

Sediment Mud Content and Sediment Accretion Rate in Estuaries

Ministry for the Environment Attribute Stocktake

Te Nui o te Paru Parakiwai me te Tere o te Whakapūranga Parakiwai i ngā Wahapū

Whakarārangi Āhuatanga a Te Manatū mō te Taiao



Ministry for the
Environment
Manatū Mō Te Taiao



Te Kāwanatanga o Aotearoa
New Zealand Government

Disclaimer

The information in this publication is, according to the Ministry for the Environment's best efforts, accurate at the time of publication. The Ministry will make every reasonable effort to keep it current and accurate. However, users of this publication are advised that:

- the information does not alter the laws of New Zealand, other official guidelines, or requirements
- it does not constitute legal advice, and users should take specific advice from qualified professionals before taking any action based on information in this publication
- the Ministry does not accept any responsibility or liability whatsoever whether in contract, tort, equity, or otherwise for any action taken as a result of reading, or reliance placed on this publication because of having read any part, or all, of the information in this publication or for any error, or inadequacy, deficiency, flaw in, or omission from the information in this publication
- all references to websites, organisations or people not within the Ministry are for convenience only and should not be taken as endorsement of those websites or information contained in those websites nor of organisations or people referred to.

Acknowledgements

This publication may be cited as: Jones H. 2025. *Sediment Mud Content and Sediment Accretion Rate in Estuaries: Ministry for the Environment Attribute Stocktake*. Ministry for the Environment, Wellington.

Published in July 2025 by the
Ministry for the Environment
Manatū mō te Taiao
PO Box 10362, Wellington 6143, New Zealand
environment.govt.nz

ISBN: 978-1-991140-99-9 (online)

Publication number: ME 1907

© Crown copyright New Zealand 2025

Contents

Introduction	4
Part A – Attribute and method	5
Part B – Current state and allocation options	10
Part C – Management levers and context	14
Part D – Impact analysis	17
References	19

Introduction

This document collates existing information and was produced by the Ministry for the Environment. It complements the Ministry's commissioned stocktake of 55 environmental attributes. The stocktake involved 43 researchers from NIWA, Manaaki Whenua Landcare Research, Cawthron Institute and Environet Limited (Lohrer et al, 2024a). The attributes covered by the stocktake are in air, terrestrial, soil, freshwater, and estuaries and coastal waters domains.

This document describes two attributes that relate to estuarine sedimentation: Sediment mud content and sediment accretion rate.

‘Sediment mud content’ is defined as the proportion of sediment particles that are less than 63 µm in size (ie, the silt and clay fraction, collectively known as ‘mud’). ‘Sediment accretion rate’, also known as ‘sediment deposition’ or ‘sedimentation rate’, refers to the change in the level of the bed sediment surface, typically over years, due to estuarine sedimentation.

These two attributes are combined into one stocktake to avoid repetition. Both are associated with sediment quantity or quality and are measured at discrete sites within an estuary. Other attributes associated with estuarine sedimentation but described in separate stocktakes are the ‘extent of mud’ attribute, which is also associated with sediment quality but is assessed over a broad (ie, estuary-wide) scale (Lohrer, 2024), and the ‘suspended sediment/water clarity/turbidity’ attribute that is a measure of water quality (Davies-Colley, 2024).

State of Knowledge conclusion

- State of knowledge of the ‘sediment mud content’ attribute: **Good/established but incomplete** – general agreement, but limited data/studies.
- State of knowledge of the ‘sediment accretion rate’ attribute: **Medium/unresolved** – some studies/data, but conclusions do not agree.

Overall, the state of knowledge for the sediment mud content attribute is ‘**good/established but incomplete**’. There is good evidence, including multiple studies done in Aotearoa New Zealand, that quantifies the link between sediment mud content and ecological integrity, and clear thresholds at which mud content has specific effects on estuarine macroinvertebrate communities. For the sediment accretion rate attribute, the state of knowledge is ‘**medium/unresolved**’, because our understanding of current state is more limited, and further research is needed to more clearly establish thresholds at which there are specific effects on ecological communities.

Management interventions to reduce sediment loads to estuaries are well understood, but implementation is likely insufficient, given adverse effects associated with sediment continue to be observed. Monitoring of both attributes is feasible and there are well-established methods, but (as for many other estuarine attributes) monitoring coverage is insufficient to either properly understand the scale of the problem or to link management interventions to the response.

Part A – Attribute and method

A1: How does the attribute relate to ecological integrity or human health?

Sedimentation (which includes accelerated sediment accretion rates, increases in sediment mud content, and/or increases in suspended sediment concentration or turbidity) has long been recognised as a major stressor on estuaries and other coastal ecosystems. Some sediment is naturally delivered to marine and estuarine ecosystems, but excess sediment can affect biodiversity and ecosystem functioning.

Excess sediment alters habitats, smothers benthic species, and suppresses important biological and biogeochemical processes such as feeding, respiration, photosynthesis, recruitment and denitrification (eg, Kennish, 2002; Thrush et al, 2004; Lohrer et al, 2004; O'Meara et al, 2017; Thrush et al, 2021). Excess sediment can also impact on estuarine productivity, fish or bird populations and result in the loss of ecosystem services provided by estuaries. These impacts include the loss or degradation of shellfish beds that may be important for cultural, recreational or commercial harvesting (eg, Thrush et al, 2013). It can also reduce recreational or commercial values if channels used for boat access fill in with sediment (or are colonised by mangroves, which tend to grow in the muddy intertidal habitat created by sedimentation), or if areas used for swimming become turbid or muddy.

In summary, sediment mud content and sediment accretion rate are important influences on the physical structure of estuarine habitat, influencing biological community composition; key taxa and taonga species, such as shellfish; and key biogeochemical processes, such as nutrient cycling. These attributes therefore have a direct, clear relationship to ecological integrity, influencing ecological representation, composition, structure and function. Note that the attributes also have an indirect relationship to human health and wellbeing via impacts on recreational, cultural and economic values.

A2: What is the evidence of impact on (a) ecological integrity or (b) human health? What is the spatial extent and magnitude of degradation?

There is clear evidence of widespread environmental degradation caused by sedimentation in New Zealand estuaries. Short-term, acute impacts associated with deposition of muddy sediments on estuarine intertidal flats (eg, following major storms) have been shown to kill seagrass and macroinvertebrate communities, and recovery from these events may take many months or years (eg, Hewitt et al, 2003; Thrush et al, 2004; Gibbs and Hewitt, 2004). Longer-term degradative change, caused by repeated depositional events, and by the continued delivery of increased sediment inputs, results in increasingly muddy sediments and gradual infilling. This also negatively impacts on macroinvertebrate communities, shellfish beds and seagrass beds (eg, Thrush et al, 2003; Morrison et al, 2009; Zaberte-Maeztu et al, 2020). Further, estuarine sedimentation has been shown to facilitate rapid mangrove expansion in estuaries in northern New Zealand (eg, Swales et al, 2020).

The substantial spatial extent and magnitude of degradation over the past 100 to 150 years, have likely affected all estuaries where there has been widespread deforestation and land-use change in the catchment. Contemporary monitoring carried out by regional councils shows that many estuaries around New Zealand contain areas where mud content is elevated to levels that are detrimental to ecosystem functioning, and have elevated sediment accretion rates (eg, Madarasz-Smith and Shanahan, 2020; Berthelsen et al, 2020; Jones et al, 2022).

A3: What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10–30 years under the status quo? Are impacts reversible or irreversible (within a generation)?

Estuaries gradually infill with sediment eroded from land, but sediment deposition rates have increased by orders of magnitude since European settlement in New Zealand (eg, Handley et al, 2017; Hunt, 2019a; Ministry for the Environment and Stats NZ, 2019, Parliamentary Commissioner for the Environment, 2020). Before human settlement, natural sedimentation rates were less than 0.5 mm/year and estuarine sediments would have been mostly sandy, rather than muddy. Sedimentation rates rose rapidly post-European settlement, however, often to between 2 and 5 mm/year, or greater than 10 mm/year in some areas such as upper tidal creeks or mangrove forests (Hunt, 2019a; Swales et al, 2012, 2021). Increased sediment mud content is often associated with the increased sedimentation rates as fine terrigenous sediments eroded from land are deposited on previously sandy estuarine sediments (eg, Thrush et al, 2004).

Accelerated sedimentation was initially caused by widespread catchment deforestation (mostly from the mid-1800s to early-1900s), but some current human activities and land-use practices cause increased rates of soil erosion, resulting in high sediment loads to estuaries (eg, Hicks et al, 2019). Consequently, under the status quo, it is expected that many estuaries will continue to infill and/or get muddier, although likely at a lower rate than in the previous century.

Impacts are not easily reversed. Restoration mostly relies on passive methods (ie, reducing sediment loads and allowing estuaries to recover naturally), which can take decades, depending on various factors – including legacy sediments present in the estuary, or in the rivers and streams that feed into the estuary. It is also likely to be extremely difficult to improve some very sheltered areas that now have very high mud content and/or where there is insufficient water movement to remobilise and disperse fine sediment. In many cases, physical removal of sediment from estuaries (eg, via dredging) may cause more damage to remaining ecological values and habitats. In some (or perhaps most) places, even substantially reducing sediment loads is unlikely to result in full recovery to a natural state (even over long timescales), due to the widespread and substantial changes in estuary morphology, sediment type, and ecological communities caused by sedimentation to date. Nevertheless, it would be desirable to halt and reverse the trend where historical sedimentation has resulted in degradation of ecological integrity.

A4: What monitoring is currently done and how is it reported (eg, is there a standard, and how consistently is it used; who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?

There is broad scientific consensus on measurement of sediment mud content and accretion rate, and many councils already monitor these attributes/indicators in estuaries using broadly consistent methodology. Methods are mostly based on the National Estuary Monitoring Protocol (Robertson et al, 2002a, 2002b, 2002c; Roberts and Stevens, 2023), which is currently being updated to include a standardised method for measuring sediment accretion rate (Stevens et al, in prep).

Land, Air, Water Aotearoa (LAWA) recently released an estuary health module that collates data from around 400 monitoring sites across around 80 estuaries, on 3 indicators of estuarine health: sediment mud content, sediment contaminants (including heavy metals and organic compounds) and estuarine macroinvertebrates (ie, sediment-dwelling animals such as crabs, shellfish and worms).¹ The data for these indicators come from state-of-the-environment monitoring programmes carried out by most (currently 14 out of 16) regional councils and unitary authorities. Not all sites have data for all indicators. A meta-analysis of council monitoring data suggests that mud content is the most commonly sampled physico-chemical indicator, with data from 338 sites (Berthelsen et al, 2020).

Note that most estuarine monitoring takes place at intertidal sites. The intertidal is the area between mean high water and mean low water. It is therefore out of the water and accessible at low tide, so is more feasible for monitoring than subtidal areas.

A4(i): Are there any implementation issues, such as accessing privately owned land to collect repeat samples for regulatory informing purposes?

Accessing estuarine monitoring sites may require permission to cross private land, or the use of a boat when access from the shore may not be possible or practical. Some parts of estuaries or surrounding shorelines can be wāhi tapu (sites of spiritual, cultural and historical significance) and so may be off limits for monitoring, or else monitoring may need to be conducted in partnership with iwi.

Health and safety also need to be considered for fieldwork in estuaries. Using boats and kayaks requires relevant training and qualifications. Fieldwork also requires hazard identification and risk management (eg, identifying and avoiding areas of deep mud, fast-flowing tidal channels).

As noted above, monitoring subtidal areas of estuaries is more challenging (and costly) than monitoring intertidal areas.

¹ Land, Air, Water Aotearoa (LAWA). Estuary Health. Retrieved 27 May 2025 from <https://www.lawa.org.nz/explore-data/estuaries>

A4(ii): What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (eg, purchase of equipment) and ongoing operational costs (eg, analysis of samples).

Monitoring sediment mud content and accretion rate is relatively inexpensive as it does not require highly specialised staff, costly equipment or analysis. Sediment mud content can be analysed by a lab for approximately \$100 per sample. Sediment accretion rate is monitored in the field by measuring sediment accretion (or erosion) over concrete paving slabs that have been buried in the sediment. Measurements are made using metal rods (or knitting needles) and should be taken annually at regularly spaced intervals (to avoid any potentially confounding effects of seasonality), with a long-term trend calculated from at least five years' data (Hunt, 2019b). The number of sites that should be sampled in an estuary will depend on the exact purpose of the monitoring, but will need to take into account likely spatial variability, location of catchment sediment inputs, tidal range and other factors.

Repeat synoptic surveys using hydrographic surveys or remote sensing (eg, using high-resolution light detection and ranging (LiDAR) or photogrammetry from drones or planes) can capture bulk patterns in sedimentation across the entire estuary. However, this type of surveying is typically not accurate enough if trying to measure sediment accretion rates of a few millimetres per year (Hunt, 2019b). However, these surveys can help determine if certain parts of an estuary might be infilling quicker than others, which might help to direct catchment management efforts. It could also indicate whether the buried plate locations are likely to be representative of the sediment accretion rates across the estuary.

A5: Are there examples of this being monitored by iwi/Māori? If so, by whom and how?

The author is not aware of either sediment mud content or sediment accretion rate, specifically, being monitored by iwi/Māori, but *tohu* (cultural health indicators) have been developed and used for estuarine monitoring and management at a local level (eg, Lang et al, 2012; Bamford et al, 2022). *Tohu* include *taonga* species, *mahinga kai* and *kai moana* (eg, *pāua*, *kina*, *tuna*), as well as measures of *hauora* (health) and *mauri* (life force), and these are used to monitor estuarine health from a *te ao Māori* perspective.² Some assessments of *tohu* may mention 'mud' (eg, Bamford et al, 2022). Moreover, sediment mud content and accretion rate are likely to influence some cultural health indicators – for example, by affecting the abundance and quality of *kai moana*, and indigenous or *taonga* species such as *seagrass*.

Ngā Waihotanga Iho, the iwi estuarine monitoring toolkit³ was developed by NIWA and iwi partners to provide guidance on estuarine monitoring for *tangata whenua*. The tools are science based and are intended to complement traditional knowledge and *kaitiakitanga*. The toolkit contains a sediment module that provides guidance on monitoring of sediment mud

² Tangaroa Tohu Mana, Tangaroa Tohu Mauri | Marine Cultural Health Programme. Monitoring. Retrieved 27 May 2025 from <https://marineculturalhealth.co.nz/>

³ National Institute of Water and Atmospheric Research (NIWA) | Taihoro Nukurangi. *Ngā Waihotanga Iho – The Estuary Monitoring Toolkit*. Retrieved 27 May 2025 from <https://niwa.co.nz/coasts/estuaries/nga-waihotanga-iho-estuary-monitoring-toolkit>

content and sedimentation rate. It is unclear how often the toolkit has been implemented around New Zealand, but Dodson and Miru (2021) document the use of the toolkit by a Kaipara hapū as a mechanism for enabling kaitiakitanga and indigenous-led environmental education.

A6: Are there known correlations or relationships between this attribute and any other attribute(s), and what is the nature of these relationships?

Within estuaries, both sediment mud content and accretion rate are likely to be negatively correlated with attributes that are adversely impacted by sedimentation, such as seagrass extent and quality, shellfish bed extent and quality, and macroinvertebrates. They may also be positively correlated with trace ('heavy') metals in sediment, water clarity/turbidity, or with the extent of mud (broad-scale) attribute. Given the links between soil erosion on land, and sediment delivery to freshwater systems and then estuaries, the estuarine sediment attributes may be positively correlated with suspended and deposited sediment attributes in rivers, and with soil erosion on land (within the estuary catchment).

Part B – Current state and allocation options

B1: What is the current state of the attribute?

The current state of sediment mud content and accretion rate is well understood at discrete sites in estuaries that are regularly monitored. Our understanding of current state comes from field-based monitoring of sites within estuaries, usually conducted by regional councils and unitary authorities, and often reported on an estuary-by-estuary basis on council websites. Sediment mud content is reported at a national level in the LAWA estuary health module, but sediment accretion rate is not yet included in the module. However, many councils are now monitoring sediment accretion rate at some sites using a broadly consistent method, which means it may be possible to report at a national level in the future. An update to the National Estuary Monitoring Protocol will include standardised methodologies for monitoring sediment mud content and accretion rate (Stevens et al, in prep). This should help to drive consistency in data collection, which, if implemented at more sites in more estuaries, will improve our understanding of the current state.

B2: Are there known natural reference states described for New Zealand that could inform management or allocation options?

Natural reference states for sediment accretion rate have been estimated for many New Zealand estuaries using sediment core studies (eg, Swales et al, 2012; Handley et al, 2017; Hunt, 2019a). Although spatially variable both within and between estuaries, natural sedimentation rates were typically between 0.02 mm and 0.5 mm/year in most places. The sediment core studies can also provide some information on historical sediment grain size (and therefore mud content), but this is also naturally spatially variable. Upper reaches of the estuary (near river inputs) will likely be naturally muddier than lower reaches (near the sea), and the edges of channels can sometimes be naturally muddier than open areas of intertidal flats. Place-based knowledge and mātauranga Māori may be useful for providing qualitative descriptions of natural reference states.

Note that a return to natural reference states is unlikely to be achievable for most estuaries, given the large-scale changes in land and forest cover in many catchments, as well as the widespread estuarine sedimentation that has already occurred.

B3: Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands (eg, US EPA, Biodiversity Convention, ANZECC, regional council set limit)?

Many New Zealand-based studies have examined how sediment mud content affects estuarine community composition and ecosystem function (eg, Thrush et al, 2003; Robertson et al, 2015; Berthelsen et al, 2020; Bulmer et al, 2022). These studies have allowed for the development of narrative and numeric bands. For example, in the LAWA estuarine health module, thresholds between bands for sediment mud content are at 3 per cent (which corresponds to the level of mud content at which macrofauna communities are the most diverse), 10 per cent (above which there are 'major declines in resilience'), 30 per cent (above which the estuarine macrofauna community is 'unbalanced'), and 60 per cent mud content (above which estuarine health is 'degraded').

Drawing on New Zealand-based studies and monitoring data, and previous work such as the Estuarine Trophic Index (ETI) (Robertson et al, 2016), a recent review recommended five narrative and numeric bands for sediment mud content (Stevens et al, 2024). These were 'Very good' (corresponding to none to minor stress on benthic fauna; <5 per cent mud content), 'Good' (minor to moderate stress; 5 per cent to <10 per cent mud content), 'Moderate' (moderate to high stress; 10 per cent to <25 per cent mud content), 'Poor' (high stress; 25 per cent to <50 per cent) to 'Very poor' (persistent high stress; >50 per cent mud content).

In contrast to sediment mud content, there are few published ecologically relevant thresholds for different levels of long-term sediment accretion rate to inform the development of narrative or numeric bands. ANZECC guidance on estuary sedimentation does, however, set a default guideline value (DGV) at 2 mm/year above the natural annual sedimentation rate (Townsend and Lohrer, 2015). Now referred to as the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG),⁴ this DGV has been adopted in the sediment objectives for the Hauraki Gulf Marine Spatial Plan. Waikato Regional Council and Auckland Council are required to monitor sedimentation rates in Hauraki Gulf estuaries against this guideline. It has also been adopted in Environment Southland's objective-setting process.

Preliminary bands have recently been proposed for sediment accretion rate based on the ANZECC/ANZG sedimentation DGV and some other studies, albeit with heavy caveats, given the relatively poor understanding of actual effects of long-term accretion rate on estuarine ecological health (Stevens et al, 2024). Further research is required to improve confidence in thresholds and bands for sediment accretion rate.

⁴ Australian Government Initiative. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Retrieved 27 May 2025 from <https://www.waterquality.gov.au/anz-guidelines>

B4: Are there any known thresholds or tipping points that relate to specific effects on ecological integrity or human health?

As described above, thresholds for sediment mud content that relate to specific effects on ecological integrity (ie, changes in estuarine macroinvertebrate communities, such as loss of sensitive species) are relatively well understood. Thresholds for long-term sediment accretion rate are less well understood, but experimental studies have established thresholds for acute (ie, short-term) sediment deposition events, which typically occur during storms. These studies suggest that a muddy sediment layer as little as 3 mm thick, deposited in a single event, can adversely affect benthic fauna (eg, Lohrer, 2004), and were the basis for the derivation of the ANZECC sedimentation DGV (Townsend and Lohrer, 2015).

B5: Are there lag times and legacy effects? What is the nature of these, and how do they impact state and trend assessment? Further, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?

Lag times exist, in terms of the time it takes for sediment to move through freshwater systems and then into estuaries. Once there, sediment can be moved around and then out of the estuary to more open coastal environments by wind waves and tidal currents (eg, Hunt et al, 2016). However, sediment deposited in sheltered estuarine environments (such as in tidal creeks and coastal wetlands) will tend to remain in place for long periods (at least decades). Selection of representative and useful monitoring sites – within both an estuary and its catchment – is key to ensuring that what is measured in the estuary can be linked back to human activities on land. Some available techniques can ‘fingerprint’ sediment sources in estuaries, which can be useful for identifying contributing sub-catchments and/or land uses (Swales et al, 2016, 2021). Legacy effects can also be present, in terms of sediment deposited in estuaries many decades ago that cannot easily be removed, either through natural processes or human intervention.

B6: What tikanga Māori and mātauranga Māori could inform bands or allocation options and how (eg, by contributing to defining minimally disturbed conditions, or unacceptable degradation)?

Sedimentation in estuaries is likely to impact on kaitiakitanga, manaakitanga, tikanga, taonga species, mahinga kai, and iwi/Māori connection to the environment. As for other estuarine attributes (eg, the extent of mud, shellfish, macroalgae), mātauranga Māori is likely to provide extensive knowledge of how estuarine ecosystems have changed over time and may be able to help define natural reference states. Mātauranga Māori is inherently place based, however, so

the definition of natural reference states and/or unacceptable degradation is likely to vary from place to place (especially given the variety of estuaries, issues and historical contexts around New Zealand).

The Sustainable Seas National Science Challenge collaborated with iwi partners, the Our Land and Water National Science Challenge, and the Ministry for the Environment to produce guidance on integrated estuarine management reflecting *ki uta ki tai* (mountains to the sea) concepts, and on improving connectivity between *mātauranga Māori* and western science (Lohrer et al, 2024b). The guidance highlights the need to engage at the local level, with face-to-face communication, to achieve meaningful co-development of policies and management interventions. A combination of *mātauranga* and environmental science was used to inform objective setting for freshwater ecosystems, including estuaries, in Murihiku Southland (Bartlett et al, 2020).

Part C – Management levers and context

C1: What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?

The state of the environment, in terms of sediment mud content and accretion rate, is influenced by historic and contemporary catchment sediment loads, and by activities within estuaries that can alter morphology and hydrodynamics, such as reclamation, dredging and coastal structures. However, because sediments can originate from multiple and variable sources, and from near and far, the direct cause-and-effect relationship may be difficult to quantify exactly.

Large-scale changes in land cover after European settlement substantially accelerated soil erosion rates, leading to large increases in sediment accumulation rates and changes in sediment mud content (eg, Handley, 2017; Hunt, 2019a; Swales, 2021). Current human activities, such as farming and forestry, can also increase soil erosion rates, although such rates are typically higher during widespread catchment deforestation. Sediment source tracking can help to identify sub-catchments or specific areas that may be contributing to sediment loads (Swales et al, 2016, 2021). Sediment loads to estuaries can be estimated based on relationships between freshwater flows and suspended sediment concentrations, and these loads have been modelled at a national scale (Hicks et al, 2019).

C2: Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?

Current regulation and catchment management activities already attempt to reduce sediment generated from various activities (eg, forestry, subdivision, road construction) and/or intercept it before it reaches waterways (eg, via sediment detention ponds, constructed wetlands, riparian planting). Evaluation of efficacy is complicated by the distance between the interventions (typically on land) and the estuary. It is apparent, however, that adverse effects of sedimentation on estuarine environmental health are still being observed, despite the existence of regulatory and non-regulatory management that aims to address the issue (eg, Berthelsen et al, 2020; Roberts et al, 2021; Jones et al, 2022).

C2(i): Local government driven

Local government is responsible for giving effect to the National Policy Statement for Freshwater Management 2020 (NPS-FM), which requires an integrated approach to management, stressing the importance of *ki uta ki tai*. The inclusion of estuaries in Freshwater Management Units (FMUs) and the objective-setting process is not mandatory, however, and the National Objectives Framework (NOF) contains no estuarine attributes. Consequently, some councils include estuaries in their NPS-FM implementation process, and some do not. The NOF specifies compulsory attributes for suspended and deposited fine sediment in rivers, but it is unknown whether managing these attributes in freshwater would protect downstream receiving environments (eg, estuaries and coastal waters) from adverse effects associated with sedimentation.

Effective integrated management is challenging, partly because regional coastal plans are generally separate from regional land and water plans, and land use is controlled by territorial authorities under district plans. A report by the Parliamentary Commissioner for the Environment (2020) highlighted the complex legislation and difficulties associated with managing estuaries and called for the mandatory inclusion of estuaries in the NPS-FM and FMUs.

Councils issue resource consents for development activities that involve earthworks (eg, subdivision, roading), which typically contain conditions requiring erosion and sediment control. Many council websites provide guides and templates for erosion and sediment control plans.

Aside from regulation, many councils also support and provide funding to catchment or harbour care groups (see sections below). These groups often undertake riparian fencing, planting and wetland restoration that may reduce sediment loads to freshwater and estuaries (eg, Sinner et al, 2022).

C2(ii): Central government driven

The management of estuaries is guided by the NPS-FM and the New Zealand Coastal Policy Statement 2010 (NZCPS). Although primarily focused on managing freshwater, the NPS-FM directs councils to consider downstream receiving environments, which may include estuaries (see above). In contrast, the NZCPS contains policies to manage the 'coastal environment', which includes the coastal marine area, offshore islands, and areas of land affecting or affected by coastal processes, which typically extend only a short distance inland.

Policy 22 of the NZCPS includes the requirement to "assess and monitor sedimentation levels and impacts on the coastal environment", along with requirements to control sediment runoff from subdivision, forestry and other activities. Councils must give effect to this policy in regional coastal plans (Department of Conservation, 2018) but only 7 out of 16 regional councils and unitary authorities had given effect to the NZCPS by 2022 (Ulrich et al, 2022), even though the NZCPS dates from 2010.

C2(iii): Iwi/hapū driven

Relevant iwi/hapū-driven initiatives include Māori-led projects for catchment management, and river and estuary care, which aim to improve water quality and protect taonga species and mahinga kai. These inherently place-based projects often incorporate mātauranga Māori. Iwi environmental management plans may also address issues associated with sedimentation in

freshwater and estuaries. Some projects are partnerships between iwi and other organisations. For example, the Kaipara Moana Remediation Programme⁵ is a partnership between iwi, and central and local government. This project aims to restore the health and mauri of Kaipara Moana by halving sediment loads to the harbour. The Mouri Tūroa Programme, funded by Jobs for Nature, aims to mitigate soil erosion, improve water quality, and enhance biodiversity within the Whanganui River catchment.⁶

C2(iv): NGO, community driven

There are hundreds of catchment and community groups across New Zealand, which may also include iwi/hapū. These groups are often supported by non-governmental organisations (NGOs) like the NZ Landcare Trust and The Nature Conservancy, and by central or local government. Much of the work done by these catchment and community groups – such as riparian planting, pest control, wetland protection and restoration – will reduce sediment loads to estuaries.

C2(v): Internationally driven (eg, obligations to Convention on Biological Diversity, Kunming-Montreal Global Biodiversity Framework)

No known international obligations apply specifically to sedimentation in estuaries. However, as a signatory to international conventions, New Zealand has obligations relating to managing estuarine pollution, and excess sediment can be considered a pollutant. For example, there are several designated Ramsar sites in and around estuaries, including the Firth of Thames, Awarua Waituna Lagoon, and Manawatū River estuary.⁷ The Kunming-Montreal Global Biodiversity Framework contains a target relating to reducing pollution, which is also broadly relevant to these sediment attributes.

⁵ Kaipara Moana Remediation. Kaipara Moana Remediation. Retrieved 27 May 2025 from <https://kmr.org.nz/>

⁶ Ngā Tāngata Tiaki o Whanganui. *Mouri Tūroa Programme*. Retrieved 27 May 2025 from <https://www.ngatangatatiaki.co.nz/our-projects/mouri-turoa/>

⁷ Department of Conservation. *Ramsar Convention on Wetlands*. Retrieved 27 May 2025 from <https://www.doc.govt.nz/about-us/international-agreements/ecosystems/ramsar-convention-on-wetlands/>

Part D – Impact analysis

D1: What would be the environmental/human health impacts of not managing this attribute?

Estuarine sedimentation affects environmental health by smothering benthic habitats, including seagrass and shellfish beds, and suppressing important biogeochemical processes, as described in Part A. Loss of recreational and cultural values due to the adverse effects of sedimentation can also impact human wellbeing and iwi/Māori connection to te taiao (the environment). Not managing this attribute will likely lead to more widespread and/or severe impacts and further environmental degradation.

D2: Where and by whom would the economic impacts likely be felt (eg, horticulture in Hawke's Bay, electricity generation, housing availability and supply in Auckland)?

Costs to manage estuarine sedimentation will vary depending on catchment size, history of catchment (and estuary) modification, scale of the current issue, current effort, and the need for development of (or increased) activities that might generate more sediment. Many catchments already have strategies or plans to better manage waterways and land, based on partnerships with industry, councils, iwi, the Department of Conservation and other groups. These could be built upon (see the examples and map on the *Our Estuaries* hub⁸).

Economic impacts include the costs associated with undertaking catchment management activities, such as riparian planting and wetland restoration. These costs fall on a wide range of individuals and organisations, such as councils, land owners, NGOs, community groups and iwi. Land owners and developers will also face compliance and operational costs to implement sediment control measures when undertaking activities, and/or to alter land use or land management. However, a range of environmental, social and cultural benefits will likely result from actions to reduce sedimentation in estuaries. For example, reduced sediment loads will improve water quality (benefiting the aquaculture and fisheries sectors) and will likely enhance recreation, amenity values and tourism potential. In the long term, reducing sedimentation could support the preservation (and potentially regeneration) of culturally significant resources and practices, mahinga kai and associated mātauranga.

⁸ Department of Conservation. *Our Estuaries*. Retrieved 27 May 2025 from <https://www.doc.govt.nz/nature/habitats/estuaries/our-estuaries/>

D3: How will this attribute be affected by climate change? What will mitigating that require, in terms of management response?

Climate change, especially more frequent and intense rainfall, is likely to exacerbate soil erosion, leading to increased sediment loads to estuaries. This means that increased sediment control measures will likely be required, to manage the impacts of climate change on soil erosion and estuarine sedimentation (eg, Herzig et al, 2024).

Sea-level rise will increase water depths in estuaries and inundate low-lying surrounding areas. This will affect wind-induced resuspension of estuarine sediments and estuarine hydrodynamics, with impacts on sediment mud content and accretion rate. However, the exact effects are likely to be highly dependent on local conditions (eg, Green and Coco, 2014; Hunt et al, 2016).

References

- Bamford N, Carrington A, Carr L, Hansen K, Griffiths R, Hoy Z, Johnson S, Shirkey T, Watson X. 2022. *Waipū Estuary SEA assessment 2021*. Whangārei: Northland Regional Council and Patuharakeke Te Iwi Trust Board.
- Bartlett M, Kitson K, Norton N, Wilson K. 2020. Draft Murihiku Southland Freshwater Objectives: *Providing for hauora, the health and well-being of waterbodies in Murihiku Southland*. Prepared by Te Ao Mārama Inc and Environment Southland. Environment Southland Publication No. 2020-06. Invercargill: Environment Southland.
- Berthelsen A, Atalah J, Clark D, Goodwin G, Sinner J, Patterson M. 2020. New Zealand benthic health indicators summarised nationally and by estuary type. *New Zealand Journal of Marine and Freshwater Research* 54(1): 24–44.
- Bulmer RH, Stephenson F, Lohrer AM, Lundquist CJ, Madarasz-Smith A, Pilditch CA, Thrush SF, Hewitt JE. 2022. Informing the management of multiple stressors on estuarine ecosystems using an expert-based Bayesian Network model. *Journal of Environmental Management* 301: 113576.
- Davies-Colley R. 2024. Suspended sediment / water clarity / turbidity. In: D Lohrer et al. *Information Stocktakes of Fifty-Five Environmental Attributes across Air, Soil, Terrestrial, Freshwater, Estuaries and Coastal Waters Domains*. Prepared for the Ministry of Environment by NIWA, Manaaki Whenua Landcare Research, Cawthron Institute, and Environet Limited. NIWA report no. 2024216HN.
- Department of Conservation. 2018. *NZCPS 2010 guidance note – Policy 22: Sedimentation*. Wellington: Department of Conservation.
- Dodson G, Miru M. 2021. Ngā Waihotanga Iho: Self-determination through Indigenous environmental education in New Zealand. *Australian Journal of Environmental Education* 37(3): 254–265.
- Gibbs M, Hewitt J. 2004. *Effects of sedimentation on macrofaunal communities: a synthesis of research studies for ARC*. Auckland Regional Council Technical Publication No. 264.
- Green MO, Coco G. 2014. Review of wave-driven sediment resuspension and transport in estuaries. *Reviews of Geophysics* 52(1): 77–117.
- Handley S, Gibbs M, Swales A, Olsen G, Ovenden R, Bradley A. 2017. *A 1,000-year history of seabed change in Pelorus Sound/Te Hoiere, Marlborough*. Prepared for the Marlborough District Council, Ministry of Primary Industries and the Marine Farming Association by NIWA.
- Herzig A, Dymond J, Neverman A, Price R, Barnes M. 2024. *Ki uta ki tai: matapono me te putaiao, nga korero whakamahuki ma te kaitiaki – whenua | From mountains to the sea: values and science for an informed Kaitiaki/Guardian – land*. Draft report for Our Land & Water National Science Challenge.
- Hewitt JE, Cummings VJ, Ellis JI, Funnell G, Norkko A, Talley TS, Thrush SF. 2003. The role of waves in the colonisation of terrestrial sediments deposited in the marine environment. *Journal of Experimental Marine Biology and Ecology* 290(1): 19–47.
- Hicks M, Semadeni-Davies A, Haddadchi A, Shankar U, Plew D. 2019. *Updated sediment load estimator for New Zealand*. NIWA Client Report No: 2018341CH. Prepared for the Ministry for the Environment by NIWA.
- Hunt S, Bryan KR, Mullarney JC, Pritchard M. 2016. Observations of asymmetry in contrasting wave-and tidally-dominated environments within a mesotidal basin: implications for estuarine morphological evolution. *Earth Surface Processes and Landforms* 41(15): 2207–2222.
- Hunt S. 2019a. *Summary of historic sedimentation measurements in the Waikato region and formulation of a historic baseline sedimentation rates*. Waikato Regional Council Technical Report No. 2019/08.
- Hunt S. 2019b. *Regional Estuary Monitoring Programme (REMP) intertidal sedimentation measurements, results and review of methodologies*. Waikato Regional Council Technical Report 2019/04.

- Jones HFE, Hunt S, Kamke J, Townsend M. 2022. Historical data provides context for recent monitoring and demonstrates 100 years of declining estuarine health. *New Zealand Journal of Marine and Freshwater Research* 56(3): 371–388.
- Kennish MJ. 2002. Environmental threats and environmental future of estuaries. *Environmental Conservation* 29(1): 78–107.
- Lang M, Orchard S, Falwasser T, Rupene M, Williams C, Tirikatene-Nash N, Couch R. 2012. *State of the Takiwā 2012 Te Āhuatanga o Te Ihutai: Cultural Health Assessment of the Avon-Heathcote Estuary and its Catchment*. Mahaanui Kurataiao Ltd.
- Lohrer AM, Thrush SF, Hewitt JE, Berkenbusch K, Ahrens M, Cummings V. 2004. Terrestrially derived sediment: response of marine macrobenthic communities to thin terrigenous deposits. *Marine Ecology Progress Series* 273: 121–138.
- Lohrer D. 2024. *Extent of mud (broad scale attribute)*. In: D Lohrer et al. *Information Stocktakes of Fifty-Five Environmental Attributes across Air, Soil, Terrestrial, Freshwater, Estuaries and Coastal Waters Domains*. Prepared for the Ministry of Environment by NIWA, Manaaki Whenua Landcare Research, Cawthron Institute, and Environet Limited. NIWA report no. 2024216HN.
- Lohrer D et al. 2024a. *Information Stocktakes of Fifty-Five Environmental Attributes across Air, Soil, Terrestrial, Freshwater, Estuaries and Coastal Waters Domains*. NIWA report no. 2024216HN. Prepared for the Ministry for the Environment by NIWA, Manaaki Whenua Landcare Research, Cawthron Institute, and Environet Limited.
- Lohrer D, Awatere S, Paul-Burke K, Kitson J, Schwarz AM. 2024b. *Ki uta ki tai: mātāpono me te pūtaiao, ngā korero whakamahuki ma te kaitiaki – From mountains to the sea: values and science for an informed kaitiaki / guardian*. Sustainable Seas National Science Challenge project Ki uta ki tai: Estuaries, thresholds and values.
- Madarasz-Smith A, Shanahan B. 2020. *State of the Hawke's Bay Coastal Marine Environment: 2013 to 2018*. Hawke's Bay Regional Council Publication No. 5425.
- Ministry for the Environment, Stats NZ. 2019. *New Zealand's Environmental Reporting Series: Our marine environment 2019*. Wellington: Ministry for the Environment.
- Morrison MA, Lowe ML, Parsons DM, Usmar NR, McLeod IM. 2009. A review of land-based effects on coastal fisheries and supporting biodiversity in New Zealand. *New Zealand Aquatic Environment and Biodiversity Report No. 37*. Prepared for the Ministry of Fisheries by NIWA.
- O'Meara TA, Hillman JR, Thrush SF. 2017. Rising tides, cumulative impacts and cascading changes to estuarine ecosystem functions. *Scientific Reports* 7: 10218.
- Parliamentary Commissioner for the Environment. 2020. *Managing our estuaries*. Wellington: Parliamentary Commissioner for the Environment.
- Roberts KL, Rabel H, Stevens LM. 2021. Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2020/2021. *Salt Ecology Report 061*. Prepared for the Greater Wellington Regional Council by Salt Ecology.
- Roberts KL, Stevens LM. 2023. Scoping review to update the National Estuary Monitoring Protocol. *Salt Ecology Report 115*. Prepared for the Ministry for the Environment by Salt Ecology.
- Robertson BM, Stevens L, Robertson B, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Oliver M. 2016. *NZ Estuary Trophic Index Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State*. Prepared for Envirolink Tools Project: Estuarine Trophic Index.
- Robertson BM, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B. 2002a. *Estuarine environmental assessment and monitoring: A national protocol. Part A. Development of the monitoring protocol for New Zealand estuaries: Introduction, rationale and methodology*. Sustainable Management Fund Contract No. 5096. Nelson: Cawthron Institute.
- Robertson BM, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B. 2002b. *Estuarine environmental assessment and monitoring: A national protocol. Part B. Development of the*

monitoring protocol for New Zealand estuaries: Appendices to the introduction, rationale and methodology. Sustainable Management Fund Contract No. 5096. Nelson: Cawthron Institute.

Robertson BM, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B. 2002c. *Estuarine environmental assessment and monitoring: A national protocol. Part C: Application of the estuarine monitoring protocol.* Sustainable Management Fund Contract No. 5096. Nelson: Cawthron Institute.

Robertson BP, Gardner JPA, Savage C. 2015. Macrobenthic–mud relations strengthen the foundation for benthic index development: A case study from shallow, temperate New Zealand estuaries. *Ecological Indicators* 58: 161–174.

Scheele S, Carswell F, Harmsworth G., Lyver P., Awatere S, Robb M, Taura Y, Wilson S. (2016). *Reporting Environmental Impacts on Te Ao Māori: A Strategic Scoping Document.* Prepared by Manaaki Whenua Landcare Research for the Ministry for the Environment by Manaaki Whenua Landcare Research.

Sinner J, Tadaki M, McCarthy A, Challies E, Thomson-Laing J. 2022. *Catchment and community environment groups in Aotearoa New Zealand: goals, activities and needs.* Cawthron Report No. 3733. Prepared for the Ministry for the Environment by the Cawthron Institute.

Stevens LM, Forrest BM, Roberts KL. In prep. Aotearoa New Zealand National Estuary Monitoring Protocol. *Salt Ecology Report 137.* Prepared for the Ministry for the Environment by Salt Ecology.

Stevens LM, Roberts KL, Forrest BM, Morrissey D, Zeldis JR, Dudley BD, Mangan S, Lam-Gordillo O, Lundquist C, Lohrer AM, Plew DR. 2024. Advice on Indicators, Thresholds and Bands for Estuaries in Aotearoa New Zealand. *Salt Ecology Report 141.* Prepared for the Ministry for the Environment by Salt Ecology.

Swales A, Gibbs M, Hewitt J, Hailes S, Griffiths R, Olsen G, Ovenden R, Wadhwa S. 2012. *Sediment sources and accumulation rates in the Bay of Islands and implications for macrobenthic fauna, mangrove and saltmarsh habitats.* NIWA Client Report No: HAM2012-048. Prepared for the Northland Regional Council by NIWA.

Swales A, Gibbs M, Olsen G, Ovenden R, Costley K, Stephens T. 2016. *Sources of eroded soils and their contribution to long-term sedimentation in the Firth of Thames.* Waikato Regional Council Technical Report 2016/32.

Swales A, Pritchard M, McBride GB. 2020. Biogeomorphic evolution and expansion of mangrove forests in New Zealand's sediment-rich estuarine systems. In: F Sidik, DA Friess (eds) *Dynamic sedimentary environments of mangrove coasts.* Amsterdam, Netherlands: Elsevier. pp. 3–45.

Swales A, Gibbs M, Handley S, Olsen G, Ovenden R, Wadhwa S, Brown J. 2021. *Sources of fine sediment and contribution to sedimentation in the inner Pelorus Sound/Te Hoiere.* Prepared for the Marlborough District Council by NIWA.

Thrush SF, Hewitt JE, Norkko A, Nicholls PE, Funnell GA, Ellis JI. 2003. Habitat change in estuaries: predicting broad-scale responses of intertidal macrofauna to sediment mud content. *Marine Ecology Progress Series* 263: 101–112.

Thrush SF, Hewitt J, Cummings V, Ellis J, Hatton C, Lohrer A, Norkko A. 2004. *Muddy waters: elevating sediment input to coastal and estuarine habitats.* *Frontiers in Ecology and the Environment* 2(6): 299–306.

Thrush SF, Townsend M, Hewitt JE, Davies K, Lohrer AM, Lundquist C, Cartner K. 2013. The Many Uses and Values of Estuarine Ecosystems. In: JR Dymond (ed), *Ecosystem Services in New Zealand: Conditions and Trends.* Manaaki Whenua Press. pp 226–237.

Thrush SF, Hewitt JE, Gladstone-Gallagher RV, Savage C, Lundquist C, O'Meara T, Vieillard A, Hillman JR, Mangan S, Douglas EJ, Clark DE, Lohrer AM, Pilditch C. 2021. Cumulative stressors reduce the self-regulating capacity of coastal ecosystems. *Ecological Applications* 31(1): e02223.

Townsend M, Lohrer A. 2015. *ANZECC Guidance for Estuary Sedimentation.* Prepared for the Ministry for the Environment by NIWA.

Ulrich SC, Wright FR, Rennie HG. 2022. Characterising the regulatory seascape in Aotearoa New Zealand: Bridging local, regional and national scales for marine ecosystem-based management. *Ocean and Coastal Management* 224: 106193.

Zabarte-Maezt I, Matheson FE, Manley-Harris M, Davies-Colley RJ, Oliver M, Hawes I. 2020. Effects of fine sediment on seagrass meadows: A case study of *Zostera muelleri* in Pāuatahanui inlet, New Zealand. *Journal of Marine Science and Engineering* 8(9): 645.