Taihoro Nukurangi

A brief evaluation of the NPS-FM attribute for deposited fine sediment

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Executive summary

The National Policy Statement for Freshwater Management (NPS-FM; Ministry for the Environment 2024) was issued by the New Zealand Ministry for the Environment (MfE) with the intention of protecting and improving the health of the nation's freshwater resources. Clause 3.25 of the NPS-FM tasks regional and unitary authorities (hereinafter simply referred to as 'councils') with monitoring deposited fine sediment (DFS) in wadeable rivers. Prior to, and since rollout of the NPS-FM, scientific and technical staff at councils have made MfE aware of several technical and logistical problems with implementation of the DFS clause.

With a goal of improving sediment management and instream outcomes, MfE contracted NIWA to evaluate the NPS-FM attribute for DFS, specifically the clarity and internal consistency of the current policy language and associated implementation guidance documents. We also sought information from councils regarding their various experiences implementing the policy in different geographic regions and river settings of Aotearoa-New Zealand (NZ) and examined the development history of the current NPS-FM DFS attribute National Bottom Line, band thresholds, and correlations between DFS and measures of ecosystem health in rivers of NZ.

Past research has firmly established that human settlement of NZ caused order-of-magnitude increases in watershed fine sediment yields, and that ongoing human-induced land disturbances (i.e., commercial forestry, grazing, road building) are persistent sources of fine sediment being delivered to rivers, estuaries, and coastal shelves. Deposited fine sediment has also been consistently mechanistically linked to reductions in macroinvertebrate-based indices of river ecosystem health.

Our evaluation of the clarity and consistency of the NPS-FM attribute policy language, and its consistency with the current sediment-specific guidance (i.e. supporting technical reports, implementation guidance, methods guidance), found the following:

- The targeted freshwater body being defined as 'wadeable' for the DFS attribute in the NPS-FM may be a source of confusion to councils because 'wadeable' is not defined and there is no guidance for calculating the current DFS attribute state when some observations are missing because a site is not wadable under some flow conditions.

- The method descriptions for determining the current attribute state for DFS in the NPS-FM and in the current guidance do not provide explicit instructions about how the attribute statistic is to be calculated nor its assumed distribution and do not provide guidance for treatment of missing data. This lack of clarity may result in inconsistent or inaccurate calculations of current attribute states, or both.

- The current NPS-FM language addressing determination of the 'natural state' of a riverbed (hard or soft bottomed) is unclear. Clause 3.25 of the NPS-FM and the current guidance document state that councils should make this determination, but Table 25 presents a pre-determined list of 'naturally soft-bottomed' REC climate-topography-geology (CTG) classes. This communicates to councils that any site located within REC-CTG classes listed in Table 25 should be treated as naturally soft-bottomed which, given the uncertainties in the methods used to determine the classes, may or may not be correct. Further, if councils determined a site in one of the REC-CTG classes listed in Table 25 to be naturally hard-bottomed, Table 16 does not have a National Bottom Line or attribute bands for councils to follow. By extension, those REC-CTG classes not listed in Table 25 (the classes listed in Table 24) could be assumed by councils (correctly or incorrectly) to mean that MfE expects them to be naturally hard-bottomed. This lack of clarity could result in, at best, confusion by councils and, at worst, target attribute states and associated planning being enacted that is not appropriate for a particular site or Freshwater Management Unit (FMU).

- The statistical models used to derive the DFS National Bottom Line (NBL) and attribute band thresholds have demonstrated alignment with conceptual understanding of landscape position and land use effects on DFS. However, those models did not demonstrate strong predictive power for percent fine sediment cover in rivers relative to hypothesized controls beyond fundamental physical principles of downstream fining. These model uncertainties are acceptable for the purposes of communicating average conditions to be expected within a representative river class defined at the national scale. However, the model uncertainties and associated impacts on the precision of the NBL in each river class are not clearly communicated in the current guidance, which may cause confusion or a lack of council confidence in whether the threshold is appropriate for a particular site.

- The NPS-FM states that DFS monitoring sites should be representative of FMUs, but there is no specific guidance that may help councils select sites or determine site representativeness for DFS. Due to financial and logistical constraints councils prefer to collect data covering a multitude of different attributes or potential stressors at the same monitoring site. However, unlike other water quality constituents, particularly those that are dissolved, DFS has strong spatial variability that can depend on channel geomorphic units (i.e. pool, run, riffle, glide). This means that sites at which water quality, periphyton, and macroinvertebrate data are appropriate to collect may not align spatially or temporally with sites appropriate for DFS monitoring, or if they do, only at a subset of sites. The lack of strategic design in monitoring networks, along with differences in sampling methodology, causes difficulties when using the data to attempt to identify potential stressors of ecological values, or to determine quantitative relationships between individual stressors (such as DFS) and ecological values (such as macroinvertebrate metrics).

We contacted personnel at all 11 regional councils and 6 unitary authorities of New Zealand by email or phone or both. Responses were received from personnel at 9 regional councils, 6 unitary authorities, and the Department of Conservation. Respondents were those personnel charged with administering or executing freshwater monitoring, including DFS, in their respective areas. In total, we conducted 11 video/phone interviews and received email responses from 4 other council personnel. From these interviews we found the following general responses regarding the NPS-FM DFS attribute:

- Most councils have implemented, or are in the process of implementing, monitoring for the deposited fine sediment attribute as described in the current NPS-FM.

- All councils have staff that are trained in the visual sediment assessment method (commonly referred to as SAM2) or other standard sediment assessment methods (if not using SAM2) and engage in regular observer quality control activities.

- Councils are using a variety of methods to determine if river sites being sampled for the DFS attribute are naturally hard-bottomed. However, respondents from many councils interpret the REC-CTG classes in Table 25 of the NPS-FM to be MfE’s determination that only those classes are naturally soft-bottomed, or that none of the classes listed in Table 25 should be naturally hard-bottomed.

- Respondents from most councils would like to see improved guidance for practical implementation of the current NPS-FM deposited fine sediment attribute and/or leeway to implement their own procedures.
- Council representatives nearly unanimously expressed concern that DFS was a stressor to the ecological health of rivers in their regions.

Although we strived for consistent language and responses, interviews and email responses were not designed to have strict categorical boundaries. Instead, we interpreted responses from each interview and grouped them into categories which, in our view, broadly captured the primary issues communicated by respondents. We then counted the number of councils whose respondents made a statement associated with that category. Based on these counts, the top three most common issues identified are as follows:

1. The sediment assessment method 2 (SAM2) method, which is the specific method called for in the NPSFM, cannot be used to make accurate measurements when streambed visibility is low to nil because of turbid waters, macrophytes, or filamentous algae.
2. Council respondents do not have confidence in the accuracy of the REC-CTG approach used to determine if a site is naturally hard or soft-bottomed (Table 25 of NPS-FM) and set attribute band thresholds, including the National Bottom Line (shown in Table 16 of NPS-FM).
3. Council respondents perceive the ranges of threshold values for the current NBL and DFS attribute bands in each river class to be narrow relative to the precision of the SAM2 method used to determine the DFS attribute state.

Additional common issues expressed by council respondents were as follows:

- A lack of guidance on monitoring protocols or calculation of current attribute states for DFS when data are missing because of unfavourable conditions.
- Frustration with the SAM2 method across a range of issues including interpretation of fine sediment cover when it is a thin veneer over coarse material, differentiation between organic and inorganic fine sediment, lack of representation of DFS thickness, and representation of interstitial spaces that may be important to macroinvertebrates.
- A lack of confidence that their current monitoring sites were adequately representing the DFS attribute for their FMUs.
- Some were struggling to add DFS monitoring to their current programs with their current resources.
- Some expressed frustration with a lack of guidance to support decision-making associated with development of action plans to reduce DFS or determination of when it may be appropriate (or not) to return a soft-bottomed river to a hard-bottomed state.
- Some were unsure that the attribute bands and sediment classes had strong ecological relevance.

Collectively our findings indicate that most councils consider DFS to be a human-exacerbated stressor to aquatic health in rivers of their regions but would like to see improvement in the current NPS-FM methodological and implementation guidance, reasoning and uncertainties in the thresholds defining attribute bands and the National Bottom Lines, and additional guidance on devising and implementing management actions or alternatives to changing the current DFS attribute state in rivers where DFS is considered to be a long-term problem.

1 Introduction

The National Policy Statement for Freshwater Management (NPS-FM; Ministry for the Environment 2024) was developed by the New Zealand Ministry for the Environment (MfE) with the intention of providing a framework for protecting and improving the health of the nation's freshwater resources. The NPS-FM is guided by the fundamental concept of Te Mana o te Wai, whereby the health of freshwater resources is central to the health of people and the broader environment (MfE 2024). The NPS-FM presents a series of 15 policies which compose the National Objectives Framework (NOF), outlines the general approach for policy implementation, and communicates specific requirements for meeting national freshwater objectives.

Clause 3.25 of the NPS-FM tasks regional and unitary authorities (hereinafter simply referred to as 'councils') with monitoring deposited fine sediment (DFS) in wadeable river sites that are currently hard bottomed or determined to be naturally hard bottomed. Under the NPS-FM, monitoring of hard bottomed rivers is required to be undertaken monthly using the instream visual assessment method SAM2 (Clapcott et al. 2011). Hard-bottomed rivers are defined as those with streambeds having less than 50 percent fine sediment cover (PFSC). Clause 3.25 defines "naturally", in relation to a site, as meaning its state before the arrival of humans in NZ. For the purposes of monitoring DFS, fine sediment is defined by Clapcott et al. (2011) as sediments with nominal diameters less than 2 mm (sand or finer).

If a wadeable river is identified as currently "soft-bottomed" but considered by the council to be naturally "hard-bottomed", the NPS-FM calls for annual monitoring and for councils to determine if it is appropriate to return the site to a hard-bottomed state. It follows that councils are required to implement a series of monitoring and decision-making actions designed to meet target attribute states (TAS). TAS must be set at or above the Baseline Attribute State (BAS) or the National Bottom Lines (NBL), whichever is the better.

National Bottom Lines are supplied for four deposited sediment river classes in NPS-FM Table 16. This table also provides attribute bands *A* through *D* enumerated as ranges of median PFSC. Band *A* describes values for rivers with minimal impacts, and band *D* describing values for rivers that are below the NBL due to high impact of DFS. Median PFSC is expected to be calculated from monthly samples observed over a five-year period.

Under the previous 2017 version of the NPSFM, which did not include a sediment attribute, the bands were required to be used to enumerate attribute state (the 'within a band' approach). However, under the current NPSFM 2020, attribute state refers to the state of the attribute as quantified using an appropriate sampling method, not to the attribute band. Clause 3.10 explains that state may be expressed in a way that accounts for natural variability and sampling error.

Prior to, and since rollout of the NPS-FM 2020, scientific and technical staff at councils have made MfE aware of several technical and logistical issues with implementation of the DFS policy (Beca Limited 2020). Some consistent challenges MfE is aware of include, but are not limited to, the following:

- Ability to accurately/objectively identify if a site is naturally hard-bottomed.
- Viability of the sediment assessment method (SAM2) methodology to detect changes or presence of DFS in various settings (e.g., soft-bottomed, cover of macrophytes or periphyton, thickness of fine sediment).

- Precision of median derived from SAM2 measurements relative to the precision of the PFSC thresholds outlined in the NPS-FM (Table 16 of NPS-FM) and how to incorporate temporal and spatial variability in PFSC into numeric attribute states.
- Achievability of NBLs under either natural conditions or whilst providing for various human uses.
- The ecological rationale supporting the attribute bands.

MfE contracted with NIWA to evaluate the NPS-FM attribute for DFS, its associated guidance, and to gather information from councils regarding their various experiences implementing the policy in different geographic regions and river settings of Aotearoa-New Zealand (NZ). We also briefly reviewed the development of the DFS attribute bands and, as DFS is closely linked to common metrics of river ecosystem health (i.e., macroinvertebrate indices), we also gathered information from councils on their perceptions of the DFS attribute as it relates to attributes of ecosystem health presented in the NPS-FM.

This report begins by providing a background of river sediment as a physical river characteristic to be used for river management purposes, a summary of human-related effects on river sediment processes in NZ, and a brief description of current scientific understanding of how DFS affects metrics of river aquatic health. These summaries should be viewed as primers on the topics, not exhaustive reviews. A brief description of the overall NPS-FM NOF is also provided as broader context for the results of the evaluation of the DFS attribute and associated river ecosystem health attributes.

1.1 Natural river sediment transport and deposition processes

Sediment runoff is a natural consequence of weathering and erosion of rock and soil in watersheds, and the size and shapes of the channels of receiving rivers broadly reflect the relative balance of the supply of sediment delivered from the upstream landscape and the local capacity of the river to transport that supply (Dade 2000; Church 2006). Most sediment in rivers (fluvial sediment) is transported during the highest flow events (Markus and Demissie 2006), which distribute and deposit sediment and nutrients within river channels, floodplains, estuaries, deltas, and near-shore marine environments (Millman and Meade 1983; Millman and Syvitski 1992). The natural mobilization, transport, and deposition of fluvial sediments is thus a primary means of creation and overturn of aquatic and riparian habitats and closely linked to the health of river and estuarine ecosystems (Junk et al. 1989; Poff et al. 1997; Tockner et al. 2000; Wohl et al. 2015).

Sediments transported in rivers (fluvial sediments) can be broadly divided into two categories, bed material and washload. Bed material are the sediments that are nearly always present in the riverbed, and compose the bedforms of the river, with the largest bedforms being channel bars (point bars, braid bars) and smaller bedforms being dunes and ripples (Church 2006). Bed material grain sizes typically scale with the slope of the river, with the steepest river channels being composed of bedrock or boulders (grains larger than 256 mm in diameter) and the flattest river channels being composed of finer sediments (grains smaller than 2 mm in diameter; Dade and Friend 1998). During floods, when the channel is redistributing its bed material, the coarsest bed material is transported as bedload (sliding, rolling, saltating), while the finer bed material is often transported, at least intermittently, as suspended load (pushed up into the water column by turbulence).

Channels composed of sand or finer grains may have relatively well-sorted (narrow) grain size distributions, but those distributions can also be difficult to quantify because of particle flocculation and the presence of organics and other fine particles that are not mineral sediments (Lamb et al. 2020). Non-mineral fine particulates, while potentially important in the context of carbon cycling and river ecosystem health, are not traditionally considered 'bed material.' Alternatively, gravel bed rivers, typically characterized as those with median bed material grain sizes larger than 2 mm, often have a coarse top layer underlain by a deposit that has higher proportions of fine sediment, a phenomenon known as 'armouring' (Vázquez-Tarrío et al. 2020). Because of their complex topography, gravel bed rivers can also have large spatial variability in the bed material grain sizes, with finer grains being more abundant in mesohabitats such as pools and runs, while coarser grains are more dominant in riffles and steps (Buffington and Montgomery 2021). Further still, the grain sizes present on the bed vary in time and can be strongly dependent on antecedent hydrologic conditions. This temporal-spatial variation introduces challenges when attempting to quantify 'representative' grain sizes for any particular location in a river (Bunte et al. 2009).

Washload are the fluvial sediments that, under natural conditions, are not well represented in the bed material (Woo et al. 1986). That is, if a person were to take samples of the bed material, the washload grains would be absent or present in only trace quantities. Washload are often derived from erosion of upper bank materials (floodplains) and hillslopes (rills, gullies, landslips) or resuspended material from bars or near-banks. Grains included in the washload are typically considered those with diameters less than 62.5 microns (silt and clay) and, as the name suggests, are assumed to be transported entirely in suspension under typical higher-magnitude streamflow events. By extension, a river channel's capacity to transport washload during flooding conditions is generally assumed to be unlimited up to sediment concentrations exceeding about 5% of the total flow volume (50,000 mg/L), a condition referred to as 'hyperconcentrated flow' (Julien 1996).

1.2 Human effects on fluvial sediment in the New Zealand context

Although sediment is a natural component of all river systems, human-induced landscape changes are widely recognized to have substantially increased global sediment loads in the world's river systems (Walling and Webb 1996; Wilkinson and McElroy 2007; Vanmaercke et al. 2015). Past research has firmly established that human settlement of New Zealand caused increases in watershed sediment yields. Initial landscape disturbances by Māori peoples caused shifts in vegetation cover from dense forest to open forest and fern-scrublands, with the bulk of the disturbances being restricted to the lowland and coastline areas (Wilmhurst 1996; Fuller et al. 2015). European colonists intensified these disturbances by clearing forests nearly entirely from lowland areas to make room for agriculture and expanding forest clearing to the steeper upland and mountainous regions to grow grasses and forbs supporting grazing of domesticated animals (Glade 2003). Although some near-natural areas are still present in NZ's landscapes, their locations are strongly biased toward upland areas, many of which are in the mountain regions of the South Island or in wilderness regions of national parks and are not intensively monitored.

Reductions in vegetation cover coupled with New Zealand's tectonically active geologic setting, increased fine sediment yields to estuaries and oceans by more than an order of magnitude (Page and Trustrum 1997; Gomez et al. 2007; Nichol et al. 2013; Marden et al. 2014; Fuller et al. 2015). Across New Zealand, pasture settings have been shown to yield substantially more fine sediment for a given precipitation event than forested settings (Quinn and Stroud 2002; Hughes et al. 2012; Smith et al. 2023). In steeper or geologically unstable regions, reductions in forest cover coupled with large-magnitude rainfall events (i.e., cyclones) initiated runaway gullying that has persisted for decades and continues to be a primary source of fluvial fine sediment (Hicks et al. 2000; Fuller et al. 2020). Likewise, commercial forestry practices, which may stabilize slopes and reduce sediment yields in the short-term (Marden et al. 2014; Smith et al. 2023), continue to be a persistent source of fluvial fine sediment during periods of harvest (Ulrich 2020; Swales et al. 2021).

1.3 Linkages between DFS and biological indicators of river ecosystem health

DFS is a compulsory ecosystem health attribute. It is closely linked to the five biophysical components of freshwater ecosystem health outlined in Appendix 1A of the NPS-FM: quality, quantity, habitat, aquatic life and ecosystem processes. Deposited fine sediment is also linked with several non-compulsory values including natural form and character, drinking water supply, wai tapu, fishing, and commercial and industrial use. The compulsory ecosystem health attributes for wadeable rivers in the NPS-FM that are most likely to be impacted by DFS are periphyton (the slime and algae found on the surface of rivers beds and plants), macroinvertebrates, and fish communities.

Macroinvertebrates are the focal aquatic life attribute of this report because DFS is commonly reported as a key stressor of macroinvertebrate communities (e.g., Clapcott et al. 2011; Townsend et al. 2008; Davis et al. 2021) and metrics summarising their communities (such as the Macroinvertebrate Community Index; MCI) are commonly used by councils and other stakeholders as indicators of river ecosystem health. Because macroinvertebrates can live up to a year or more in a waterbody their communities generally summarise the impacts of potential stressors over longer time periods than water quality or periphyton samples. Data availability for macroinvertebrate communities is also generally greater than for fish communities, which are commonly monitored less frequently and in fewer locations.

Under the NPS-FM councils are tasked with monitoring macroinvertebrate community metrics annually, as they are a compulsory attribute of the ecosystem health value. The macroinvertebrate metrics are the Macroinvertebrate Community Index; MCI, it's quantitative variant; QMCI (Stark and Maxted 2007) and Average Score Per Metric; ASPM (Collier 2008). MCI is calculated based on the presence of macroinvertebrate taxa and organic pollution tolerance scores assigned to taxa. The QMCI is calculated in a similar manner and incorporates the abundance of the taxa present. ASPM is an average of the normalised scores of MCI and the abundance and richness of three orders of generally pollution-sensitive macroinvertebrates (mayflies; Ephemeroptera, stoneflies; Plecoptera and caddisflies; Trichoptera (EPT). The pollution tolerance scores for MCI and QMCI have two variants, one set designed for use in soft-bottomed rivers and another for use in hard-bottomed rivers.

The NPS-FM specifies that macroinvertebrate metrics are calculated as the median 5-year annual value and, as with the DFS attribute, are assessed against four bands regardless of the position of the site in the landscape, where band *A* indicates pristine or near reference site conditions while band *D* is below the NBL and indicates severe organic pollution and loss of ecological integrity. If monitoring identifies either that sites are 'degraded' (i.e., not meeting national bottom-line or target attribute states) or are 'degrading' (i.e., a deteriorating trend is detected that is due to a non-natural process), an action plan can be used to identify how the attribute state will be improved (Clause 3.20 of the NPS-FM).

The main mechanism through which DFS impacts macroinvertebrate communities is through changes to habitat. Deposited fine sediment smothers bed substrate and reduces interstitial spaces, which are habitat for macroinvertebrates and can be refugia during high flows (Sedell et al. 1990). Deposits of fine sediment can be frequently mobilised by changes in water velocity. This unstable bed substrate is unsuitable habitat for periphyton growth, an important food resource for many macroinvertebrates, and for many macroinvertebrate taxa, particularly those that contribute to higher macroinvertebrate metric scores.

Thorough reviews of the evidence for impacts of PFSC in New Zealand are provided in Clapcott et al. (2011) and Franklin et al. (2019). The Clapcott report summarises the quantitative relationships developed between DFS and macroinvertebrates and fish communities in New Zealand prior to 2011 and assesses relationships between metrics of DFS and macroinvertebrates. More recent studies (e.g., Scarsbrook 2016; Matthaei and Piggot 2019) have found similar results to those in Clapcott et al. (2011). Most notably that, while individual taxa respond differently to PFSC, macroinvertebrate metrics in the NPS-FM, which reflect community assemblage, (see Section 4.1.4 of this report) nearly always show negative responses to high PFSC. Rapid declines in macroinvertebrate metrics occur around 20 – 30 PFSC (Niyogi et al. 2007; Burdon et al. 2013; Franklin et al. 2019).

The development of more detailed quantitative relationships between macroinvertebrate community metrics and PFSC is complicated by several factors (e.g., Franklin et al. 2019; McKenzie et al. 2023). First, in rivers impacted by human activities there is common co-occurrence of multiple stressors such as high deposited fine sediment cover which makes habitat unsuitable, excess periphyton growth that smothers habitat and is an unsuitable food resource, inputs of contaminants, high nutrient concentrations and periods of extremely high or low water flows or high water temperature (e.g., Pingram et al. 2019). These stressors can interact synergistically (e.g., Wagenhoff et al. 2011; Davis et al. 2018), adding noise that makes development of direct and clear quantitative relationships between any individual stressor and a macroinvertebrate metric challenging. Second, commonly used macroinvertebrate metrics are generally not able to detect stressor-specific responses because the metrics are a univariate summary of complex responses by individual taxa (or community assemblages) to multiple co-occurring stressors (e.g., Wagenhoff et al. 2018). Third, deriving empirical relationships between DFS and macroinvertebrate metrics with existing data is complicated by: 1) a lack of consistent and extensive datasets due to the different methods and metrics for monitoring and reporting both DFS and macroinvertebrate responses (e.g., Franklin et al. 2019); and 2) potentially high temporal variability in DFS and macroinvertebrate metrics within sites impacted by human activities (Davis et al. 2021).

1.4 Purpose and Scope

The purpose of this report is to summarize the results of a brief evaluation and information gathering exercise relating to the DFS attribute as described the current NPS-FM (MfE 2024) and associated guidance (Clapcott et al. 2011; MfE 2022). The goal of the evaluation was to generate context for potential gaps in understanding, methods, or details of the current NPS-FM language and the data collection and implementation guidance. The goal of the information gathering was to generate a description of the *state of play* for regional implementation of the NPS-FM DFS guidance across Aotearoa-NZ and identify if there are areas where the current guidance could be improved to better meet the policy goals. This evaluation is in alignment with the 'adaptive approach' recommended by Stoffels et al. (2020b) for the DFS attribute, whereby the NPS-FM language and guidance are revised as information and feedback from councils allows.

The timeline for the evaluation, information gathering, and initial reporting to MfE was limited to less than three weeks, this report is therefore not comprehensive. Our study was limited to wadeable rivers as this is the primary freshwater resource associated with the DFS attribute as described in the NPS-FM (MfE 2024).

2 The National Policy Statement for Freshwater Management

Although excess fine sediment has been historically viewed as detrimental to river water quality and ecosystem health in NZ, the most current NPS-FM is the only version that has specifically referred to DFS and suspended sediment as attributes and enumerated specific TASs over a range of different river settings. The previous iteration of the NPS-FM was published in 2014, with amendments published in 2017 (MfE 2017). In that document, the word 'sediment' appears only five times, nearly all in statements mentioning compulsory or national values, but there is no mention of DFS as a specific attribute (MfE 2017). So, it is important to note that the DFS attributes defined in the NPS-FM 2020 and associated guidance were the first attempt to quantify DFS under an NPS-FM framework in NZ.

The NPS-FM (MfE 2024) includes the National Objectives Framework (NOF) process, whereby councils are asked to:

1. Identify freshwater management units (FMU) in their respective regions. FMUs are defined in the NPS-FM as "all or any part of a water body or water bodies and their related catchments…appropriate…for freshwater management and accounting purposes."
2. After engaging with communities and tangata whenua, identify values for each FMU. Compulsory values include ecosystem health, human contact, threatened species, and mahinga kai. Other values that may be considered include natural form and character, drinking water supply, wai tapu (places of ritual and ceremony), transport, power generation, animal watering, food and beverage production, and commercial and industrial use.
3. Set environmental outcomes for each value and include them as objectives in regional plans.
4. Identify attributes for each value and identify baseline states for those attributes. Attribute is defined in the NPS-FM as a "measurable characteristic (numeric, narrative, or both) that can be used to assess the extent to which a particular value is provided for."
   - 4.1 Attribute states and baseline states may be expressed in a way that accounts for natural variability and sampling error (clause 3.10(4)), rather than by referring to bands. The 'within an attribute band' requirement to describe attribute state was removed with the 2020 amendments.
5. Set target attribute states, environmental flows and levels, and other criteria to support the achievement of environmental outcomes.
6. Set limits as rules in plans and prepare action plans (as appropriate) to achieve environmental outcomes.
7. Monitor water bodies and freshwater ecosystems.
8. Take action if an FMU is degraded (below NBL) or degrading. Degraded is essentially defined in the NPS-FM as a site, sites, part of FMU or the FMU to which a target attribute state applies and which is below the National Bottom Line, not achieving or likely to achieve its target attribute state or provide for any value described in Appendix 1A or any value identified for it under the NOF. Degrading is defined as "*…any site or sites to which a*

target attribute state applies is experiencing, or is likely to experience, as a result of something other than naturally occurring process, a deteriorating trend."

Implementation of the NPS-FM thus hinges on two key elements in the list above, (2) identification of values for each FMU, and (4) use of attributes to define a measurable aspect of the values and target states against which observations can be compared. Values are benefits that the community want to be preserved or provided with by councils in their management of the FMU. Ecosystem health is a compulsory value, of which DFS is an attribute. Attributes are measurable characteristics (numeric, narrative, or both) that can be used to assess the extent to which a particular value is provided for. The NPS-FM provides metrics for each attribute and, in some cases, provides multiple metrics.

As part of the NOF process, councils must engage with communities and tangata whenua to set TASs, and no TAS may be lower than the national bottom-line (NBL), which are enumerated for each attribute in appendices 2A and 2B of the NPS-FM. If the baseline state is above the NBL, the TAS must be set to maintain or improve the baseline state. Baseline state refers to the quantified state of the attribute (refer to clause 3.10(4)) and is defined in clause 1.4 of the NPS-FM as the best state of the following:

A. The state of the attribute on the date it is first identified by a regional council under clause 3.10(1)(b) or (c);

B. The state of the attribute on the date on which a regional council set a freshwater objective for the attribute under the National Policy Statement for Freshwater Management 2014 (as amended in 2017);

C. The state of the attribute on 7 September 2017.

To set the BAS, Clause 1.6 directs councils to use the best information available at the time, which means, if practicable, using complete and scientifically robust data. In the absence of monitoring data councils may use information obtained from modelling, as well as partial data, local knowledge, (e.g. communities and tangata whenua) and other information obtained from other sources. A council must not delay making decisions solely because of uncertainty about the quality. If the information is uncertain, councils must interpret it in the way that will best give effect to the NPS-FM.

Attributes outlined in appendices 2A and 2B of the NPS-FM apply to two primary freshwater body types: lakes; and rivers. Lakes are subdivided into 'lakes' and 'seasonally stratifying lakes', and rivers are subdivided into rivers, lake-fed rivers, and wadeable rivers.

Through the NOF process, councils are required to identify attribute monitoring sites and 'primary contact sites', which are defined as "*a site…regularly used, or would be regularly used but for existing freshwater quality, for recreational activities…, and…for activities where there is a high likelihood of water or water vapour being ingested or inhaled.*" (see page 7 of NPSM for full definition). The Ecosystem health attribute monitoring sites are required to be either representative of the FMU (or part of the FMU) or one or more primary contact sites in the FMU, or both. Monitoring sites related to Māori freshwater values, which must be identified by working with tangata whenua, are not required to, but can, represent the FMU or primary contact sites.

3 Methods

We briefly reviewed the development of current DFS attribute bands using previously published reports, memos, scientific literature, and current guidance documents. We focused on understanding the scientific basis used to derive the current DFS attribute, including the utility of DFS as a predictor of river ecosystem health, as well as the methods used to predict the spatial distribution of naturally hard-bottomed rivers at the national scale and derive the number and values for DFS attribute bands and classes. We also examined the clarity of the current DFS guidance (Clapcott et al. 2022; MfE 2022; MfE 2024) for utility in practical application.

As the second primary component of work, we contacted relevant staff at regional and district councils across Aotearoa, and conducted interviews with those staff who were available within the timeline of June 10 through June 25, 2024. Regional councils are the primary entities charged with environmental management of natural resources in New Zealand and thus our primary engagement was directed at the 11 regional councils (Northland, Waikato, Bay of Plenty, Hawke's Bay, Taranaki, Manawatu-Whanganui, Greater Wellington, West Coast, Environment Canterbury, Otago, and Southland), and the six unitary authorities with powers of regional councils (Auckland Council, Gisborne District Council, Tasman District Council, Nelson City Council, Marlborough District Council, and Chatham Islands Council). An example of the questionnaire sent to council staff can be found in Appendix A of this report.

4 Results

Below we present the results of our evaluation of the DFS attribute as described in the current NPS-FM its associated guidance, and information gathered from surveys of council representatives. Key summary statements are presented as **in boldface**.

4.1 Current NPS-FM language and guidance for DFS

The focus of this report is deposited fine sediment as a freshwater attribute in the context of the NPS-FM. However, DFS has connections to other attributes outlined in the NPS-FM, including a strong connection to attributes of river ecosystem health as measured by metrics of river macroinvertebrates. These metrics are helpful in establishing a basis for how DFS may affect river ecosystem health by changing the abundance and diversity of river macroinvertebrates.

4.1.1 Targeted water bodies

The attribute states for DFS are presented in Table 16 of Appendix 2B of the NPS-FM (MfE 2024). That table indicates that the DFS states are applicable to 'wadeable rivers.' Importantly for practical implementation purposes, the term 'wadeable river' is not defined in the NPS-FM document (MfE 2024), nor in the NPS-FM sediment requirement guidance document (MfE 2022). The primary DFS methodology reference for New Zealand, Clapcott et al. (2011), also does not define wadeable rivers, but does state that their methods *do not* apply to 'non-wadeable waterways.' Joy et al. (2013), which is used as a primary reference for river fish attributes in the NPS-FM, define 'wadeable streams' as "*locations where at least 90% of site is ≤0.6 m deep and mean wetted width is ≤12 m.*" Other technical references cited in the NPS-FM and which contain the term 'wadeable' in their titles, also do not contain definitions of the term, although another document cited (Stark and Maxted 2007) suggested that 89% of 1st to 3rd order rivers in NZ should meet the definition of wadeable, and some higher order rivers, particularly braided rivers, should have wadeable threads.

This definition is important because implementation of the NPS-FM calls for establishing the current attribute state of a site representing an FMU using the median of five years of monthly data collection <u>regardless of flow conditions</u>. As described in the summary of interviews below, if a river is not wadeable councils cannot safely make field observations which, in some cases, results in substantial periods of missing data. Missing data will have the effect of reducing the precision or biasing the median estimate of PDFS, or both (see additional discussion of the potential effect of missing data on the estimate of the median in Section 4.1.2 below).

The targeted freshwater body being defined as 'wadeable' for the DFS attribute in the NPS-FM (MfE 2024) may be a source of confusion because there is no guidance about treatment of missing data for sites that are functionally non-wadable for certain times of year. This confusion may result in councils attempting to monitor rivers that are not functionally within the definition of the targeted freshwater body (wadeable rivers), resulting in wasted time and resources.

4.1.2 DFS attribute states

The DFS attribute is percent fine sediment cover (PFSC) calculated from observations taken using the instream visual assessment of sediment method, commonly referred to as 'SAM2' (Clapcott et al. 2011). The method calls for measurements of PFSC at 20 randomly distributed points, four each at five transects spanning the wetted width of the channel. The measurements are taken by trained field personnel, typically using a bathymetric viewing scope with a bottom lens divided into quadrats or a grid (see Clapcott et al. 2011 for further details). The operator uses the scope to view the streambed and estimate how much of the bed is covered in fine sediment within each of the four quadrats. Other methods including a bankside visual estimate (i.e., 'SAM1'), Wolman pebble count ('SAM3'), Quorer method ('SAM4'), and resuspendable sediment ('SAM5'; also known as the 'shuffle method') are presented as alternatives in Clapcott et al. (2011), although the NPS-FM sediment-specific implementation guidance (MfE 2022) explicitly calls for use of the SAM2 method.

Two key steps are required for evaluating PFSC. In the first key step councils must determine if a monitoring site representing an FMU is soft-bottomed, which is defined as a site where the riverbed has greater than 50% areal cover of sediment grains with nominal diameter less than 2 mm. If the site is determined to be soft-bottomed, councils must further determine if the site is 'naturally' soft-bottomed or hard-bottomed. If a site is observed to be soft-bottomed, but is determined to be naturally hard-bottomed, the NPS-FM calls for alternative habitat monitoring to occur at the site whereby the annual measurements of PFSC are taken using the SAM2 method, and alternative metrics of freshwater habitat are employed.

The second key step in evaluating an attribute is to determine its current state, which is used to either inform setting of the TAS or evaluating performance against a TAS already set. Setting of the TAS was explained in Section 2 previously. The NOF table provides four 'attribute bands' as general guidance for interpreting the quality of ecosystem health supported by a particular state of DFS. These four bands span from nearly pristine (A band), to severely degraded (D band). The NBL is located at the upper boundary of the D band, and its value is relevant to council policy because the TAS must be set at or above the BAS, and at or above the NBL threshold unless special circumstances apply (i.e. part of a hydro-electric generation scheme).

In the case of DFS, the NPS-FM acknowledges that it would not be appropriate to apply the same attribute bands to all sites because natural DFS would be expected to vary across the landscape. The NPS-FM identifies different values for a given attribute band that are dependent on four 'deposited fine sediment classes', each of which are associated with the hydroclimatic, and physical setting of the observed site as defined by groupings of a modified (simplified) version of level 3 of the New Zealand River Environment Classification (REC; Snelder et al. 2010) (Table 4-1), which is based on local climate, topography, and geology of the watershed (REC-CTG). Table 24 of Appendix 2C in the NPS-FM assigns each level 3 modified REC class into one of four deposited sediment classes.

Importantly, the NPS-FM does not call for monitoring of DFS attributes in five specified classes of river as determined by the REC system (Snelder et al. 2010). These river classes are contained in Table 25 of Appendix 2C of the NPS-FM and are excluded from the DFS attribute policy because they were estimated to be naturally soft-bottomed. All the excluded classes are in rivers classified as 'warm-lowland' or 'warm lake-fed'.

Table 4-1: Deposited fine sediment attribute bands and classes as defined in Table 16 of Appendix 2B in the NPS-FM.

Attribute band and description	Numeric attribute state by deposited sediment class			
	Median			
	1	2	3	4
A Minimal impact of deposited fine sediment on instream biota. Ecological communities are similar to those observed in natural reference conditions.	≤7	≤10	≤9	≤13
B Low to moderate impact of deposited fine sediment on instream biota. Abundance of sensitive macroinvertebrate species may be reduced.	>7 and ≤14	>10 and ≤19	>9 and ≤18	>13 and ≤19
C Moderate to high impact of deposited fine sediment on instream biota. Sensitive macroinvertebrate species may be lost.	>14 and <21	>19 and <29	>18 and <27	>19 and <27
National bottom line	**21**	**29**	**27**	**27**
D High impact of deposited fine sediment on instream biota. Ecological communities are significantly altered and sensitive fish and macroinvertebrate species are lost or at high risk of being lost.	>21	>29	>27	>27

The current attribute state of the river is expected to be based on a median value from 5 years of monthly monitoring using the SAM2 method "regardless of weather and flow conditions." Thus, a complete dataset would equate to 60 site visits, with 20 data points each, for a total of 1200 raw measurements. Clapcott et al. (2011) call for the value from each site visit to be the "*average of all quadrats as a continuous variable*". The NPS-FM does not specify a particular median for the attribute value. For example, the median could be taken from the 60 mean values (median of 20 mean values from each of 60 site visits), or as the median of 1200 measurements. In theory these would be the same for a perfectly symmetric distribution, but the distribution is not known or assumed in the NPS-FM. There is also no guidance for treatment of missing data when calculating the median because of unsafe wading conditions for all or some of the wetted width, nor for when a river is completely or nearly completely dry.

The method descriptions for determining current attribute state for DFS in the NPS-FM (MfE 2024) and in the current guidance (Clapcott et al. 2011; MfE 2022) do not provide explicit descriptions of the attribute statistic nor its assumed statistical distribution and, perhaps more importantly, do not provide guidance for treatment of missing data due to unsafe wading conditions or unfavourable sampling conditions (ex. turbid waters, macrophyte or periphyton overgrowth, dry streambed). Practical application of the DFS attribute is therefore hindered by lack of prescriptive instructions about how to determine the attribute state for DFS from field observations that include missing data. Data may be missing in time due to changes in flow. Data may be missing in space within a site due to changes in hydraulics or riverbed conditions. A lack of clarity in practical application of the DFS attribute may result in determinations of current attribute states that are

biased toward lower magnitude flow conditions or away from periods that may be representative of the most sediment enriched conditions.

The four deposited sediment classes used for the DFS attribute bands are directly linked to the assumption that the rivers in the REC-CTG groups of the NPS-FM Appendix 2C Table 24 are likely to be naturally hard-bottomed. As noted above, the NPS-FM Appendix 2C Table 25 indicates that only five REC-CTG classes of river were predetermined by MfE to be characterised as being naturally soft-bottomed. Clause 3.25 in the NPS-FM, however, indicates that councils should make the determination of the natural state of a riverbed, and the DFS guidance document (MfE, 2022) states that "*Councils can use a combination of field investigation, historical research and statistical study/GIS classification to determine whether a currently soft-bottomed wadeable stream would be a hard-bottomed stream under natural conditions."* There is no language in the NPS-FM or the associated sediment specific guidance (MfE 2022) to instruct councils if they should ignore application of the DFS attribute for sites in REC-CTG classes listed in Table 25, or if they should make the determination themselves when determining whether a currently soft-bottomed wadeable river would be a hard-bottomed river under natural conditions. Likewise, we did not find language to instruct councils as to how they would set attribute band thresholds for sites contained in Table 25 if they determined them to be naturally soft-bottomed.

The current NPS-FM language addressing determination of the 'natural state' of a riverbed (hard or soft bottomed) is unclear. Clause 3.25 of the NPS-FM and the current guidance document state that councils should make this determination, but Table 25 presents a pre-determined list of 'naturally soft-bottomed' REC climate-topography-geology (CTG) classes. This could be interpreted by councils (correctly or incorrectly) to mean that any site located within REC-CTG classes listed in Table 25 should be naturally soft-bottomed. Further, if councils determined a site in one of the REC-CTG classes listed in Table 25 to be naturally hard-bottomed, Table 16 does not have attribute band thresholds for councils to apply. By extension, those REC-CTG classes <u>not listed</u> in Table 25 (the classes listed in Table 24) could be assumed by councils (correctly or incorrectly) to mean that MfE expects them to be naturally hard-bottomed. This lack of clarity could result in, at best, confusion by councils and, at worst, incorrect management action plans being applied.

4.1.3 A brief history of development of current DFS attributes and guidance

As part of this evaluation, we examined some of the recent (past 10 years) efforts to develop statistical relationships between land use and deposited fine sediment, including the modelling efforts used to develop the current attribute band river classes and associated thresholds. Here we include a summary of this examination as context for development of the DFS attribute as an 'Action Plan' limit in the current NPS-FM (i.e. an attribute which requires an action plan to respond to degradation and achieve the TAS).

Exploration of correlations between land use and DFS in rivers at the national scale appears to have begun with Hicks et al. (2016). Their analysis used 16,934 data points of deposited fine sediment to examine correlations and predictive statistical relationships between DFS and various river and watershed attributes, with a focus on relations between various metrics of river sediment load and DFS. The bulk of the response data were extracted from the New Zealand Freshwater Fish Database (NZFFD) and only included measurements taken using standardized methods (SAM1 through SAM5, as defined by Clapcott et al. 2011), although the majority (70%) were taken using the SAM1 method (riverside visual assessment), which is considered the least precise; some information regarding mesohabitat type was also included. Hicks et al. (2016) found weak statistical relations between DFS and an array of explanatory variables, of which elevation and river slope had the strongest explanatory power. After extensive interrogation of the data, Hicks et al. (2016) concluded that "*Based on the results of the current analysis there is no empirical relationship that could robustly be used for predicting the response of DS* [DFS] *in streams to land-based management actions. We do not think that any of our current models can be confidently used to describe the relationship between sediment load…and DS.*"

Although not part of DFS attribute development, the work of Haddadchi et al. (2018) is cited in the sediment specific NPS-FM guidance document (MfE 2022) as a method that can be used for assessing if a river segment is naturally hard bottomed or soft bottomed. Haddadchi et al. (2018) used 73,550 observations from 229 sites of channel bed grain surface grain sizes (boulder to mud) to build predictive statistical models onto the NZ REC river network. They used many topographic, channel morphologic, land cover, geologic, and hydroclimatic explanatory variables to inform three different types of statistical models. Their models showed that river slope was the most powerful predictor of channel bed grain sizes, and that the coefficient for river slope roughly scaled with grain size. They demonstrated that their models could replicate downstream fining patterns in NZ rivers, but the models performed poorly in regional cross validation tests and Haddadchi et al. (2018) suggested caution when applying the models to areas where no training data were available. Nonetheless, the Haddadchi et al. (2018) model is used as a decision tool for predicting dominant streambed grain sizes where no other data are available and is one of several methods the current NPS-FM sediment guidance (MfE 2022) recommends councils use for determining the current and or natural state of a streambed.

From our exploration of published MfE reports, the first iteration of attribute thresholds for DFS was published in June 2019 (Franklin et al. 2019). Franklin et al. (2019) derived sediment reference states for sites on rivers across NZ using a hierarchical approach in which PFSC data from the NZFFD and State of the Environment (SOE) surveys were used to inform statistical models across a range of different 'spatial aggregations' of 'climate, topography, and geology' (CTG) classes in their modification of the original REC system (some original classes were joined e.g., glacial mountain was joined with mountain). Their analysis examined four levels of REC-CTG aggregation with 2, 4, 8, and 12 reference state classes. Franklin et al. (2019) noted that the level of aggregation had substantial influence on the bias of threshold states, and that too much aggregation (fewer classes) resulted in unacceptably large threshold ranges. Fewer classes resulted in more certainty in the thresholds being appropriate for the overall collection of sites comprising the class (due to a greater number of sites allowing a more certain estimates of the threshold) but a greater chance that an individual site was paired to an inappropriate threshold (due to a widespread variability in conditions at sites comprising the class). More classes result in less certainty on the thresholds (less confidence in the threshold characterising the overall collection of sites comprising the class) but less chance of a site being paired to an inappropriate threshold (due to a narrow spread in variability in conditions at sites comprising the class). Consequently, Franklin et al. (2019) proposed using the lowest level of 12 reference state classes for DFS, with the NBL values for PFSC ranging from 21 to 97 percent.

Stoffels et al. (2020a) revisited the dataset of Franklin et al. (2019) and concluded that the NZFFD data used to derive the attribute states was biased high relative to newer DFS data. Stoffels et al. (2020a) recommended a reanalysis of the thresholds using higher quality, but less well spread across the landscape, SAM2 data available from the NZ State of the Environment (SOE) surveys. Stoffels et al. (2020b) re-examined the thresholds using the SAM2 data and recommended lowering (more protective) the reference state thresholds for DFS below those proposed by Franklin et al. (2019).

The explanatory power of the models used by Stoffels et al. (2020b) diminished substantially for spatial aggregations beyond more than four classes.

Although we could find no final document whereby the Stoffels et al. (2020b) analysis was explicitly adopted, a report to the Minister for the Environment (STAG, 2019) contains a statement whereby members of a Science Technical Advisory Group (STAG) supported "*the proposed band and bottom line thresholds, the spatially explication classification systems proposed and Franklin et al's (2019) recommendation of using the least aggregated classification system for both suspended and deposited sediment.*" Consequently, we surmise that these four classes (the least aggregated system proposed by Franklin et al. [2019] and recommended by Stoffels et al. [2020b]) are those adopted into the current NPS-FM (MfE 2024), and the basis for the current DFS attribute band thresholds (Table 4-1).

The statistical models used to examine relationships between DFS and land use (Hicks et al. 2016; Haddadchi et al., 2018) and those used derive the DFS attribute bands (Hicks et al. 2016; Franklin et al. 2019; Stoffels et al. 2020b) have demonstrated alignment with conceptual understanding of landscape position and land use effects on DFS. However, those models did not demonstrate strong predictive power for PFSC in rivers relative to hypothesized controls beyond fundamental physical principles (i.e., grain size in a riverbed is most strongly related to river slope and its capacity to transport sediment), although it should be acknowledged that the models were developed using data whose collection was uncontrolled (NZFFD) or collected over limited time periods at limited sites (SAM2). These model uncertainties are acceptable for MfE's freshwater management objectives to provide appropriate thresholds at the national scale (i.e., each threshold is the best estimate of the true but unknown average conditions within its representative class), but their site-level consequences (i.e., each threshold is not the best estimate of the true but unknown condition at each individual site to which it is being applied) are not currently communicated in the NPS-FM nor its associated guidance. At best the lack of explanation of model uncertainties may manifest as a lack of confidence or council confusion in the PFSC thresholds being appropriate for monitored sites; at worst, target attribute states and associated planning may be enacted that is not appropriate for a particular site or FMU that the site represents.

4.1.4 Alignment between monitoring networks for DFS and other river ecological health attributes

The majority of council State of the Environment (SOE) monitoring networks are designed to monitor the current state and trends in DFS, water quality, periphyton and macroinvertebrate communities. Ideally, data from the monitoring networks could also assist in identifying potential causes of any ecological changes (e.g. in periphyton biomass or macroinvertebrate or fish communities). Historically, monitoring networks were designed to best suit the local requirements of a council and the environmental conditions, which has led to some regional differences in monitoring methods and in the spatial and temporal resolution of data for different variables (e.g., Pingram et al. 2019, Gray 2022). The relatively recent introduction of the NPS-FM and subsequent National Environmental Monitoring Standards has further challenged councils to maintain historical consistency of their long-term datasets while also generating more national consistency in monitoring methods and environmental reporting.

Using data from SOE monitoring networks to identify potential stressors (e.g., DFS) of ecological attributes, such as macroinvertebrates, is challenging because the networks were not designed for this purpose. The most ideal sites to monitor attributes such as macroinvertebrates, periphyton and DFS commonly do not commonly align spatially or temporally. Councils monitor macroinvertebrates annually, and historically, for most councils, in riffle habitat. Periphyton is commonly monitored monthly, at least during the summer months, and usually in un-shaded runs (Biggs and Kilroy 2000). Periphyton monitoring may be targeted at sites of high recreation value to monitor formation of cyanobacteria mats, which can be toxic to humans and dogs. Water quality (e.g., dissolved nutrients, conductivity, water temperature, pH etc) monitoring sites are commonly monitored more frequently than macroinvertebrate sites (often monthly) due to the influence of river flow on water quality variables. Water quality sites may be located at the same sites as periphyton monitoring sites or located in larger downstream reaches that represent the water quality of a larger catchment. These reaches are often not wadeable and unsuitable for periphyton and macroinvertebrate monitoring.

DFS monitoring may be paired with periphyton, macroinvertebrate or water quality monitoring. DFS cover using SAM2 is commonly, but not always, paired with visual assessments of periphyton cover using an underwater viewer as both methods can be conducted on the same transects/viewing points (Biggs and Kilroy 2000). However, councils use different methods or sites for monitoring DFS, depending on the environmental conditions, the goal of their monitoring, environmental conditions, and site logistics.

Councils are limited financially and logistically to the sites at which they can collect data for different attributes or potential stressors. Sites at which water quality, periphyton, macroinvertebrate and DFS data are collected do not often align spatially or temporally, or if they do, only at a subset of sites. This, along with differences in sampling methodology, causes technical difficulties when using the data to attempt to identify potential stressors of ecological values, or to determine quantitative relationships between individual stressors (such as DFS) and ecological values (such as macroinvertebrate metrics).

4.2 Council interviews

We contacted personnel at all 11 regional councils and six unitary authorities of New Zealand by email or phone or both. Our initial means of contact was a mass email to several council personnel known to us or MfE through previous work, and thus did not include contacts from all councils. This initial email indicated the basic scope of the project, and our intentions to follow up with individuals to schedule phone/video conference interviews. Our initial intention was to conduct interviews using a set of pre-defined questions to help keep responses consistent (Appendix A). However, in most cases, council respondents wanted to see a list of questions that would allow them to prepare for the interviews, and these respondents were sent the questions shown in Appendix A.

By 25 June 2024, responses had been received from personnel at nine regional councils, six unitary authorities, and the Department of Conservation (DOC; Table 4-2). Some respondents chose to answer a series of questions via email, and some were not available during the timeline for this work specified by MfE. In total, we conducted 11 video/phone interviews and received email responses from four additional council respondents. Although we strived to get direct (quantifiable) answers to the questions we identified as most important (Appendix A), in some cases the answers had to be interpreted post-facto in a qualitative manner and are thus expressed using phrases such as ‘some’ or ‘most’ when we identified a finding was common among respondents.

Table 4-2: List of personnel from councils that responded to our questionnaire. Respondents were identified as those involved in administering or executing freshwater monitoring in their respective councils at the time of the interviews (June 10 to July 5, 2024).

Organisation	Type	Response method	Respondent
Northland	Regional	Interview	Manas Chakraborty – Resource Scientist; Megha Sethi – Freshwater Policy Analyst
Auckland	Unitary	Email	Rhian Ingley – Senior Scientist – Water Quality; Sheldon Benito – Senior Environmental Specialist
Waikato	Regional	Interview	Michael Pingram – Team leader – Water Quality and Ecology; Nicole Squires – Environmental Monitoring Scientist
Bay of Plenty	Regional	Interview	Alastair Suren – Freshwater Ecologist
Gisborne District	Unitary	Email	Peter Hancock – Environmental Monitoring Team Leader
Hawkes Bay	Regional	Interview	Sandy Heidekker – Principal Scientist Freshwater Quality and Ecology
Taranaki Regional Council	Regional	Interview	Brian Levine – Scientist-Land and Soils
Horizons Regional Council	Regional	Email	Multiple (declined to be named)
Greater Wellington	Regional	Interview	Amanda Valois – Team Leader–Water Monitoring
Tasman District	Unitary	Interview	Trevor James – Senior Resource Scientist Freshwater & Estuarine Ecology; Jonathan McCallum – Environmental Monitoring Officer
Nelson City	Unitary	Interview/email	Paul Fisher – Senior Freshwater Scientist; Harry Allard – Coastal and Marine Scientist
Marlborough District	Unitary	Interview	Steffi Henkel – Environmental Scientist
Environment Canterbury	Regional	Interview	Sriyan Jayasuriya – Senior Environmental Scientist
Environment Southland	Regional	Interview	Katie Blackmore – Senior Scientist – Surface Water Quality
Chatham Islands	Unitary	Email	Adrian Meredith (ECAN) – Principal Water Quality Scientist
Department of Conservation	Central Government	Interview	Dave West – Science Advisor-Freshwater; Craig Woodward – Technical Advisor-Freshwater

We did not make contact directly with representatives of the Chatham Islands Council, but instead received an email response from a staff member at Environment Canterbury (ECAN), who has been assisting with freshwater monitoring there. This response indicated that Chatham Islands has an established freshwater monitoring network but is not regularly monitoring for DFS via the NPS-FM. The response stated that Chatham Islands had a somewhat unique geology, including an abundance of peat, making water clarity low because of staining, which makes bed-sediment surveys difficult. Nonetheless, a recent report (PDP 2020) containing data from ecological sampling in nine rivers on the Chatham Islands indicated that six rivers had no fine sediment present on the bed, two had as much as 10 percent, and one had 95 percent. However, only a single river had more than one observation of DFS. It should also be noted that the Chatham Islands do not have a REC system, and therefore cannot currently apply the NPS-FM DFS attribute band thresholds listed in Table 16.

For the purposes of summarizing numbers of responses below, we excluded responses from Chatham Islands because they are somewhat different than the North and South islands of Aotearoa/NZ. We also excluded responses from DOC because they do not have NPS-FM DFS specific monitoring programmes. That is, although we received responses from 16 entities, we are considering a maximum of 14 responses for the purposes of summarizing responses from council personnel. Where appropriate, we summarize findings for Chatham Islands and DOC as separate statements. Not all council respondents provided answers to every question, and, in those cases, we use the phrase 'responding councils.'

4.2.1 Implementation of the NPS-FM DFS attribute

Most councils have implemented, or are in the process of implementing, monitoring for the deposited fine sediment attribute as described in the current NPS-FM (MfE 2024).

- Of the 14 councils that provided responses, eight were implementing programmes to monitor for DFS as outlined in the NPS-FM (i.e., measuring DFS at all their monitoring sites), 4 were doing so partially (i.e., measuring DFS at some of their monitoring sites), 1 was piloting in reference sites, and 1 was not implementing the DFS guidance.
- We received counts of monitoring sites from all 14 councils indicating at least 755 sites were being monitored for DFS nationally, with most of those being monitoring monthly for at least half of the year.
- Those councils not implementing, or only partially implementing, the DFS attribute monitoring were all conducting some form of DFS monitoring but were using methods other than SAM2, often because personnel there did not believe SAM2 was the most appropriate method for the rivers in their monitoring network (e.g., naturally soft-bottomed rivers; rivers dominated by macrophyte growth).
- At least 3 councils are using multiple SAM methods to determine which method may be the most accurate for their purposes.
- Most councils were implementing DFS monitoring in conjunction with existing monthly periphyton monitoring.

Councils are using a variety of methods to determine if sites are naturally hard-bottomed, but most council respondents indicated they are not confident in use of Table 25 from the NPS-FM to distinguish naturally soft-bottom sites (MfE 2024).

- Five of the 14 responding councils were using site-based assessments to determine whether a site is naturally hard-bottomed or soft-bottomed. We interpreted this to mean that they used their own local knowledge and observations at the sites to determine if a site was naturally hard bottomed.
- Seven councils were using the REC-based system presented in the NPS-FM for their determinations, although many felt the REC system was incorrect.
- Two councils had contracted with the Institute of Geologic and Nuclear Sciences (GNS) to make field geology-based determinations of the 'natural' condition of rivers. These two councils were very satisfied with these determinations.

All councils have staff that are trained in SAM2 and other sediment assessment methods and engage in regular observer quality control activities.

- Of the 13 councils who gave responses about training, all were doing some form of DFS training.
- Seven councils had formal training programmes, including two that contracted with the Cawthron Institute for formal, field-based training.
- Nearly all council respondents indicated their teams did some form of field-based personnel 'calibration' whereby individuals took measurements at the same locations and compared values.
- Some councils coordinated training with other councils or consultants and attended conferences and workshops, indicating they were attempting to gain understanding of how other teams were performing DFS data collection and monitoring.
- All councils have at least one person on staff whose full-time job was to run some form of monitoring that included DFS measurements as well as seasonal staff to assist that person. This indicates that there is some year-to-year consistency in the DFS data collection and monitoring programmes.

Most council respondents indicated they would like to see improved guidance for practical implementation of the current NPS-FM deposited fine sediment attribute.

- Personnel from four of 12 responding councils indicated they were not satisfied with the current guidance, five wanted improvements, two were partially satisfied, two did not give an answer, and one was satisfied.
- Common comments of dissatisfaction with current guidance included, but were not limited to the following:
  - Lack of guidance when the REC-based system incorrectly classifies a site (affects National Bottom Line and attribute band thresholds).
  - Precision of attribute band thresholds is narrow relative to expected within operator error (+/- 5%) and between operator error (+/- 10%).
  - Lack of guidance on how to calculate median values when there are large numbers of missing observations because of unsafe wading conditions, turbid water, or other conditions preventing accurate SAM2 measurements.

4.2.2 Perceptions of deposited fine sediment

Council respondents nearly unanimously expressed that DFS was a key stressor to ecological health in rivers of their regions.

- Personnel from 12 of the 14 councils responded that they believed DFS was a key stressor on rivers in their region; two responded 'maybe.'
- Our qualitative interpretation of council respondents' perceived severity of DFS in their region (number/length of rivers) varied widely, ranging from a 'few rivers' to 'most rivers'.

- In the networks of the five councils with respondents that provided some quantitative estimate of the severity of DFS in their networks, 10% or less of their monitoring sites were below the NBL, and most were in the B band or above. An additional council respondent indicated that 60 percent of their monitoring sites were currently in the C band or lower (below NBL), although that region was strongly affected by Cyclone Gabrielle in 2023.
- DOC representatives estimated that 80% of their sites were affected by DFS, although most of their data collection were 'one-offs' as they do not have a persistent monitoring programme or consistent network of sample sites.

4.2.3 Top 3 most common issues with NPS-FM DFS attribute

Although we strived for consistent language and responses, interviews and email responses were not designed to have strict categorical boundaries. Instead, we interpreted bits of language from each interview and grouped them into categories which we felt broadly captured the essence of the primary issues that were communicated. We then simply counted the number of councils which made a statement associated with that category. Based on these counts, the top three most common issues identified are as follows:

A. **The SAM2 method cannot be used to make accurate measurements when streambed visibility is low to nil.** Respondents from 10 of 14 councils indicated that they had problems making accurate (or any) measurements of streambed grain size using SAM2 when macrophytes or filamentous algae were present, or conditions were too turbid or dark to see the bottom.

B. **Respondents did not have confidence in the REC-based system used to determine river classes for the DFS attribute**. Respondents from 10 of the 14 councils expressed at least some uncertainty in the current REC-based system in the NPS-FM correctly identifying their rivers as naturally hard bottomed or naturally soft-bottomed, and this was creating frustration for deciding on attribute states (National Bottom Line) and monitoring protocols.

C. **The ranges of threshold values for the current DFS attribute bands are perceived to be outside of, or equal to, the boundaries of the precision of the SAM2 method**. Respondents from 7 of the 14 councils expressed discomfort with the fact that their most accurate SAM2 measurements had an assumed error of +/- 5% (range of 10%), while the threshold attribute bands had ranges of 7 to 10%.

4.2.4 Other primary issues

There were a wide range of additional issues identified by respondents from councils. Although these specific issues were less commonly expressed, our interviews were generally limited to less than an hour, so we cannot confidently infer whether this lower frequency indicates that these issues are of minor significance or less widespread.

D. **Respondents do not have guidance on monitoring or determining current attribute states for DFS when data is missing because of unfavourable site conditions.** Respondents from 6 of the 14 councils expressed frustration with the fact that current guidance tasks them with determination of the current attribute state of site based on monthly measurements taken over a period of 5 years "regardless of flow conditions", but some of their sites were not accessible for certain months because of unsafe wading conditions. In extreme cases, up to six months of data were missing from certain years.

E. **Respondents from councils expressed frustration with the SAM2 method across a range of technical implementation and conceptual issues.** In addition to the issues mentioned above, the following were mentioned by council respondents at least once:

- A lack of guidance on how to interpret fine sediment deposited on top of coarser particles (ex. a 1 mm thick coating of fine sediment deposited on top of an 80 mm diameter cobble).
- SAM2 measurements are not reflective how fine sediment impacts interstitial spaces for macroinvertebrates.
- Thickness of DFS may be important but is not captured with SAM2.
- Differentiation of sludge (organic-dominated particles) from fine sediments composed of mineral particles.

F. **Respondents from councils were not confident that their current monitoring sites were adequately representing their FMUs in regard to the DFS attribute.** Most respondents were implementing their DFS monitoring at existing freshwater monitoring network sites, usually defined by a periphyton monitoring programme. This is because DFS and periphyton monitoring are done in a similar fashion, and it is most efficient to deploy similar monitoring when other measurements are already being taken by trained individuals. Respondents from 5 of 14 councils expressed that their periphyton sites may not be representing DFS across the FMU, but they were hesitant to develop entirely new monitoring networks because of the resources required to do so, and a lack of confidence that they could find a better site.

G. **Respondents from some councils indicated they were struggling to add DFS monitoring to their monitoring programmes within their current resources.** Respondents from three councils expressed that implementation of the DFS attribute monitoring was pushing the limits of the financial resources at their disposal.

H. **Respondents from some councils expressed frustration with a lack of decision-making guidance for development of action plans or alternatives.**

- A respondent from one council expressed frustration that the current tools available for making decisions around land-use changes and alternatives did not appear to generate accurate predictions.
- A respondent from one council expressed concern that the NPS-FM did not provide guidance for situations when it may be more appropriate to leave a naturally hard-bottomed river in its currently soft-bottomed condition, especially if its current state supported values that were potentially important to local iwi or other stakeholders. Alternatively, there was no guidance for rivers in urban settings that may be currently hard-bottomed, but naturally soft-bottomed (as might be the case it a natural wetland had been turned into a river via engineering).

4.2.5 Alignment with biological indicators of ecosystem health

Several common themes were raised by respondents from councils regarding concerns of the alignment between the DFS attribute with ecological attributes. Some of these are touched on above in the primary concerns, but here we provide additional details communicated by respondents. These include, but are not limited to, the following:

1. **Council respondents were concerned that the locations where they monitor DFS may not reflect broader patterns of DFS across FMUs/catchments.** The locations at which DFS is monitored are restricted by logistical and financial feasibility (e.g., paired with periphyton or invertebrate monitoring) rather than proactively chosen to represent DFS. For example, macroinvertebrate samples have commonly historically been collected in riffle habitats, which are generally not impacted by DFS, or recover more quickly than slower flowing reaches after a large event (such as Cyclone Gabrielle). In addition, localised sampling locations may not reflect potentially spatially patchy DFS within segments of a river.

2. **Not all council respondents were confident that the attribute bands and sediment classes had strong ecological relevance.** The very slight differences in the numeric thresholds of the attribute bands across the four sediment classes are unlikely to be ecologically relevant. The attribute bands (A to D) broadly reflect known ecological impact thresholds (i.e., 20 to 30% PFSC), however their precision (e.g., <7%) does not reflect the variability present in empirical estimates of such thresholds (generally ± 5 to 10%), or in the relationship to macroinvertebrate measures over time.

3. **Inter-operator and inter-council variability in application of SAM2 may lead to inconsistent results.** Respondents are concerned that this impacts how confident users can be that rivers are being judged fairly and accurately within and across regions. Distinguishing inorganic fine sediment from organic fine sediment (such as the periphyton category ‘sludge’ or loose unconsolidated algae[1]) is important when considering mitigation methods but is challenging and resolved in varying ways. Estimating PFSC when the streambed is obscured by macrophytes, detritus, or filamentous algae can involve estimates based on visible streambed, clearing of obstructions or using condition-based rules (e.g., 100% PFSC under dense macrophytes).

[1] available here: https://www.nems.org.nz/documents/periphyton

5 Conclusions

We evaluated the policy and methodological approach for the deposited fine sediment attribute in the current National Policy Statement for Freshwater Management (NPS-FM). We also compiled a state of play for implementation of the DFS attribute in NZ using phone, videoconference, and email correspondence with relevant personnel at eight regional councils and six unitary authorities (councils), and the Department of Conservation.

We evaluated the development of the DFS attribute in the current NPS-FM. We found that the statistical models used to develop attribute bands and classes demonstrated consistency with the scientific community's understanding of landscape and land use effects on DFS in rivers of NZ, but the models did not demonstrate strong predictive power and had large uncertainties. These types of uncertainties are not uncommon given the data quality, nor necessarily unacceptable for the purposes of regulating DFS. The relevance in terms of the resulting accuracy and precision of river classes and associated National Bottom Lines and associated attribute bands are not communicated in any guidance documents, which may result in confusion to councils attempting to apply the DFS policy.

We evaluated the current DFS methodological guidance for: (a) identifying appropriate DFS monitoring sites (i.e., wadeable rivers or exemptions expressed by Table 25), (b) determining the natural state of a river as hard or soft-bottomed (Clause 3.25), and (c) the use of the required sediment assessment method 2 (SAM2) to determine a stream's current DFS attribute state (Table 16). We found that these three aspects of guidance lack clarity and specificity needed to assure minimally consistent implementation by regional and unitary authorities across NZ.

Our compilation of the state of play for implementation of the NPS-FM DFS attribute in NZ indicated that nearly all councils were implementing the policy at existing or new monitoring sites, were using SAM2 or some other SAM method, were training their staff to use SAM2 or other methods and had some forms of quality control and assurance on their methods. That said, at least half of council respondents indicated they were deviating in some way from the suggested policy approach and/or guidance, often because they felt it was not appropriate for rivers in their areas.

Nearly all council respondents expressed that DFS was a problem that needs to be managed in the rivers of their regions but did not feel the DFS attribute presented in the current NPS-FM was adequately capturing the fine sediment problem, its associated risks posed to freshwater ecosystem health, and would like to see improved guidance. The top three most common issues we recorded from councils were as follows:

1. The SAM2 method cannot be used to make accurate measurements when streambed visibility is low to nil, which causes missing values yet it is unclear how missing values should be treated when calculating site-medians.
2. Council respondents did not have confidence in the REC-based system used to determine river classes for the DFS attribute and associated National Bottom Lines.
3. Council respondents perceive the ranges of threshold values for DFS attribute bands (and NBL) in each river class to be narrow relative to the precision of the SAM2 method used to determine the DFS attribute state.

A range of other issues were also identified including a lack of guidance for missing data, consistency interpreting SAM2 data, representation of current monitoring sites relative to broader systematic

DFS behaviour, a lack of resources, and a lack of guidance for management alternatives. There appears to be some confusion over the role of the attribute bands following the 2020 amendments to the NPSFM, under which their function to describe attribute states in the NOF was removed.

Councils also expressed that they were not confident that their current monitoring networks, which were often designed for periphyton data collection, were adequate for capturing the risks posed by DFS to freshwater ecosystem health in their regions, that the DFS attribute bands and classes were ecologically relevant, or that there was operator methodological consistency across regions such that the ecological impact of DFS was being captured across NZ.

Collectively our findings indicate that most councils consider DFS to be a stressor in the rivers of their regions that should be managed but would like to see improvement in the current NPS-FM methodological and implementation guidance, and additional guidance on management actions and decision-making alternatives in rivers where DFS is perceived as a long-term problem.

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7 Glossary of abbreviations and terms

DFS	Deposited fine sediment
DOC	Department of Conservation
ECAN	Environment Canterbury
GNS	Institute of Geologic and Nuclear Sciences
MfE	Ministry for the Environment
NBL	National bottom line
NIWA	National Institute for Water and Atmospheric Research
NOF	National Objectives Framework
NPS-FM	National Policy for Freshwater Management
PFSC	Percent fine sediment cover
SAM	Sediment assessment method; SAM1 through SAM5 (Clapcott et al. 2011) are methods referred to in this report.
SOE	State of the Environment
TAS	Target attribute state

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Appendix A Questions sent to councils

- Have you or your staff been implementing the NPS-FM sediment requirements?
  - How many sites have you been making observations/monitoring?
  - How often do you monitor your sites?
  - What methods have you been using?
- Are you having challenges implementing NPS-FM sediment requirements? If so, what are your biggest challenges?
  - 'top 3' challenges?
  - Other challenges?
- Based on your experience in your area, do you think deposited fine sediment is a key stressor to streams you are monitoring?
  - What proportion of streams?
  - What types of streams?
- Are your staff trained in SAM2 and other sediment data gathering methodologies?
  - What types of training (i.e., field based, office based, teams)?
  - Numbers of operators?
- How have you been determining if your streams are naturally 'hard-bottomed' or 'soft-bottomed'?
  - Is the NPS-FM guidance for classifying streams as 'hard-bottomed' or 'soft-bottomed' at monitoring sites in your area working? If not, where? What about Haddachi et al. (2018)?
- Do your staff observe substantial temporal variability in data collected using the SAM2 method at certain sites?
  - What are common levels of variability (in percent) observed for percent fine sediment cover using the SAM2 method?

<u>Other key questions:</u>

- How much temporal variation do you observe in stream ecosystem health measures associated with deposited fine sediment (eg. MCI, QMCI, ASPM). Does this variation span attribute states outlined in the NPS-FM guidance?
- Do you or your staff have suggestions for improving guidance for DFS?
- Have you or your staff been testing other methods for measuring deposited fine sediment and ecosystem health? To what extent and success?

- Do you have specific examples of where current DFS guidance is failing (e.g., REC incorrectly identifies stream as 'naturally hard bottomed' or vice versa)? Would you be willing to provide information on this example that could be used in our report?
- What kind of guidance would be most helpful for your staff to clarify strategies for quantifying and monitoring DFS?
- Are there any other challenges or issues with NPS-FM DFS and stream aquatic health measures?
- *Are you OK with your name being acknowledged our report?