Memo

From	**Paul Franklin, Doug Booker, Rick Stoffels**
To	Stephen Fragaszy
Date	16 March 2020
Subject	Contract 23184: Task 7 - Turbidity and visual clarity thresholds at SSC Level 2

1 Background

The Ministry for the Environment (MfE) requested that we explore the underlying causes of differences between the data-derived visual clarity reference state estimates at the second level of aggregation (Level 2 with 4 classes) of the sediment state classification (SSC) presented in in Franklin et al. (2019) and those arising from conversion of the data-derived turbidity reference state estimates presented in in Franklin et al. (2019) to visual clarity using the national regression relationship derived in Task 2 (see Task 2 memo).

2 Method

As outlined in Franklin et al. (2019), numerous sources of uncertainty exist within the data and processes used to classify sediment state, as well as predict reference states and attribute thresholds and bottom-lines. These include the accuracy, precision and representativeness of the input data, the impact of normative decisions on the analytical procedure, mathematical uncertainty arising from different analytical techniques, and natural environmental variability.

The main steps in our analytical process are set out in Figure 1. We took the approach of sequentially working through each step leading to the prediction of ESV reference states. At each step we checked for and, where possible, corrected sources of error. We then reviewed the consequences of any changes on the overall process used to predict reference state.

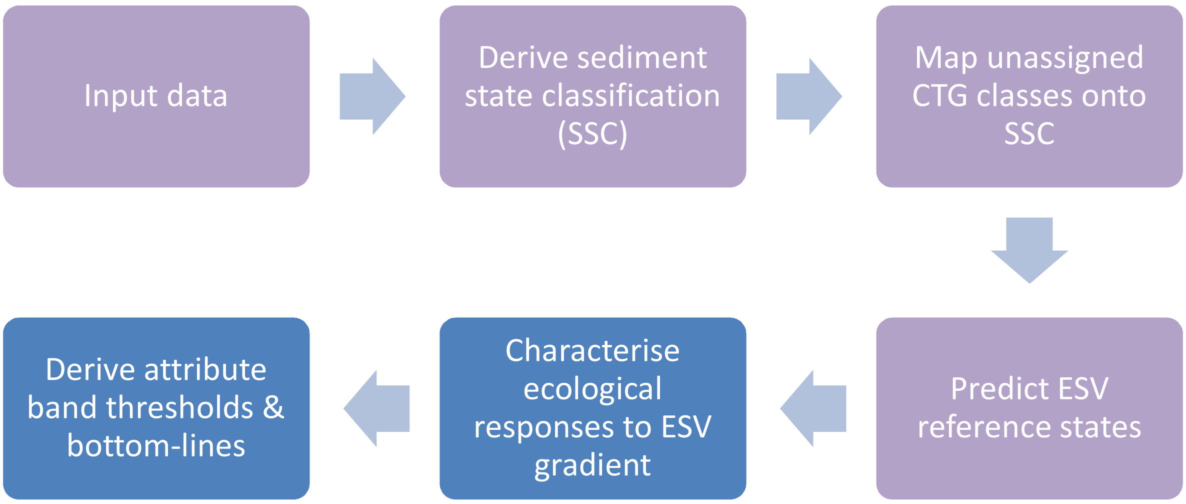

Figure 1: Summary of primary analytical steps involved in deriving attribute band thresholds and bottom-lines for suspended sediment. CTG is Climate-Topography-Geology classes. ESV is Environmental State Variable. Activities defined in purple boxes were the focus of this task.

3 Results

3.1 Input data

Several errors were identified in the ESV input data set collated by Whitehead (2019) that was ultimately used for deriving the sediment state classification and ESV reference states for visual clarity and turbidity by Franklin et al. (2019). These errors were identified after finalisation of the Franklin et al. (2019) report. The main issue identified was that a sub-set of sites had been mapped to incorrect reaches on the national digital river network and, hence, were allocated to the wrong Climate-Topography-Geology (CTG) class and had different landcover characteristics (e.g. catchment proportion of heavy pasture). We also identified that the data for selected National River Water Quality Network (NRWQN) monitoring sites had been duplicated in the input data file, which effectively gave those sites double the weighting in subsequent analyses. After correcting these errors, we re-ran the analytical procedures used to derive the sediment state classification (SSC).

3.2 Sediment state classification

No changes were made to the analytical procedures for deriving the sediment state classification, but minor changes to the resulting SSC arose due to the correction of errors in the input data set.

3.3 Mapping of unassigned CTG classes

The process for allocating unassigned CTG classes to SSC classes is described in the memo for Task 1.

3.4 Prediction of ESV reference states

We updated the methodology for calculating ESV reference state by implementing a new workflow that involved mapping unassigned CTG classes to SSC classes prior to predicting ESV reference state. This allowed us to incorporate data from sites tied to unassigned CTG classes when predicting ESV reference state. In the previous workflow, data from sites in unassigned CTG classes were excluded from the regression analysis. Inclusion of these data increased the number of SSC classes where the minimum threshold of 20 sites was met for predicting reference state, and in some classes helped to increase the spread of contributing data across the gradient of catchment alteration (e.g. heavy pasture). The resulting predicted reference states for all classes at all levels of the SSC are presented in Table 1 and 2 for visual clarity and turbidity, respectively.

Table 1. Estimated reference values (Ref) for visual clarity (m) for each class, at each level of aggregation of the suspended sediment classification.

<table>
<tr><th>Agg. L1</th><th>Ref</th><th>% River Net.</th><th>Agg. L2</th><th>Ref</th><th>% River Net.</th><th>Agg. L3</th><th>Ref</th><th>% River Net.</th><th>Agg. L4</th><th>Ref</th><th>% River Net.</th><th>CTG Classes</th></tr>
<tr><td rowspan="9">1</td><td rowspan="9">2.64</td><td rowspan="9">73.9</td><td rowspan="5">1</td><td rowspan="5">2.01</td><td rowspan="5">51.5</td><td>1</td><td>2.60</td><td>9.4</td><td>1</td><td>2.69</td><td>9.4</td><td>CD_Low_HS
WW_Low_VA
WW_Hill_VA</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">2.08</td><td rowspan="2">24.9</td><td>7</td><td>2.21</td><td>13.5</td><td>CD_Low_Al
CW_Hill_SS
CW_Mount_SS</td></tr>
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CD_Hill_SS
CD_Hill_VA
CD_Low_VA
CW_Low_VA
CW_Mount_VA</td></tr>
<tr><td>6</td><td>1.58</td><td>15.8</td><td>12</td><td>1.90</td><td>15.8</td><td>CW_Mount_HS
CD_Mount_Al
CW_Hill_Al
CW_Mount_Al</td></tr>
<tr><td>7</td><td>0.90</td><td>1.5</td><td>2</td><td>9.84</td><td>1.5</td><td>WD_Low_Al</td></tr>
<tr><td rowspan="4">3</td><td rowspan="4">3.35</td><td rowspan="4">22.4</td><td rowspan="2">4</td><td rowspan="2">3.73</td><td rowspan="2">12.6</td><td>8</td><td>4.10</td><td>10.4</td><td>CW_Hill_HS
CW_Lake_Any
CD_Lake_Any
WW_Lake_Any</td></tr>
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CD_Hill_Al
CD_Mount_HS
CD_Mount_SS
CD_Mount_VA</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">1.35</td><td rowspan="3">26.1</td><td rowspan="2">2</td><td rowspan="2">1.11</td><td rowspan="2">19.8</td><td rowspan="2">2</td><td rowspan="2">1.11</td><td rowspan="2">19.8</td><td>5</td><td>1.07</td><td>15.6</td><td>CD_Low_SS
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WW_Low_SS
WW_Hill_HS
WW_Hill_SS
WW_Low_Al</td></tr>
<tr><td>6</td><td>0.45</td><td>4.2</td><td>WD_Low_SS
WD_Lake_Any
WD_Low_HS
WD_Low_VA</td></tr>
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</table>

Table 2. Estimated reference values (Ref) for turbidity (NTUs) for each class, at each level of aggregation of the suspended sediment classification.

<table>
<tr><th>Agg. L1</th><th>Ref</th><th>% River Net.</th><th>Agg. L2</th><th>Ref</th><th>% River Net.</th><th>Agg. L3</th><th>Ref</th><th>% River Net.</th><th>Agg. L4</th><th>Ref</th><th>% River Net.</th><th>CTG Classes</th></tr>
<tr><td rowspan="9">1</td><td rowspan="9">1.17</td><td rowspan="9">73.9</td><td rowspan="5">1</td><td rowspan="5">1.95</td><td rowspan="5">51.5</td><td>1</td><td>1.33</td><td>9.4</td><td>1</td><td>1.33</td><td>9.4</td><td>CD_Low_HS
WW_Low_VA
WW_Hill_VA</td></tr>
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CW_Hill_SS
CW_Mount_SS</td></tr>
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CD_Hill_VA
CD_Low_VA
CW_Low_VA
CW_Mount_VA</td></tr>
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CD_Mount_Al
CW_Hill_Al
CW_Mount_Al</td></tr>
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<tr><td rowspan="4">3</td><td rowspan="4">0.94</td><td rowspan="4">22.4</td><td rowspan="2">4</td><td rowspan="2">0.84</td><td rowspan="2">12.6</td><td>8</td><td>0.75</td><td>10.4</td><td>CW_Hill_HS
CW_Lake_Any
CD_Lake_Any
WW_Lake_Any</td></tr>
<tr><td>10</td><td>0.95</td><td>2.2</td><td>CW_Low_HS</td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">0.93</td><td rowspan="2">9.9</td><td>4</td><td>0.55</td><td>2.0</td><td>CW_Low_Al</td></tr>
<tr><td>11</td><td>0.92</td><td>7.9</td><td>CD_Hill_HS
CD_Hill_Al
CD_Mount_HS
CD_Mount_SS
CD_Mount_VA</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">3.13</td><td rowspan="3">26.1</td><td rowspan="2">2</td><td rowspan="2">5.11</td><td rowspan="2">19.8</td><td rowspan="2">2</td><td rowspan="2">5.11</td><td rowspan="2">19.8</td><td>5</td><td>4.84</td><td>15.6</td><td>CD_Low_SS
WW_Low_HS
WW_Low_SS
WW_Hill_HS
WW_Hill_SS
WW_Low_Al</td></tr>
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WD_Lake_Any
WD_Low_HS
WD_Low_VA</td></tr>
<tr><td>4</td><td>2.72</td><td>6.3</td><td>8</td><td>2.72</td><td>6.3</td><td>3</td><td>2.72</td><td>6.3</td><td>CW_Low_SS</td></tr>
</table>

3.5 Comparison between turbidity and visual clarity reference states

Figure 2 compares the updated predicted median turbidity and median visual clarity reference states for each class at all levels of the SSC with the national regression relationship between median visual clarity and median turbidity. All individual site data used to derive the national regression relationship are plotted as blue crosses, showing a relatively large amount of scatter about the regression line at a site level.

At Level 1 and 2 of the SSC, all SSC classes now plot close to the national regression line and are well within the range of variability observed across sites. Greatest conformity between the visual clarity and turbidity reference states occurs at Level 2 of the classification – this indicates that the corrections made to the input data and the revised workflow for reference state estimation have (at this level of aggregation) resolved the discrepancies between the ESV reference state predictions given in Franklin et al. (2019). We recommend, therefore, use of the data-derived visual clarity reference states presented in Table 2 if it is decided that Level 2 of the classification is to be adopted.

At lower levels of aggregation (i.e. SSC Level 3 and 4) most classes continue to plot close to the national regression line, but a small number of classes begin to deviate from the regression line and sit on the boundaries or outside of the range of variability across sites in the national data set (e.g. L3.7, L4.2, L4.4, L4.6; Figure 2). Several reasons could account for this deviation including differences in input data or spatial differences in the turbidity versus visual clarity regression relationship.

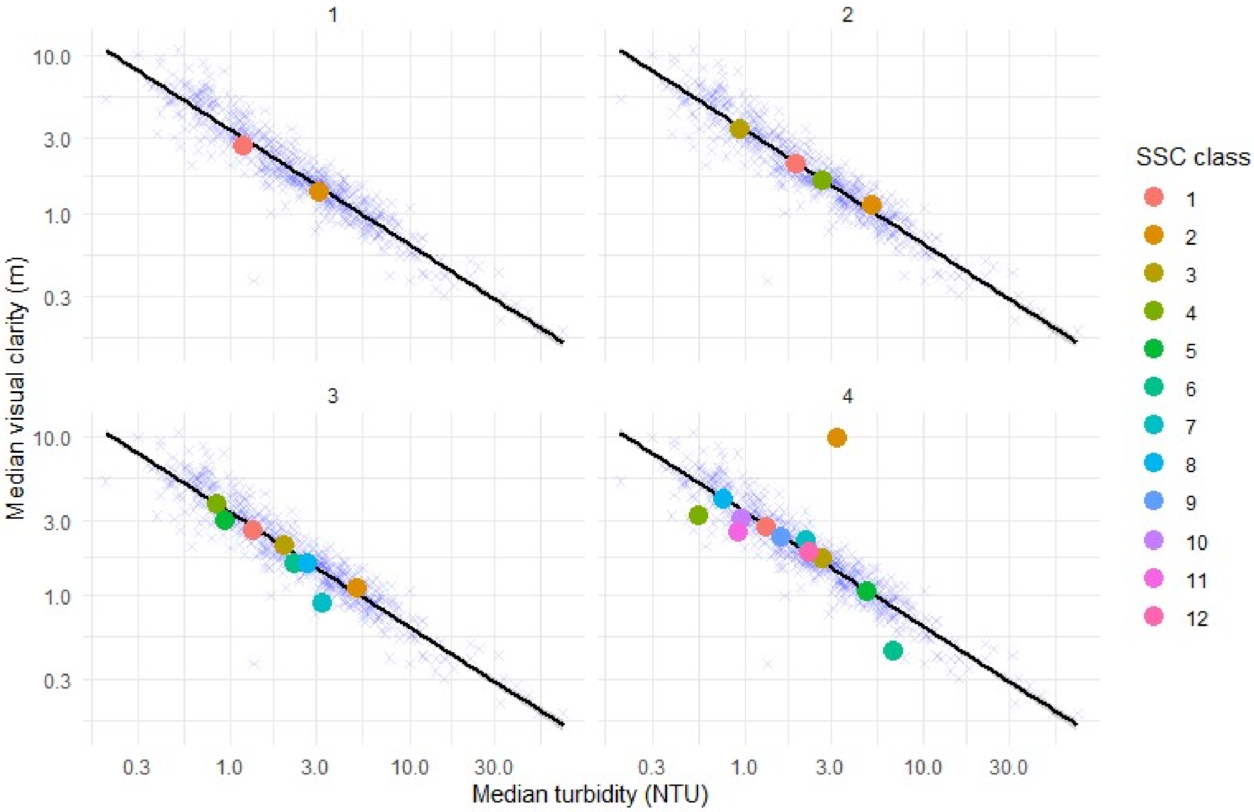

Figure 2: Scatter plot between the predicted reference states for turbidity and visual clarity for all classes at each level of the sediment state classification (SSC) overlaid on the national regression relationship (black line) and underlying data (blue crosses). Points for the predicted reference states are coloured by SSC class.

Visual inspection of the turbidity versus visual clarity regression relationships within classes at each level of aggregation (Figure 3) shows that while there are subtle differences, there is little variation in the independently derived slopes or intercepts between classes, particularly at higher levels of aggregation (Level 1 and 2). Consequently, there is a low chance that the large deviations from the national regression relationship (e.g., as observed in class L4.2) can be explained by spatial differences in the visual clarity and turbidity regression relationship. However, spatial differences may contribute to the smaller deviations that are observed in some classes.

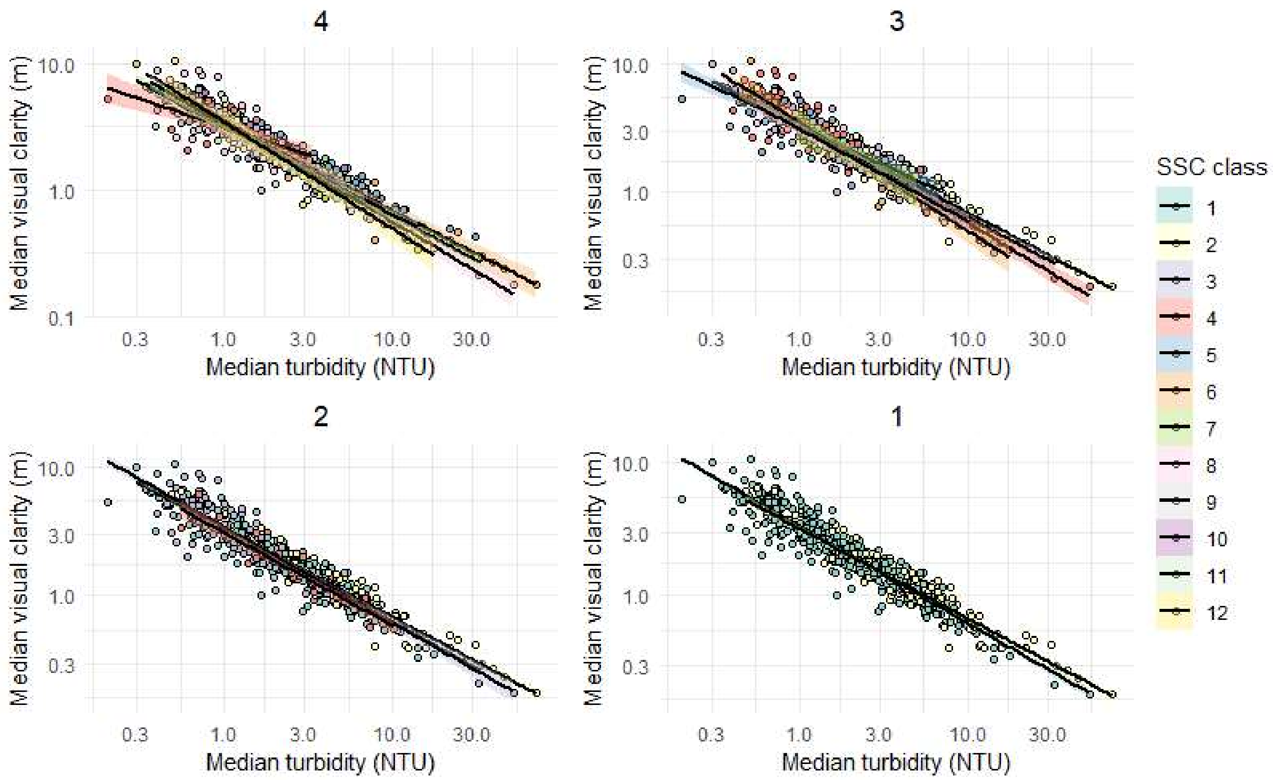

Figure 3: Comparison of turbidity versus visual clarity regression relationships by class within the four levels of the SSC. Where the regression lines over plot each other it signifies a commonality in the regression relationship between classes.

Figure 4 illustrates the spatial distribution of sites used for suspended sediment monitoring and for these analyses. At most sites both visual clarity and turbidity data are available. In the Gisborne, Marlborough and Otago regions, only turbidity data are available for most sites. There is a notable lack of monitoring sites from the mountainous areas extending from Fiordland to Marlborough. However, in all classes at all SSC levels, sufficient data exists for most sites used in these analyses to calculate a median for both turbidity and visual clarity (Figure 5). In a few classes (e.g. L4.7 and L4.11), the proportion of sites with only turbidity data is relatively high compared to other classes. However, there is no correspondence between those classes where a higher proportion of sites have only turbidity data and those classes where there is poor correspondence between the predicted visual clarity and turbidity reference states. Consequently, we concluded that while the differences in geographical coverage of ESV data types within classes could contribute to a lack of convergence between reference state estimates for the two ESVs at lower levels of the hierarchical classification, there was little evidence to suggest that this was the cause of differences in some classes at Level 3 and 4 of the SSC.

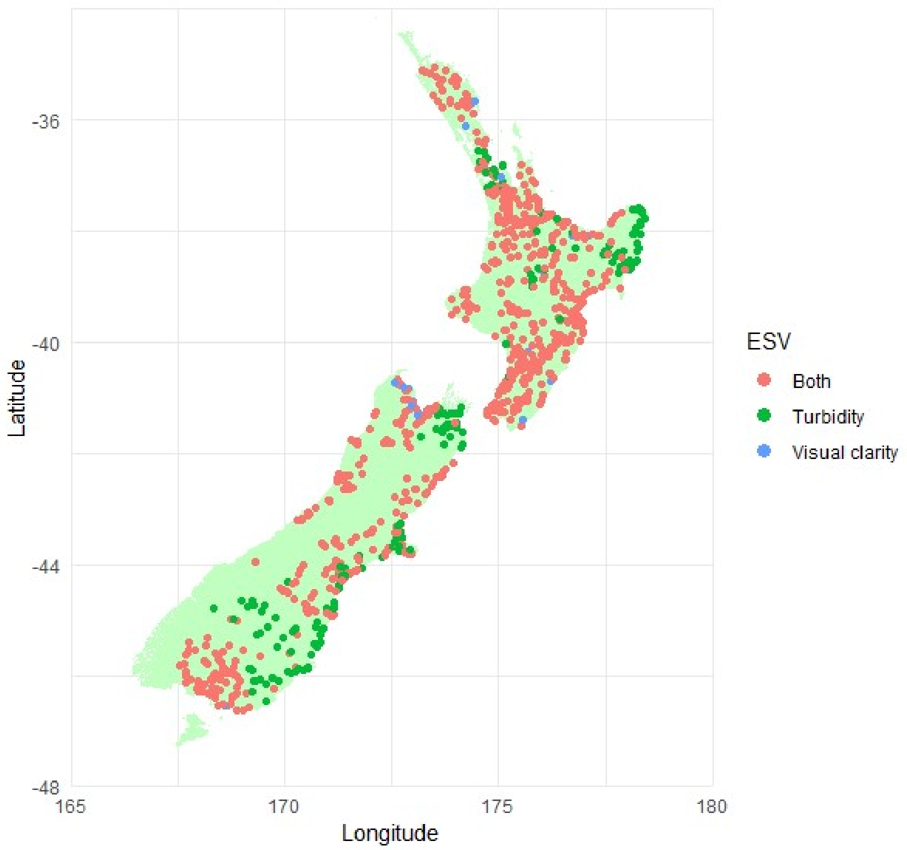

Figure 4: Locations of the monitoring sites used to derive the predicted reference states for visual clarity and turbidity indicating the relative geographical coverage of the different suspended sediment ESV measures.

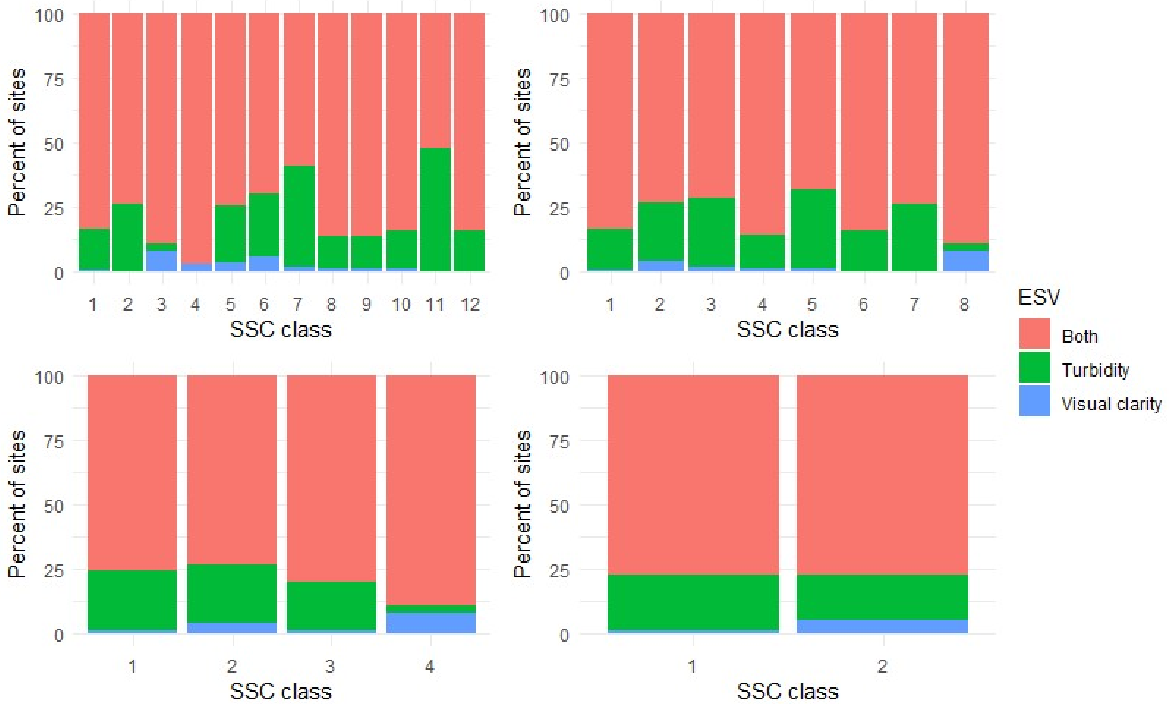

Figure 5: Percentage of sites within each class at each level of the SSC where both turbidity and visual clarity, just turbidity or just visual clarity data are available.

Further exploration of the input data led us to conclude that a low number of sites contributing to the regression analysis that were poorly represented across the heavy pasture gradient were the main cause of a lack of correspondence between the visual clarity and turbidity reference states (Figure 6 & 7). Classes L4.2, 4.4 and 4.6 have the smallest number of sites contributing to their reference state estimate, other than class L4.12. The former also have a bias towards sites located in areas with a high percentage cover of heavy pasture. This bias causes high uncertainty in the regression relationships used to estimate reference state, particularly at the intercept. From this information, we conclude that choosing a higher level of aggregation for setting attribute thresholds and bottom-lines is supported at present. Further information regarding this recommendation is provided in the memo for Task 2.

Figure 6: Regression relationships between heavy pasture and visual clarity. The black circles represent site median visual clarity observations. The black line shows the fitted regression line with 95% confidence interval shown in orange.

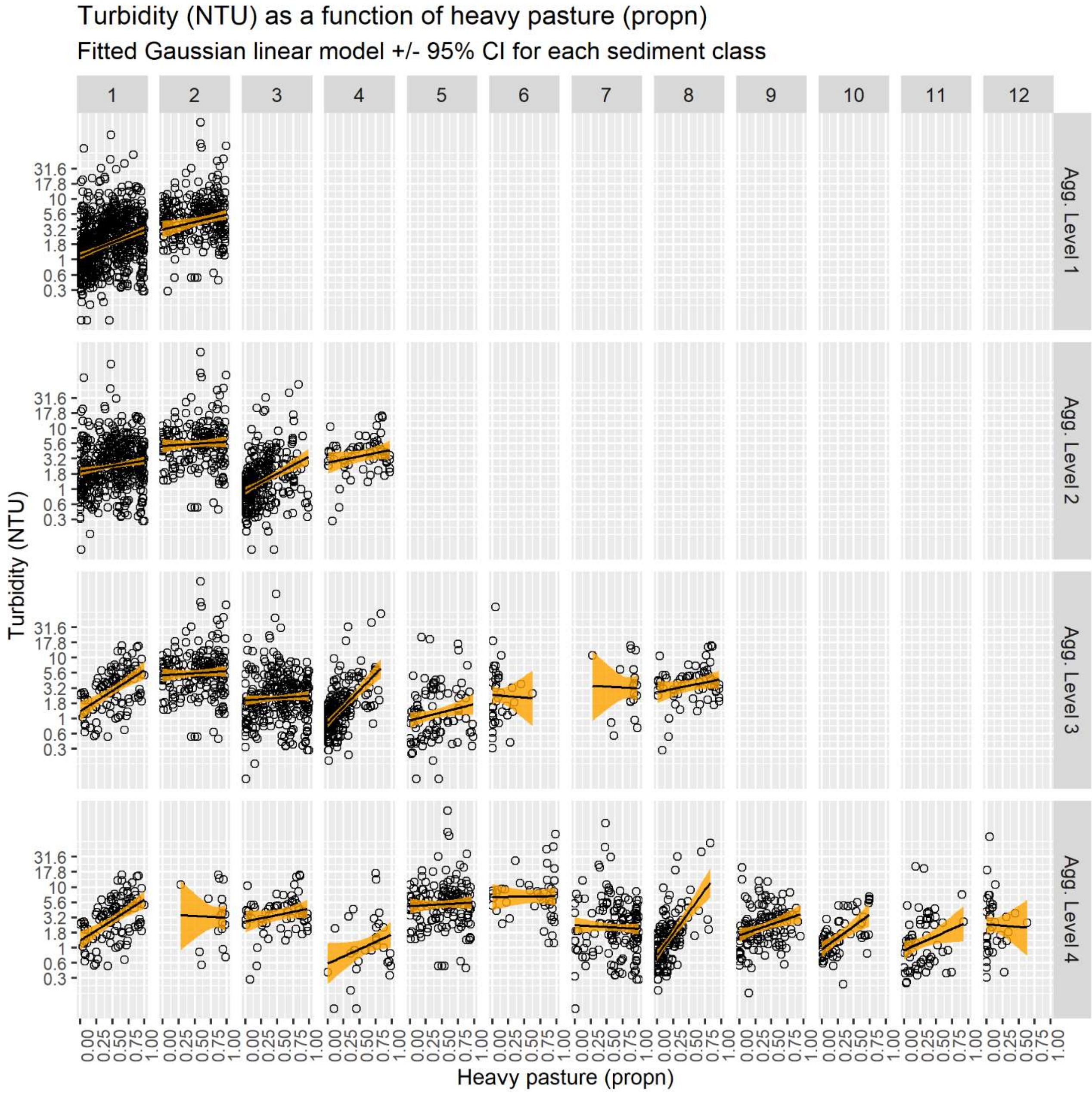

Figure 7: Regression relationships between heavy pasture and turbidity. The black circles represent site median visual clarity observations. The black line shows the fitted regression line with 95% confidence interval shown in orange.

3.6 Attribute bands and bottom-lines

Following calculation of the corrected reference states, we applied the community deviation method described in Franklin et al. (2019) to derive updated attribute band thresholds and bottom-lines for visual clarity (Table 3) and turbidity (Table 4). The numbers presented in these tables are based on the data-derived reference states presented in Table 1 and 2 for visual clarity and turbidity respectively. As noted above, reference state predictions depart notably from the national regression relationship in some classes. All band thresholds and bottom-lines for these classes should be treated with caution. For further discussion regarding these classes see memo for Task 2.

Table 3: Site-median visual clarity (m) band thresholds and bottom-lines for each class at all levels of the SSC. Thresholds derived using the community deviation method described in Franklin et al. (2019). * denotes classes that depart notably from the national regression relationship and should be treated with caution.

SSC Level	SSC class	Reference state	Band threshold (m)		
			A/B	B/C	C/D
1	1	2.64	2.33	2.04	1.76
	2	1.35	1.14	0.94	0.77
2	1	2.01	1.78	1.55	1.34
	2	1.11	0.93	0.76	0.61
	3	3.35	2.95	2.57	2.22
	4	1.60	1.38	1.17	0.98
3	1	2.60	2.19	1.83	1.50
	2	1.11	0.93	0.76	0.61
	3	2.08	1.83	1.60	1.37
	4	3.73	3.28	2.87	2.47
	5	2.97	2.62	2.28	1.97
	6	1.58	1.43	1.30	1.16
	7*	0.90	0.74	0.60	0.47
	8	1.60	1.38	1.17	0.98
4	1	2.69	2.28	1.90	1.56
	2*	9.84	8.56	7.38	6.28
	3	1.73	1.49	1.27	1.07
	4*	3.22	2.80	2.41	2.05
	5	1.07	0.89	0.73	0.59
	6*	0.45	0.37	0.29	0.23
	7	2.21	1.95	1.69	1.46
	8	4.10	3.63	3.17	2.75
	9	2.35	2.07	1.81	1.57
	10	3.03	2.62	2.25	1.91
	11*	2.52	2.23	1.95	1.69
	12	1.90	1.73	1.57	1.41

Table 4: Site-median turbidity (NTU) band thresholds and bottom-lines for each class at all levels of the SSC. Thresholds derived using the community deviation method described in Franklin et al. (2019). * denotes classes that depart notably from the national regression relationship and should be treated with caution.

SSC Level	SSC class	Reference state	Band threshold (NTU)		
			A/B	B/C	C/D
1	1	1.17	1.35	1.58	1.86
	2	3.13	3.85	4.83	6.19
2	1	1.95	2.25	2.63	3.11
	2	5.11	6.41	8.21	10.79
	3	0.94	1.09	1.27	1.51
	4	2.72	3.23	3.91	4.80
3	1	1.33	1.63	2.04	2.59
	2	5.11	6.41	8.21	10.79
	3	1.99	2.30	2.68	3.17
	4	0.84	0.98	1.15	1.37
	5	0.93	1.07	1.25	1.47
	6	2.29	2.53	2.83	3.19
	7*	3.28	4.07	5.17	6.74
	8	2.72	3.23	3.91	4.80
4	1	1.33	1.63	2.04	2.59
	2*	3.28	4.07	5.17	6.74
	3	2.72	3.23	3.91	4.80
	4*	0.55	0.66	0.80	0.98
	5	4.84	6.05	7.72	10.12
	6*	6.83	8.64	11.19	14.89
	7	2.20	2.55	2.99	3.54
	8	0.75	0.88	1.03	1.22
	9	1.61	1.86	2.15	2.54
	10	0.95	1.13	1.37	1.67
	11*	0.92	1.05	1.22	1.42
	12	2.29	2.53	2.83	3.19

4 Discussion & conclusions

The predicted reference states and proposed attribute thresholds for turbidity were derived independently from those for visual clarity by Franklin et al. (2019). Differences in the spatial coverage and overall availability of turbidity data relative to visual clarity data have the potential to influence the precision and statistical uncertainty of estimated reference conditions and, therefore, proposed band thresholds for the two environmental state variables (ESV). Once errors in the input data were corrected, we found that the most significant cause of divergence between predicted reference states for the two ESVs was insufficient data within classes at lower levels of aggregation, and a bias towards sites with a high proportion of heavy pasture within a class.

In our view, these observations support the hierarchical classification approach proposed in Franklin et al. (2019). It should be noted that although statistical uncertainty of estimated reference conditions increases at lower levels (more groups) of the hierarchical classification, the ability to discriminate between landscape-scale variations in ESV state increases at lower levels of the hierarchical classification. Greater predictive strength and statistical certainty in the reference state prediction can be realised by moving up the hierarchy to higher levels of aggregation. However, greater levels of aggregation may also increase uncertainty in management outcomes because the magnitude of 'unders' and 'overs' at a site level within a class becomes greater. This has consequences for monitoring, assessment of attributes, and ability to implement management actions likely to eventuate in sites meeting the designated C/D threshold.

Insufficient data currently exist to provide robust and defensible estimates of reference state for either turbidity or visual clarity in several classes at the lower levels of aggregation (Level 3 and 4). This situation supports the use of higher levels of aggregation for implementing a suspended sediment attribute; in our view use of Level 2 of the classification currently offers the best trade-off between data availability and uncertainty in management outcomes. We also recommend that supplementary monitoring be implemented to better-represent classes at lower levels of the SSC to support and inform future adaptive management efforts, and to potentially improve the accuracy of estimates of reference conditions at lower levels of the classification.

5 References

Franklin, P., Stoffels, R., Clapcott, J., Booker, D., Wagenhoff, A., Hickey, C. (2019) Deriving potential fine sediment attribute thresholds for the National Objectives Framework. Client report to the Ministry for the Environment, 2019039HN. 290pp.