Fisheries New Zealand

Tini a Tangaroa

# Best management practice guidelines for salmon farms in the Marlborough sounds

## Part 2: Water quality standards and monitoring protocol (Version 1.0)

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## GLOSSARY

| Term | Description |
| --- | --- |
| Adaptive management | Flexible decision-making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process (MfE 2016). |
| Amber state | A state of non-compliance for water quality, during which response monitoring is required to determine the probable cause of water quality changes. |
| Best practice | Agreed standards and guidelines following expert review. See Section 1.3 for a more detailed description. |
| Breach | A single result that is beyond one of the WQS thresholds. For most criteria, several sequential breaches (of the same WQS over time) are required before the amber state is triggered. |
| Board of Inquiry (BoI) | An independent process administered by the New Zealand Environmental Protection Agency under the Resource Management Act 1991. Its use in this document refers to NZ King Salmon's 2012 resource consent application for nine new salmon farms in the Marlborough Sounds. Three of these salmon farm consents were granted (termed 'BoI farms'). The BoI farms are located in Waitata Reach and Richmond Bay (Kōpaua) in Pelorus Sound, and Ngamahau Bay in Tory Channel. |
| Denitrification | A process where denitrifying bacterial species can take nitrate and change it back to nitrogen gas. It is by denitrification that some nitrogen is lost/exported from the water column. |
| Ecologically significant | Specifically, to make a distinction between statistically significant (where there can be a 'significant' effect detected statistically, but which is not necessarily ecologically meaningful) and an effect that is ecologically significant, usually as judged by one or more suitably qualified scientists (noting, that within the term 'ecologically significant' a continuum exists, where an effect can be ecologically significant with varying degrees of severity). |
| Enrichment | In this document, enrichment refers primarily to additional nutrients (primarily nitrogen) in the water column that drive increases in primary productivity (plant growth, in this case mainly of phytoplankton). |
| Exceedance | In the context of the WQS, an exceedance is when the same WQS is breached in three successive months within either Pelorus Sound, or Queen Charlotte Sound, triggering an amber alert. Pelorus Sound includes Kenepuru Sound. See Section 3.5. |
| Far-field | Out to tens of kilometres, but not within several hundred metres of the farm. A far-field change could arise at a considerable distance beyond a farm, but may still be moderately localised (i.e. need not extend through the entire region/Sound). |
| Green state | A state of compliance for water quality, the pre-existing or natural state. |
| High-flow | Mean mid-water current speeds of ≥ 10 cm/second |
| Inner-Sound vs. outer-Sound | No strict definition or boundary for inner- or outer- Sound exists, because an explicit boundary would be somewhat arbitrary. However, in a relative sense, the inner-Sound could be described as being least connected to the Cook Strait, by either distance or water-current connectivity, and the outer-Sound as being most connected. |
| Localised / local-scale effects | Refers to those described in Section 1.2.1 |
| Low-flow | Mean mid-water current speeds of < 10 cm/second |

| | |
|---|---|
| Operational policy (for water quality) | Environmental performance objectives for salmon farms water quality effects, which were paraphrased (for clarity) from the formal 'water quality objectives' defined in the BoI consent conditions. |
| Near-farm | Within several hundred metres of a salmon farm. |
| Nitrification | Aerobic process where bacteria change ammonia to nitrite and nitrite to nitrate. All forms of nitrogen in the nitrification process are dissolved, and biologically available. |
| Peer review panel (PRP) | The peer review panel is an independent body, with expertise in marine seabed and water column ecology. The PRP was convened by NZ King Salmon as a requirement under the BoI salmon farm consents, primarily to review and provide recommendations to the Marlborough District Council on matters such as the establishment of baseline and annual monitoring. |
| Regional scale | On the spatial scale of region, with region defined as a single Sound (i.e. Queen Charlotte/Tōtaranui or Pelorus Sound/Te Hoiere). Pelorus Sound includes Kenepuru Sound. With regard to effects, an enrichment effect at the regional scale could, but does not necessarily, comprise an entire region, or it could comprise one or more small areas within a region, that are not necessarily adjacent to a fish farm. |
| Red state | A state of non-compliance caused by salmon farming. Once the system is deemed to have entered this state, the fish-farm operator must implement a management plan designed to restore the system back into a green state within an agreed time-period. |
| Social license | Refers to acceptance of a company or industry by its stakeholders (employees, local community groups, general public etc). |
| Water quality standards (WQS) | Numerical thresholds (for chlorophyll-a, dissolved oxygen and total nitrogen) that, if exceeded sufficiently, usually sequentially (as shown by routine monitoring), will induce a management response (i.e. responsive monitoring, additional analyses of data, and if required, mitigation action by the farm operator(s)). |
| Water quality objective (WQO) | According to the BoI consent conditions, water quality objectives are environmental quality standards that describe operational performance outcomes of salmon farm activities as they relate to water quality effects. |
| Well-flushed | A high level of water exchange, where strong currents (i.e. high-flow) occur regularly in a location that allows mixing with water from outside a semi-enclosed area (e.g. outer sounds area located in channels). |

## EXECUTIVE SUMMARY

**Elvines, D.; Preece, M.A.; Baxter, A.; Broekhuizen, N.; Ford, R.; Knight, B.; Schuckard, R. Urlich, S.C. (2019).**
**Best management practice guidelines for salmon farms in the Marlborough sounds**
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***New Zealand Aquatic Environment and Biodiversity Report No. 230.* 63 p.**


The New Zealand King Salmon Co. Limited (NZKS) were granted resource consent for three new salmon farms in the Marlborough Sounds by the Environmental Protection Authority (EPA) in 2012. The consent conditions were determined by the EPA's Board of Inquiry (BoI) which required NZKS to monitor broader scale effects in the water column of their nitrogen discharge. The conditions also required the setting of numerical thresholds, or 'interim water quality standards' (WQS) for ecologically important water column attributes: chlorophyll-a, total nitrogen and dissolved oxygen. The consents required the interim WQS to be reviewed by the end of 2018. Two additional farms which had been separately re-consented following the BoI also required the interim WQS to be reviewed by the end of 2018. These farms are all sited in locations of high current flows (high-flow) within the Marlborough Sounds.

A working group was set up to provide advice to The New Zealand King Salmon Co. Limited (NZ King Salmon) and Marlborough District Council (MDC); the group included representatives from Fisheries New Zealand, Department of Conservation (DoC), Cawthron Institute, National Institute of Water & Atmospheric Research (NIWA) and the Sounds Advisory Group to MDC (SAG). The working group was tasked with reviewing and recommending 'best practice[1] guidelines' detailing WQS, a monitoring protocol, and a management response framework for these high-flow farms to follow. The review was to be informed by international examples of best practice and customised to the biophysical conditions of the Marlborough Sounds.

The primary purpose of these guidelines is therefore to provide a central set of WQS, and requirements for monitoring and managing potential water column nutrient enrichment from salmon farms in the Marlborough Sounds. The overall framework will provide the regulator and consent holder with early detection, or warning signs, of a deterioration in water quality from nutrient enrichment, at a regional-scale. The review also acknowledged the importance of the wider environmental context, because dissolved nutrient inputs come from a range of other sources (e.g., upwelling from Cook Strait, catchment run-off). Aspects of this framework may also be broadly applicable to other fin-fish farms or feed-added aquaculture, and/or existing salmon farms in low-flow locations. However, these were not a specific consideration in the review.

The guidelines define the management framework, which includes environmental performance criteria and intervention points, as well as recommendations for monitoring design and delivery of monitoring information. The monitoring structure is tiered, and consists of routine monitoring (Tier 1) against the WQS. An exceedance of the WQS triggers Tier 2 monitoring to determine, using a weight of evidence approach, whether salmon farm inputs are likely to be the primary cause. If proven likely to be cause, changes to management could be triggered. If more intensive monitoring is required, then Tier 3 monitoring can be initiated on a case-by-case basis, by either NZKS or MDC.


[1] The term 'Best Practice' in the context of these guidelines means to; a) provide a framework for protecting the Marlborough Sounds against salmon farm induced nutrient enrichment effects, b) be consistent with the intent of the rulings of previous resource consent requirements, and c) incorporate new information and technological advancements, as well as international practice.

These guidelines represent our proposed ‘best practice’ for salmon farm water column effects management within the Marlborough Sounds. The content was based on the best information available at the time of the review (June – October 2018), and the guidelines will be reviewed at least every five years. The purpose of each review will be to ensure that the WQS, monitoring and management of possible salmon farm induced water quality effects in the Marlborough Sounds remains cognisant of emerging local and international practices and knowledge, and new monitoring technologies.

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# 1 INTRODUCTION

## 1.1 Background

This document is intended as guidance to inform the development and implementation of water quality monitoring programmes and environmental standards for salmon farms in the Marlborough Sounds. Its development follows on from the Part 1 Best Management Practice Guidelines: Benthic (Keeley et al. 2019), developed through a similar process.

The salmon farming industry in the Marlborough Sounds has developed to a stage where clear articulation of Best Management Practice (BMP) is desired by all for consistent environmental standards, and the monitoring and management of water quality effects. Having 'BMP' guidance in place, will enable a common understanding of how the effect of existing and developing industry is managed, both from an operational perspective and with respect to expectations of environmental performance.

There are eleven sites allocated for salmon farming in Queen Charlotte Sound/Tōtaranui (hereafter Queen Charlotte Sound) and Pelorus Sound/Te Hoiere (hereafter Pelorus Sound) (Figure 1). These sites are located in areas with both high-flow and low-flow current regimes. Resource consents for these existing salmon farms in the Marlborough Sounds span three decades. Over this time production has increased and environmental standards have become increasingly stringent in response to evolving knowledge, technological improvements and community concerns. The most recently consented farms, which are all in high-flow environments (see Figure 1), have a variety of conditions for monitoring, environmental standards and management for water column effects (Appendix 1). It is also worth noting that the primary salmon farm producer in the Marlborough Sounds is The New Zealand King Salmon Co. Ltd. (hereafter 'NZ King Salmon'). Accordingly, almost all of the local-to-farm information referenced within this document is associated with NZ King Salmon farms.

## 1.2 Effects on water quality

As well as being sinks for dissolved oxygen from fish respiration, salmon farms are also sources of soluble nutrient and particulate organic detritus (Hartsein & Oldman 2015). About 70% of all nitrogen in the salmon feed supplied is released into the environment. About 85% of the nitrogenous waste will be in dissolved forms (ammonium and urea), and the rest is in particulate form (Zeldis 2008). Some of the particulate nitrogen load can also be remineralised in dissolved forms (e.g. ammonium and nitrate) through detrital feeders and seabed processes[2].

### 1.2.1 Localised effects

The localised and direct water quality effects from salmon farms are elevated nitrogen and reduced dissolved oxygen. These effects are well documented around finfish farms (e.g. Buschmann et al. 2007; Wang et al. 2012; Price et al. 2015, Jansen et al. 2018). However, it is important to note that these effects

[2] Previous modelling has assumed about 25% of the particulate nitrogen will become available through remineralisation (e.g. Broekhuizen & Hadfield 2016a,b).

are largely periodic (occur in pulses) and are associated with periodic feed / excretion / respiration patterns (Tomasso 1994). The immediate impact signal of a salmon farm decays rapidly with distance, primarily due to mixing with more distant waters, but also due to uptake by primary producers. The signal is rarely detectable at distances greater than a few hundred metres from the pens (e.g. Knight & Beamsley 2012, Price et al. 2015, Bennett et al. 2018a).

### 1.2.2 Effects on primary productivity (nutrient enrichment)

Finfish farms release dissolved nutrients, and because the Sounds tend to be nitrogen-limited, release of nitrogen is of relatively higher concern than release of other nutrients. All forms of dissolved nitrogen are used for algal growth, and excessive amounts of dissolved nitrogen can also cause increases in primary productivity[3], and indirectly cause broader-scale changes related to nutrient enrichment (MPI 2013). Phytoplankton biomass (including blooms) may increase after interacting with the localised nutrient gradients around the farm. However, this effect would likely not be seen around the farms themselves (Tett et al. 2018), rather, effects would manifest at some distance away. This lagged response is due to the doubling time of phytoplankton (days-weeks). The location where these effects manifest would be determined by the water current movement during the ensuing growth period. Therefore, the focus of this BMP is on the broader scale nutrient enrichment effects within a region, rather than on localised effects around the farms themselves.

It is also important to contextualise these potential far-field or regional-scale enrichment effects within the broader biophysical system of the Marlborough Sounds. Dissolved nutrient inputs to the system from salmon farms is cumulative with other nutrient sources (e.g. terrestrial run-off via. rivers/streams, oceanic inputs [i.e. from Cook Strait]) also influencing the system. We also acknowledge that water quality issues in the Marlborough Sounds are also presently associated with terrestrial run-off (e.g. sedimentation) (Urlich 2015; Henkel 2018). These other stressors should always be taken into consideration when reviewing management frameworks.

[3] Such that 16 molecules of nitrogen can stimulate the production of 106 molecules of carbon. This ratio is referred to as the Redfield ratio (Redfield 1934).

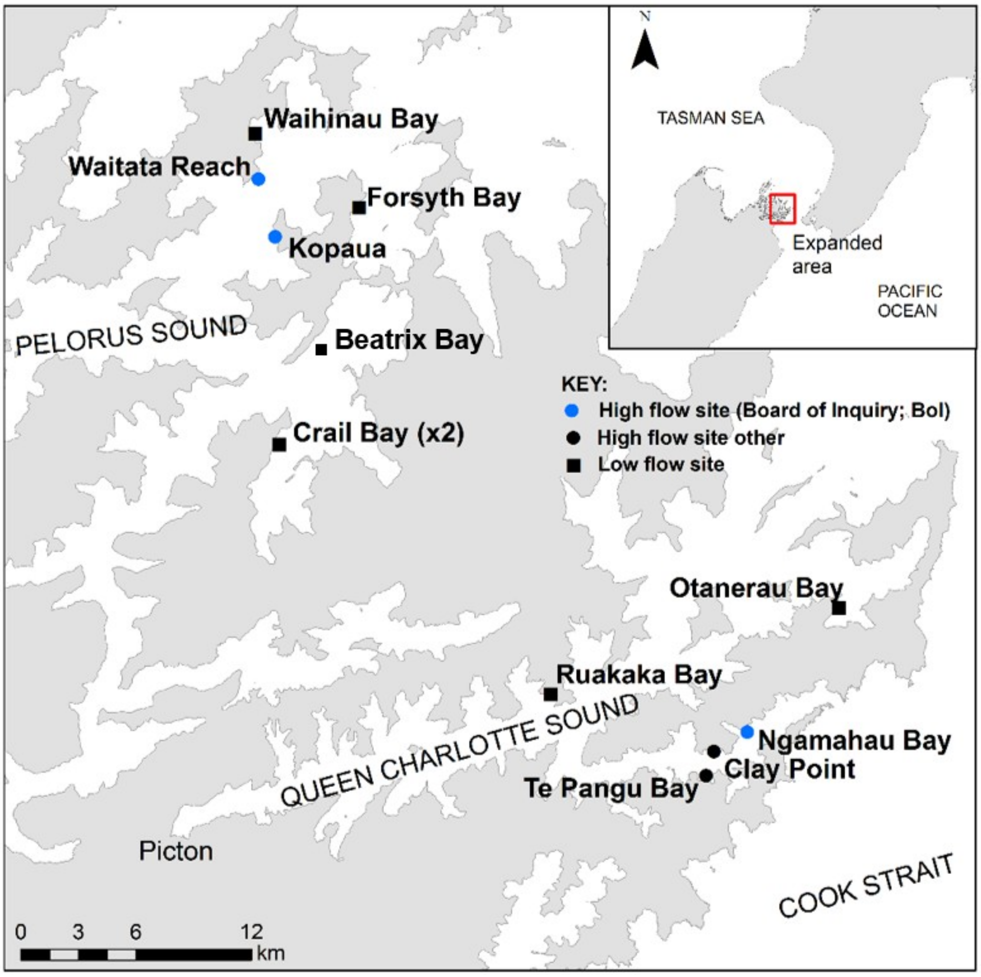


**Figure 1: The 12 locations consented for salmon or other fin-fish farming within the Marlborough Sounds at the time of writing.**

## 1.3 Purpose of the guidelines

Water quality management regimes and monitoring requirements for salmon farming in the Marlborough Sounds are presently contained within multiple individual resource consents, and consent-related monitoring reports (see Appendix 1 for further detail). The dispersed and poorly-linked nature of this information made for inconsistent monitoring requirements and regulation of salmon farming with respect to water quality. In addition, new information on water quality effects has become available since the most recent consents were granted. Thus, a central authoritative document is needed to articulate and justify current best practice.

The primary purpose of the guidelines is therefore to provide consistent and clear requirements for the monitoring and management of salmon farm water quality effects. Central to this is a set of agreed environmental quality standards or thresholds with accompanying rationale for their selection and guidance for their use. Specific aims of the guidelines are therefore to:

- Provide a single information source that describes the monitoring protocols, environmental standards and management framework.
- Set out a process for the review and update of this information.

- Describe a monitoring design that facilitates early identification of adverse effects on water quality, based on the best available information (what should be measured, where, and how often).
- Define how the monitoring results feed back into salmon farm management, and when salmon farm management actions are required (e.g. if certain environmental performance criteria are not met).
- Identify gaps in understanding, that if filled, would enable more effective monitoring / management of salmon farming.

The guidelines can be used to inform aquaculture planning and the development of consent conditions that relate to water column effects from salmon farming (and, perhaps, any other feed-added aquaculture including other fin-fish species). They may also be used for existing resource consents[4] for salmon farms sited in high-flow locations[5]. It is also intended for the guidelines to be a living document that will be reviewed, updated and amended to accommodate evolution in knowledge and technologies.

We note that best practice as defined in these guidelines would not necessarily be best practice in other parts of New Zealand's coast, or internationally. Therefore, the term 'Best Practice' in the context of these guidelines means; deemed by a diverse group of experts representing different interests, to:

- Provide a framework for protecting the Marlborough Sounds against salmon farm induced nutrient enrichment effects, without being cost prohibitive,
- Be consistent with the intent of the rulings of previous resource consent requirements,
- Incorporate new information and technological advancements, as well as international practice where applicable and practicable.

### 1.3.1 Limitations of water quality monitoring within these guidelines

There are several important limitations of water quality monitoring techniques that should be acknowledged up-front. These limitations will be discussed later in the document where applicable, but in summary they are:

- The scale of monitoring is such that it focuses on broader-scale changes within a given Sound, and with one exception, does not attempt to characterise or monitor for localised effects[6]. The exception to this is monthly spot-check measurements of DO within 250 m of the farm. Localised effects monitoring can be performed under the Tier 3 framework of these guidelines on a case-by-case basis.
- The routine monitoring described within this document will not in itself determine a cause for water quality nutrient enrichment effects; it is designed only to detect symptoms that might be consistent with changes induced by nutrient-enrichment. It is not designed with a view to confidently diagnose the cause of the symptoms.

[4] Either where flexibility allows this within the existing consent, or by a s127 application to vary the conditions of a consent.

[5] Salmon farms sited in areas with low-flow current regimes were not specifically considered as part of this document, but the guidelines could nonetheless also be adopted at these sites.

[6] However, there are several other monitoring programmes in place for most existing salmon farms which can provide useful time-integrated information on enrichment in closer proximity to the farms (i.e. benthic monitoring provides context on seabed conditions under the farms, and reef monitoring checks for nutrient enrichment effects in proximity to some farms).

- While the overall monitoring framework accommodates a second tier of monitoring that will attempt to attribute or rule out salmon farms as a primary cause in the event of water quality deterioration, establishing a causal link cannot be guaranteed. It is hoped that scientific methods to enable this causal link to be established will improve over time.
- The design for monitoring to date[7] was primarily focussed on main channels through the Marlborough Sounds, thus existing data used to inform the guidelines has a mid-channel bias.
- The data used to inform the guidelines was based on single-point-in-time monthly sampling events, which do not fully capture smaller scale temporal variability (e.g. diel).

In addition, we stress the importance of understanding system-wide nutrient exchange dynamics. Previous estimates have shown that finfish farms are a relatively large source of nitrogen into the Marlborough Sounds, and in some years may be comparable to some of the other inputs to the Sounds (e.g. riverine input or oceanic upwellings; Table 1, data for illustrative purposes only). Information on the contribution of salmon farm nitrogen into the Sounds with respect to other sources will be useful for any interpretation of results relating to nutrient enrichment effects, as the relative contribution from salmon farming can change from year-to-year, and season-to-season.

**Table 1: Estimates of potential inputs and losses of nitrogen (N) from Pelorus and Queen Charlotte Sounds. Salmon farming inputs are estimated here assuming that 49 kg of nitrogen is released per ton of feed (see narrative below table). Other losses and inputs are sourced from Knight (2012). The contribution of other sources of nitrogen to the Marlborough Sounds is also covered to some degree by several other pieces of work (Gillespie et al. 2011, Hadfield et al. 2014, Broekhuizen et al. 2015).**

| Description | N input (or loss) in tonnes per year | |
|---|---|---|
| | Pelorus Sound | Queen Charlotte Sound |
| Salmon farming* | 310.5 | 660.6 |
| Riverine input** | 580.1 | 25.6 |
| Oceanic input** | 4200 | 1650 |
| Mussel harvesting | (266) | (11.8) |
| Denitrification | (465) | (367) |

*See Appendix 2

** Inputs will vary largely from year to year and season to season.

## 1.4 Guideline formation process

The working group was comprised of representatives from NZ King Salmon, Marlborough District Council (MDC); Fisheries New Zealand which is a business unit of the Ministry for Primary Industries (MPI); Department of Conservation (DOC); Cawthron Institute (Cawthron); National Institute of Water and Atmospheric Research (NIWA); and the Sounds Advisory Group (SAG) to MDC (Appendix 6).

[7] The Marlborough District Council State of Environment monitoring, and the monitoring commissioned by NZ King Salmon for farms that were granted consent through the Board of Inquiry.

The guidelines were developed through a series of workshops in 2018 (see synopsis of the Terms of Reference in Appendix 7). Their development comprised a review of new and existing information on salmon farm water quality effects, monitoring and management.

It is noted that this version of the guidelines does not consider other resource use which affects water quality in the Marlborough Sounds (for example, sediment run-off from modified catchments or nutrients from agriculture). A future aspiration for the water quality of the Marlborough Sounds may be that its monitoring and management evolves to become a more fully integrated framework with contributions from all resource users that may impact on the water quality of the Sounds.

# 2 WATER QUALITY MONITORING OBJECTIVES

To ensure monitoring yields information that is useful for management and compliance purposes, both the monitoring design and compliance framework should be based around the same overall aim. Based on the water quality objectives described in the Board of Inquiry (BOI)[8] process (see Section 2.3), the working group considered that the overarching aim of the monitoring was:

To provide early detection, or warning signs, of a deterioration in regional water quality from nutrient enrichment from salmon farming.

A deterioration in water quality could manifest broadly (e.g. anywhere within a Sound, even many kilometres from a salmon farm), or on a smaller scale (e.g. individual embayments closer to the salmon farm). With the exception of dissolved oxygen[9], the monitoring design does not give regard to localised water quality effects (see Section 2.1). Rather, it gives regard to broader-scale changes – whether arising throughout much of the Sound or only in some parts of it.

## 2.1 Water quality monitoring for localised effects

If the water column characteristics of the site are known, the expected amount of total dissolved nitrogen (TDN) loading from a farm can be easily estimated from the daily feed discharge amount (see Appendix 2).

The challenge of validating these salmon farm nutrient loading dynamics is that the influencing factors are not evenly distributed in space and/or time. That is, fish are not evenly distributed in the net pen, feed is not discharged constantly, and the fish excrete nutrients and respire in 'pulses'. Accordingly, model assumptions (and output values) are unlikely to be met at any one point in time, and fluctuations of dissolved nitrogen and oxygen around the pens could easily be missed, or poorly represented, by single-point-in-time sampling events (more so than in the far-field monitoring due to the higher variability pen-side). This complexity means that sampling results could easily deviate from the modelled expectation. A temporally-robust sampling design would need to be employed to provide empirical information on localised effects (e.g. Merceron et al. 2002, Karakassis et al. 2001, Merino et al. 2007).

### 2.1.1 Case study: initial consent requirements for monitoring of localised effects

The BOI consent conditions required transect based surveys to be carried out initially to monitor for localised effects. The requirement was for the surveys to be undertaken twice per year until two years after the farm reaches a stable level of maximum feed discharge levels and no future increases are proposed. The objectives of the monitoring were to;

- Quantify the localised effect of the marine farm on surrounding water quality
- Understand near-farm mixing properties
- Provide context for the Water Quality Standards (WQS)

[8] Environmental Protection Authority (EPA) Board of Inquiry 2012 into an application by the New Zealand Salmon Company Co. Ltd for nine new salmon farm sites in the Marlborough Sounds. https://www.epa.govt.nz/database-search/rma-applications/view/NSP000002

[9] Which has been retained in the interim, for measuring compliance against the near-farm DO WQS (see Appendix 3)

The NZ King Salmon sampling programme has provided results from these transect-based monitoring surveys from six sampling occasions at three farms over three years (e.g. Elvines et al. 2017a&b, Bennett et al. 2018a). Of these surveys, the highest recorded concentration of TN at the downstream edge of the farm was 359 mg/m$^3$, while TN concentrations 250 m downstream (215 mg/m$^3$) were at (or even below) background values as determined by reference site TN concentrations (219 – 283 mg/m$^3$; Elvines et al. 2017a). Although localised effects were sometimes measured in these surveys, effects invariably decayed to be indistinguishable within a few hundred metres from the farm. Of course, definitive conclusions from this local-scale monitoring are precluded by the known limitations of single-point-in-time sampling; at best, the sampling should only be considered a 'randomised check' on downstream water quality. Using a more robust design to quantify localised effects, for example that used by Merceron et al. (2002), Karakassis et al. (2001) and Merino et al. (2007), would be cost prohibitive if performed according to the monitoring schedule set out in the BOI consent conditions.

## 2.2 An operational policy for salmon farm water quality effects

The working group recognised that the Water Quality Objectives (WQO) defined in the BOI process would be difficult or impractical to meet if compliance monitoring results were measured against them. That is, the results would not be able to explicitly inform whether the objectives have been met. Instead, it is more practical if they are used as an 'operational policy', that defines what the unacceptable impacts to water quality would look like.

In addition, to operationalise and improve clarity around each WQO, we have rephrased them, striving to preserve our interpretation of the intent of the original objective. A direct extract of the BOI water quality objectives and the rephrased 'operational policies' are compared below.

**Direct extract of the water quality objectives, from one of the salmon farm consents granted through the board of inquiry process.**

43. The marine farm shall be operated at all times in such a way as to achieve the following Water Quality Objectives in the water column:
    a) *To not cause an increase in the frequency, intensity or duration of phytoplankton blooms (i.e. chlorophyll-a concentrations $\geq 5$ mg/m$^3$) [Note: water clarity as affected by chlorophyll-a concentrations is addressed by this objective];
    b) To not cause a change in the typical seasonal patterns of phytoplankton community structure (i.e. diatoms vs. dinoflagellates), and with no increased frequency of harmful algal blooms (HABs) (i.e. exceeding toxicity thresholds for HAB species);
    c) *To not cause reduction in dissolved oxygen concentrations to levels that are potentially harmful to marine biota [Note: Near bottom dissolved oxygen under the net pens is addressed separately through the EQS – Seabed Deposition];
    d) *To not cause elevation of nutrient concentrations outside the confines of established natural variation for the location and time of year, beyond 250 m from the edge of the net pens;
    e) To not cause a statistically significant shift, beyond that which is likely to occur naturally, from a oligotrophic/mesotrophic state towards a eutrophic state;
    f) To not cause an obvious or noxious build-up of macroalgal (e.g. sea lettuce) biomass [Note: to be monitored in accordance with Condition 66h].

**Salmon farm 'operational policy' for water quality in the Marlborough Sounds.**

The operation of salmon farms in the Marlborough Sounds should seek to avoid the following:

1. An increase in the frequency, intensity or duration of phytoplankton blooms.
2. An increase in the frequency of harmful algal blooms.
3. A change in the typical seasonal patterns of phytoplankton community structure.
4. Reduction in dissolved oxygen to levels that are potentially harmful to marine biota
5. Elevated nutrient concentrations outside the confines of established natural variation for the location and time of year. This excludes near-farm effects.
6. An ecologically significant** shift towards a more enriched state of the water column.
7. To not cause an obvious or noxious build-up of macroalgal biomass***

*Salmon farms operating within the WQS are considered to be meeting these criteria (see Section 3.5; WQS).

**See glossary. We note that this does not imply a 'jump' from one trophic state classification to another, rather, a deterioration along a continuum of 'higher' nutrient enrichment. A categorical shift (i.e. into a eutrophic state) was considered to be less conservative than a trending shift along a continuum of higher nutrient enrichment. Therefore, the latter more conservative option was used in this case.

***This policy objective pertains to reef monitoring, not water quality monitoring.

# 3 ADAPTIVE MANAGEMENT FRAMEWORK

An adaptive management framework has been devised, setting out different types of monitoring for salmon farming in the Marlborough Sounds. Results from all monitoring performed under the framework should feed back to improved monitoring and management to ensure that best practices can evolve over time.

The priority of water column monitoring is to provide a means of early detection of changes in water quality (Section 2). This priority is reflected in the first 'Tier' of monitoring (Figure 2). Determining a causal link to water quality changes is secondary to this aim and is captured in Tier 2 monitoring. Any significant information gaps on salmon farm effects that need to be addressed to meet the water quality objectives can be performed through one-off, objective-based studies. These studies would fall under a third tier of monitoring (Tier 3).

The tiers are further described in the following subsections. Management responses for Tier 1 / Tier 2 monitoring are set out in Section 3.5.

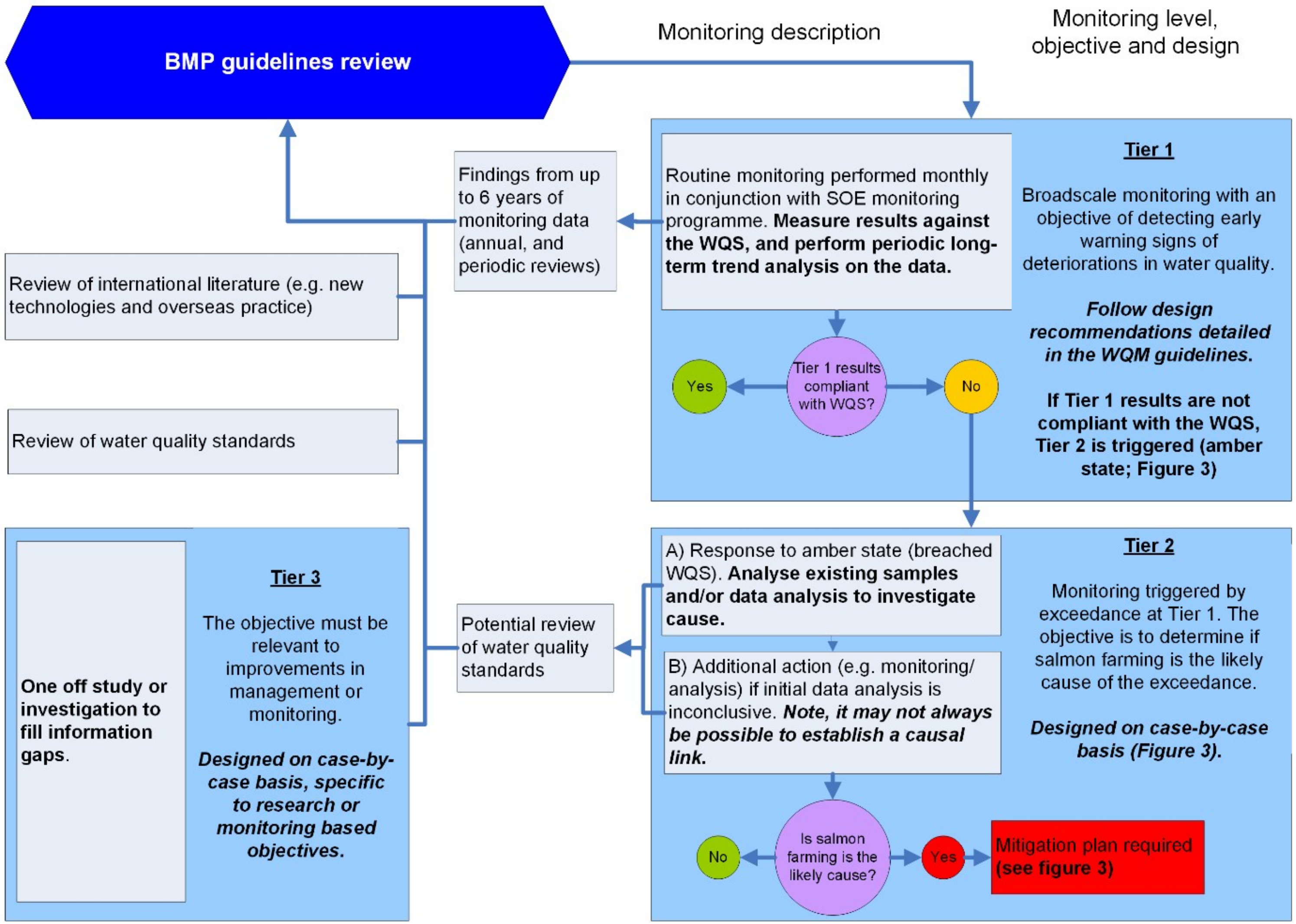


**Figure 2: Tiered monitoring framework and feedbacks for review, compliance monitoring, and management triggers.**

## 3.1 Tier 1

Routine (Tier 1) monitoring is designed to detect changes in water quality early on, utilising a set of water quality standards (WQS; thresholds set for certain water quality parameters, see **Section 3.5**) and periodic (about 3 years) trend analysis on regional scale data (see **Section 6.3**). The design of Tier 1 monitoring is set out in **Section 4**. The associated management response framework for Tier 1 monitoring explicitly classifies water quality into three categories of 'compliance' with the WQS; compliant (green state), alert (amber state), or non-compliant (red state) state (Section 3.6).

Tier 1 monitoring is ongoing, even if additional monitoring is performed under Tier 2 and Tier 3.

## 3.2 Tier 2

Tier 2 water quality monitoring for salmon farming is triggered if WQS are breached, usually successively (this is identified as an 'amber state'; explained in Section 3.5). The aim of this monitoring is to determine the probable cause of any observed deteriorations in water quality using a weight of evidence approach (i.e. is salmon farming likely to have been the primary cause of the exceedance, and if so, is the cause farm-specific?).

Weight of evidence could be taken from a range of sources and resources, and may include, but is not limited to, the following:

- A review of existing monitoring data from the MDC SOE monitoring programme (Section 5.1) and any other known monitoring programmes that may permit the use of their data (e.g. the Marlborough Sounds Shellfish Quality Programme; MSQP, or on-farm monitoring data, or historical research data).
- Analysis of archive samples for a wider suite of parameters (i.e. those collected as part of the Tier 1 monitoring).
- Commissioning of additional sampling, for example to quantify cross-channel nutrient gradients near the area where the breach has occurred, or temporarily increasing the temporal resolution of sampling in some areas.
- Additional numerical modelling. Examples include;
  - running existing models using actual feed input data (from the consent holder) and environmental data (e.g. observed or simulated river-flows, winds etc that may be available from organisations such as MDC, NIWA) leading up to the amber state,
  - modelling nutrient budgets (using, for example, the LOICZ approach; Gordon et al. 1996) and partitioning results from existing models by the relevant season.
- Model validation work (e.g. experimental studies to further validate key model assumptions).

The initial investigation would focus on one or more resources that could provide the most rapid turnaround and best cost effectiveness for narrowing down the causative factor. However, if the initial analysis does not yield enough information, or if there is still unacceptable uncertainty about the cause, additional testing or more comprehensive data analysis may be required. It is important to note that the multiple nutrient sources to the Marlborough Sounds, and the complex bio-physical factors that govern the dynamics of the water column environment, make it challenging to attribute observed water column changes to any potential source (this is discussed further in Section 3.3). Hence, we have adopted a weight of evidence approach, which seeks to determine the most plausible cause of a breach in the WQS.

If salmon farming is found to be the probable or most plausible cause, the system will be considered in a red state and the consent holder will develop and adopt a mitigation plan to revert the 'red state' back to a 'green state'. This plan should include an indication of the anticipated time-to-recovery[10]. If the salmon farm is deemed unlikely to be the cause, it may be necessary to re-evaluate the application of the WQS thresholds[11]. *Note that the steps of the Tier 2 monitoring should be completed in full, regardless of whether or not the system reverts back to a 'green state' within this timeframe.*

### 3.2.1 Tier 2 monitoring limitations

It is widely accepted that primary production can increase in response to nutrient discharges from salmon farms. However, there are inherent difficulties associated with quantifying nutrient transfer and flow-on effects from salmon farms, as well as in understanding the relative contribution of other influences in time and space. While there are multiple methods for tracing salmon farm nutrients and waste near to the farms (and some studies have done so), no empirically tested methods currently exist for tracing salmon farm waste nutrients at a far-field scale greater than about a kilometre. Tracing salmon farm waste nutrients will remain a challenge for water quality management until significant methodological advances are made.

Nonetheless, attempting to determine the contribution from salmon farms on any observed water quality changes will be undertaken on a case-by-case basis (as Tier 2 monitoring) as depicted in the management response decision tree (Figure 3).

[10] The time-to-recovery must be agreed to by the regulator. Specifying the recovery period in advance will avoid the possibility of the farmer being repeatedly penalised for an ongoing breach that could not yet realistically have been resolved. At the same time, it will also provide the regulator with surety that they will be able to monitor progress towards compliance and intervene further if compliance is not achieved within a specified time-frame.

[11] To prevent the occurrence of false positives. For example, it may be more appropriate to adopt season- or area-specific thresholds, or ones that relate to long term weather cycles; La Niña/El Niño (Morrisey et al. 2015).

## 3.3 Tier 3

Tier 3 monitoring is a research level of investigation, and does not necessarily have to be commissioned as 'monitoring' of the salmon farming industry. It should be used to fill knowledge gaps that are important for salmon farm effects monitoring or management in the context of water quality. Tier 3 research commissioned by the industry would be based on discussions between industry and the regulator (i.e. the implementation would not necessarily be a requirement in a resource consent).

Examples include:

- Field tests to understand the source concentrations and level of dilution and mixing around a salmon farm to validate modelling (e.g. surveys of localised farm effects) (i.e. monitoring for local-scale effects that is not measured against compliance criteria, such as that carried out at the BoI farms under conditions 65/66e of the present consents).
- Field measurements of connectivity between salmon farms and other areas/significant habitats in the Marlborough Sounds, to validate modelling (e.g. using tracers of salmon farm nutrients),
- Quantifying change in, or refining estimates of, other nutrient sources to the Marlborough Sounds systems, to provide context for salmon farm nutrient inputs.
- Validation and improved parameterisation of the Marlborough Sounds bio-physical model (e.g. seasonal phytoplankton abundance, mineralisation rates).
- Quantifying natural nutrient gradients within the Sounds (e.g. along cross-channel transects and in seafloor seep areas) to help inform monitoring station placement and provide context to the WQS thresholds.

It is also noted that relevant research may also be undertaken independently of this process (see Section 7.2.3), for example as part of a public or industry-funded science programme. The outcomes of such research could be integrated into the water quality guideline framework during subsequent review of the guidelines.

## 3.4 The water quality standards (WQS)

For Tier 1 monitoring, there are 'thresholds' for three water quality parameters: total nitrogen, dissolved oxygen and chlorophyll-a (Table 2). The initial thresholds were established by Morrisey et al. (2015) and are the 'water quality standards' (WQS) that monitoring results are compared against in order to maintain the Marlborough Sounds water quality status. The WQS were initially set with the intention that, if there is an unusual change in water quality, it will trigger an alert or response (Tier 2) notifiable by NZ King Salmon to MDC (Figure 3).

The WQS thresholds are intentionally conservative, in the sense that they are set below levels at which there would be imminent environmental harm. If one or more WQS are breached, it does not necessarily provide evidence that fish-farms are the cause of the breach (Morrisey et al. 2015).

The water quality standards were developed in such a way that, should water quality in the Marlborough Sounds become inconsistent with the water quality objectives, the WQS would trigger a management response. As such, by monitoring solely against the WQS thresholds, it was implied (see Morrisey et al. 2015) that several of the water quality objectives were being met (i.e. no monitoring additional to this should be required; also see note in Section 2.3).

The WQS are required to be reviewed periodically[12], and details of the first review are provided in Appendix 3**.**

**Table 2:Summary of the three WQS and how they are applied (see Appendix 3 for background on these thresholds). See Figure 4 for locations of QCS01 and QCS02. Chla; chlorophyll-a, TN; total nitrogen, DO; dissolved oxygen, WQS; water quality standard.**

| | Chl*a** | TN | DO | | | |
|---|---|---|---|---|---|---|
| WQS | ≤ 3.5 mg/m$^3$ | ≤ 300 mg/m$^3$ | > 70 %** | > 80 % | > 60 % | > 48% |
| Location | All stations | All stations | Within 250 m of the farm | All stations >250 m from the farm, except (QCS01 & 02) | All stations >250 m from the farm, (except QCS01) | QCS01 |
| Sample | 0–15 m depth integrated sample | | Everywhere in the water-column – based upon aggregated sensor data into 1 m depth bins and averaging readings within each bin individually | | | |
| Tolerance | Three consecutive months: at any one station, or at any station within the same Sound for three consecutive months | | | | On any single occasion | |

* As measured from water samples after passing through a GF-C filter (particles > approx. 1.2 µm).
**The near-farm (< 250 m) DO WQS and how compliance is measured against this WQS has been flagged as requiring a review at the next opportunity (see Section 7.2.2 and Appendix 3).

## 3.5 Management response

There are three 'states' within the management response chart (Figure 3): green, amber, and red. A breach of the same WQS in three consecutive months will trigger an amber state for compliance, and further action will be required (i.e. Tier 2 monitoring), potentially escalating to a red state (management actions to reduce water quality effects).

Each WQS will be treated in isolation for the purposes of counting successive breaches. For example, if a chlorophyll standard is breached in two successive months, and then a dissolved oxygen standard is breached (but the chlorophyll one is not) in a third successive month, this shall NOT constitute an exceedance.

[12] According to the BOI resource consent conditions.

The states as defined in Morrisey et al. (2015), are described below.

- **Green state**: is the default state, where the Tier 1 regional scale water-quality monitoring indicates nothing unusual. Monitoring and farming can continue.
- **Amber state**: One or more of the WQS thresholds has been exceeded. The water quality is in an unusual state. Analysis must be undertaken to determine whether fish-farming might be the cause, but in the meantime fish-farming may continue as normal.
- **Red state**: It has been determined that fish-farming was the probable cause of entry into the amber state, and the consent holder must develop and adopt a mitigation strategy aimed at returning the system to the green state. This strategy must include a deadline[13] by which restoration of a green state should be achieved.

The point at which a green state can be considered 'restored' following an amber or red state may need consideration on a case-by-case basis, and thus may call for consultation and expert judgement[14]. For example, if the weight of evidence compiled through the amber state had ruled out salmon farming as the likely cause of the exceedance, but the state of water quality had not returned to within the WQS within that time. In such a case, the WQS may need to be revised in some way that prevents repeated false positives and subsequent management actions from the consent holders for the same ongoing or repeated water quality issue.

13 This deadline will be determined by the Marlborough District Council as the regulator, in consultation with the fish farm operator. It will take due account of anticipated ecological response time-scales (including seasonality) and practicalities of implementing the intervention.

14 For example. in consultation with MDC, the relevant science provider, the Water Quality Standards Working Group and/or the Peer Review Panel.

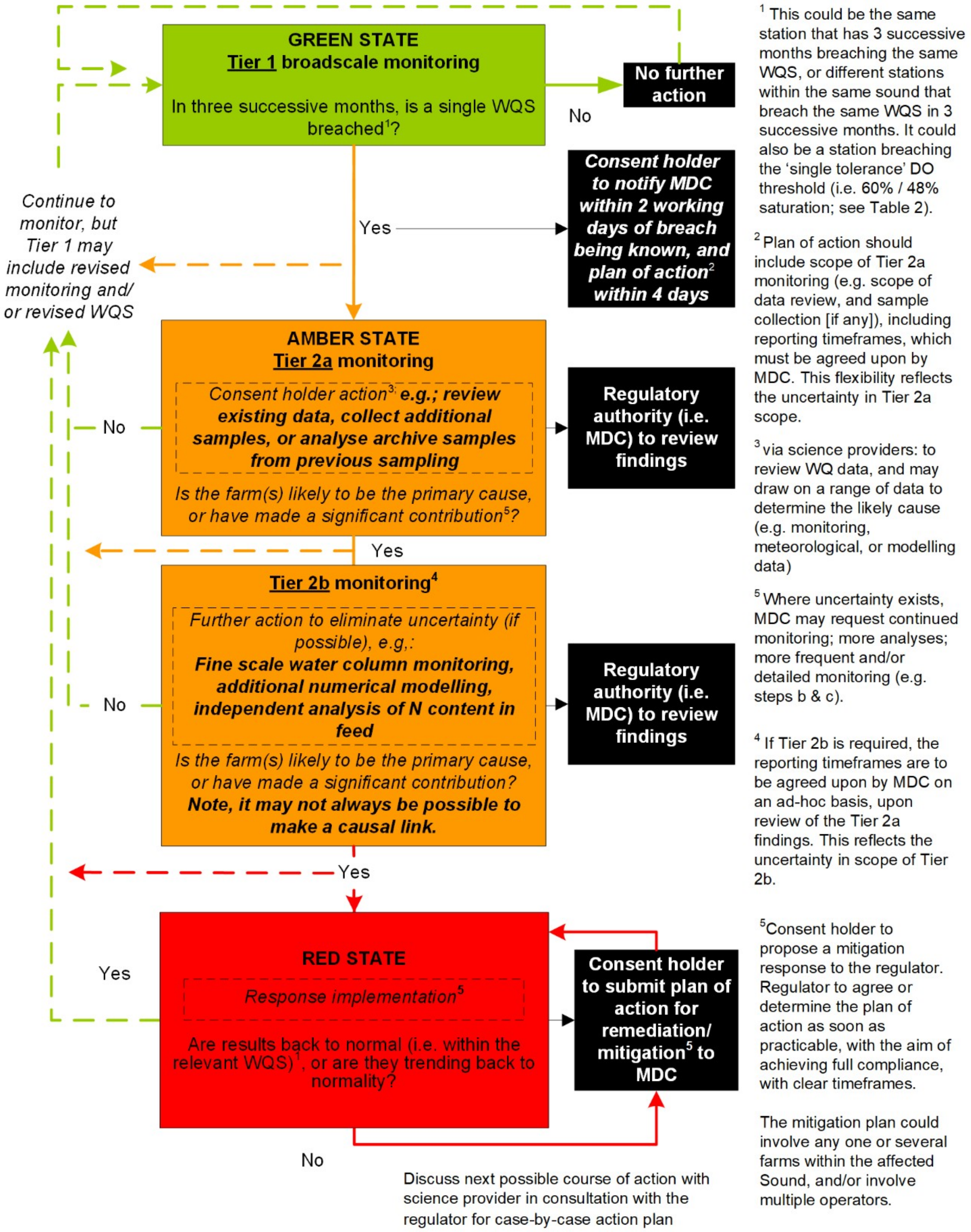


**Figure 3: Flow diagram illustrating the two-step water quality management regime and decision tree for water quality monitoring and management. Breach – a single result that lies outside of the WQS. Amber state –three consecutive months within each of which there was one or more breaches (of the same WQS) from within the same sound, or if the single tolerance DO threshold is breached.**

# 4 MONITORING GUIDELINES FOR TIER 1

Long-term and widescale monitoring has a greater ability to detect far-field effects of multiple farms contributing to the nutrient budgets of the wider ecosystem, than do short term or small-scale monitoring programmes. The Tier 1 monitoring design integrates with the Sounds-wide monthly monitoring, currently undertaken by MDC for State of Environment (SOE) monitoring (hereafter 'MDC monitoring').

Broad-scale monitoring is required since the effects of multiple farms on water column processes (e.g. phytoplankton production) may occur over time scales (days) and spatial scales (kilometres from farms) that lie outside the scope of farm-scale monitoring programmes (see Olsen et al. 2008).

While there is an explicit design for Tier 1 monitoring (Section 4), the design of Tier 2 and Tier 3 monitoring is only discussed conceptually within this document because these types of monitoring would be designed and performed on a case by case basis.

# 5 DESIGN CONSIDERATIONS FOR TIER 1 MONITORING

The water column monitoring design has been the result of an iterative process (which will continue into the future). The first step in this process comprised past discussions through the Board of Inquiry process for salmon farm applications, and subsequent work under the successful operational consents. Accordingly, during the development of these guidelines, specific consideration was given to:

a) New data from the MDC monitoring, and NZ King Salmon water column monitoring programmes, that have become available since the BOI process.
b) New information relating to salmon farm water quality effects both in the Marlborough Sounds, and in an international context. Of particular note, was modelling performed on the effects of existing and proposed mussel and fin-fish farms on water quality in the Sounds (Broekhuizen et al. 2015) and for potential and proposed salmon farm relocations (Broekhuizen & Hadfield 2016a, 2016b).
c) The initial water column monitoring design detailed in the baseline plan (Morrisey et al. 2014) and the subsequent NZ King Salmon monitoring plans (e.g. Elvines et al. 2016 and Bennett et al. 2018b), all of which gave regard to the consent conditions and water quality objectives from the BOI process. Specifically, the existing monitoring was evaluated against the following:
    - Do the data feed into management of salmon farms in the context of preventing water quality issues?
    - Do the data meet an overarching objective, that will lead to an increase in our ability to manage salmon farm effects on water quality?
    - Can specific objectives or monitoring needs be met more effectively using new or alternative techniques or sampling designs?

Regard was also given to the past recommendations from the annual monitoring reports (e.g. Elvines et al. 2017a) and baseline report (Morrisey et al. 2015).

The data from the mandated monitoring (e.g. Elvines et al. 2017a, b, Bennett et al. 2018a) at 500 m from the farms, and the results of the recent modelling performed for the region (Broekhuizen & Hadfield 2016a,b) support the need for a design that has less emphasis on monitoring in proximity to the salmon farms, and more emphasis on sampling for water quality on a wider-scale. Sample locations were 'selected' if they offered one or more of the following:

a) Increased coverage of areas within the Sounds that were shown to be susceptible to salmon farm nutrient enrichment effects[15]. Therefore, allocating sample stations in 'hot-spots' for phytoplankton growth in the Marlborough Sounds (areas such as Onapua Bay within Tory Channel/Kura Te Au, Kenepuru Sound and Tennyson Inlet).
b) Increased systematic spread of the sampling sites, including a range of site types (located in the mid- and far-field locations), to cover some locations where an effect would not be expected.
c) A dataset of historical water quality sampling data.
d) Integration with one or more existing monitoring programmes such as the monthly MDC monitoring or weekly Marlborough Shellfish Quality Programme (MSQP) monitoring. For example, the mid-channel focus that exists in the MDC monitoring programme means that the proposed new sampling areas would be more valuable in embayment locations.

Because water column monitoring was designed to operate in tandem with the MDC monitoring programme, we note that the Tier 1 monitoring design assumes that the MDC monitoring does not change. Should changes to the MDC monitoring occur, the monitoring design will need to be reviewed in light of those changes.

[15] Bio-physical water column modelling performed by Broekhuizen et al. (2016a&b) shows that generally the more elongated inner embayments within both Pelorus and Queen Charlotte are most susceptible for manifesting salmon farm nutrient enrichment effects, as these are the areas with higher water retention times. The majority of these 'most susceptible' areas are not monitored as part of the SOE sampling programme, nor the present salmon farm water column sampling programme.

## 5.1 MDC monitoring of the State of Environment (SOE)

The existing salmon farm water column monitoring design is integrated with the state of environment monitoring programme carried out by MDC, and the two sampling programmes will continue to be integrated going forward. A short description of the SOE sampling programme is provided below.

### 5.1.1 Monitoring programme overview

For the SOE monitoring programme, sampling occurs monthly, typically in the third or fourth week of each month. One day is spent sampling each of the Pelorus and Queen Charlotte Sounds. Monitoring stations are sampled using a 15 m hose sampler to collect a single integrated sample of the surface 15 m of water. A Van Dorn sampler is also used to collect a single water sample just above the seabed. One litre of water is drawn from each hose and Van Dorn sampler. They are individually bottled and chilled immediately.

A CTD cast is made at each station to measure turbidity, salinity, dissolved oxygen, temperature and fluorescence. In addition, a measurement of Secchi depth is also made at every station. Some monitoring stations do not have water sample collection. The distinction between these stations is shown in Figure 4.

Water samples are couriered (same day) chilled to the NIWA laboratory in Hamilton where they are filtered (if required) within 24 hours, and either analysed or stored for later analysis. With some exceptions, water samples are analysed for phytoplankton cell counts and biomass, suspended solids, volatile suspended solids, inorganic suspended solids, dissolved reactive phosphorus, ammonium, nitrite + nitrate, total dissolved nitrogen, total nitrogen, chlorophyll-a, dissolved reactive silica, total dissolved phosphorus, particulate nitrogen, and particulate carbon. For further detail, see the most recent report summarising the results (Broekhuizen & Plew 2018).

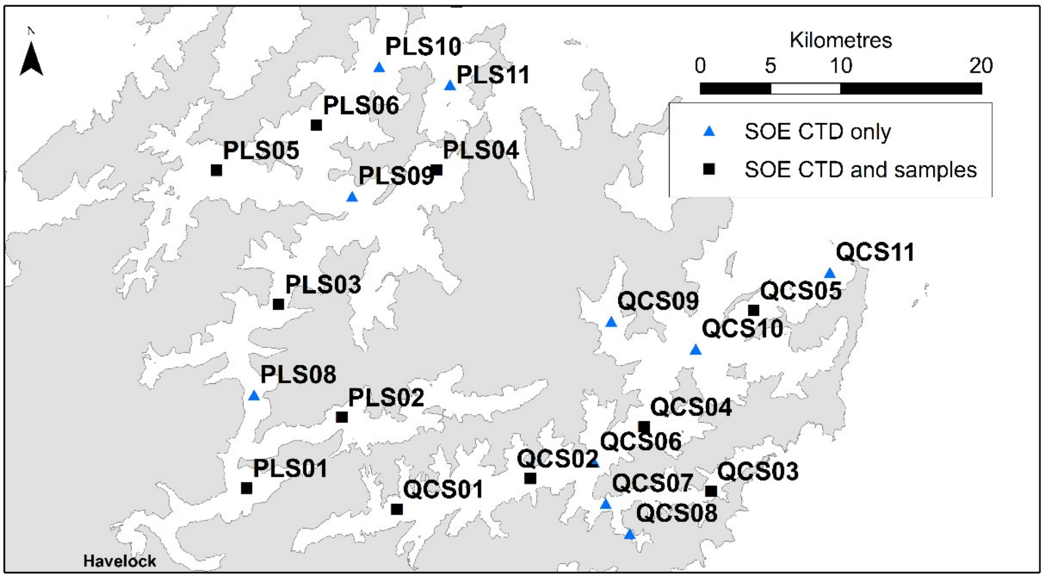


**Figure 4: MDC monitoring stations in the Marlborough Sounds.**

## 5.2 Tier 1 monitoring design

### 5.2.1 Station re-allocation

While the previous routine water column sampling design for the BoI farms comprised sampling stations clustered around each farm, the Tier 1 sampling station arrangement (Table 3**,** Figure 5) has a more regional-scale sampling approach. The working group saw little compelling justification for including near-farm monitoring in Tier 1 sampling (see Section 6.2.1). The exception to this is monitoring of near-farm dissolved oxygen; near-farm CTD casts have been retained in the interim, until the near-farm DO WQS can be comprehensively reviewed (see discussion in Appendix 3).

Tier 1 monitoring includes all MDC monitoring stations, as well as an additional five stations to be sampled each month (see Figure 5), located:

In Pelorus Sound:

- Tennyson Inlet
- Waitaria Bay
- Richmond Bay

In Queen Charlotte Sound:

- Onapua Bay
- Entrance to Tory Channel

The MDC sampling station QCS01 in Grove Arm was also seen as important to the salmon farming sampling programme (see Table 3).

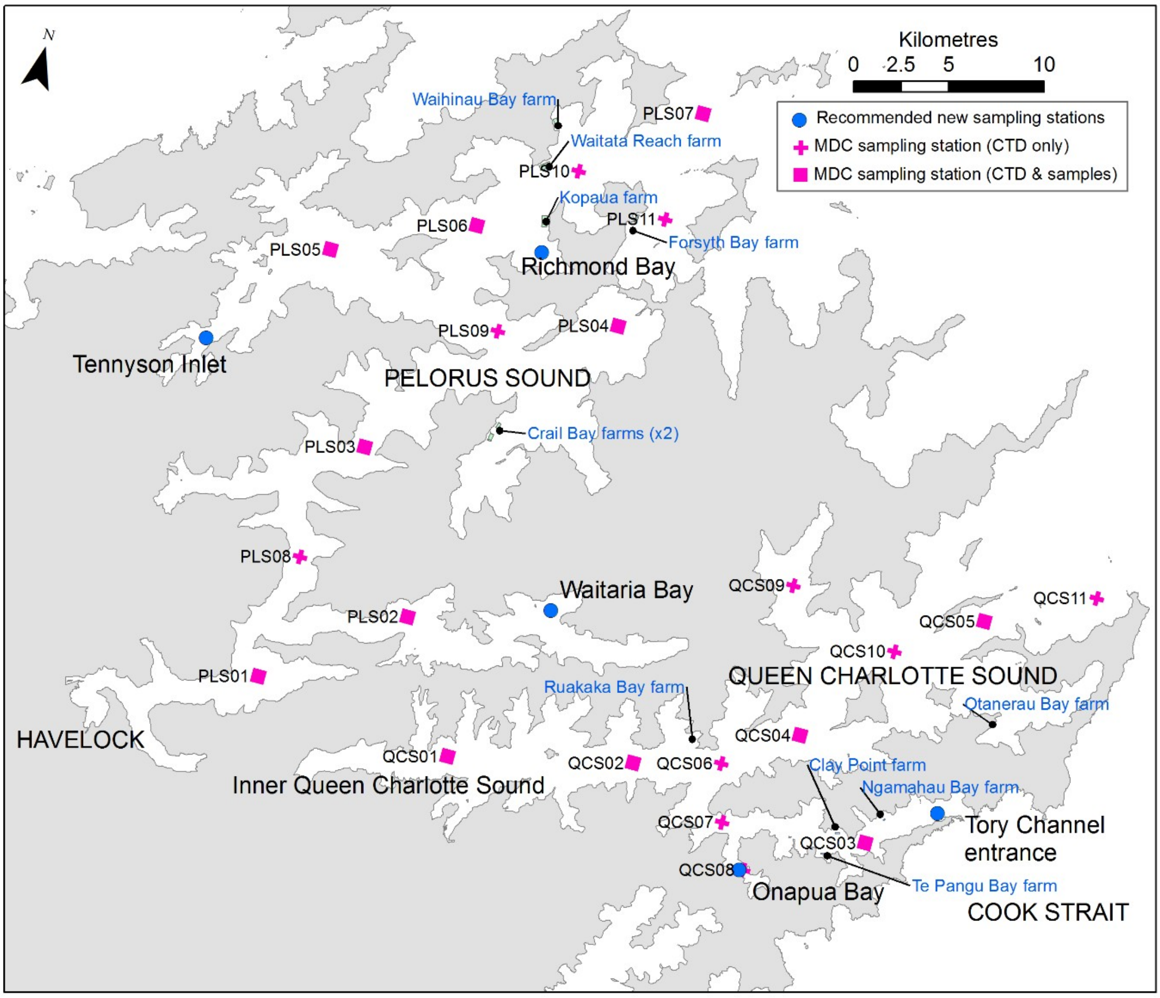


**Figure 5: Sampling stations for salmon farm Tier 1 water quality monitoring in the Marlborough Sounds, integrated with the MDC monthly state of environment (SOE) monitoring programme (PLSxx - QCSxx). CTD cast stations to monitor for near-farm DO are not shown.**

**Table 3:Sampling locations for the Tier 1 salmon farm water quality monitoring. It is not recommended the WQS be applied at new sampling locations (Onapua Bay, Tennyson Inlet, Waitaria), because the WQS thresholds were based on analysis of a dataset that had a mid-channel bias, thus there will be a high risk of false positives from the new locations which are in enclosed waters. These stations will be evaluated in the context of their incorporation into the WQS framework once sufficient data from these stations has been reviewed (see Section 6.2.2). 'Owner' defines which party is responsible for sampling at each location. CTD = conductivity (salinity), temperature, depth. Optional variables measured during a CTD cast are fluorescence as a proxy for chlorophyll-a, and turbidity.**

| Station | Variables measured | Owner | Comments | Comply with WQS? |
|---|---|---|---|---|
| Pelorus Sound/Te Hoiere | | | | |
| Tennyson Inlet | TN, Chla, depth resolved DO, temperature and salinity, phytoplankton | NZKS | Identified as an area susceptible to nutrient enrichment effects by the bio-physical modelling, optimises the spread of existing sampling stations within the Marlborough Sounds, and has publicly available historical information (Mackenzie 2018). | ✗ |
| Waitaria | TN, Chla, depth resolved DO, temperature and salinity, phytoplankton | NZKS | Identified as an area susceptible to nutrient enrichment effects by the bio-physical modelling, improves the spread of existing sampling stations within the Marlborough Sounds, and the nearby MSQP station means there are existing historical data in the area. | ✗ |
| Richmond Bay NZKS05 | TN, Chla, depth resolved DO, temperature and salinity, phytoplankton | NZKS | Improves the spread of existing sampling stations within the Marlborough Sounds, and has historical data from near to the site (Morrisey et al. 2015, NZKS annual monitoring data 2016–2018 and Gibbs et al. 1991, 1992). This site is also nearby to another salmon farm proposed relocation site and could thus act as a cumulative effects monitoring station for two farms, if the relocation proposals are granted. | ✓ |
| PLS01 - 07 | CTD and samples (see Section 5.1) | MDC | Existing MDC monitoring station | ✓ |
| PLS08 - 11 | CTD only | MDC | Existing MDC monitoring station | ✓ |
| Near-farm | Depth resolved DO, temperature and salinity. | NZKS | Retained for compliance with near-farm DO WQS. Measured 250 m downstream and upstream of the farm*. | ✓ |

| Station | Variables measured | Owner | Comments | Comply with WQS? |
|---|---|---|---|---|
| Queen Charlotte Sound/Totaranui | | | | |
| Onapua Bay | TN, Chla, DO, temperature, salinity, phytoplankton. | NZKS | Identified as an area susceptible to nutrient enrichment effects by the bio-physical modelling, improves the spread of existing sampling stations within the Marlborough Sounds, and has publicly available historical information as well as ongoing in-depth sampling for Chlorophyll-a and phytoplankton, including a moored sampling platform (e.g. Mackenzie et al. 2013). | ✗ |
| Tory Channel entrance (NZKS22) | TN, Chla, DO, temperature, salinity. | NZKS | This sampling station is important to provide context on incoming water quality to Tory Channel. There is also existing information from this station (NZKS baseline and monitoring data). | ✓ |
| QCS01 - 05 | CTD and samples (see Section 5.1) | MDC | Existing MDC monitoring station | ✓ |
| QCS06 - 11 | CTD only | | Existing MDC monitoring station | ✓ |
| Near-farm | DO, temperature and salinity. | NZKS | Retained for compliance with near-farm DO WQS. Measured 250 m downstream and upstream of the farm*. | ✓ |

* At fixed locations along the main flow axis.

### 5.2.2 Field methods and sample analysis

Tier 1 sampling stations should be sampled at the same time as sampling is carried out for the MDC monitoring, which is typically in the third or fourth week of every month. We do note that there are inherent limitations with single point in time sampling, in that it is unable to capture smaller-scale temporal variability (e.g. diel). Until such time as continuous monitoring data is able to be meaningfully incorporated into the BMP framework (e.g. see Section 7.2.3), monthly sampling for Tier 1 represents the best available technique that also meets practical considerations.

Sample collection protocols for Tier 1 sampling should also be adopted from the MDC sampling framework where applicable, so data collected under both sampling programmes are comparable. Specifically, surface to 15 m integrated water samples should be collected from each station, to obtain a single 1 L sample. *We note that this sampling regime differs from the MDC monitoring programme in that Tier 1 sampling does not require a near-bed sample to accompany the surface depth-integrated one.* The unfiltered sample should be kept on ice and sent to the laboratory on the day it is collected, so it can be filtered within 24 hours. The sample should be analysed promptly[16] for total nitrogen (TN) and chlorophyll-a (Chla). *We note that this analyte suite differs from the MDC monitoring programme* [17]. Remaining filtered sample and sample filters should be archived, frozen, in case required for further analysis in the event of an amber state. It is not recommended that filtering takes place in the field, as this may affect the comparability with the MDC sampling results.

Phytoplankton sampling (for taxonomic composition) is to be done at the broader scale Tier 1 monitoring stations, except at the entrance to Tory Channel (NZKS22; because this is a well mixed and highly flushed area more likely to reflect oceanic conditions from Cook Strait than conditions in the Sounds). Therefore, phytoplankton should be collected from the surface 15 m at consent holder sampling stations in Richmond Bay, Waitaria, Tennyson Inlet, and Onapua Bay[18].

Consistent with the MDC monitoring, CTD casts of the full water column profile should also be performed at all stations[19]. Preferably, the same CTD should be used for the both the MDC and the other Tier 1 station sampling on any given day, to ensure comparability among the data collected. Data collected should include depth profiles for at least:

a) Dissolved oxygen

[16] Once filtered and frozen, samples can be stored without degradation. The 'prompt' stipulation relates to any requirements that the regulator may place upon reporting times rather than any laboratory analysis requirements.

[17] All of the parameters selected for Tier 1 monitoring were considered individually for their usefulness, and this review is detailed in Appendix 4. In summary, measuring a large suite of parameters was not considered an informative exercise for the following reasons:

- the level of integration with the MDC programme, which provides monthly analysis on the full suite of variables, and
- the fact that samples can be archived for later analysis if required for a specific investigation into any observed water quality changes
- the fact that the three variables used for compliance with the WQS can themselves reflect changes in water quality.

[18] These stations were selected for phytoplankton sampling because there are presently few phytoplankton samples being collected in the most sensitive areas in terms of potential fish farm nutrient enrichment effects.

[19] Caution must be applied when performing the CTD cast to ensure the CTD does not disturb the seabed as this could affect the near-bed DO measurements (lower DO near seabed when disturbed by the CTD). Similarly, the CTD should be lowered and recovered slowly (<0.5 m $s^{-1}$) – so that the sensors have sufficient time to respond changing local conditions (the DO sensor, in particular, takes several seconds to equilibrate with the local environment – see page 157 of Broekhuizen & Plew (2018)).

b) Salinity and temperature.

Additional profile data that would add value to the monitoring includes:

c) Turbidity

d) Fluorescence.

To ensure comparability with the MDC sampling results, the lab methods, and CTD data processing methods should be the same as that used for MDC sample and data analysis. There are also recommendations listed in Appendix 5 to guide QA/QC processes, for integrated sampling programmes to ensure that the data remain robust and comparable. These water quality sampling and data storage protocols may need to evolve over time to ensure that data remains comparable.

# 6 REPORTING

These guidelines include reporting on several different time-scales: sub-annual, annual, and periodically (at least every six years).

## 6.1 Sub-annual reporting

Monthly results for total nitrogen, chlorophyll-a and dissolved oxygen from all Tier 1 monitoring stations must be reviewed by the science provider each month throughout the year, as soon as these results become available. Should there be a non-compliant event, the WQS and management response framework relies on rapid identification of potential compliance issues. It is therefore important to have a results processing system that prevents compliance issues being missed.

Ideally, the results would be openly accessible in an online platform (e.g. https://cawthron.shinyapps.io/WQ-Marlborough/) that is able to track compliance throughout the year leading up to annual reporting.

The results summaries for notification of non-compliance should be sent to monitoring@marlborough.govt.nz.

## 6.2 Annual reporting

The annual monitoring reports required under a resource consent should summarise the results from each year, as they pertain to compliance with the WQS. This reporting should include a summary of findings from any reef monitoring to aid interpretation and allow for comparisons between data sets. Specifically, regard should be given to the following information in the annual reports:

6.2.1 **Compliance with the WQS**. Results for TN, Chla and DO from surface samples at all stations within the 12-month period should be summarised in the annual monitoring reports. Assessment of compliance within that period in the context of the WQS and management response measures taken should also be provided.

While temporal comparisons of the monthly data need not be made formally (these are performed as part of the periodic review every 5 years, see next section), new data should be plotted with the historic time series, and regard should be given to trending change in a qualitative sense. If the data show anomalous patterns (i.e. trending change), the annual reports can recommend that a full statistical trend analysis be performed on the relevant sample parameters.

6.2.2 **Macroalgal biomass** increases (where relevant). This factor is presently addressed through reef monitoring, whereby a multivariate time series analysis on macroalgal prevalence is performed every alternate year (e.g. see Bennett et al. 2018b).

6.2.3 Discussion of any sampling difficulties or technical and data issues encountered during that year.

6.2.4 Feed (and nitrogen) discharged from the farm, including context of feed (and N) discharged from all farms within the same Sound within that 12 month period.

Physical water column properties from CTD casts (temperature, salinity, turbidity) need only be presented in the reports where context is required for interpreting focal data.

## 6.3 Periodic analysis of results

A periodic comprehensive analysis of all monitoring data would allow detection of any unexpected gradual trends in the data. The analysis would determine environmental performance in relation to the operational policy for water quality that are not able to be captured by the WQS compliance framework (e.g., phytoplankton compositional changes, or an increase in single-occasion exceedances of the WQS threshold). The analysis and interpretation could also elucidate system-wide changes that are not related to salmon farming, but that might feed into the adaptive management framework.

The report should comprise trend analyses[20] on key water quality indicators (see below) from both the consent holder and MDC monitoring stations. Feed inputs from for each Sound should be summarised in the report.

Specific questions that the periodic data analysis would address are:

6.3.1 Has there been an ecologically significant change in phytoplankton community composition? For example, dinoflagellate vs. diatoms, or more comprehensive taxon changes such as may be indicated by the phytoplankton community index (PCI; Tett et al. [2008]).

6.3.2 Is there an increased prevalence (frequency, intensity) of harmful algal blooms? A harmful algal bloom is defined as the cell concentration of a harmful algal species exceeding toxicity thresholds.

- These should be assessed in the context of existing/historical data, using the best available statistical techniques.

[20] For example Theil (1950), or Sen et al. (1968). Relevant examples of application can be found in Larned et al (2015) and Broekhuizen & Plew (2018).

In addition, although somewhat covered by the water quality standards compliance framework, the following should also be discussed:

a) Prevalence (frequency, intensity) of phytoplankton blooms. A phytoplankton bloom in this case is defined as chlorophyll-*a* ≥ 5 $mg/m^3$ (see Section 2.3), with no distinction being drawn between blooms which contain substantial proportions of harmful algae and those which do not.
b) Dissolved oxygen concentrations, as profile data, and as trends in reduced seasonal DO minima.
c) Nitrogen concentrations over time, as statistically tested trends[21].
d) Overall status of water quality, in the context of changes over time (specifically, deteriorations in water quality).

This periodic review should be done at least every six years, unless an earlier review is needed (e.g. review of the water column BMP guidelines, WQS non-compliance issues, feed step increases[22]). The analysis would ideally be performed in conjunction with reporting of MDC monitoring data, with the findings summarised in the annual monitoring report for that year, and in conjunction with review of the WQS (which are required every three years).

# 7 REVIEW OF THE GUIDELINES

## 7.1 Review process

The water column BMP guidelines are intended to be a living document that incorporates best available knowledge and technological developments into monitoring design, to ensure that the design always meets best practice. Accordingly, the guidelines will be reviewed every six years, unless an earlier review is needed. For example, an earlier review may be warranted if there are new salmon farm developments imminent, if fundamental methodological changes are proposed,[23] or if the WQS have been revised/need revising.

Similar to the development of these current guidelines, future reviews will involve a series of targeted workshops among the members of the working group, as well as external peer review by the peer review panel (PRP) set up through the Board of Inquiry process.

The working group recognises that the ability to: a) detect early signs of a deterioration in water quality; and b) attribute a cause to observed water quality deteriorations is limited by current state of understanding and monitoring technologies. Accordingly, we stress that future reviews of the water column BMP will incorporate new information (including from other research avenues) and technical innovations, to ensure that monitoring and management of water quality in the Marlborough Sounds remains current with best international practice and knowledge.

[21] As examples only; the probability distribution of the 70th percentile for each station, or a station/season basis.
[22] It is noted that the salmon farm staged developments are enforced with a minimum period of three years between feed discharge increases. The full review of results should be performed within two years prior to a feed step increase.
[23] The implication for the WQS process and framework from changes to the monitoring programme should be always be a review consideration (e.g. incorporating continuous monitoring platforms or more inner-embayment sampling stations into the monitoring programme).

Reviews should also take account of changes in pressures on the Marlborough Sounds and improvements in our understanding of the functioning of the Sounds that might warrant changes in the monitoring systems and thresholds, or interpretation of data etc.

## 7.2 Other considerations

### 7.2.1 Monitoring for localised effects

Monitoring of localised effects of the farm on water quality presents significant challenges. Further, the collection of these monitoring results has no clear objective or pathway to feed back into farm and effects management. A summary of key points made during the review in this regard are summarised below:

a) The link between feed input and single-point-in-time water nutrient sampling results near salmon farms is poorly correlated due to the dynamic nature of the environment (see Section 2.1 for further discussion). These single timepoint transect-based surveys are therefore unable to properly represent local-scale water column effects. Accordingly, the design is inadequate for meeting the objectives set out in the BoI consent conditions under condition 65/66e (see Section 2.1).

b) Increasing the sampling frequency or temporal resolution of regular surveys quickly becomes cost prohibitive.

c) Any monitoring for localised effects should be designed to address specific information gaps or clear objectives, which will contribute to the monitoring and management framework. This would fall under ‘Type 3’ monitoring under the water column BMP framework.

d) Such monitoring should be performed with a robust design that is able to meet objectives relevant to monitoring or management of water quality effects from the farm.

e) Questions on local-scale effects could be effectively answered by doing several, high-resolution time series sampling events at farms that are already operating at high production levels. This is the recommended approach for quantifying local-scale monitoring effects, but we note that the frequency of this approach is not consistent with that set out in initial consent conditions at the BoI farms (see Section 2.1), whereby original conditions required six-monthly surveys at all of these farms.

The objectives and how the results will feed into the monitoring/management framework should be well defined.

### 7.2.2 Future review considerations

During the guideline formation process, several matters were flagged as points to be given special consideration during the next review of the guidelines:

#### 7.2.2.1 DO WQS

Through the guideline formation process, the working group identified several considerations that need to be addressed with respect to the DO WQS that applies within 250 m of the farm during the next review opportunity. These are discussed in Appendix 3.

In addition, the inclusion of a 3-month criterion at QCS01 and QCS02, could be considered for these stations (in conjunction with the 1 month criteria), to ensure that sustained marginal conditions that do not breach the 1 month WQS are formally detected.

- **Phytoplankton monitoring at Waitaria Bay, Kenepuru**

Phytoplankton monitoring at the Waitaria monitoring station should be evaluated in the next review. This is because it was uncertain how distinct the phytoplankton communities in this new sampling location would be compared to existing nearby monitoring stations, and therefore how valuable continued phytoplankton monitoring would be at this location.

- **WQS for new monitoring stations**

We note that several new monitoring stations were added to the monitoring design of these guidelines. Three of these five monitoring stations are located in sheltered embayments (Tennyson Inlet, Waitaria, Onapua Bay). The historic Marlborough Sounds monitoring data that were used to derive the present WQS are mostly located in areas that are likely to be characteristically different to these areas, with respect to water column biological and physical properties (e.g. likely have higher water retention times / less-flushing and more stratification). That is, although there are some exceptions, much of the historic data comes from mid-channel locations within the Sounds, resulting in a mid-channel bias in the dataset. As such, and considering the scarcity of historical data from the three new stations, it was agreed that it would not be appropriate to immediately apply the present WQS to these new monitoring locations due to a high risk of false positives.

The next review of the guidelines should therefore seek to set WQS for the three new monitoring locations, when several years of data exist for these sites. Other historic data from these locations could be included in the analysis if these data are accessible.

- **Inclusion of continuous monitoring platforms**

A review of the MDC monitoring programme by Forrest et al. (2016) identified an opportunity for integration of real-time monitoring platforms and remote sensing data to increase the temporal (and spatial) resolution of the sampling for parameters like chlorophyll-a and dissolved oxygen. As research and validation enables the adoption of this technology for routine monitoring, this technology should be considered for use within the BMP framework.

Although not an alternative to taking physical water samples, the inclusion of these types of platforms into monitoring programmes needs be done with careful consideration, including how the data will be summarised and used, particularly in relation to any set compliance thresholds.

If continuous data are to be used as part of Tier 1 monitoring, the WQS would need to be reviewed in this context, and some of the scientific uncertainties around some of the data would first need to be overcome (see further discussion in Section 7.2.3). Nonetheless, the next review of the guidelines should include a review of relevant existing continuous data-sets to evaluate their use in the context of these guidelines.

- **National environmental standards**

MPI are investing in development of national environmental standards (NES), including those for marine aquaculture[24]. The NES for aquaculture is planned for release in approximately 2020 and may contain relevant information pertaining to these guidelines.

- **Salmon farms in low-flow environments**

Although it is also envisaged that the guidelines will be used for existing resource consents, the present guidelines were considered for application only to salmon farms that are sited in well-flushed locations (i.e. with high current flows).

At the time of writing, six consented salmon farming locations in the Marlborough Sounds were sited in low current flow (low-flow) environments. However, the fate of these low-flow farms was uncertain pending a central government decision on the potential re-location of some farms to high-flow locations. Given the time-constraints of the guideline formation process, and the uncertainty on whether these locations would be farmed in the long-term, no specific consideration was made for salmon farm water quality effects in low-flow environments. It is noted that all the low flow farm consents expire in either 2021 or 2024 and it is possible that MDC as the regulator will consider introducing these guidelines should new consents be sought, if they are not adopted voluntarily before the consents expire.

- **Review of the WQS: Changes in the mean without accompanying changes in the frequency of breaches**

The proposed management framework is focused on limiting the frequencies at which any part of a Sound exhibits characteristics that might indicate a trend towards an undesirable state. The framework also limits the extent to which any unwanted degradation of the Sounds-wide average state can occur[25]. However, a more stringent limit upon the 'degree of change' allowed for the Sound-wide, time-averaged state for each WQS (e.g. chlorophyll) has not been considered as part of the framework review, because:

(a) we have not yet accrued sufficient data to adequately characterise the extent of natural variability in on an embayment (or regional) scale, or annual-scale for these parameters and

(b) we are uncertain as to how one might go about defining absolute threshold concentrations (for example for chlorophyll or TN), which, if crossed might imply an 'ecologically

[24] http://www.mfe.govt.nz/marine/reforms/proposed-national-environmental-standard-marine-aquaculture

[25] As part of the investigations for the framework review, the existing data were interrogated to confirm that there was a moderately tight (also, positive and near linear) relationship between Sound-wide 'worst-case' state (e.g. maximum across all sampling locations for Chla or TN concentration) and the corresponding Sound-wide average state.

meaningful' change in other properties of the system (e.g. population or community characteristics in higher levels of the foodweb).

We suggest that endeavouring to identify such thresholds is a worthy long-term goal but that it will constitute a major research undertaking (perhaps, something more ambitious than even a Tier 3 activity).

The above discussion is not a formal recommendation to undertake such work as part of the next guideline, or WQS, reviews. However, it is something that should be borne in mind, and/or recognised as a limitation of the present WQS framework. This limitation with the WQS framework also highlights the importance of the periodic analysis of monitoring results.

### 7.2.3 Research needs

To help direct research funding relevant to salmon farm water quality effects monitoring and management, several priorities were identified during the workshops. These are summarised in the following paragraphs, with the first two being the highest priorities.

- **Tools for tracing salmon farm waste**

Research for tracing salmon farm nutrient waste (particularly dissolved waste) is very much in its infancy. In addition, there is limited understanding of the impact of salmon nutrient waste on primary production. Recent research has investigated the use of stable isotopes for tracing salmon farm dissolved wastes (e.g. Fossberg et al. 2018), but most has focussed on particulate wastes (e.g. Lojen et al. 2005, Holmer et al. 2007, White et al. 2017, Mayor et al. 2017, Colombo et al. 2016).

The working group identified the development and application of robust tracing tools (or suite of tracing tools) for the Marlborough Sounds as a priority area for future research. Having such tools would vastly improve our ability to attribute observed changes to salmon farming, or other nutrient sources (i.e. a method that would fit into Tier 2 monitoring).

- **High resolution sampling**

This could include field tests to understand the source concentrations and level of dilution and mixing around a salmon farm to validate modelling. For example, it could entail a comprehensive study to provide robust evidence on the localised effect of the marine farm on surrounding water quality. This could be done for several representative scenarios, including a 'worst case', in conjunction with modelling.

In addition, quantification of natural nutrient gradients within the Sounds (e.g. along cross-channel transects and in seafloor seep areas) may be useful to help inform monitoring station placement and provide context to the WQS thresholds.

- **Research for model parameterisation**

Perform investigative studies for validation or improved parameterisation of the Marlborough Sounds bio-physical model (e.g. seasonal phytoplankton abundance, mineralisation rates).

- **Nutrient sources in the Marlborough Sounds**

The working group noted that better quantification of other nutrient sources to the Sounds would improve our understanding of the system's primary productivity, and the relative importance of nutrient contributions from salmon farms. For example, current estimates of oceanic inputs, which are likely to be the largest source of nutrients to the regions, are very limited and improved information from continuous monitoring and improved modelling would improve the accuracy of these estimates.

There is also high interannual (and seasonal) variation in the amount of nitrogen contributed to the Marlborough Sounds system from rivers and oceanic sources. This variation is driven primarily by climatic factors. So, despite salmon farm nutrient contributions remaining reasonably predictable among years, salmon farm nitrogen emissions are relatively more influential to the Marlborough Sounds system during years in which river and oceanic inputs of nitrogen are 'low'. In addition, WQS are more likely to be exceeded when natural inputs are particularly high. Thus, quantifying the nutrient inputs from sources other than salmon farms should improve our ability to investigate causality for water quality changes, and contribute to developing ecosystem-based management approaches.

The working group therefore identified that a better understanding of nutrient contributions to the Marlborough Sounds would be a key area for future research.

#### 7.2.3.1 Operational model with 'smart triggers'

The working group notes that new and/or existing models could be developed to improve our ability to interpret data and anticipate responses to system disturbances. One such example is developing an operational model for managing the risk of water quality effects occurring. The model could incorporate what is already known about seasonally varying nutrient contributions to the Sound from all sources (including existing research and models), with a 'smart trigger' system using WQS.

The WQS would only initiate a management response sequence if the contribution of salmon farm nutrients were found to be high relative to other sources. The model could also be extended to include climatic factors, which increase the risk of natural algal blooms occurring, and allow the farms to be managed in such a way as to reduce both the potential for farming to exacerbate algal blooms, and the potential impact of blooms on salmon farms.

#### 7.2.3.2 Continuous and near-real-time monitoring (buoy platforms), remote sensing (satellite)

The use of these technologies, in parallel with existing data collection could form a more effective integrated design that could capture multiple stressors/discharge sources in the Marlborough Sounds region, not just those from salmon farming. However, many of these technologies and methods are still in their infancy (e.g. marine nitrate sensors and *in situ* cytometric phytoplankton cell count technologies) and a need has been identified for further testing and validation before significant investment for large monitoring programmes. Careful planning at a Sounds-wide level would optimise the use of these tools within the existing monitoring regimes, rather than employing this technology on an ad-hoc basis such as in individual consents or sub-areas within the Sounds (Forrest et al. 2016).

#### 7.2.3.3 Seabed sampling for water quality monitoring

Other types of sampling may be just as effective as water sampling (if not more so) at capturing changes in water quality or system productivity. Certain benthic indicators can integrate water quality changes over a longer period. A signal may be apparent in the benthos after the system has reverted to a normal state (e.g. bloom events). Examples of these indicators include organic material, nitrogen and phosphorus, and biological activity measures such as microbial biomass and nitrification (Meyer-Reil & Köste 2000, Dell'Anno et al. 2002). Another example is the use of reef monitoring (e.g. Dunmore 2017) to indicate nutrient enrichment effects on these hard substrate habitats adjacent to the farms, with particular regard given to macroalgae, which assimilates nutrients directly from the water column.

At present, although benthic monitoring is required under salmon farm consents, these programmes do not target locations within the Marlborough Sounds most susceptible to eutrophication effects (e.g. enclosed embayments). The SOE monitoring programme does not have a benthic monitoring component, but this is something that could be considered for integrating into monitoring for detecting regional system changes.

# 8 ACKNOWLEDGMENTS

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# 10 APPENDICES

## 10.1 Appendix 1. History of water quality sampling under salmon farm resource consents in the Marlborough Sounds.

Prior to 2015, water column monitoring consent requirements for salmon farms in the Marlborough Sounds typically focussed on localised effects. Monitoring involved water sampling and CTD casts, often just collected annually (at a single point in time) in close proximity to the farms (within several hundred metres).

The 2012 resource consent application (or Board of Inquiry; BOI) process for three new farms (see EPA 2013) highlighted the potential for wider scale water quality effects in the Marlborough Sounds from salmon farming, as increased dissolved nutrient loading (primarily nitrogen) to the system (also see Gillespie et al. 2011). The application process also revealed a lack of long term datasets for understanding baseline conditions in the Marlborough Sounds. Accordingly, the new farms were required to follow a staged farm development approach, along with a management framework that established and implemented interim Water Quality Standards (see Appendix 3). The staged development started with low annual feed discharge levels, that ramped up after certain criteria were met. This precautionary approach was implemented so that any unexpected effects (especially to the water column) had enough time to become evident, and appropriate action taken should thresholds be exceeded.

In addition to the staged approach and the interim water quality standards, an intensive water column sampling programme was prescribed through the consenting process. To comply with requirements laid out for the BOI, the sampling programme concentrated almost all of its effort nearby (at 500 m from the farm, and at the net pen) to each of the three new salmon farming sites (NZ King Salmon sampling programme; see Morrisey et al. 2015). The sampling stations for the NZ King Salmon monitoring programme were located according to areas identified by physical modelling that predicted the dispersion of nutrients derived from salmon waste around farms. The modelling was conservative in the sense that it did not incorporate biological parameters, such as assimilation of nutrients by phytoplankton. In addition, contextual information on water quality in the Marlborough Sounds was provided by the State of Environment (SOE) water column monitoring programme run by Marlborough District Council (see Section 5.1).

The three new farms that were granted consent began operating in 2015/2016, after baseline water column data had been collected over a period of 1.5 years (in 2013 and 2014; see Morrisey et al. 2015). During the first three years of the new farms' operation (2016 – 2018), the results from the NZ King Salmon sampling programme were measured against 'compliance' thresholds (Water Quality Standards; WQS) for certain water column parameters (chlorophyll-a, total nitrogen and dissolved oxygen). In addition, periodic transect-based near-farm water sampling was performed as a requirement under the initial consent. The associated conditions required that these transect-based surveys be undertaken at each farm, twice per year, until two years after a stable level of maximum feed discharge level was reached, and no future increases were proposed.

In 2015 and 2016, new resource consents were also granted for two existing farms (Figure 1), that had been in operation since 1992 (in Te Pangu Bay) and 2007 (at Clay Point). These consents both adopted similar interim Water Quality Standards to those established for the BoI sites. This means that all of the high-flow farms in the Marlborough Sounds are now required to operate under the water quality standards management framework. The seven remaining farm sites, which are all in low-flow areas (Figure 1) are due to be considered for consent renewal in 2021, 2024, and 2031.

## 10.2 Appendix 2. Calculating nitrogen released from salmon farms.

Protein is composed of approximately 16% nitrogen by weight (Stead & Laird 2002), and this equates to an average nitrogen content of about 6.5% of the dry weight of feed. About 30% of this is retained by the fish, thus about 70% is released into the environment (e.g. Gowen & Bradbury 1987, Stead & Laird 2002). The amount of nitrogen released into the environment can therefore be reliably estimated from feed use.

- The NZ King Salmon annual report for the 2017/2018 period reports the biological feed conversion ratio (bFCR[26]) to be 1.81% (which includes fish that did not survive to harvest) (NZKS 2018).
- Values of feed protein content and the weight of feed discharged at the BoI salmon farms from 1 January 2017 to 28 February 2018 (values provided by NZ King Salmon) suggest that the weighted-average protein content in salmon feed is about 40.8%.
- Using 40% as an approximate feed protein content, we can estimate that for every tonne of feed used, 49 kg of nitrogen is released (or, 88.6 kg of nitrogen released per tonne of salmon production).

These calculations could be scaled to a farm, or a Sound (with multiple farms), to obtain good estimates of the nitrogen contributions from salmon farming over a given period of time.

The estimates are reasonably robust against changes in the FCR, for instance, a ±10% change equates to about a ±3% change in the nitrogen emission estimate. However, the emission estimate is more sensitive to the protein content, with a ±10% difference in the protein content equating to about a ±13% change in emissions.

## 10.3 Appendix 3 Review of the 'initial water quality standards' set in Morrisey et al. 2015.

### 10.3.1 Background

The initial water quality standards (WQS) were developed by Morrisey et al. (2015), as part of the baseline reporting for the three salmon farms granted through the BOI process (see Appendix 1). The initial WQS were used for the first three years of salmon farm operation (2016–2018) for these farms. Morrisey et al. (2015) made it clear that; a) the initial WQS thresholds and framework represented a 'precautionary' regime, and b) the initial WQS were the first iteration to an adaptive process for managing salmon farm water quality effects, and should be reviewed and changed where necessary[27].

The resource consents that were granted through the BOI process required the initial WQS to be comprehensively reviewed[28] after three years in operation. It was recommended that the review include not only initial WQS thresholds, but also the management response framework, sampling frequency and the variables selected for use as WQS (Morrisey et al. 2015). This appendix provides an overview of the first

[26] The bFCR describes the proportion/amount of dry feed amount (e.g. kg) that is required for a one unit increase in wet fish biomass (e.g. 1 kg), and is estimated from the industry reported figures (which also include fish that died, but were not sold). The bFCR was selected for estimating nitrogen release as it best describes the nutrient retained by the fish removed at harvest and the fraction of nutrient lost to the environment can be estimated from this. By contrast the economic FCR (eFCR) value may be higher, as it only considers the fish that are able to be sold after harvesting(i.e. excludes mortalities).

[27] For example, a more detailed analysis of field data may be necessary to select more "biologically significant" thresholds.

[28] As stated in the consent conditions.

3-year review. For more information on how the initial WQS were set, readers are referred to Morrisey et al. (2015)

### 10.3.2 Supporting information

Modelling to predict salmon farm effects (performed since the Board of Inquiry proceedings), does not predict large changes in water quality from the consented salmon farm developments (Broekhuizen et al. 2016a,b), and at most there would be less than a 10% change in chlorophyll standing stock in sheltered embayments.

The most recent review of the SOE data shows that there has been;

- evidence of a subtle increase of suspended inorganic solids in Pelorus Sound since mid-2014 (most notably, inner Pelorus Sound), and
- some evidence of increased nitrate in both sounds, concurrent with a reduction in ammonium.

The review concluded that "The nutrient and chlorophyll concentrations are consistent with the view that these sounds are near the oligotrophic-mesotrophic boundary, in terms of trophic classification" (Broekhuizen & Plew 2018). The Marlborough Sounds were said to be in an oligotrophic-mesotrophic state prior to the 2015–16 salmon farm developments (EPA 2013 and references therein).

### 10.3.3 1-3 year review considerations

The first review of the initial WQS comprised evaluating the present WQS framework according to the two key questions below:

- Is the monitoring frequency appropriate?
  The monitoring frequency was considered with respect to the ability for the WQS to elicit a management response in a timely manner. No analysis was performed to answer this question, but there was a consensus that the sampling frequency was set appropriately and could effectively elicit a management response. Less frequent sampling would make the period too long between water sampling events to detect a change (false negatives), and potentially increase the time over which effective additional monitoring/management actions could take place. More frequent sampling would a) increase the risk of false positives, b) require a restructure of the WQS compliance regime which is presently structured to evaluate results from successive sampling events on a monthly scale[29] (see Section 3.5), and c) become prohibitively more expensive.

- Is the numerical threshold and the way it is applied appropriate for each WQS parameter?
  The appropriateness was evaluated by performing trend analysis (see Broekhuizen & Plew 2018) for each water quality parameter[30] measured in the surface samples from stations that are part of the SOE monitoring programme. The objective of this was to determine if there had been any trending change in each of the measured parameters. Had there had been a deterioration apparent in the analysis of any of the parameters (indicating a deterioration in water quality), the DO, Chla,

[29] More frequent sampling would require an analysis into temporal autocorrelation for each variable to prevent the occurrence of false positives (e.g. ensuring non-compliance would not result from one short-term one-off water quality event that was measured on multiple sampling occasions).

[30] The full suite, as measured in the SOE monitoring programme

and TN thresholds would have been considered for their effectiveness at eliciting an alert or management response within this time period (i.e. are the thresholds too high?). In contrast, the occurrence of false positives (threshold possibly too low?) was considered.

It is noted that the previous WQS framework was applied only to stations within the NZ King Salmon monitoring programme (i.e. those clustered around the farms, as well as several reference stations that are shared with the SOE monitoring station). This review process has brought to light that this approach was not aligned with how the TN and Chla WQS were intended to be applied (as specified in Morrisey et al. 2015). Rather, both the TN and Chla WQS[31] should have been testing for compliance at the NZ King Salmon monitoring stations, *as well as all of the SOE monitoring stations*. Accordingly, the following sections summarise TN and Chla results in the context of SOE monitoring results only (consistent with the new design in these guidelines, which looks at changes at the scale of region). Results from Tier 1 monitoring stations are summarised in the annual monitoring reports for these farms. Other threshold specific details are provided in their relevant sections.

### 10.3.4 Total nitrogen (TN) WQS

Total nitrogen was implemented as an initial WQS because in nitrogen limited systems it can be a useful indicator of potential productivity of the system, thus relevant for assessing water quality shifts relative to historical probability distributions (Morrisey et al. 2015).

The initial TN WQS threshold of 300 $mg/m^3$ was set using existing historical information up to 2015. Specifically, 300 $mg\ N\ m^{-3}$ equated to approximately the $95^{th}$ percentile of the data that were available when the preliminary WQS for TN was set (Morrisey et al. 2015). Accordingly, the occurrence of any surface samples within a Sound[32] that has concentrations above this threshold in three consecutive months would elicit an amber state. The threshold was not intended to apply to within 250 m of the net pen edge.

Looking only at the SOE monitoring data, there have been no occasions when an amber state would have been triggered in either Sound during this time using the present WQS threshold. The SOE data has shown no significant increase in TN concentrations in either sound, with the exception of one sampling station (PLS4; Broekhuizen & Plew 2018). The ecological significance of this should not be overstated given the short time series of data, and the small scale of the trend. Further, the marginally increased nitrate concentrations and decreased ammonium concentrations within the Sounds are not an effect that would be expected to manifest from salmon farms.

### 10.3.5 Chlorophyll a WQS

Chlorophyll a (chla) was implemented as an initial WQS because it is also an indicator of primary productivity, thus can inform assessments of system nutrient enrichment.

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[31] Dissolved oxygen WQS framework was correctly applied to only the NZ King Salmon monitoring stations.
[32] It is noted that this interpretation differs from the WQS framework that was implemented previously (see Section 4.5 in Elvines et al. 2016), whereby only results from the NZKS monitoring station clusters were compared with the TN (and DO) WQS.

The initial chla WQS threshold of 3.5 mg/m$^3$ was set using historical data up to 2015. This value equates to approximately the 95$^{th}$ percentile of chlorophyll concentrations measured in the Sounds in the past (see Morrisey et al. 2015). The occurrence of any surface samples within a Sound with concentrations above this threshold in three consecutive months would elicit an amber state.

Prior to the WQS becoming operative, there were two events that would have comprised an 'amber alert' under the WQS framework (one in each of Pelorus and Queen Charlotte Sound; Figure 6). In Queen Charlotte Sound, one amber state would have been triggered in September 2017 by the innermost QCS sampling stations (QCS01 and 02). Since 2011, there has been no meaningful increase in Chla concentrations in this Sound (Broekhuizen & Plew 2018). Several PS sampling stations (PLS4, 5 and 7) in surface or nearbed samples show a significant increase in Chla, but the ecological significance of this should not be overstated given the short time series, and the small scale of the trends. Since the WQS have been in operation, and looking only at the SOE monitoring data, there have been no occasions in Pelorus Sound whereby an amber state has been triggered in either sound during this time using the present WQS threshold.

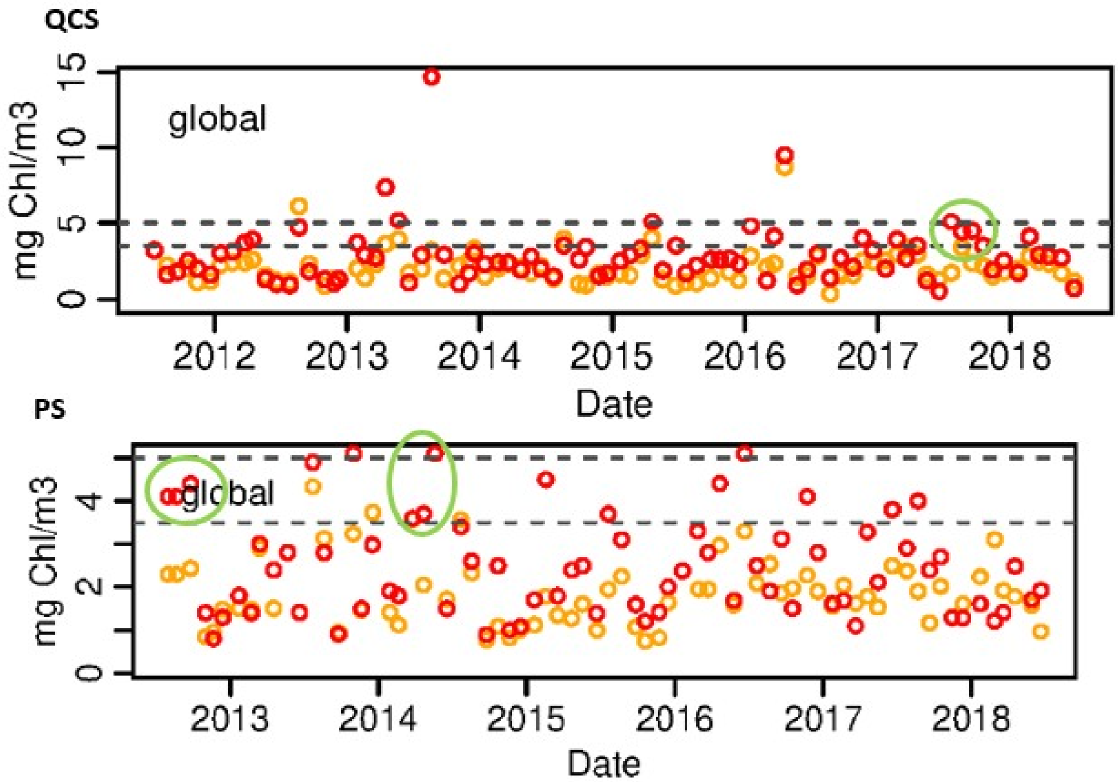


**Figure 6: Chlorophyll a concentrations (mg/m$^3$) in surface 15 m integrated samples (red) and as fluorescence (orange) from each SOE station within Queen Charlotte (QCS) and Pelorus (PS) Sounds (from Broekhuizen & Plew 2018). Green circles indicate events that are consistent with 'amber alert' criteria. Note that stations from the NZ King Salmon sampling programme are not included.**

#### 10.3.5.1 The Chla WQS in relation to the 'eutrophic' state classification boundary

The working group thought that it was important to clarify the Chl-a WQS threshold (3.5 $mg/m^3$) in the context of the trophic state classifications as discussed in the board of inquiry process.

The lowest bound of a eutrophic state as defined in the Board of Inquiry process (EPA, 2013), was 3.0 $mg/m^3$, simply representing a category boundary along a continuum of nutrient and productivity characteristics of a water body. The Chl-a WQS threshold is higher than this (at 3.5 $mg/m^3$), but was set to take into account historic system variability in Chl-a concentrations (being approximately the 95$^{th}$ percentile of chlorophyll concentrations measured in the Sounds in the past [Morrisey et al 2015]). This variability arises naturally, for example from seasonal phytoplankton bloom events within the Marlborough Sounds, which is a system presently classified as oligotrophic/mesotrophic. If chlorophyll concentrations were shown by the monitoring results to rise such that they were persistently close to (or above) the 3.5 mg Chl $m^{-3}$ threshold, the system would have meaningfully moved towards a eutrophic state. The threshold of 3.5 mg Chla $m^{-3}$ does not imply that such a change is acceptable, rather, the implementation of the threshold provides confidence that any such change would be unlikely to go without detection. Firstly, just three sequential breaches are required to trigger an investigation (rather than the many that would typically be required before change could be considered persistent). Secondly, using the data gathered to date, there was found to be a moderately tight, positive near-linear correlation between the maximum chlorophyll concentration measured anywhere within a Sound and the sound-wide average concentration, and the mean and medians are both invariably substantially smaller than the maximum. Thus, by constraining the frequency with which the maxima can exceed a given threshold, the extent to which an upward trend in the Sounds-wide average chlorophyll concentration can occur before it is detected has also been constrained. Finally, by introducing a periodic analysis that explicitly requires calculation of long-term trend characteristics, it has been ensured that such trends will be detected even if no exceedances are triggered beforehand.

### 10.3.6 Dissolved Oxygen WQS (life supporting capacity)

Dissolved Oxygen (DO) is essential for healthy system functioning and can therefore be useful for indicating the system's overall health. Reductions in DO can indicate excessive nutrient loading from an increase in primary productivity, without there being a measurable increase in either TN or Chla. This is because concentrations of Chla (and indirectly, TN) can be kept in check (up to a point) by zooplankton grazing. Thus, the DO WQS represents water quality measure that is a quasi-independent from TN and Chl-a.

It is important to note that DO can also fluctuate naturally with temperature and upwellings of oceanic water, as well as on a daily scale in response to diel changes in biological activity, and this must be borne in mind when interpreting DO in an effective consent compliance sense.

The threshold for net pen, 500 m and reference stations for each farm was that DO (as % saturation) should not drop below 90%. The threshold was derived from baseline data collected at these monitoring stations prior to farm installation (i.e. in the outer Pelorus Sound, and in the outer Tory Channel regions). The threshold was applied to all depths[33], for data collected from stations only in the region of the salmon farms (i.e. only to data from the NZKS monitoring stations).

In addition, there was a numerical threshold for the net pen station; whereby DO (as % saturation) should not drop below 70%. Similar to the 90% threshold, this applied to all depths.

#### 10.3.6.1 Revision of the DO WQS (more than 250 m from the farm)

The panel considered the intent of the DO threshold in light of the BOI consent conditions; which is to preserve ecological integrity. Significant changes to the DO WQS more than 250 m from the farm are recommended on the basis of the intent of this WQS. The changes are that:

a) the DO WQS should be applied Sound-wide, in order to capture DO changes in the entire system that might be a result of nutrient enrichment, rather than around the farms themselves, which is more likely to be related to fish respiration and excretion. This would be consistent with TN and Chl-a WQS. However,
b) the initial DO WQS of 90% or more (for the 500 m and reference stations), which was based on data collected from farm sites, would not be an appropriate threshold to apply to all regional Tier 1 monitoring stations within the sounds (e.g. inner Sounds). Accordingly, the WQS threshold of 90% needs to be revised.

An analysis of the Sounds-wide DO data collected to date shows that the present 90% threshold would have triggered an amber state on five occasions for each Sound if it were to have been applied to SOE monitoring results from the entire Pelorus and Queen Charlotte Sound systems. In fact, rarely were all monitoring stations above this threshold. The stations consistently falling well below this threshold were the inner Sound SOE monitoring sites; QCS01 and QCS02.

The data from all SOE monitoring stations are shown in Figure 7, and the number of theoretical occurrences of 'amber states' in the dataset are shown in Table 4, for both Queen Charlotte and for Pelorus Sound. Results using lower thresholds of 80%, 70% and 60% are also shown in both. The deeper waters of inner Queen Charlotte Sound (stations QCS01 and QCS02) have exhibited moderately low oxygen saturations during late summer/early autumn in most years. This is believed to be reflect the combination of: (a) oxygen consumption as organic matter which accrued in this region during the summer months breaks down, (b) relative isolation from the atmosphere (due to stratification within the water-column) (c) relatively slow horizontal exchange with the more rapidly flushed and persistently high-DO waters of Tory Channel and central/outer Queen Charlotte Sound and (d) the fact that (recently discovered) freshwater seeps at the seabed are likely to be introducing water that has a low oxygen content. In addition, although it is less frequent, DO is often less than 90% at the entrance to both Sounds due to an upwelling of oceanic bottom waters with lower DO saturation values, or warming events (e.g. El Niño) resulting in overall reduced systemic DO (e.g. Bennett et al. 2018a).

The previous DO WQS dealt with low DO events in proximity to the farm using a 'second step' threshold measure, which comprised calculating a new threshold based on outer Sound, upstream 'reference site' DO

[33] For data processing, the CTD down-cast data were averaged to depth bins of 1m. The minimum average bin value observed throughout the binned profile is relevant to compare with the DO WQS.

saturations (PLS06 and 07 in Pelorus Sound, or QCS22 in Tory Channel). This meant that stations near to the farm with DO similar (within 1.2%) to that at the upstream reference sites would not constitute a breach of the WQS. However, this second step measure would not prevent false breaches from sites within the inner sound when these stations are included into the WQS compliance regime.

These natural low DO events have triggered what are now believed to be 'false positives' (i.e. potentially prompting a salmon farm management response to effects when there are none). Given that the low DO events were not likely to have been triggered by the fish-farming activities, we think it prudent to revise the DO WQS to reduce the risk of future false positives.

The new DO WQS is 80%, for both Sounds, at all monitoring stations with the exception of QCS01 and QCS02[34]. This lower threshold will help prevent false positives while still ensuring that DO is kept at a level well above that required to maintain healthy (aerobic) function within a coastal water-body and also retaining reasonable ability to detect more subtle decreases in DO. It is noted that this threshold is lower than the previous 90% threshold, which was aimed at detecting system change within a small sub-region of the Sounds. Having a DO WQS that is more sensitive to smaller system changes within all areas of the Sounds would require site-specific DO thresholds, rather than a single numerical threshold for all stations.

An additional 'bottom line' threshold for DO has also been integrated into the framework as an additional safeguard to trigger action when the DO saturation is at somewhat of a 'historical extreme', and low enough to cause chronic stress.

The bottom line WQS threshold for all stations (except QCS01) is 60%. The relevance of the 60% level of DO saturation is that it represents a biologically significant threshold (Vaquer-Sunyer & Duarte 2008). Dissolved oxygen below this level is likely to be harmful for marine biota such as fish and crustaceans if sustained for long periods. At QCS01 we adopted a different threshold; of under 48%, in recognition of the fact that dissolved oxygen saturation values have dropped below 60% during late summer/early autumn in all but one year since monitoring began (but show no sign of long-term downward trend that might be associated with the fish-farms that are already present in Tory Channel and wider Queen Charlotte Sound).

[34] Where low systemic DO is known to occur for extended periods (months).

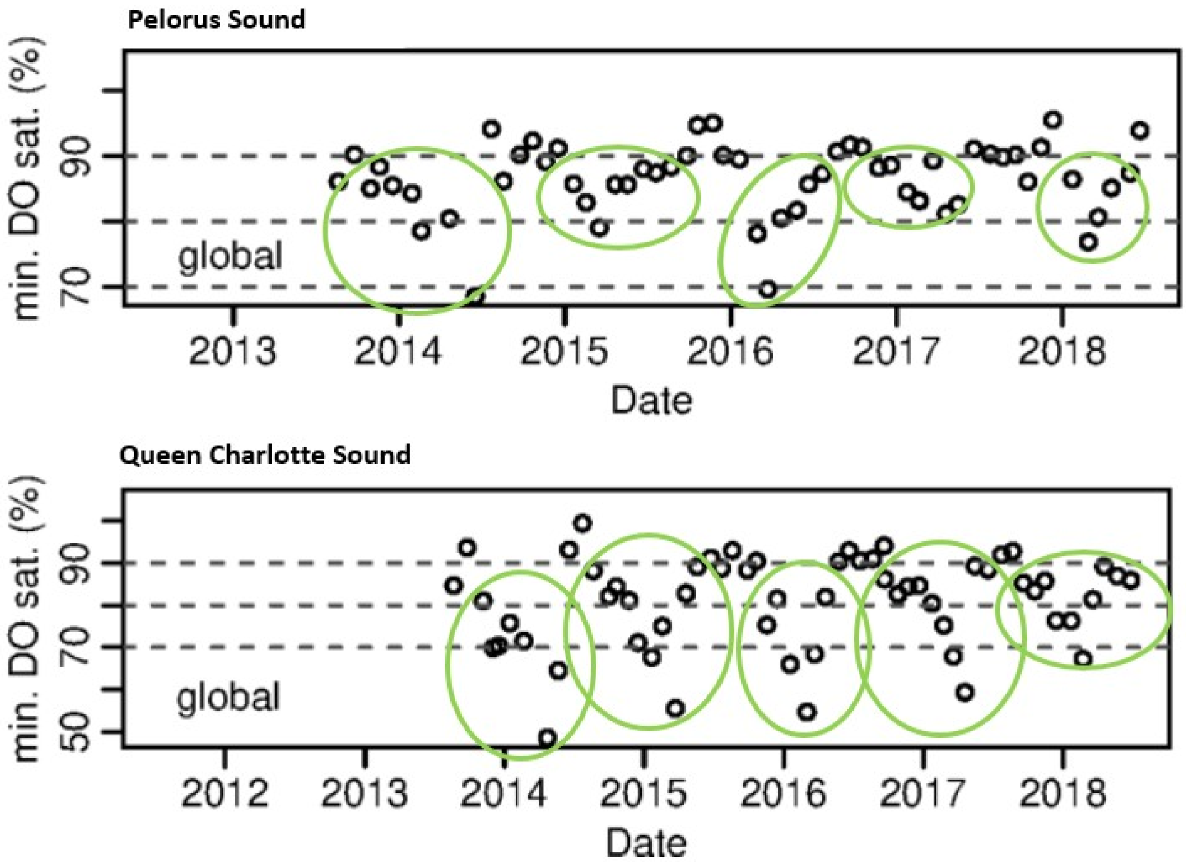


**Figure 7: DO time series at all stations, displaying minimum average DO from 1 m depth bins across the full water column profile at each station within Pelorus Sound (top) and Queen Charlotte Sound (bottom). Green circles indicate events that are consistent with 'amber alert' criteria. Note that stations from the NZ King Salmon sampling programme are not included.**

**Table 4: Summary of dissolved oxygen saturations at the SOE monitoring stations for varying DO saturation thresholds in Pelorus and Queen Charlotte Sounds. The number of theoretical equivalents to an 'amber state' is also shown (summarised from Broekhuizen & Plew 2018)**

| Sound | Saturation threshold | No./proportion of months with 1 or more station below the threshold | | # of events that would comprise an 'amber state' |
|---|---|---|---|---|
| Pelorus Sound | 90% | 39 (of 57) | 68% | 5 |
| | 80% | 6 (of 57) | 11% | 0 |
| | 70% | 2 (of 57) | 4% | 0 |
| | 60% | 0 (of 57) | 0% | 0 |
| Queen Charlotte Sound | 90% | 46 (of 59) | 78% | 5 |
| | 80% | 20 (of 59) | 34% | 5 |
| | 70% | 11 (of 59) | 19% | 1 |
| | 60% | 4 (of 59) | 7% | 0 |

#### 10.3.6.2 Considerations for the near-farm DO WQS (less than 250 m from the farm)

The primary mechanisms causing reductions in DO in proximity to the farm are fish respiration and increased biological activity from microbial degradation of farm-derived organic matter. Both of these mechanisms cause pronounced ‘episodes’ of low DO related to feeding activities, thus DO reductions around the farm are not only influenced by tides and mixing but also by fish activity throughout the course of a day. By contrast, at a broader scale, potential reductions in DO related to salmon farming are more likely to be caused by increases in primary productivity (and subsequent degradation of phytoplankton biomass) from farm-related nutrient enrichment effects, and are inherently less variable at daily time scales compared to near-farm DO levels.

The working group questioned the need for routine monitoring of near-farm DO levels. However, based on the mechanistic differences behind the near-farm and broad-scale DO WQS, and time constraints on the guideline development process, a comprehensive review of this WQS was precluded on this occasion. Accordingly, the working group proposes the near-farm DO WQS, and how compliance is monitored against it, is reviewed at the next available opportunity, with the following considerations in mind:

- DO is not effectively monitored pen-side using single-point-in-time CTD casts given the potential daily fluctuations in DO around the farms. Further, non-compliance only after a three-successive monthly breach would be likely to result in false negatives, thus possibly not triggering management actions if required.
- It is in the interest of the consent holder to maintain water quality (in particular DO) around the farm. Because a good DO environment is necessary for fish health, there is an incentive for the consent holder to manage DO levels around the farms.
- The consent holder therefore typically monitors DO on a daily basis; for example using spot measurements or continuous loggers.
- Localised DO reductions around the farm can be modelled as can be done for nutrient increases around the farm.
- Finer-scale temporal resolution sampling (or use of continuous data loggers) can provide a better picture of diel changes in DO around the farm to better understand the risk of occurrence of DO reductions that might be harmful to marine biota.

Until the near-farm DO WQS can be comprehensively reviewed, existing monitoring (monthly CTD casts within 250 m of the farm) should be continued for assessing compliance with this WQS.

### 10.4 Appendix 4. Overview of water quality monitoring parameters

The samples collected under the SOE monitoring programme are analysed for a large number of parameters. The BOI consent conditions also prescribe a large number of parameters to be measured during initial sampling. Many of these parameters do not provide good context for nutrient enrichment from salmon farming, or for causality if water quality deteriorations are observed. The selected sub-set of variables for Tier 1 monitoring (TN, Chla and DO) act as an early warning for system wide change. Stored samples can be analysed for additional parameters should the need for this information arise. Extended storage timeframes (more than two months) may need to be arranged with the laboratory by special request.

We note that there is an existing knowledge base for water column dynamics of sheltered embayments in several case study areas (i.e. Grove Arm (Broekhuizen & Plew 2018), Onapua Bay (e.g. Mackenzie et al. 2013), Tennyson Inlet (Mackenzie 2018)). If further information gaps are identified which need to be addressed, this monitoring (e.g. including additional parameters) can be performed under Tier 3.

The following table provides background information for each measure used to infer water quality, in the context of nutrient enrichment from salmon farms.

| | |
|---|---|
| Nitrogen | Nitrogen is contained in salmon feed as proteins, and fish metabolic waste is nitrogenous (Bureau 2004). Salmon excrete dissolved nitrogenous waste through the gills, in the form of ammonium and urea (approximately 80–90%, and 10–20% respectively). This results in localised, elevated dissolved nitrogen concentrations in the water column around finfish farms. The rate of excretion of both dissolved nitrogen forms in teleost fishes is highly variable in time (Karakassis et al. 2001), and can be related to (but not necessarily coinciding with) feed consumption among other things (Merino et al. 2007 and references therein). Ammonium and urea are either a) taken up by phytoplankton or c) converted through biological processes (nitrification) to nitrate-N/nitrite-N; nitrate nitrogen may be assimilated by phytoplankton or lost from the system (denitrified) on time-scales of days-weeks. Particulate nitrogen (PN) is also a type of nitrogen sourced from salmon-farms, as uneaten fish food and faeces.<br><br>Increased nitrogen in marine systems can increase primary productivity if the system is nitrogen limited, which is the case in the Marlborough Sounds (Gibbs et al. 1992). If excess nitrogen levels are sustained, the system dynamics (e.g. primary productivity) can shift and water quality can deteriorate (MPI 2013). |
| Total Nitrogen (TN) | The Total Nitrogen (TN) analysis measures all of the nitrogen within a sample. Nitrogen is usually present in various forms (particulate and dissolved nitrogen species – see above). Therefore, monitoring the TN concentration means none of this nitrogen 'picture' is missed in the monitoring results. Accordingly, TN has been assigned a WQS threshold for monitoring and management framework. TN should be measured at all stations. Constituent nitrogen species (e.g. $NH_4$, $NO_3$) in the sample can be measured from archived samples retrospectively, if further information is needed. |
| Ammonium ($NH_4$) and urea-N | Ammonium is the main form of dissolved N excreted by salmon, but it is also ubiquitous in the marine environment and is readily taken up by phytoplankton. Urea-N is also excreted by salmon, and both urea and ammonium concentrations would be expected to be elevated around the net pens during periods following feeding. There are a multitude of other sources of ammonium in the marine environment (e.g. mussel farms). In comparison, urea has relatively fewer sources; e.g. marine mammal excretions and other (non-farmed) fish excretions. Net pen concentrations of these forms of nitrogen could provide context on the local-scale increases in dissolved nitrogen at the farm, if measured in time with episodes when the salmon are excreting. Local-scale effects are not monitored as part of Tier 1 monitoring, so measuring these forms of nitrogen is not required for the Tier 1 monitoring programme. As mentioned above, nitrogen species can be measured from archived samples retrospectively, if further information is needed. |
| Nitrite + nitrate ($NO_2$ + $NO_3$). Combined analysis expressed as '$NO_x$' | Nitrate and nitrite (NOx) is a measure of the soluble oxidised, inorganic nitrogen compounds. The combined measure is dominated by nitrate, and is used to infer nitrate concentrations. NOx is ubiquitous in the marine environment, and readily taken up by phytoplankton (bioavailable). Nitrogen originating from salmon feed would only be present as NOx after undergoing remineralisation, following phytoplankton/bacterial uptake of $NH_4$ and decay of these organisms, and is thus not informative for looking |

at localised effects of salmon farms. Nitrate can be measured from archived samples retrospectively, if required.

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| Particulate nitrogen (PN) and particulate carbon (PC) | Particulate nitrogen, as the name suggests, is a measure of all nitrogen in a sample present in particulate form. In context of salmon farms, PN is sourced from uneaten feed and faeces. In addition, a major source of PN in a sample includes the water column phytoplankton and zooplankton. The latter means that PN (as well as particulate carbon; PC) is a good measure of system state, because it is an integrated measure of primary production. Increases in primary production may more reliably manifest in PN and PC rather than in Chla. PN and PC can both be measured retrospectively from archive samples if required for Tier 2 monitoring. Based on a recommendation in Morrisey et al. 2015, particulate nitrogen (PN) was measured in the NZ King Salmon water quality monitoring programme for at least the first 12 months of monitoring. It was recommended that it be measured because it is a good indicator of seston abundance, and is thus capable of integrating increases in primary productivity. However, to date, there has been no comprehensive evaluation of its usefulness for providing context on water quality changes. Accordingly, PN was evaluated as part of this review for integration into the WQS framework. The evaluation can be found in detail in section 6 of Broekhuizen & Plew (2018), but in summary, PN shows autocorrelation on timeframes of more than 1 month. Chlorophyll has no autocorrelation at one month intervals, meaning that changes in primary productivity are integrated into the PN (and PC) fraction for a longer period than for Chlorophyll. This means that because chlorophyll is more variable in time (than PN or PC), it might be difficult to identify meaningful increases or change, compared to PN and PC, which show more stability in changes over time. While Chlorophyll-a provides a WQS for Tier 1 monitoring, the results of this cursory assessment indicate that PN and/or PC would be useful parameters for providing context for Tier 2 monitoring. Both could also be used in targeted studies to confirm modelling outputs. It is important to bear in mind other particulate sources (i.e. terrestrial) when interpreting results for these parameters. |
| Silicate (DRSi) | Silicate is a structural element of the diatom phytoplankton group, thus the available form of silicate (dissolved reactive silicate) is essential for diatom growth. While nitrogen is the main limiting nutrient in Pelorus Sound (Gibbs et al. 1992), under certain conditions, diatom growth can be limited by the availability of silicate. Limited diatom growth provides an opportunity for other phytoplankton groups to dominate (e.g. dinoflagellates).<br><br>Silicate is only a minor component within salmon feed, and natural silicate concentrations in Pelorus Sound are at levels that rarely (if ever) limit diatom growth (Broekhuizen & Plew 2018, Heyns 2018). As long as this remains the case, localised increases in dissolved nitrogen such as those associated with salmon farms are not likely to result in compositional changes to phytoplankton communities. The monthly MDC monitoring collects silicate data using a spatially robust monitoring design for this purpose, and as such, it was not considered appropriate to extend the monitoring of this parameter to additional stations. |
| Phosphorus (DRP, TP) | The soluble form of phosphorus; dissolved reactive phosphorus, is used for algal growth (phytoplankton and macroalgae). The total phosphorus (TP) measure of a sample includes all forms of phosphorus (particulate, organic, and inorganic). Phosphorus is a more important measure in coastal ecosystems with long residence |

times, such as some areas in the Marlborough Sounds. Sustained high phosphorus levels can cause algae to proliferate, but only in systems that are phosphorus limited. Phosphorus is a small component within salmon feed, and is excreted through fecal material, thus is mostly associated with the particulate fraction.

Phosphorus is ubiquitous in Pelorus Sound (Broekhuizen & Plew 2018) and as such should not be limiting to algal growth. Accordingly, any periodic increases in this nutrient is not likely to increase phytoplankton growth. However, changes in nutrient ratios (specifically N:P:Si; nutrients that limit phytoplankton growth) have the potential to alter phytoplankton composition. For this reason, it is important that data from SOE monitoring locations continues to feed into trend analyses of elemental ratios as in Broekhuizen & Plew (2018).

The monitoring data from the BOI salmon farms, which are located in well-flushed locations, shows occasional concentrations of both TP and DRP that are marginally elevated in close proximity to the net pens (sampled downstream; e.g. Elvines et al. 2017a). Reef monitoring to date at these locations do not show any signs of excessive macroalgal growth, and none would be expected with the level of mixing that occurs at these sites, and the marginal and localised nature of the increases observed around the farm.

The monthly MDC monitoring collects P data (DRP, TDP) using a spatially robust monitoring design for Sounds-wide monitoring purposes, and as such, it was not considered appropriate to extend the monitoring of this parameter to additional stations. Furthermore, ongoing reef monitoring, and/or benthic monitoring in embayments nearby to the salmon farms should detect any increases in excessive macroalgal growth in proximity to the farms should they occur.

Phytoplankton

Phytoplankton are the base of the food chain in marine ecosystems. They are responsible for primary production, and cycling of nutrients. These communities respond to the availability of nutrients in the water column, but community dynamics are also governed by other physical factors such as mixing. Increases in nitrogen (in a nitrogen limited system such as the Marlborough Sounds) would see increased phytoplankton growth, and under the 'right' conditions (stratification, warmer water) could also result in more frequent bloom events. Changes in the nutrient ratios (N:P:Si) could mean that other phytoplankton groups could dominate. The Marlborough Sounds has diatom dominated phytoplankton communities, where nitrogen is presently the limiting nutrient (Broekhuizen & Plew 2018; Gibbs et al. 1992).

Having historical data that can indicate what the expected composition of phytoplankton might be in an area at a given time of year is useful for determining shifts in community composition. While the presence of a harmful algal (HA) species or bloom would not immediately indicate eutrophication, if the waters in Pelorus sound were becoming enriched, HA species may become more prevalent in samples, and harmful (and non-harmful) algal blooms may become more frequent.

Compositional phytoplankton community data can also be used to estimate taxa specific biomass. However, unless considerable time is spent deriving taxon specific cell sizes (at a low enough taxonomic resolution) within the samples, these estimates are relatively crude. Although crude, the cell count derived biomass method does have the advantage of being able to provide relative biomass estimate for each taxon group (diatoms vs. dinoflagellates). There is presently technology under development to automate this process (e.g. https://mclanelabs.com/imaging-flowcytobot/).

Embayments are the most likely places where phytoplankton community changes would manifest (Broekhuizen et al. 2015), so regional scale monitoring of phytoplankton communities was identified as an essential component for Tier 1 monitoring. Context on elemental ratios can be provided by data from the SOE monitoring locations.

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| Chlorophyll-a | Chlorophyll-a is a proxy for phytoplankton biomass, and is the most widely used indicator of phytoplankton biomass globally. Chlorophyll-a can be measured directly from water samples, or can be measured using fluorescence as a proxy. Although there are constraints with using this proxy (e.g. quenching, calibration and data validation requirements), chlorophyll-a as fluorescence has the advantage of being able to be measured continuously (e.g. from a mooring platform, or deployed sensor for water column profiling). In addition, fluorescence can be obtained from satellite images. Chlorophyll-a is important for Tier 1 monitoring as an indicator of primary production, and there was an initial WQS set for Chla in 2015. |
| Dissolved oxygen | Primary production (photosynthesis) generates free oxygen, but the subsequent decay of the organic matter generates a corresponding oxygen demand. Increased primary production in a given period of time (e.g. over spring and summer) can result in decreased oxygen availability later (during autumn / winter). Thus, a decrease in oxygen availability would be expected with a decrease in water quality from nutrient enrichment. A longer-term trend of reduced dissolved oxygen relative to previous seasons may indicate increased respiration from increased phytoplankton growth. Dissolved oxygen is an important parameter to measure in Tier 1 monitoring. The WQS for this parameter has been revised to be able to accommodate sampling data from all monitoring stations.<br><br>It is important to note that phytoplankton respiration rates (and therefore dissolved oxygen) fluctuate on a diel scale (increased respiration during dark hours), as well as on a seasonal and annual basis. There are also significant seasonal physical influences on dissolved oxygen concentrations, for example, stratification, upwelling of deep oceanic water, and the correlation between dissolved oxygen and temperature.<br><br>Near bed reductions in DO occur naturally as a result of a) different water column properties lower in the depth profile, and b) benthic respiration. Increased enrichment of seafloor sediments once the farm is in operation may increase benthic respiration and thus, a more dramatic decrease in near-bed DO might be observed on a localised scale; beneath the farms (but would not necessarily indicate wider-scale eutrophication effects). In addition, salmon respiration would result in episodes of reduced DO near the net pen in surface waters. |
| Salinity and temperature | These two measures can be used to determine mixing and exchange properties at a given site, and to compare the 'likeness' of the water body at different monitoring locations, to give context to the nutrient and phytoplankton results seen in the monitoring. This context is important to interpretation of results. Because salinity and temperature are easy to measure and provide important context these parameters, they will be measured at all locations for Tier 1 monitoring. |

Turbidity

Turbidity is the inverse of the clarity of a water body, and turbidity can thus be used as a proxy for clarity. Turbidity can be slightly increased in close proximity to salmon farms by dislodged fouling material from net cleaning, and by the increased particulate matter from feed and faecal matter. Many factors affect turbidity in the Marlborough Sounds, including sediment and freshwater run-off (which bring with them nutrients) and resuspension. As such, turbidity levels have high natural variability, particularly in Pelorus Sound which has a major riverine input and is in a highly modified catchment/coastline. Because freshwater and sediment run-off can be indicated by changes in turbidity, these data can help to provide context about the likely sources of nutrients if increases are observed, for example, following a large rainfall event.

A reduction in water clarity would be expected if Pelorus Sound waters shift toward a more eutrophic state, due to the increase in primary productivity (phytoplankton growth). Although this is measured as chlorophyll-a in Tier 1 monitoring, turbidity can be measured through an additional sensor attached to a CTD to provide an additional (optional) measure of water turbidity.

## 10.5 Appendix 5. Quality assurance / quality control (QA/QC) processes for data collected under the integrated monitoring programme

An integrated monitoring approach does require good management to ensure data consistencies and sound record keeping. To ensure that the requirements of all parties within the sampling programme are met, there are several important considerations. These are listed below as guidelines, to minimise data handling risks, and to increase the efficiency of data handling and data processing for all parties:

- Sample labelling/ID protocols. Ensure both parties are using, and agree on, a consistent approach. Sample ID conventions should be intuitive, and database-query friendly.
- Chain of custody forms for sample collection and receipt.
- Instrumentation QC:
    - Instrument selection – is the resultant data quality fit for purpose?
    - Keep good records of instrument calibrations and measurement configurations.
    - Perform cross checking of instruments periodically.
    - Communicate instrument changes to other parties.
- Perform QC tests:
    - Duplicate a sample each month from one station/sample (i.e. 15 m integrated and near-bed water samples for laboratory analysis).
    - Send a field-filtered sample for analysis against a non-filtered sample.
    - Perform a CTD comparison cast on every occasion that multiple CTDs are used.
- Use comparable methods. To ensure comparability with the sample results between both components of the sampling programme (i.e. SOE and consent holder), the lab methods should be the same. If not, methodological or inter-laboratory comparisons should be performed regularly (e.g. phytoplankton cell counts are currently done at two different labs). Analytical considerations should include;
    - Detection limits (and analytical precision)
    - Laboratory accreditations
    - Laboratory blanks (often required for field filtration)
- Data QC protocols. For example, if anomalous values are detected or discarded from one dataset, what are the recording procedures and when/how should this information be communicated to other users?
- Define the data sharing and exchange processes and standards. Specify:
    - The 'state' of the data that gets shared (raw and uncleaned, cleaned, or processed [CTD]).
    - The format in which the data is exchanged.
    - How retrospective data corrections are managed.
    - CTD data processing methods (if sharing processed data).

## 10.6 Appendix 6. Members of the working group from left to right; Andrew Baxter (Department of Conservation), Steve Urlich (Marlborough District Council [now Lincoln University]), Mark Preece (NZ King Salmon), Rob Schuckard (Sounds Advisory Group), Ben Knight (Cawthron Institute), Richard Ford (Fisheries New Zealand), Niall Broekhuizen (NIWA), Deanna Elvines (Cawthron Institute).

## 10.7 Appendix 7. Synopsis of Terms of Reference for the formation of these guidelines.

### Best Management Practice guidelines for salmon farm management in the Marlborough Sounds: Water quality

Terms of Reference for the development of best practice guidelines for water quality standards

#### 1. PURPOSE

The New Zealand King Salmon Co Ltd (NZ King Salmon), Marlborough District Council (Council) and the Ministry for Primary Industries (MPI) are committed to ensuring Marlborough has salmon farming practices which are environmentally, economically, socially and culturally sustainable.

The co-development of best practice management guidelines ('guidelines') for water quality standards is a key contribution towards this goal. Should this be achieved, the guidelines will complement the successful development of benthic (seabed) guidelines in 2014, which have been adopted in several consent renewals and are now widely accepted by the community.

The development of water column guidelines will provide a standardised and accepted framework for performance assessment. It will establish performance expectations; and provide a flexible protocol which can be responsive to the development of new monitoring technologies.

The guidelines will seek to ensure that salmon farming is undertaken within the carrying capacity of the Marlborough Sounds environment.

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#### 2. RATIONALE

Salmon farming in the Marlborough Sounds is a relatively young industry (~30 years). There has been rapid evolution in consenting arrangements for existing farms over the last decade as experience and knowledge has grown, such that there is now a wide range of consent conditions for water quality (Appendix 1). Associated with these changes has been significant progress in the development of farm techniques and environmental monitoring models.

The 2012 Board of Inquiry (BOI) appointed by the Environmental Protection Authority (EPA) canvassed the state of existing knowledge on salmon farming in the Sounds. Considerable uncertainty was highlighted in identifying and determining the significance of environmental effects of salmon farming and how they should be managed. The BOI paid particular attention to water quality and hydrodynamics in deciding to grant consents.

To manage the risk and uncertainty the BOI agreed to an adaptive management regime for each of the three new farms. The aim of adaptive management is to manage the effects on the environment avoid compromising near- and far-field biological values. This is to be informed by monitoring of benthic and water-column conditions, and of threatened species.

The BOI granted consents for farm sites at Ngamahau in Tory Channel, and Waitata and Kopaua (Richmond) in Pelorus Sound. These consents set water quality standards (Appendix 1). Baseline monitoring for a year was required before each farm could be established. In addition to a compilation and review of historical water quality data, dedicated baseline monitoring for a year was required before each farm could be established. The consents enabled interim water quality standards to be developed for nitrogen, chlorophyll and dissolved oxygen. These are due for review in December 2018.

Water quality standards are also up for review at Te Pangu farm in Tory Channel in January 2019, following the renewal of the resource consent in 2016. The consent renewal implemented interim water quality standards which were consistent with Ngamahau, Waitata and Kopaua.

By 2019, there will be at least seven years of water quality monitoring data collected at monthly intervals by Council in both the Pelorus and Queen Charlotte Sound for its state of the environment programme. This has been augmented by concurrent monthly data collected by NZ King Salmon at Waitata, Ngamahau, and Kopaua since 2014 for consent compliance purposes.

This provides a greater empirical basis on which to review interim water quality standards for chlorophyll a (as a proxy for marine photosynthesis and productivity), total nitrogen (as an indicator of trophic status) and dissolved oxygen (as a measure of life-supporting capacity).

There is also the possibility that monitoring may become more frequent should continuously recording instruments on moored buoys be installed at some future time. The substantial increase in real time data will also inform the iterative development of hydrodynamic models to characterise the far-field effects of farms on water quality throughout the Marlborough Sounds and to enable a reduction of individual site water column monitoring.

These developments reflect the ongoing improvements in monitoring to detect and understand the effects of aquaculture on the coastal waters of the Marlborough Sounds. This will enhance the precision of adaptive management responses to ensure sustainable management. As such, the guidelines would be subject to periodic review as the information base grows over time.

## 3. GOALS, PRINCIPLES AND OBJECTIVES

Best Management Practice guidelines could contribute to the following goals:

- Marlborough benefiting environmentally, economically, socially, and culturally from a well-managed salmon industry.
- Providing assurance to all sectors of the community that the environment is being well managed.
- Optimising the production capacity at farm sites within appropriate constraints.
- A future regulatory regime that provides greater simplicity, flexibility and certainty.

The objectives of the Best Management Practice guidelines are to:

- Facilitate early identification of adverse effects
- Define the necessary response and remedial action if necessary.
- Define best practice monitoring and reporting.
- Contribute to the development of appropriate planning and consent conditions.

- Set out a process for regular review of the guidelines.

In the development of the best practice guidelines, consideration of the manner in which regulatory control is exercised is important. The guidelines will be designed to help standardise existing consent conditions across all farms and inform future consenting arrangements. They should also assist in the ongoing evolution of the wider regulatory framework at the regional scale.

Council and NZ King Salmon have agreed to work together to develop the guidelines by late 2018. The Ministry of Primary Industries has also agreed to assist the parties, as the guidelines will contribute towards the successful implementation of the Government's Aquaculture Strategy.

## 4. SCOPE

Currently NZ King Salmon have 11 sites consented for salmon farming in the Marlborough Sounds (Figure 1). These have a range of water quality standards and consent conditions associated with feed discharge (Appendix). There is also an MPI-led farm relocation process underway, which may result in changes to the consent regime should a number of farms be shifted to areas of higher water flow.

NZ King Salmon is the sole producer of salmon in the Marlborough Sounds. It operates its Clay Point farm in partnership with Te Ātiawa o Te-Waka-Māui Limited.

The guidelines would initially apply to those farms which have a consent requirement to review the water quality standards by the end of 2018 for Waitata, Kopaua (Richmond), Ngamahau, and early 2019 for Te Pangu. Clay Point can also be brought under the guidelines, given the consent conditions allow for adaptive management and monitoring.

These are all farms in "high flow" environments, which are characterised by strong currents and relatively wide dispersal of fish farm waste. The other six existing farm sites are in "low flow" environments, being located in relatively sheltered embayments. This results in poorer dispersion of fish waste relative to high flow sites. These "low flow" sites are subject to the MPI-led salmon relocation process, which is currently before the Minister for Aquaculture for consideration.

The guidelines for water column are intended to be developed by the end of 2018, during which time the location and timing of any farm relocations will become apparent. The completed guidelines will reflect the best practice involved in successfully managing high- and low-flow sites.

The guidelines are in essence a voluntary initiative, which will assist all relevant parties with management in accordance with the Resource Management Act 1991 (RMA). In the event the process results in the successful development of water quality standards which are accepted in accordance with individual farm consent conditions, then those standards will become binding. The less palatable alternative is for NZ King Salmon to review the water quality standards through the requirements of individual consent conditions for high flow farms, and through consent renewal processes of low flow farms that may not be subject to the relocation process.

## 5. ROLES AND REPORTING

NZ King Salmon will lead the development of the guidelines drawing on expert advice and community input through a technical working group. Experts from the Cawthron Institute and the National Institute of Water & Atmospheric Research (NIWA) will be involved in the formulation of the guidelines as will Council, MPI and the Department of Conservation.

The guidelines will be developed progressively to allow for peer review and input along the way. The three farms granted by the BOI have conditions that established an independent scientific Peer-Review Panel. This is funded by NZ King Salmon to review monitoring plans, data and reports, and make recommendations for improvements. The Peer-Review Panel will provide independent feedback on the development of the guidelines.

The BOI farm consents also have a requirement for a Tangata Whenua Panel for Waitata and Kopaua and for Te Atiawa to be involved for the Ngamahau farm. Currently Te Atiawa representation is through a member of the Peer Review Panel NZ King Salmon propose to use the Tangata Whenua Panel as a reference group to help guide the development of the guidelines, and provide feedback during the process.

In addition, NZ King Salmon would like to invite a representative of the Sounds Advisory Group to the Council to participate. Representatives from the Sounds Advisory Group participated in the development of the benthic best practice guidelines and the farm operational guidelines in 2014.

Council may commission an independent peer-review of the draft guidelines to ensure that they are fit for purpose. Council utilised an international expert from the Scottish Association of Marine Sciences (SAMS), Professor Kenny Black, for the benthic guidelines. If required, Council will approach SAMS for expert review informed by international best practice.

The Ministry for Primary Industries (MPI) guidance package for aquaculture will inform this process. MPI's involvement will contribute to the successful development of the guidelines, and to the implementation of the Government's 2012 Aquaculture Strategy (http://www.mpi.govt.nz/growing-and-harvesting/aquaculture/strategy/).

The strategy's goals include: *Promote environmental sustainability and integrity of aquaculture*; and: *Strengthen the partnership with government and other stakeholders.*

## 6. FUTURE DEVELOPMENT

The guidelines will be written for a review at 5 yearly intervals or sooner if new monitoring and reporting technologies and improved knowledge can lead to replacement of current practices and technologies.