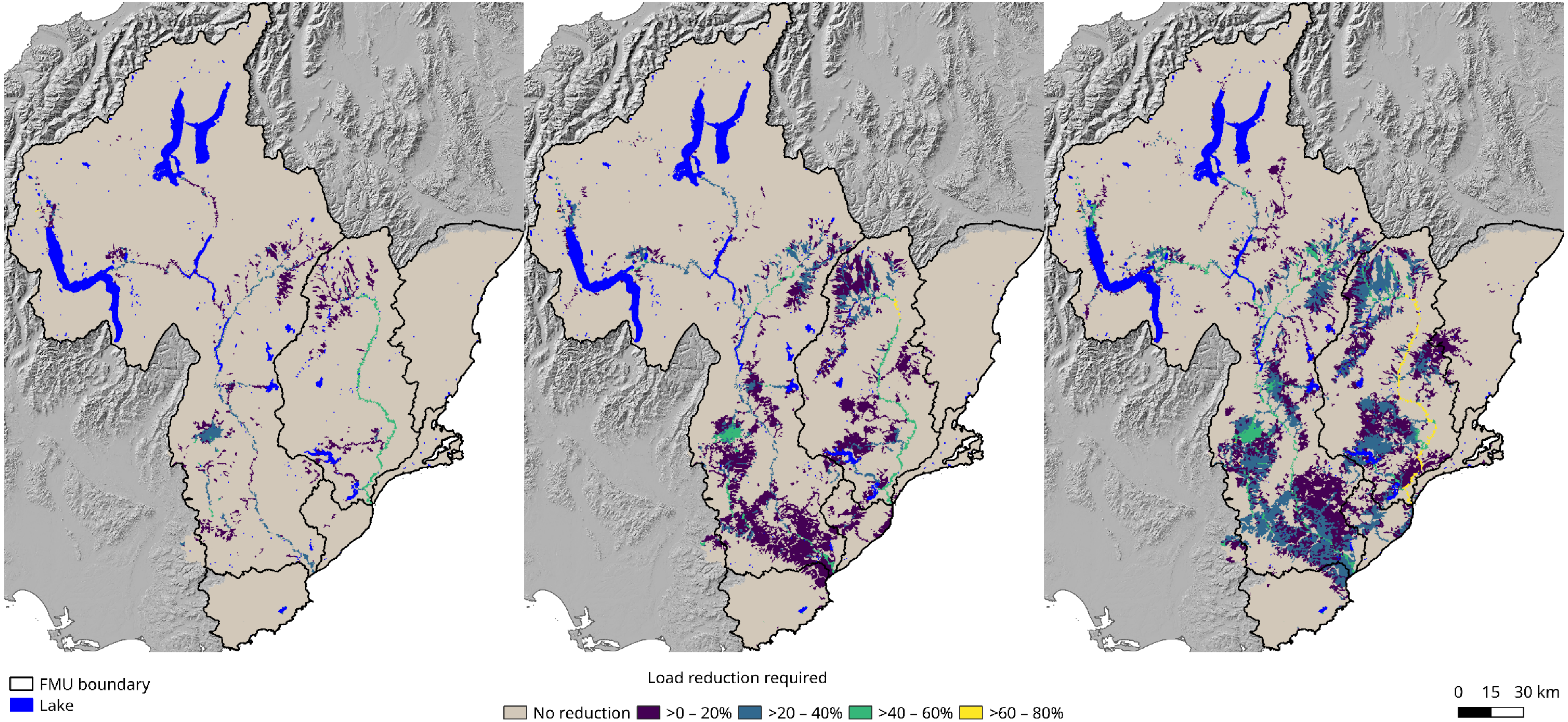

Figure 2. Proportional reduction in suspended sediment load required to achieve band C (left), band B (centre), and band A (right).

3.2 GMP and GMP+ compliance

The segment level reductions in baseline mean annual suspended sediment load required to achieve each attribute band as well as the attribute band achievable under the mitigation scenarios are provided as shapefiles accompanying this memo, and are described in the accompanying data dictionary, which is also appended here.

To identify the attribute band achievable under each mitigation scenario, we compare the proportional reduction in mean annual suspended sediment load achieved between the baseline and mitigation scenarios with the proportional reduction in load required to achieve each target attribute band (Equation 1). This is performed for each segment in the REC2 digital stream network with modelled baseline median visual clarity and suspended sediment load.

The reductions in mean annual suspended sediment load achieved between the baseline and mitigation scenarios are summarised in Neverman and Smith (2022a, 2022b) and are not repeated here. Table 7 summarises the length of streams achieving the attribute bands within each FMU and across Otago for the baseline and mitigation scenarios. The GMP and GMP+ scenarios produce similar levels of compliance with ≥93% of the stream network in band A, and ≤2% below the NBL under both scenarios across the FMUs and region.

The Taieri FMU has the largest improvement in compliance, with 30% of segments moving into band A, and 5% moving above the NBL. 17% of segments in the Clutha Mata-Au and 19% in the Dunedin & Coast FMUs move into band A, with 3% of the stream network moving above the NBL in the Clutha Mata-Au FMU. Smaller improvements occur in the Caitlins and North Otago FMUs. This is due to the already high baseline compliance with band A meaning potential improvements in visual clarity will not result in a change to the attribute band. Across the region, this results in 18% of the stream network moving into band A, and 3% moving above the NBL under both the GMP and GMP+ scenarios.

Those segments which do not achieve the NBL are predominately suspended sediment class 3 (Table 8), and tend to be higher order segments (Table 8) located along the main stem of the major rivers (Figure 2 and Figure 3). Class 3 requires the highest visual clarity, with a NBL of 2.22 m. This is consistent with the previous results at SoE sites, where 11 of 12 sites unable to achieve the NBL were sediment class 3 (Neverman & Smith 2022a, 2022b). Further reductions required to achieve target attribute bands under the GMP and GMP+ scenarios are summarised in Table 9. Similar proportions of the stream network require reductions between the scenarios, although lower reductions are required under GMP+.

Table 6. Proportional reduction in baseline mean annual suspended sediment load required to improve the attribute band of stream segments, summarised by length (km and %) of the FMU and regional stream network. Segments which already achieve the band and do not require a reduction are excluded.

	Catlins			Clutha Mata-Au			Dunedin & Coast			North Otago		
Proportional reduction required	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
>0 – 10%	21 (1%)	77 (4%)	–	1,381 (5%)	1,586 (5%)	503 (2%)	111 (7%)	158 (10%)	4 (<1%)	100 (2%)	16 (<1%)	–
>10 – 20%	49 (3%)	33 (2%)	–	1,659 (5%)	1,125 (4%)	329 (1%)	99 (6%)	58 (4%)	2 (<1%)	74 (2%)	–	–
>20 – 30%	87 (5%)	–	–	1,726 (6%)	531 (2%)	217 (<1%)	167 (10%)	6 (<1%)	–	<1 (<1%)	–	–
>30 – 40%	2 (<1%)	–	<1 (<1%)	791 (3%)	285 (<1%)	187 (<1%)	11 (<1%)	–	–	–	–	–
>50 – 60%	<1 (<1%)	<1 (<1%)	–	251 (<1%)	25 (<1%)	–	–	–	–	–	–	–
>60 – 70%	<1 (<1%)	–	–	11 (<1%)	3 (<1%)	3 (<1%)	–	–	–	–	–	–
>40 – 50%	–	<1 (<1%)	<1 (<1%)	372 (1%)	237 (<1%)	23 (<1%)	–	–	–	–	–	–
>70 – 80%	–	–	–	3 (<1%)	–	–	–	–	–	–	–	–
Total length requiring reduction	**160 (9%)**	**111 (6%)**	**<1 (<1%)**	**6,194 (20%)**	**3,792 (12%)**	**1,262 (4%)**	**388 (24%)**	**223 (14%)**	**6 (<1%)**	**175 (4%)**	**16 (<1%)**	**–**

Table 6 (cont.)

Proportional reduction required	Taieri			Otago		
	A	B	C	A	B	C
>0 – 10%	927 (10%)	799 (9%)	348 (4%)	2,540 (5%)	2,636 (6%)	855 (2%)
>10 – 20%	781 (8%)	652 (7%)	142 (2%)	2,663 (6%)	1,867 (4%)	473 (<1%)
>20 – 30%	976 (10%)	307 (3%)	21 (<1%)	2,956 (6%)	844 (2%)	238 (<1%)
>30 – 40%	448 (5%)	82 (<1%)	17 (<1%)	1,252 (3%)	367 (<1%)	205 (<1%)
>50 – 60%	36 (<1%)	161 (2%)	22 (<1%)	287 (<1%)	186 (<1%)	22 (<1%)
>60 – 70%	150 (2%)	14 (<1%)	–	161 (<1%)	18 (<1%)	3 (<1%)
>40 – 50%	120 (1%)	18 (<1%)	152 (2%)	492 (1%)	255 (<1%)	176 (<1%)
>70 – 80%	8 (<1%)	–	–	11 (<1%)	–	–
Total length requiring reduction	**3,445 (37%)**	**2,033 (22%)**	**702 (8%)**	**10,363 (22%)**	**6,174 (13%)**	**1,971 (4%)**

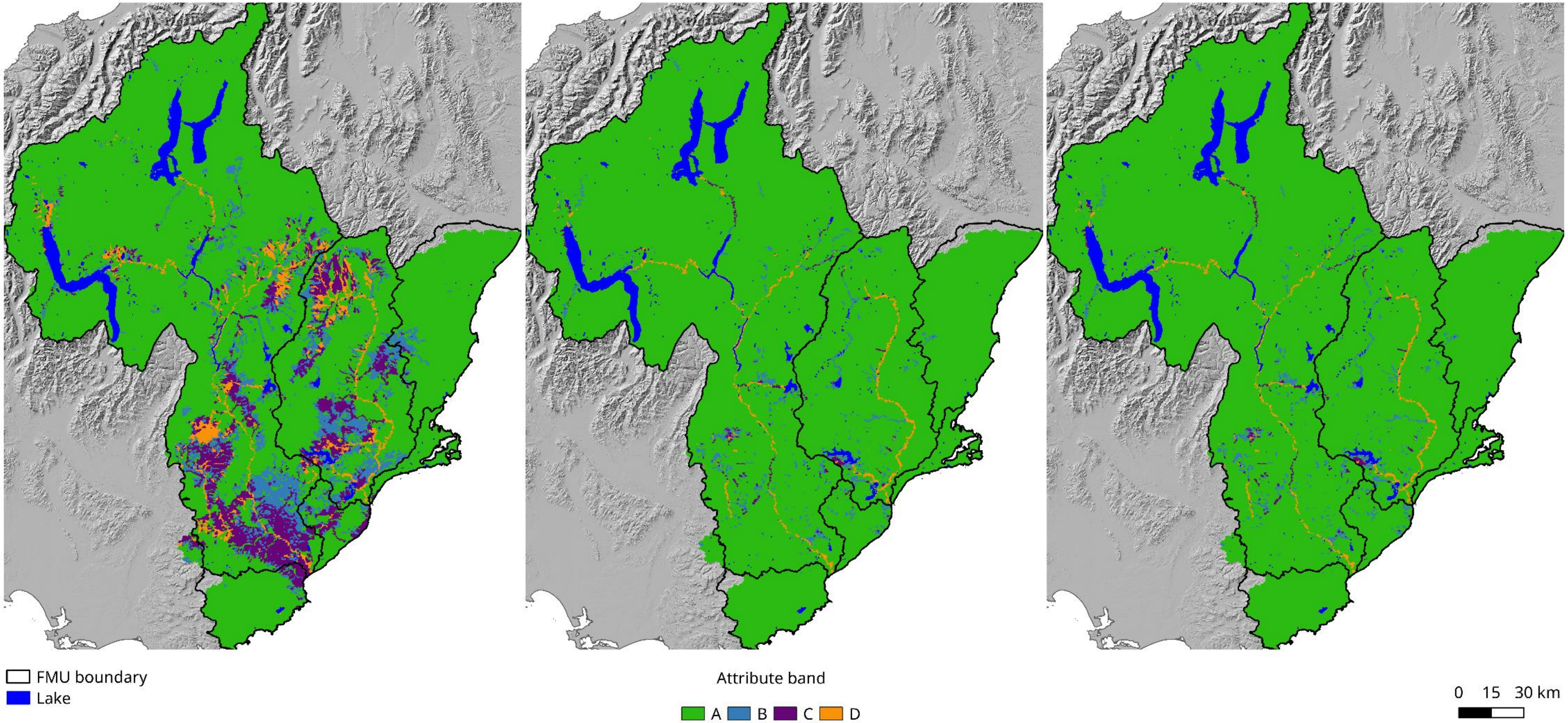

Figure 3. Attribute band achieved for each REC2 segment across the region for the baseline (left), GMP (centre), and GMP+ (right) scenarios.

Table 7. Length (km and %) of the stream network by FMU and across the region in each attribute band under the baseline, GMP, and GMP+ scenarios.

	Baseline				GMP				GMP+			
FMU	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Catlins	1,698 (91%)	49 (3%)	110 (6%)	<1 (<1%)	1,853 (99%)	3 (<1%)	2 (<1%)	<1 (<1%)	1,853 (99%)	3 (<1%)	2 (<1%)	<1 (<1%)
Clutha Mata-Au	24,404 (80%)	2,402 (8%)	2,530 (8%)	1,262 (4%)	29,456 (96%)	595 (2%)	214 (<1%)	332 (1%)	29,471 (96%)	588 (2%)	211 (<1%)	328 (1%)
Dunedin & Coast	1,256 (76%)	166 (10%)	216 (13%)	6 (<1%)	1,568 (95%)	70 (4%)	6 (<1%)	–	1,568 (95%)	70 (4%)	6 (<1%)	–
North Otago	4,142 (96%)	159 (4%)	16 (<1%)	–	4,301 (99%)	15 (<1%)	–	–	4,301 (99%)	15 (<1%)	–	–
Taieri	5,891 (63%)	1,413 (15%)	1,331 (14%)	702 (8%)	8,729 (93%)	304 (3%)	73 (<1%)	230 (2%)	8,741 (94%)	293 (3%)	73 (<1%)	229 (2%)
Otago	**37,391 (78%)**	**4,189 (9%)**	**4,202 (9%)**	**1,971 (4%)**	**45,907 (96%)**	**988 (2%)**	**296 (<1%)**	**563 (1%)**	**45,934 (96%)**	**969 (2%)**	**293 (<1%)**	**558 (1%)**

Table 8. Length (km and %) of the FMU and regional stream network below the national bottom line, summarised by stream order and suspended sediment class. FMUs and stream orders with no segments below NBL are excluded. The proportion is calculated relative to the total length of the stream network below the national bottom line.

FMU	Stream Order	GMP Sediment class 1	GMP Sediment class 2	GMP Sediment class 3	GMP Sediment class 4	GMP+ Sediment class 1	GMP+ Sediment class 2	GMP+ Sediment class 3	GMP+ Sediment class 4
Catlins	1	–	–	<1 (100%)	–	–	–	<1 (100%)	–
Clutha Mata-Au	1	–	–	14 (4%)	–	–	–	14 (4%)	–
	2	–	–	15 (4%)	–	–	–	15 (4%)	–
	3	–	–	–	–	–	–	–	–
	4	–	–	3 (<1%)	–	–	–	3 (<1%)	–
	5	11 (3%)	–	21 (6%)	–	11 (3%)	–	21 (6%)	–
	6	–	–	35 (10%)	–	–	–	34 (10%)	–
	7	–	–	99 (30%)	–	–	–	97 (30%)	–
	8	–	–	135 (41%)	–	–	–	134 (41%)	–
Taieri	1	–	–	3 (1%)	–	–	–	3 (1%)	–
	2	–	–	–	–	–	–	–	–
	3	–	–	<1 (<1%)	–	–	–	<1 (<1%)	–
	4	–	–	20 (9%)	–	–	–	20 (9%)	–
	5	–	–	33 (14%)	–	–	–	33 (14%)	–
	6	–	–	173 (75%)	–	–	–	173 (76%)	–

Table 8 (cont.)

FMU	Stream Order	GMP Sediment class 1	2	3	4	GMP+ Sediment class 1	2	3	4
Otago	1	–	–	17 (3%)	–	–	–	17 (3%)	–
	2	–	–	15 (3%)	–	–	–	15 (3%)	–
	3	–	–	1 (<1%)	–	–	–	1 (<1%)	–
	4	–	–	23 (4%)	–	–	–	22 (4%)	–
	5	11 (2%)	–	54 (10%)	–	11 (2%)	–	54 (10%)	–
	6	–	–	208 (37%)	–	–	–	207 (37%)	–
	7	–	–	99 (18%)	–	–	–	97 (17%)	–
	8	–	–	135 (24%)	–	–	–	134 (24%)	–

Table 9. Proportional reduction in mean annual suspended sediment load under the GMP and GMP+ scenarios required to improve the attribute band of stream segments, summarised by length (km and %) of the stream network. Segments which already achieve the band and do not require a reduction are excluded.

FMU	Proportional reduction required	GMP A	GMP B	GMP C	GMP+ A	GMP+ B	GMP+ C
Catlins	>0 – 10%	1 (<1%)	<1 (<1%)	–	1 (<1%)	<1 (<1%)	–
	>10 – 20%	2 (<1%)	2 (<1%)	<1 (<1%)	2 (<1%)	2 (<1%)	<1 (<1%)
	>20 – 30%	<1 (<1%)	–	–	<1 (<1%)	–	–
	>30 – 40%	<1 (<1%)	<1 (<1%)	–	<1 (<1%)	<1 (<1%)	–
	>40 – 50%	<1 (<1%)	–	–	<1 (<1%)	–	–
	>50 – 60%	–	–	–	–	–	–
	>60 – 70%	–	–	–	–	–	–
	Total	**6 (<1%)**	**3 (<1%)**	**<1 (<1%)**	**6 (<1%)**	**3 (<1%)**	**<1 (<1%)**
Clutha Mata-Au	>0 – 10%	433 (1%)	131 (<1%)	185 (<1%)	426 (1%)	126 (<1%)	205 (<1%)
	>10 – 20%	233 (<1%)	104 (<1%)	101 (<1%)	229 (<1%)	118 (<1%)	80 (<1%)
	>20 – 30%	112 (<1%)	228 (<1%)	42 (<1%)	127 (<1%)	212 (<1%)	38 (<1%)
	>30 – 40%	273 (<1%)	76 (<1%)	5 (<1%)	256 (<1%)	76 (<1%)	5 (<1%)
	>40 – 50%	84 (<1%)	7 (<1%)	<1 (<1%)	81 (<1%)	7 (<1%)	<1 (<1%)
	>50 – 60%	7 (<1%)	<1 (<1%)	–	7 (<1%)	<1 (<1%)	–
	>60 – 70%	<1 (<1%)	–	–	<1 (<1%)	–	–
	Total	**1,142 (4%)**	**547 (2%)**	**332 (1%)**	**1,127 (4%)**	**539 (2%)**	**328 (1%)**
Dunedin & Coast	>0 – 10%	62 (4%)	6 (<1%)	–	62 (4%)	6 (<1%)	–
	>10 – 20%	11 (<1%)	<1 (<1%)	–	11 (<1%)	<1 (<1%)	–
	>20 – 30%	3 (<1%)	–	–	3 (<1%)	–	–
	>30 – 40%	–	–	–	–	–	–
	>40 – 50%	–	–	–	–	–	–
	>50 – 60%	–	–	–	–	–	–
	>60 – 70%	–	–	–	–	–	–
	Total	**77 (5%)**	**6 (<1%)**	**–**	**77 (5%)**	**6 (<1%)**	**–**

Table 9 (cont.)

FMU	Proportional reduction required	GMP A	GMP B	GMP C	GMP+ A	GMP+ B	GMP+ C
North Otago	>0 – 10%	13 (<1%)	–	–	13 (<1%)	–	–
	>10 – 20%	2 (<1%)	–	–	2 (<1%)	–	–
	>20 – 30%	–	–	–	–	–	–
	>30 – 40%	–	–	–	–	–	–
	>40 – 50%	–	–	–	–	–	–
	>50 – 60%	–	–	–	–	–	–
	>60 – 70%	–	–	–	–	–	–
	Total	**15 (<1%)**	**–**	**–**	**15 (<1%)**	**–**	**–**
Taieri	>0 – 10%	242 (3%)	53 (<1%)	35 (<1%)	232 (2%)	55 (<1%)	35 (<1%)
	>10 – 20%	82 (<1%)	27 (<1%)	69 (<1%)	81 (<1%)	25 (<1%)	81 (<1%)
	>20 – 30%	49 (<1%)	36 (<1%)	99 (1%)	48 (<1%)	41 (<1%)	87 (<1%)
	>30 – 40%	47 (<1%)	127 (1%)	17 (<1%)	46 (<1%)	129 (1%)	17 (<1%)
	>40 – 50%	130 (1%)	49 (<1%)	9 (<1%)	135 (1%)	43 (<1%)	9 (<1%)
	>50 – 60%	50 (<1%)	11 (<1%)	–	46 (<1%)	9 (<1%)	–
	>60 – 70%	8 (<1%)	–	–	7 (<1%)	–	–
	Total	**608 (7%)**	**304 (3%)**	**230 (2%)**	**595 (6%)**	**303 (3%)**	**229 (2%)**
Otago	>0 – 10%	752 (2%)	192 (<1%)	220 (<1%)	735 (2%)	188 (<1%)	240 (<1%)
	>10 – 20%	330 (<1%)	133 (<1%)	170 (<1%)	326 (<1%)	145 (<1%)	161 (<1%)
	>20 – 30%	165 (<1%)	264 (<1%)	141 (<1%)	179 (<1%)	253 (<1%)	126 (<1%)
	>30 – 40%	321 (<1%)	203 (<1%)	22 (<1%)	303 (<1%)	206 (<1%)	22 (<1%)
	>40 – 50%	214 (<1%)	56 (<1%)	9 (<1%)	217 (<1%)	50 (<1%)	9 (<1%)
	>50 – 60%	57 (<1%)	11 (<1%)	–	52 (<1%)	9 (<1%)	–
	>60 – 70%	8 (<1%)	–	–	7 (<1%)	–	–
	Total	**1,847 (4%)**	**860 (2%)**	**563 (1%)**	**1,820 (4%)**	**851 (2%)**	**558 (1%)**

4 Limitations

Limitations relating to the modelling of mean annual sediment loads for the baseline, GMP, and GMP+ scenarios are discussed in Neverman and Smith (2022a, 2022b) and are not repeated here.

There are several areas which contribute to uncertainty in estimating the change in suspended sediment load required to achieve a target median visual clarity.

Proportional reductions in mean annual suspended sediment load required to achieve target attribute bands have been estimated using empirical models relating improvements in visual clarity to reductions in suspended sediment fitted to a national dataset (Hicks et al. 2019), as recommended by Ministry for the Environment (2022). This relationship assumes visual clarity at any given segment is primarily affected by suspended sediment and does not account for local variability in the relationship between suspended sediment concentration and visual clarity that arises from differences in sediment characteristics between segments, such as in the proportion of fine-grained clay minerals which dominate light attenuation by sediments (Davies-Colley & Smith 2001). It is also assumed the relationship between suspended sediment concentration and flow remains consistent at a site. Warrick (2015) and Hicks et al (2016) illustrated that changes in sediment load may not affect the shape of the relationship between suspended sediment concentration and flow, particularly when catchment hydrology is unaltered. However, changes in catchment land cover, land use, or climate may alter the relationship between flow and suspended sediment concentration due to changes in catchment hydrology or sediment supply dynamics. As data are not presently available to model the effects of these changes on the relationship between suspended sediment concentration and flow, we assume that the associated relationships remain constant across the mitigation scenarios.

Baseline median visual clarity is modelled from monthly fixed-interval turbidity sampling at SoE sites. Franklin et al. (2019) note the relationship between turbidity and visual clarity is often site-specific. Davies-Colley et al. (2021) and Davies-Colley and Smith (2001) have also highlighted issues related to the uncertainty in turbidity measurements, and the challenges of comparing turbidity between sites and instruments. Fixed-interval sampling likely results in turbidity predominantly being measured at or near baseflow, when most of the suspended sediment load may be derived from within-channel sources (e.g. remobilisation from channel bed or from bank erosion). In contrast, the modelled mean annual suspended sediment loads also capture storm event-driven erosion and sediment loads. Hence, the link between reductions in storm-generated sediment loads and increases in visual clarity at generally low flows may depend in part on a reduction in the storage and subsequent remobilisation of storm-derived fine sediment in the channel network.

The potential influence of other matter, such as tannins or waste discharges, on visual clarity are also not accounted for. Point source discharges such as effluent and sewage have been documented to occur in the Taieri catchment (ORC 2003, 2004), and tannins are a widely documented cause of water discolouration in Otago rivers and streams, such as in the Taieri catchment (ORC 2003, 2004; Uytendaal & Ozanne n.d.). Glacial flour also affects streams in Otago.

These sources of uncertainty may lead to errors in the estimation of baseline visual clarity, misclassification of the baseline attribute band, and errors in the reductions in suspended sediment load required to achieve target attribute bands.

5 References

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6 Data dictionary

The segment level outputs are supplied as vector data (ESRI Shapefiles). The attribute fields for the files are described below.

The data layer **Otago_network_sediment_attribute_bands.shp** contains model outputs for the baseline, GMP, and GMP+ scenarios.

The shapefile includes the following attributes:

Attribute Field	Description
nzsegment	Stream segment ID from REC2 v2.4.
SegLength	Stream segment length (m) from REC2 v2.4.
FMU	FMU the segment belongs to.
IsLakeSeg	Binary field indicating if the segment was classified as belonging to a lake (1) or not (0) for the purpose of sumamrisation.
SedClass	Suspended sediment class for the reach from Hicks and Shankar (2020).
BaseClar	Baseline median visual clarity (m) as modelled by Ton Snelder (LWP) and provided by ORC.
BaseBand	Baseline NPS-FM 2020 attribute band for suspended fine sediment.
PrNBLBase	Proportional reduction in baseline mean annual suspended sediment load required to achieve the national bottom line.
PrBBase	Proportional reduction in baseline mean annual suspended sediment load required to achieve band B.
PrABase	Proportional reduction in baseline mean annual suspended sediment load required to achieve band A.
AbNBLBase	Absolute reduction in baseline mean annual suspended sediment load (t/yr) required to achieve the national bottom line.
AbBBase	Absolute reduction in baseline mean annual suspended sediment load (t/yr) required to achieve band B.
AbABase	Absolute reduction in baseline mean annual suspended sediment load (t/yr) required to achieve band A.
PrAchGMP	Proportional reduction in mean annual suspended sediment load achieved between the baseline and GMP scenarios.
AbAchGMP	Absolute reduction in mean annual suspended sediment load (t/yr) achieved between the baseline and GMP scenarios.
GMPBand	NPS-FM 2020 suspended fine sediment attribute band under the GMP scenario.
PrNBLGMP	Proportional reduction in GMP mean annual suspended sediment load required to achieve the national bottom line.
PrBGMP	Proportional reduction in GMP mean annual suspended sediment load required to achieve band B.
PrAGMP	Proportional reduction in GMP mean annual suspended sediment load required to achieve band A.

Attribute Field	Description
AbNBLGMP	Absolute reduction in GMP mean annual suspended sediment load (t/yr) required to achieve the national bottom line.
AbBGMP	Absolute reduction in GMP mean annual suspended sediment load (t/yr) required to achieve band B.
AbAGMP	Absolute reduction in GMP mean annual suspended sediment load (t/yr) required to achieve band A.
PrAchGMPp	Proportional reduction in mean annual suspended sediment load achieved between the baseline and GMP+ scenarios.
AbAchGMPp	Absolute reduction in mean annual suspended sediment load (t/yr) achieved between the baseline and GMP+ scenarios.
GMPpBand	NPS-FM 2020 suspended fine sediment attribute band achievable under the GMP+ scenario.
PrNBLGMPp	Proportional reduction in GMP+ mean annual suspended sediment load required to achieve the national bottom line.
PrBGMPp	Proportional reduction in GMP+ mean annual suspended sediment load required to achieve band B.
PrAGMPp	Proportional reduction in GMP+ mean annual suspended sediment load required to achieve band A.
AbNBLGMPp	Absolute reduction in GMP+ mean annual suspended sediment load (t/yr) required to achieve the national bottom line.
AbBGMPp	Absolute reduction in GMP+ mean annual suspended sediment load (t/yr) required to achieve band B.
AbAGMPp	Absolute reduction in GMP+ mean annual suspended sediment load (t/yr) required to achieve band A.

7 Appendix

Statistic	Description
n	Number of samples used for modelling
R^2	Coefficient of determination: derived from a regression of the observations against the predictions. Shows the proportion of the total variance explained by the regression model.
NSE	Nash-Sutcliffe model efficiency coefficient: assesses overall model performance. A value of 1 corresponds to a perfect model fit, 0 indicates model predictions are no better than using the mean, and <0 indicates the mean is a better predictor.
RMSD	Root mean square deviation: mean deviation of predicted values with respect to the observed values.
Bias	Model bias: measures the average tendency of the predicted values to be larger or smaller than the observed values. Positive values indicate underestimation and negative values indicate overestimation.

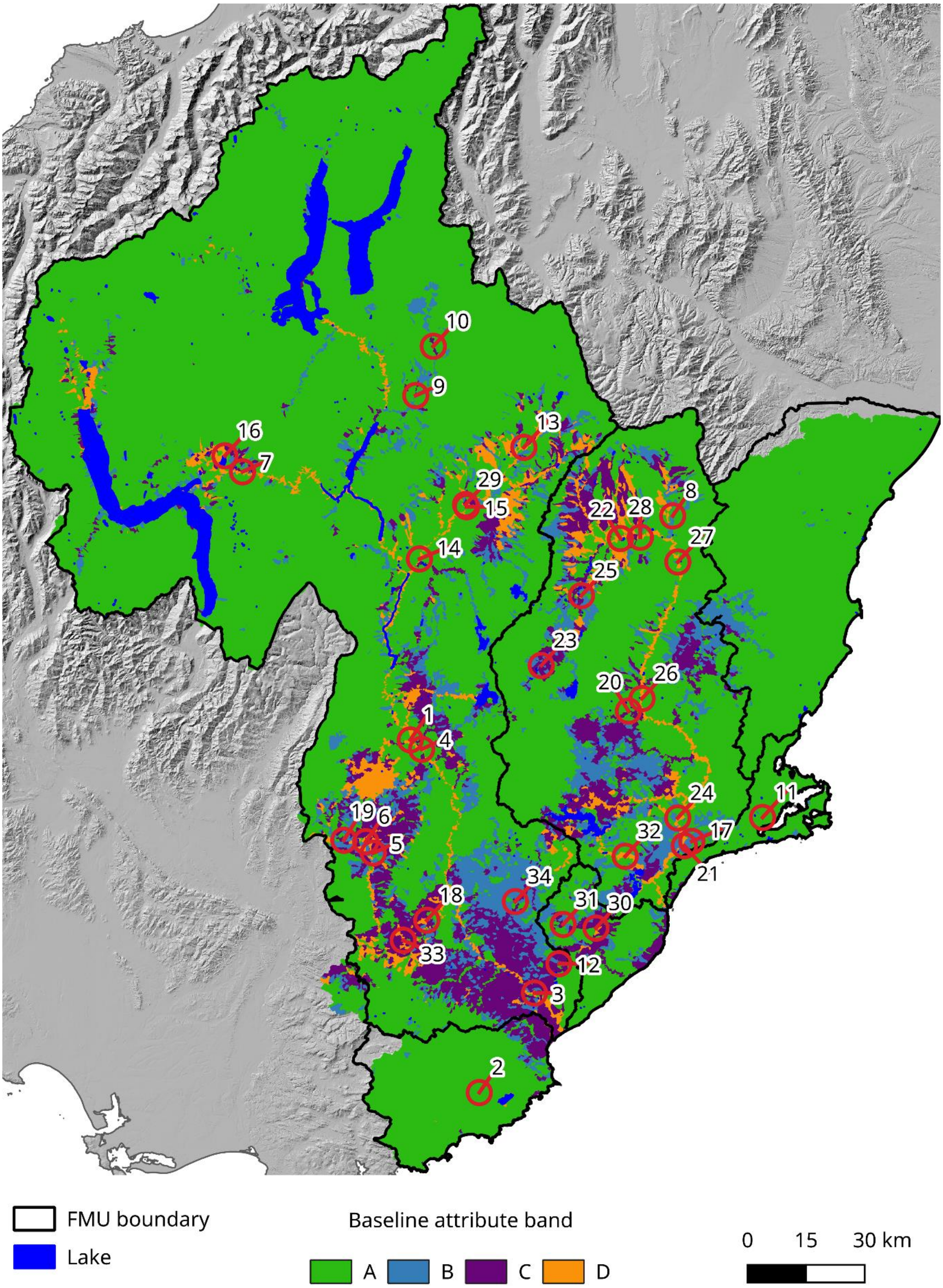

Figure 4. Location of SoE monitoring sites used in Neverman and Smith (2022a, 2022b), overlaid on a map of the baseline attribute band for each REC2 segment derived from the LWP modelled median visual clarity (from Figure 1) used in the present work.