Traverse Environmental

Water quality in the Waihemo/Shag River catchment

Current state, trends and issues

Prepared for: East Otago Catchment Group

March 2026

Water quality in the Waihemo/Shag River catchment: Current state, trends and issues

Prepared for:	East Otago Catchment Group
Prepared by:	Juliet Milne, Principal Scientist
Date of issue:	31 March 2026

Reviewed by:	Laura Keenan, Senior Freshwater Scientist	LFKeenan
Approved for release by:	Dr Olivier Ausseil, Principal Scientist/Director	
Report status:	FINAL	

Cover photo: Waihemo/Shag River near Inch Valley (Juliet Milne)

Recommended citation: Milne J. (2026) Water quality in the Waihemo/Shag River catchment: Current state, trends and issues. Traverse Environmental Client Report prepared for the East Otago Catchment Group. 53 p.

Executive summary

The East Otago Catchment Group (EOCG) is helping facilitate farmer-led change towards the improvement of waterways and streams in five freshwater catchments in the East Otago area. One of several focus areas for the EOCG is maintaining and improving water quality in the Waihemo/Shag River catchment, located in the Waitaki District. This report has been prepared to support that work. Specifically, the report:

- outlines details of current and historical water quality monitoring, investigations and research carried out by different organisations, and
- summarises what we know about water quality state and trends, based on an assessment of existing readily available reports and data.

Monitoring activities and information

A considerable amount of information exists on water quality in the Waihemo/Shag catchment. Routine water quality monitoring began in the mid-1980s with the Otago Catchment Board, the precursor to the Otago Regional Council (ORC). The ORC's current state of the environment (SOE) monitoring programmes include physical, chemical and microbiological water quality monitoring at three sites on the river's mainstem (SH85, Craig Road and 'Goodwood Pump' (Chisholm Rd)) and three groundwater sites. Ecological monitoring is also carried out annually at all river sites, and both water temperature and dissolved oxygen are monitored at high frequency at Craig Road. The ORC also monitors ecological health at two sites within the Waihemo/Shag Estuary.

Other organisations collecting significant amounts of water quality information in the Waihemo/Shag catchment on an ongoing basis are:

- the Waitaki District Council (WDC) in relation to raw water sourced for drinking water supplies, and discharges to land from the wastewater treatment plant and recently closed landfill in Palmerston, and
- OceanaGold in relation to discharges associated with its gold mining operation at Macraes.

River water quality and health

Water quality and aquatic invertebrate health are 'excellent' in the upper reaches of the Waihemo/Shag River and 'fair' in the lower reaches, Overall, water quality compares favourably with the attribute[1] bands in the current (2020) National Policy Statement for Freshwater Management (NPS-FM) and nutrient concentrations decreased (i.e. improved) in the lower river reaches over the 10-year period to June 2022. A decrease in nitrate-N concentrations was also found in a shallow groundwater well over the 15 years to October 2023 (when monitoring of the well ceased).

Visual clarity is high most of time and only one very low oxygen episode has been captured in the four years of high frequency dissolved oxygen monitoring at Craig Road to date. Significant faecal contamination (defined as *E. coli* concentrations greater than 540 MPN/100mL) is also infrequent and limited to very wet weather when water-based recreational activities are not likely to occur.

While concentrations of toxicants (e.g. ammonia, arsenic) and plant-available[2] phosphorus are low across the catchment, plant-available nitrogen concentrations increase from the upper to lower catchment. This pattern reflects increasing intensity of land use and along short reaches of river downstream of Craig Road nitrate-enriched groundwater enters from the shallow Shag Alluvium Aquifer. The plentiful supply of nitrogen, in combination with stable flows for extended periods of time and good sunlight levels, contribute to significant year-round periphyton (i.e. algae) growth in the lower river reaches (equating to NPS-FM band D – which is

[1] An attribute essentially refers to a measurable form of an indicator (e.g. nitrate-nitrogen concentration).
[2] Plant available refers to dissolved reactive phosphorus and dissolved inorganic forms of nitrogen (principally present as nitrate-nitrogen).

below the national bottom line (i.e. minimum acceptable state) – at the ORC's Goodwood Pump monitoring site). Periphyton is often at nuisance levels in summer/autumn low flows, reducing streambed habitat quality and favouring a poorer quality invertebrate community more tolerant of these conditions. Despite this, brown trout are present in these reaches. While trout are likely supported in part by access to downstream estuarine food sources, their presence suggests that invertebrates important in their diet remain sufficiently abundant, and that some localised areas of cover and/or cooler water persist during summer. Native fish diversity is also high in the lower reaches, reflecting good access to the sea, which many species need to complete their lifecycle. Regular electric fishing at Craig Road since 2008 has recorded īnanga, longfin eel, shortfin eel, pouched lamprey, redfin bully, bluegill bully, common bully, upland bully, brown trout, torrentfish, Canterbury galaxias and Taieri flathead galaxias. Of these, upland bully is consistently found in the highest numbers.

Recent ecological data for the Deepdell Creek subcatchment and other tributaries monitored by OceanaGold show Taieri flathead galaxias are regularly recorded in Tipperary and Highlay creeks and kōura/freshwater crayfish are found at most sites. However, low stream flows and an apparent increase in streambed sedimentation and macrophyte (i.e. aquatic plant) cover over time are degrading stream habitat, particularly at sites located downstream of the mine operation where invertebrate community health is typically rated only 'poor' to 'fair'. Low intensity farming in the area is likely a contributing factor to habitat degradation (e.g. via stock access to streams).

Estuary water quality and health

The Waihemo/Shag Estuary is in a 'moderate' ecological condition. Although elevated water column nitrogen concentrations have been recorded, the estuary's very high flushing rate reduces the risk of water column algal blooms. Muddy, poorly oxygenated sediments are the primary issue limiting the health of the macroinvertebrate community, with few bivalves (e.g. cockles) or gastropods (e.g. mudflat whelks) recorded in routine ecological surveys to date. The most recent estuary surveys in 2023 indicate that both the extent and depth of mud-enriched sediments have increased since monitoring began in 2016, reinforcing that muddy sediments are a key pressure on ecological health.

Management considerations

Most of the sediment, phosphorus and pathogen (as indicated by *E. coli*) load enters the Waihemo/Shag River in wet weather, most likely through overland flow and bank erosion. While some targeted sampling under heavy rainfall could be beneficial to better estimate the sediment load entering the estuary, a greater gain would come from completing LiDAR mapping of the catchment. This would allow erosion hotspots and sediment source areas to be precisely identified, enabling mitigation efforts to be targeted where they will deliver the greatest reduction in sediment loss.

Significant amounts of nitrogen are lost from leaching through the soil profile in the lower catchment where the most intensive farming and cropping land use occurs. The fertile, porous soils along the river flats are prone to the highest nitrate leaching and require careful management.

The river is fully allocated under the ORC's Regional Plan Water and drains a naturally water-short catchment, with potential evapotranspiration exceeding rainfall for multiple months of the year. During very low flows in warm, dry summers, river water temperatures can rise to levels than can cause acute thermal stress for sensitive aquatic insects and fish. Any land-use changes that significantly reduce catchment water yield have the potential to exacerbate these conditions.

Contents

1 Introduction

The East Otago Catchment Group (EOCG) was established in August 2019 to help facilitate farmer-led change towards the improvement of waterways in five freshwater catchments in the East Otago area. One of those catchments is the Waihemo/Shag River catchment, located near Palmerston in the Waitaki District.

One of several focus areas for the EOCG is maintaining and improving water quality. There is a particular interest in better understanding current issues with, and potential future risks to, water quality so that this can inform identification of practical, effective on-the-ground management actions in freshwater farm plans (or their future equivalent). This report has been prepared to support that work.

1.1 Purpose and scope

The aim of this report is to collate what is known about water quality in the Waihemo/Shag River catchment to inform freshwater farm plan development and other activities, such as community-based monitoring and restoration. Specifically, the report:

- details current and historical water quality monitoring, investigations and research carried out by different organisations,
- summarises what we know about water quality state and trends, based on existing readily available reports and data, and
- identifies potential management considerations and information gaps.

1.2 What's in this report?

This report begins with a brief introduction to the Waihemo/Shag catchment and key features of relevance to water quality (section 2) followed by a description of the monitoring and research carried out to date by different organisations (section 3). Section 4 summarises the key findings from this monitoring, drawing on both existing reports and interpretation of more recent and additional data and information. The Waihemo/Shag Estuary, as the primary receiving environment for river inputs, is considered alongside the Waihemo/Shag River in this section. Section 5 outlines management considerations and information gaps, and conclusions are presented in section 6.

1.3 Approach taken

This report focuses on water quality to support ecosystem health and human health for recreation, two compulsory values fresh waters must be managed for in New Zealand under the National Policy Statement for Freshwater Management 2020 (NPS-FM)[3]. While water quality that is suitable for ecosystem and human health is also suitable for most other purposes (e.g. irrigation and stock drinking water), this does not necessarily mean it is satisfactory for cultural use. Assessment of cultural and spiritual values rests with Kāti Huirapa Rūnaka ki Puketeraki and Te Rūnanga o Moeraki as mana whenua of the Waihemo/Shag area and is outside the scope of this report.

Water quality is only one component of a healthy stream; aquatic life (e.g. invertebrates and fish), physical habitat (e.g. riparian cover), ecosystem processes (e.g. nutrient cycling) and water quantity are also key components (Figure 1). These components are interrelated and so all are considered in this report.

[3] The NPS-FM and Resource Management Act are currently under review but the Government has signalled through the Natural Environment Bill that limits will be required to protect both ecosystem health and human health.

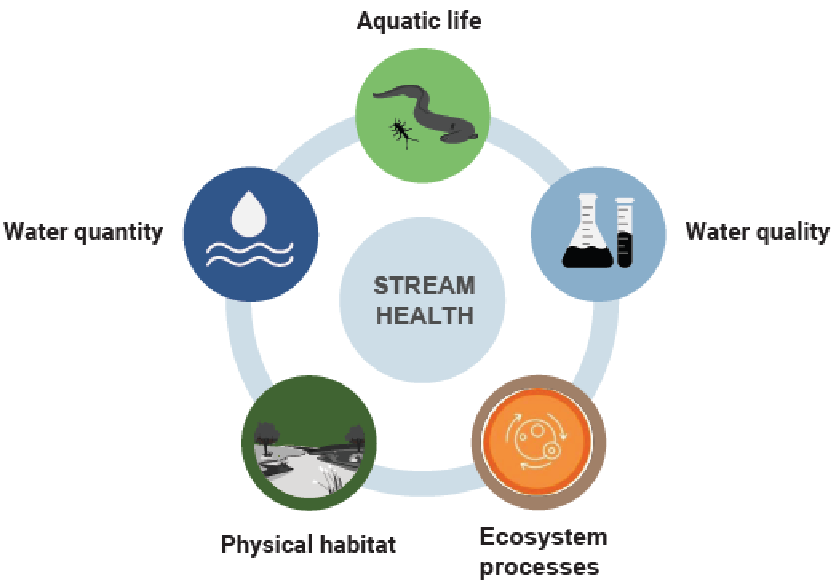

Figure 1: The five key components of freshwater ecosystem health recognised in the National Policy Statement for Freshwater Management 2020. Water quality itself is characterised by a range of physical (e.g. water temperature) chemical (e.g. nutrients) and – in this report – microbiological indicators (e.g. *E. coli*). Adapted from Milne et al. (2023).

1.4 Limitations

This report relies heavily on existing reports and collated or summarised data from third parties. Incomplete details, conflicting information and errors were followed up where possible, but it was beyond the scope of this project to re-examine the underlying data sets. Additional analyses of reported data were also out of scope but some recently collected, or previously unreported, data were assessed to better understand different aspects of water quality and wider ecosystem health. With data provided from many multiple sources, there is a mix of monitoring methods, indicators and time periods monitored. While this prevents robust comparisons between sites and assessment of trends over time, it has allowed an understanding of catchment water quality to be pieced together that would not have been as comprehensive had only one organisation's data been relied upon.

Although freshwater quality information associated with university research projects and resource consents is summarised, the search was not exhaustive and it is very likely that additional information exists.

2 Catchment overview

The Waihemo/Shag River rises on the slopes of Kakanui Peak (1528 m) and flows almost 90 km in a south-easterly direction past the township of Palmerston before entering the Pacific Ocean just south of Shag Point/Matakaea (Figure 2). While the northern tributaries rise on the slopes of the Kakanui Mountains and Horse Range, the southern tributaries drain rolling hill country. Deepdell Creek, draining from Taieri Ridge near Macraes Flat, is the largest tributary. The other main tributaries include Shingle Creek, Shingly Creek, Coal Creek and McCormicks Creek.

Palmerston, located west of the estuary, is the most densely populated township in the catchment, with a population of 1,080[4]. The smaller township of Dunback (population ~200) is located further inland. Kāti Huirapa Rūnaka ki Puketeraki and Te Rūnanga o Moeraki are the mana whenua for the area.

A large part of the 544 km^2 catchment is rolling/hill country, with most of the flat land found in the valley at the lower end of the catchment.

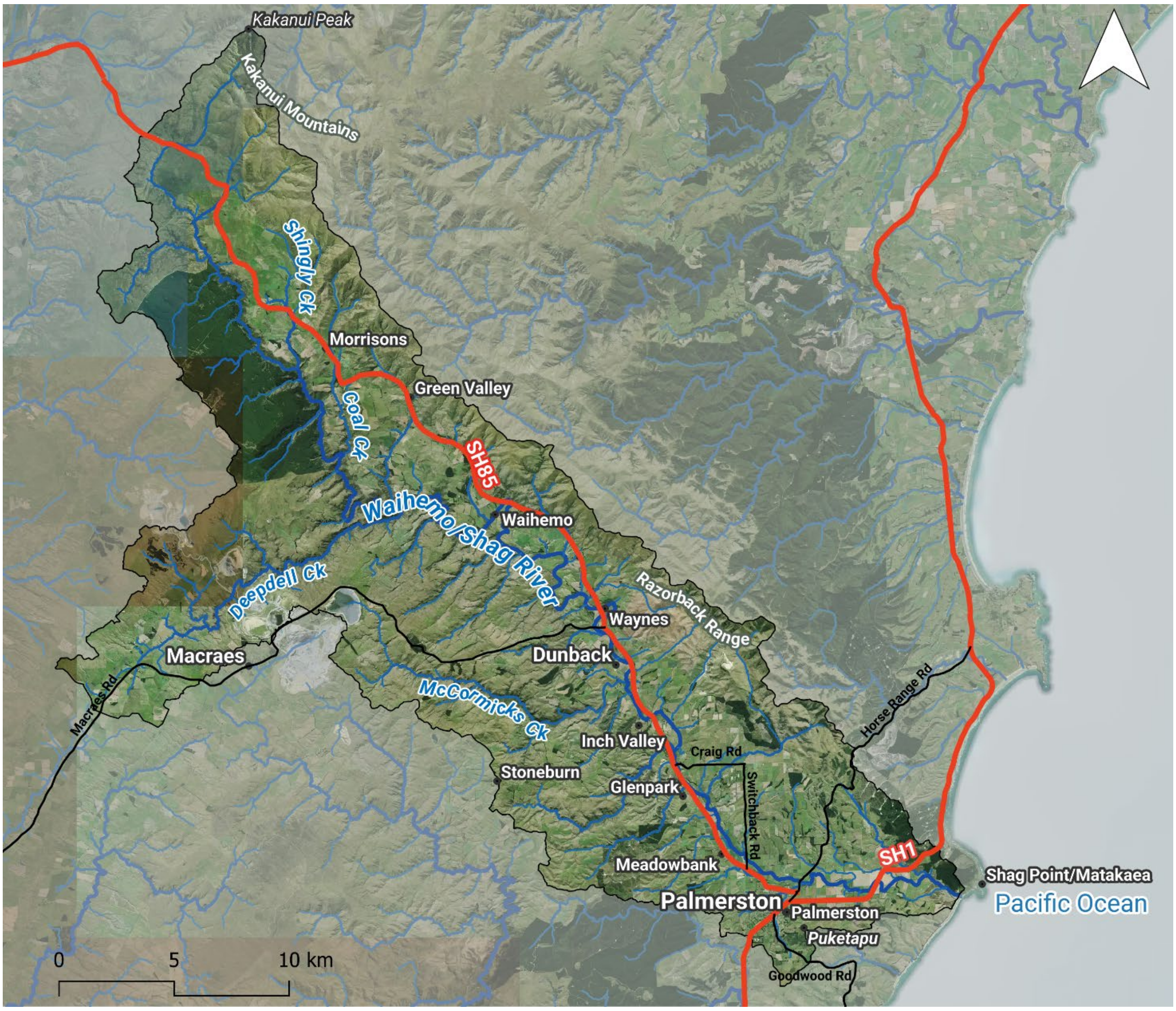

Figure 2: Overview of the Waihemo/Shag River catchment.

[4] As at June 2024: Stats NZ data.

2.1 Climate

Most of the Waihemo/Shag catchment is classified as having a 'cool-dry' climate, based on an annual average temperature of <12°C and average effective[5] precipitation of ≤500 mm (Snelder and Biggs 2002). Annual rainfall varies across the catchment, ranging from >1,000 mm in the Kakanui Mountains and declining in a downstream direction to <600 mm around Palmerston (Olsen 2014, Figure 3).

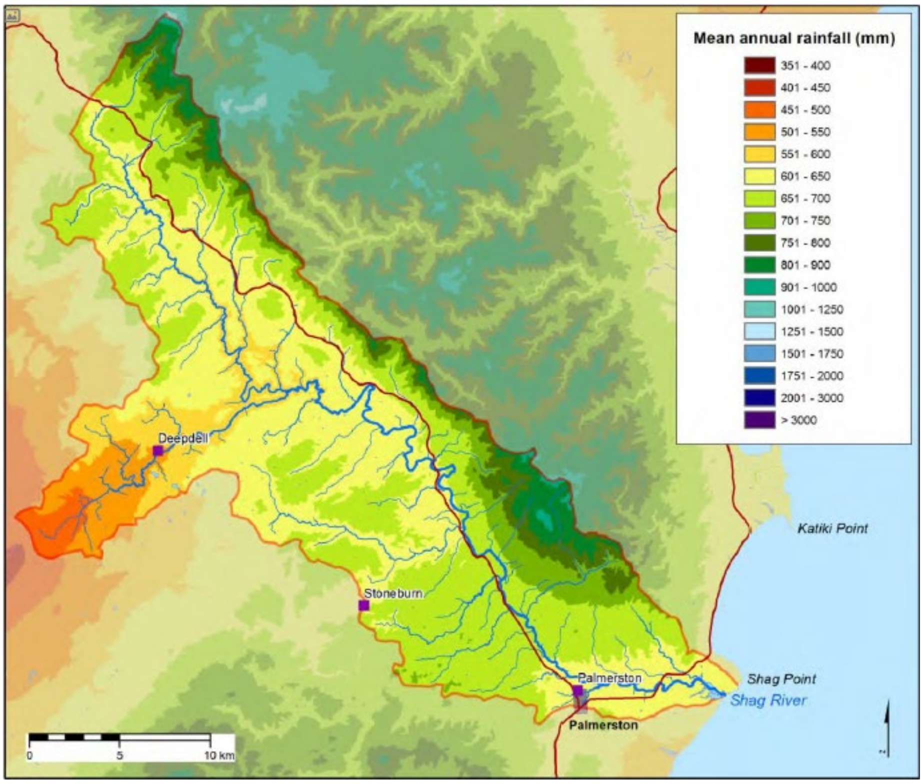

Figure 3: The distribution of rainfall across the Waihemo/Shag River catchment. Reproduced from Olsen (2014).

Monthly average rainfall is distributed relatively evenly throughout the year, although totals in December and January are often a little higher (Appendix A), likely boosted from summer thunderstorms. Evapotranspiration often exceeds rainfall between mid-spring and late summer, depleting soil moisture and creating challenging conditions for farming (ORC 1991). Overall, monthly rainfall can vary widely between years (Appendix A), indicating rainfall is often sporadic and unreliable.

2.2 Geology, geomorphology and soils

The base geology of the Waihemo/Shag catchment is dominated by Otago Schist, a hard metamorphic rock that controls much of the catchment's topography and drainage pattern (Forsyth 2001, Mortimer 2003). The schist is overlain by patches of younger marine sedimentary rocks near the coast, mainly sandstones, mudstones and limestones of the Caversham Formation and Goodwood Limestone, and by Quaternary alluvial and loess deposits along the river valley and floodplain (GNS Science QMAP, NZLRI 2020).

The schist-dominated hill country produces thin, stony soils and rapid runoff, while the younger sedimentary and alluvial materials in the lower catchment form more fertile but erodible soils on gentler slopes and along the river valley (NZLRI 2020). Together, these materials create a catchment with contrasting land stability and erosion risk.

[5] The amount of precipitation that contributes to soil moisture or usable water, after accounting for losses from evaporation, runoff, etc.

For much of its course the Waihemo/Shag River flows through confined, meandering channels, with a bed of mixed gravel, boulder and bedrock. Significant bank erosion has been a feature of the lower reaches of the river (Williams 2014), and bed and bank erosion in the headwaters. Other forms of erosion also occur, including sheet erosion in the hill country and high mountain soils of the Kakanui Mountains (ORC 1991).

Most of the catchment comprises brown or pallic soils, with well-drained recent soils restricted to the river margins (NZLRI 2020).

2.3 Hydrology

Flows in the Waihemo/Shag River are highly variable and in the lower reach (downstream of Craig Road), are intricately linked with the underlying shallow groundwater aquifer – the Shag Alluvium Aquifer (Mourot et al. 2022). At times, surface flows can disappear entirely underground in some reaches, which is reflected in the name 'Waihemo' (meaning 'a river that has gone away' or 'dwindled'). Investigations carried out by the ORC in 2017 and 2018 (refer section 3.1.6) identified several river reaches where flow is gained from groundwater and several reaches where it discharges (loses) water to groundwater (Figure 4). These gaining and losing reaches are relevant not only for movement of water but also movement of contaminants, particularly nitrate that is readily leached from soils into the aquifer.

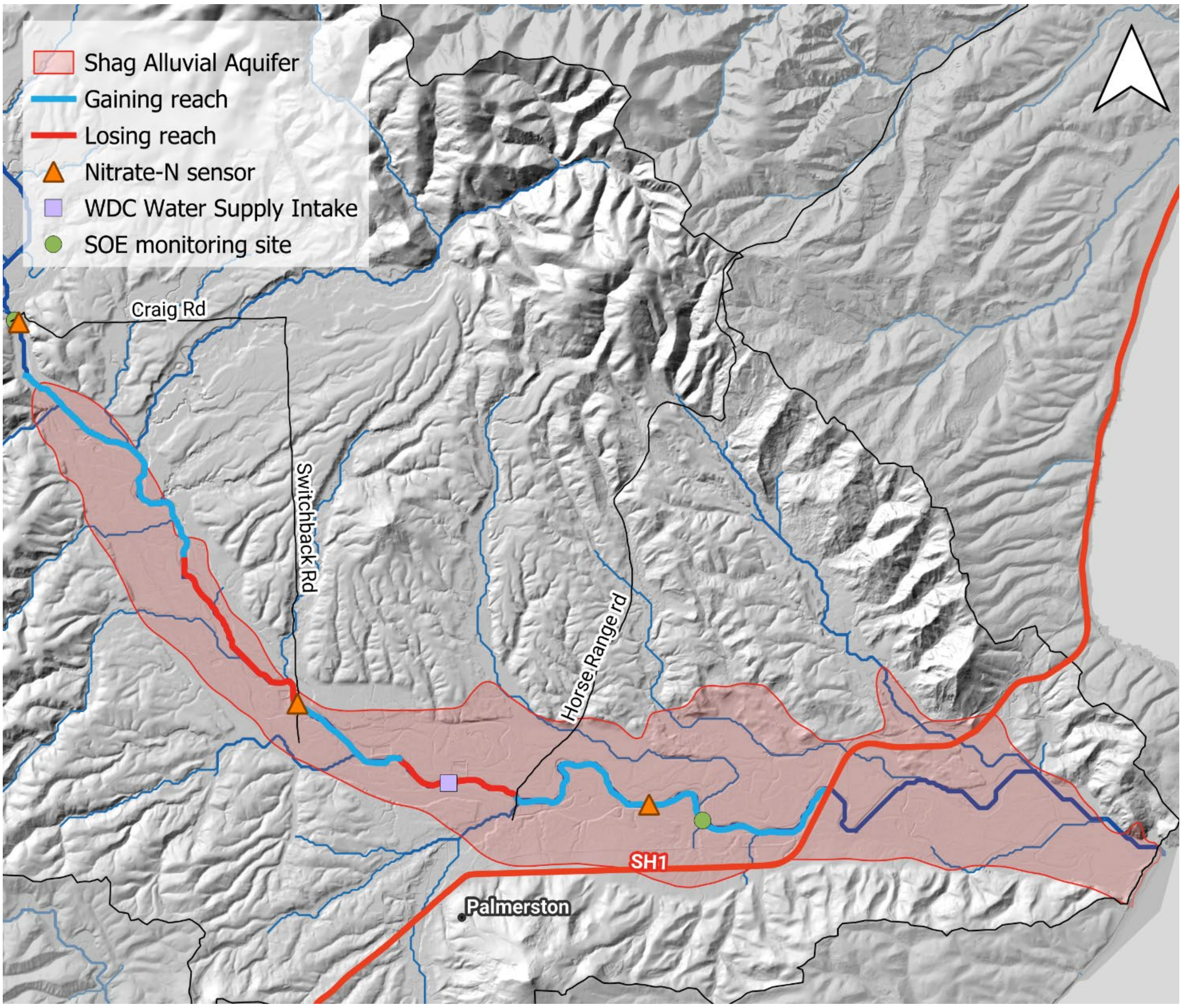

Figure 4: Indicative reaches of the Waihemo/Shag River that gain water from groundwater and lose water to groundwater within the Shag Alluvium Aquifer. Based on the findings from Mourot et al. (2022). Groundwater is not necessarily gained (or lost) over the entire marked reaches; groundwater is thought to enter through localised upwellings and horizontal flow.

Based on 20+ years of flow records summarised in Olsen (2014) the Waihemo/Shag River has:

- a median flow of 0.589 m$^{3/}$s and a mean flow of 1.70 m$^{3/}$s L/s at The Grange, and
- a median flow of 0.714 m$^{3/}$s and a mean flow of 2.19 m$^{3/}$s L/s at Craig Road.

The river generally has its highest flows in winter (June–August) and lowest flows in late summer/autumn (January–March), reflecting the region's rainfall and evapotranspiration cycle. The river is prone to both extended low-flow periods and significant flood events (Figure 5), so flows vary widely, from less 0.025 m^3/s during summer low flows to over 400 m^3/s in very large floods (Olsen 2014).

The Waihemo/Shag River has a history of flooding, with rural pastoral land predominantly affected. Most flood events in the catchment (and wider Waitaki District) are caused by persistent rain-bearing easterlies, with short duration and high intensity rainfall events or continual rainfall over several days saturating the soil, leading to rapid runoff. These types of events can happen at any time of the year but generally occur in late summer to late autumn (ORC 2025).

Figure 5: Waihemo/Shag River in flood, looking downstream at Horse Range Road bridge and Palmerston Wastewater Treatment Plant, 17 June 2013. Source: Williams et al. (2018), ORC.

The lower reach of the river through the estuary is tidally influenced. The estuary itself is classified as a shallow, intertidal-dominated estuary, and discharges to the sea via a permanently open tidal mouth at Shag Point/Matakaea.

2.3.1 Water abstraction and use

The total consented water allocation in the Waihemo/Shag catchment was 0.262 m^3/s in 2013 (Olsen 2014), compared to a primary allocation limit of 0.280 m^3/s in the ORC's Regional Plan: Water for Otago (RPW). This allocation is made up of 17 consented surface water takes, the majority being for irrigation. There are a further four consented supplementary water takes, totalling 0.1275 m^3/s (Olsen 2014).

Minimum flows, below which water abstraction must reduce or cease, are in place at both Craig Road (0.150 m^3/s) and Goodwood Pump (0.028 m^3/s).

Water is also abstracted from the shallow aquifer, including for irrigation and by Waitaki District Council for the Dunback, Palmerston and Goodwood drinking water supplies.

2.4 Land cover and land use

The majority of the Waihemo/Shag catchment consists of agricultural grasslands. The upper catchment is dominated by tall tussock grassland and low producing grassland while the lower part of the catchment and most of the flat land in the valley floor is dominated by high producing grasslands.

The catchment is largely used for sheep and beef farming (83%), with some exotic forest (14%, an increase on the 11% reported by Olsen, 2014) found in the upper catchment adjacent to Collins Bridge and on hill country to the north of the Shag River/Waihemo Estuary (Figure 6). Cropping also occurs in the lower catchment, with the largest cropping area east of Palmerston.

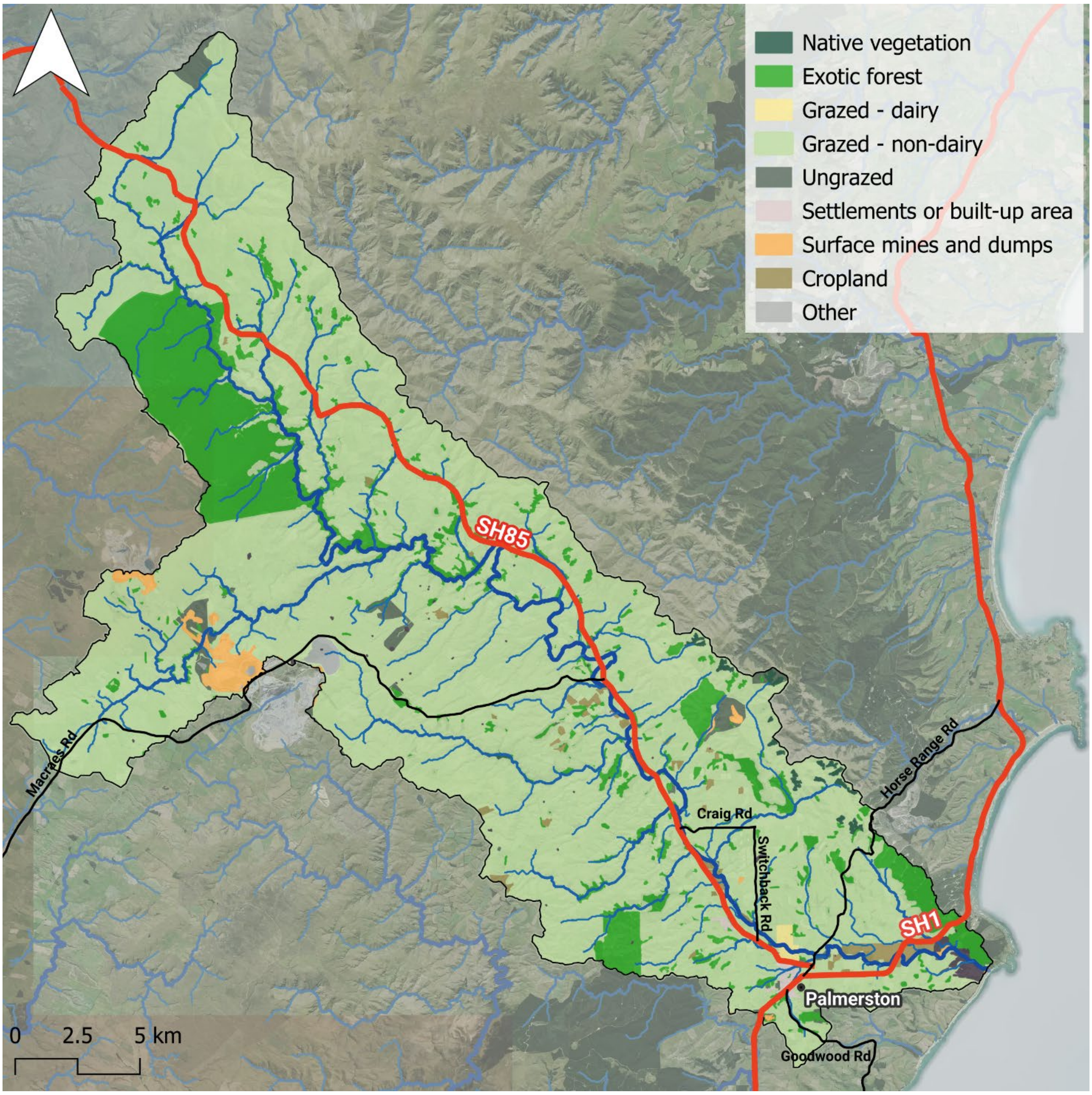

Figure 6: Land cover in the Waihemo/Shag catchment, based on aerial imagery from summer 2020/21 summarised in Land Use and Carbon Analysis System (LUCAS) 2020 version 5.0 (checked against Landcover Database version 6.0).

OceanaGold has a large gold mining operation in the upper catchment at Macraes Flat that has been operational since 1990 (Figure 6). The company holds resource consents to discharge water and contaminants from tailings storage facilities to several tributaries of the Waihemo/Shag River (Deepdell Creek catchment, Tipperary Creek and a tributary of McCormicks Creek).

Other consented discharges within the catchment include stormwater and leachate from the former Palmerston Landfill[6], treated wastewater from Palmerston township, lime kiln waste products from the Makareao Lime Processing Plant, and multiple farming and on-site wastewater discharges. All of these discharges are to land, although many are discharged in a manner where contaminants are expected to (ultimately) enter water.

2.5 Freshwater values

As well as significant cultural and spiritual values, the Waihemo/Shag River catchment is recognised in the RPW for a range of ecological values, including (Schedule 1):

- seven indigenous fish species classified as “declining”,
- significant habitat for Taieri flathead galaxiid, kōaro and lamprey,
- īnanga spawning in the lower tidal reaches,
- rare invertebrates in the middle reaches,
- spawning areas for trout,
- areas for the development of juvenile fish, and
- presence of eel and brown trout.

Schedule 3 of the RPW identifies the Shag Alluvium Aquifer, which is closely interconnected with the Waihemo/Shag River, as a critical source for WDC’s Dunback, Palmerston, and Goodwood water supplies. The aquifer is also recognised as a source of water for stock drinking and irrigation.

Downstream, swamp area within the Waihemo/Shag Estuary is recognised in Schedule 9 of the RPW as a regionally significant wetland and wetland management area. The estuarine mudflats are also recognised in Schedule 2 of the Regional Plan Coast for Otago for feeding and roosting by various bird species and as a stop-over area for migratory species such as the eastern bar-tailed godwit and oystercatcher.

Both the river and estuary support multiple recreational values, including whitebaiting, trout fishing, swimming, waterfowl hunting, bird watching and walking.

[6] Palmerston Landfill at the top of Falcon Street was operational between early 1991 and October 2023 (Clarke 2024).

3 Water quality monitoring – who, what and where?

Routine water quality monitoring in the Waihemo/Shag catchment began in the mid-1980s. While the ORC has carried out most of the monitoring to date, the Waitaki District Council and OceanaGold also carry out monitoring associated with drinking water supplies and resource consents (Figure 7). This section presents a summary of these monitoring activities, with a focus on what each organisation has monitored, where and when. Some relevant University of Otago research is also briefly outlined.

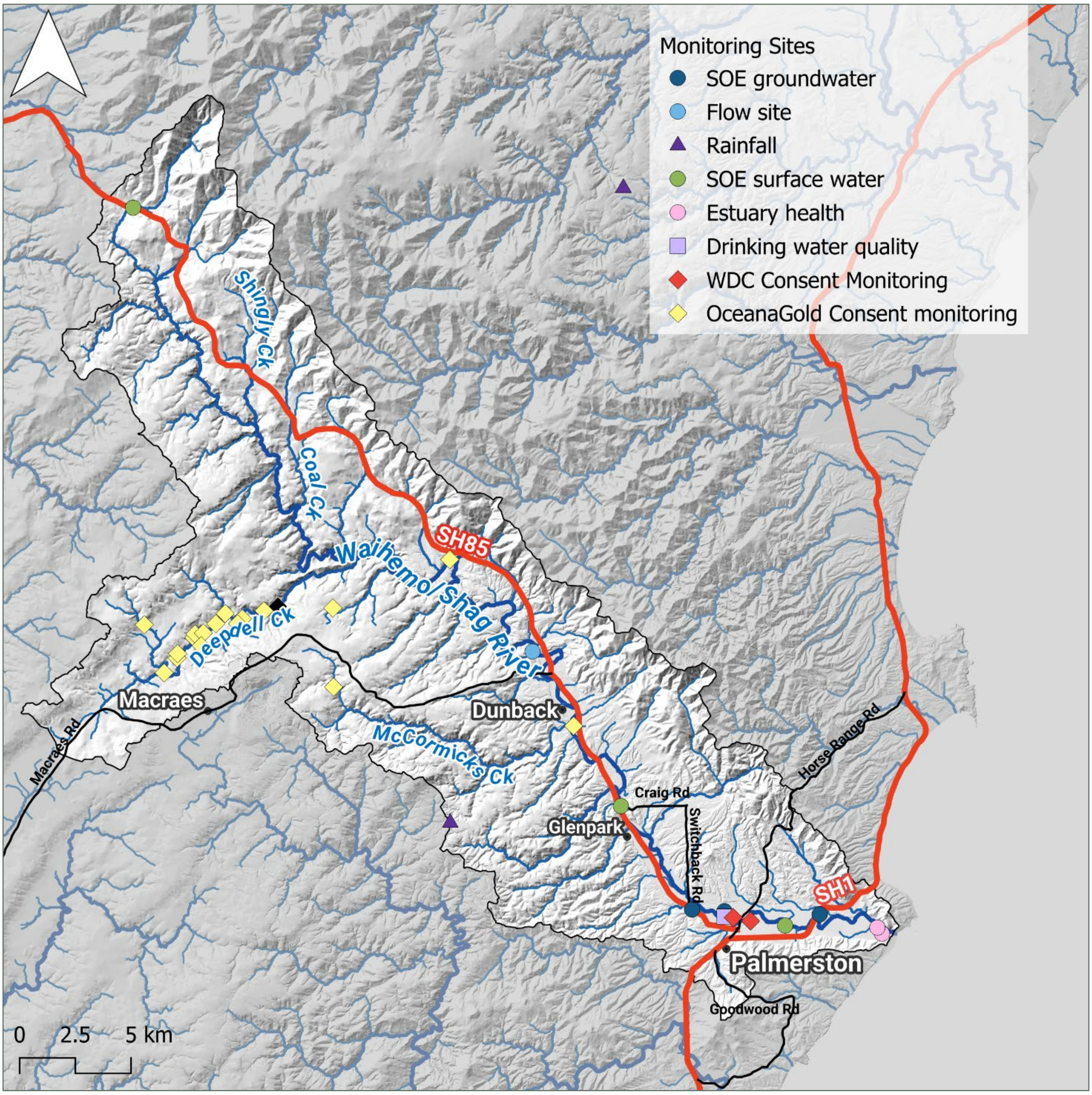

Figure 7: Summary of known water quality monitoring locations within the Waihemo/Shag River and Estuary.

3.1 Otago Regional Council

3.1.1 River water quality and ecology

The ORC carries out routine State of the Environment (SOE) water quality and ecological monitoring in the Waihemo/Shag River (Figure 7). Two long-term monitoring sites are in the mid to lower reaches, at Craig Road and ‘Goodwood Pump’ (Chisholm Road). An additional upper catchment site (‘Upper Shag at SH85 culvert’) was added to ORC’s regional SOE programme in August 2018 and provides a largely unimpacted reference site for the catchment.

Water samples are collected monthly and measured for water temperature, pH, turbidity and concentrations of dissolved oxygen (DO), conductivity, plant-available nutrients (ammoniacal nitrogen, nitrate-nitrite nitrogen and dissolved reactive phosphorus (DRP)), total nitrogen (TN), total phosphorus (TP) and *E. coli* indicator bacteria. This measurement suite is similar to that adopted by most regional councils, the main difference being that most councils also routinely measure visual water clarity (as discussed later in this report, the ORC estimates this from turbidity measurements).

Once a year during stable river flows in late summer/early autumn, the riverbed invertebrate community (e.g. insects, snails and worms) is sampled at each site. In addition:

- the fish community has been monitored approximately annually at Craig Road since autumn 2007 (15 occasions to date),
- rapid assessments have been made annually of physical habitat quality (e.g. bank stability, riparian vegetation, shade) at Craig Road and Goodwood Pump since around 2014,
- periphyton growth (as chlorophyll *a* biomass, determined from rock scrapings) has been monitored monthly at Goodwood Pump since February 2019 along with estimates of the percentage of the riverbed covered in periphyton and fine sediment,
- annual estimates of ecosystem metabolism[7] began at Goodwood Pump in June 2020, and
- water temperature has been monitored at high frequency (every 5-15 minutes) at Craig Road since August 2001, with high frequency monitoring of dissolved oxygen added in late May 2021.

3.1.2 Estuary ecology

The ecological health of the Waihemo/Shag River Estuary is assessed using two types of monitoring:

- broad scale – estuary-wide mapping of the habitat types (e.g. sand, mud and vegetation) present and their condition, and
- fine scale – more detailed assessments of the near-surface sediments at three locations within the estuary to assess sediment quality (e.g. mud content and nutrient and metal contamination), sediment accumulation rates, and the macrofauna that live in and on the surface sediments.

Three broad-scale surveys have been carried out to date, in November 2006 (Stewart 2007), December 2016 (Stevens and Roberston 2017) and November 2023 (O’Connell et al. 2024). Fine-scale monitoring following national estuary monitoring protocols commenced in December 2016 at two sites in the main channel and one site in the upper estuary. Some water quality assessments were also carried out at this time and, at two of the sites, plates were installed below the surface sediment to track the rate of fine sediment accumulation. The depth to these plates is measured annually while the full fine-scale assessment is typically carried out five-yearly (S. Thomas, ORC, pers. comm. 2025).

3.1.3 River flow/level and rainfall

Flow is continuously monitored in the Waihemo/Shag River at The Grange and Craig Road. Some historical data are also available for Collins Bridge, Dunback and Switchback Road, and for Deepdell Creek.

The ORC operates a rainfall station at Stoneburn (January 1985 to date), just outside the western boundary of the Waihemo/Shag catchment, as well as a site (‘The Dasher’) in the neighbouring Kauru River catchment to the east (Figure 7). Historical records are also available for other locations, including sites near Macraes.

---

[7] Ecosystem metabolism is a common measure of how well an ecosystem is functioning and was introduced as a mandatory NPS-FM attribute in 2020. High frequency water temperature and dissolved oxygen measurements are critical to its calculation.

3.1.4 Groundwater quality

Routine groundwater quality monitoring is carried out in three wells in the shallow unconfined aquifer in and around Palmerston (Figure 7, Appendix A). Routine sampling in these wells began in August 2017 as part of a series of wider catchment groundwater investigations (see section 3.1.6). The original well used for SOE monitoring (J43/0006, located adjacent to Mill Road and Waitaki District Council's water supply intake) was dropped from the monitoring programme in 2023 following the completion of these investigations. Around 15 years of data are available for the well, although the record prior to mid-2011 is limited to twice yearly sampling.

Water samples are collected four times a year from the current wells and tested for a typical groundwater SOE water quality suite, including ammoniacal nitrogen, nitrate nitrogen, DRP, trace elements (e.g. calcium, magnesium) and *E. coli* bacteria. The water level in each well is also measured on a continuous basis (A. Levy, ORC, pers. comm. 2026).

3.1.5 Soil quality

The ORC's regional soil quality programme currently includes three sites within the Waihemo/Shag catchment: one site under each of drystock farming, dairy farming and exotic forestry. Soil properties tested include soil acidity (pH), nutrient and organic carbon content, and two indicators of soil compaction (bulk density and macroporosity). All sites have been sampled once to date in spring 2022 or 2023.

3.1.6 Targeted investigations and monitoring

The ORC has carried out multiple investigations in the Waihemo/Shag catchment over the last 10-15 years. The most recent surface water quality and ecology investigation, reported by Olsen (2014), involved fortnightly water sample collection and one-off ecological assessments between July 2012 and April 2013 at five sites on the Waihemo/Shag main stem and a site on each of two tributaries (Deepdell and McCormick creeks). As well as periphyton and macroinvertebrate sample collection, the ecological assessment included electric fishing and an assessment of trout condition. Water temperature loggers were also installed for six months at two sites.

In 2023, nutrient losses across 14 farms and the Palmerston WWTP land treatment site were estimated using OverseerFM and LICU-AG models. Three temporary surface water quality monitoring sites were added as part of this project, which sought to identify areas of high nutrient loss and then test a range of different mitigations using LUCI-Ag scenario modelling to assess their likely impact (Crawford et al. 2023). The Waihemo/Shag Estuary has also been included within Otago-wide modelling assessments of catchment sediment and nutrient loads discharged to estuaries (Plew 2021, Snelder and Fraser 2023).

Many investigations specific to the Waihemo/Shag catchment have focused on groundwater, notably the availability of water from the shallow alluvial aquifer for abstraction (e.g. Stewart 2003, Cameron et al. 2003, Turnbull and Fraser 2005). The most recent series of investigations began in 2017 to better characterise the aquifer and its interaction with the river, and to estimate nitrogen fluxes between land, groundwater and surface water. These investigations included a drilling campaign (eight bores), hydraulic testing, water level and water quality monitoring (eight river sites and eight bores), water dating, tracer measurements (radon, stable isotopes) and high-frequency nitrate sensing (three river sites and one bore – refer Figure 4). Most of the investigations were undertaken between February 2017 and August 2018, with some sites still being monitored in November 2022 (Mourot et al. 2022).

Other ORC investigations have focused on channel morphology and riparian management (e.g. Williams 2014, Williams et al. 2018) to inform gravel extraction and flood management. This work is underpinned by periodic cross-sectional surveys of the lower river from McLew Road bridge downstream to Switchback Road dating back to 1977.

3.2 Waitaki District Council

3.2.1 Source water monitoring

The Waitaki District Council (WDC) monitors the quality of the shallow groundwater aquifer underlying the Waihemo/Shag River (Figure 7) as part of its raw source water monitoring for the Dunback, Palmerston and Goodwood drinking water supplies. The scope and frequency of monitoring increased several years ago in response to new regulations introduced by the Water Services Authority (Taumata Arowai 2022). Current monitoring of the raw source water consists of:

- continuous (every 1 min) monitoring of turbidity,
- fortnightly monitoring of *E. coli* and nitrate-N,
- monthly monitoring of iron, manganese and colour, and
- six-monthly monitoring of total concentrations of heavy metals.

3.2.2 Palmerston Wastewater Treatment Plant

In January each year, the WDC monitors water quality in the Waihemo/Shag River up to 100 m upstream and 100 m downstream of the Palmerston WWTP land application area (Figure 7). The shallow groundwater downgradient of the land application is also sampled at this time. All samples are tested for total nitrogen, total phosphorus and *E. coli.* More frequent monitoring was carried out under previous consents but monitoring reduced when the land application area was increased and the method of application changed from border dyke to spray irrigation in the mid-2010s.

3.2.3 Palmerston Landfill

Surface water and groundwater quality in the vicinity of the Palmerston Landfill have been monitored since 1997 (Sycamore 2007). Under the current resource consent, surface water samples are collected quarterly from four locations, including an unnamed ephemeral tributary of the Waihemo/Shag River below the landfill site. Samples are tested for pH, conductivity and a range of contaminants: chemical oxygen demand (COD) and 5-day Biological Oxygen Demand (BOD_5), chloride, arsenic, boron, iron, lead and zinc. Groundwater samples are also collected quarterly from two locations and tested for pH, conductivity, chloride, ammoniacal nitrogen and nitrate nitrogen.

3.3 OceanaGold

OceanaGold carries out both water quality and ecological monitoring at multiple river and stream sites as part of resource consent requirements to discharge contaminants from its gold mining operation at Macraes.[8] Twelve sites monitored for water quality are located within the Deepdell Creek catchment, including three ‘control’ sites and four ‘impact’ sites on the creek’s mainstem (Figure 7). One site is also monitored on each of Tipperary and Cranky Jims creeks outside of the Deepdell Creek catchment. Water samples are collected monthly and tested for pH, sulphate and a range of metals and nutrients. All sites are also sampled quarterly for macroinvertebrates and 14 are sampled annually for periphyton, macrophytes and fish. Monitoring records date back to 1999 at six sites and from May 2012 at most other sites.

3.4 Other

Fire and Emergency NZ has a weather station at Macraes that measures soil moisture and soil temperature. NIWA, now Earth Sciences Research New Zealand (ESNZ), operated a weather station at Palmerston between 1969 and 2024 and a rain gauge at Bushey Park in the lower catchment between 1908 and 1977.

[8] Groundwater quality monitoring is also carried out to track the movement of contaminant plumes offsite.

The Department of Conservation, Fish and Game Otago and others have carried out fish surveys in the Waihemo/Shag River and some of its tributaries. Data are freely available from the National Freshwater Fish Database operated by ESNZ.

The University of Otago has carried out research in the Waihemo/Shag catchment involving the collection and/or analysis of water quality, fish and other data. Much of this research has focused on geology and the environmental impacts of mining operations in the Macraes area (e.g. Black et al. 2004, Craw and Pope 2017, Blake et al. 2019, Weightman 2020).

4 Current state and trends

This section summarises what is known about the current condition (state) of, and trends over time in, water quality and ecological condition in the Waihemo/Shag catchment. River and estuary health are addressed in separate sections, with river water quality addressing four groups of common contaminants (sediment, nutrients, pathogens and toxicants).

Assessing water quality and the NPS-FM

A range of targets, guidelines and standards exist for fresh water that are linked with protection of different values. This section uses those that are relevant to aquatic ecosystem health and human health for recreation; these are two values that regional councils have been directed to manage rivers and lakes for since the 2014 version of the National Policy Statement for Freshwater Management (NPS-FM) came into force.

The NPS-FM introduced the term **attributes.** An attribute is a measurable characteristic (e.g. nitrate-nitrogen or *E. coli* concentration) of a river or lake and is used to assess the extent to which a certain freshwater value (e.g. ecosystem health) is provided for. Measurements of each attribute are graded in bands from A to D, or A to E. The NPS-FM specifies a minimum acceptable state for different attributes of stream health, referred to as the national bottom line (NBL). In most cases the NBL is the boundary of bands C and D.

The NPS-FM 2020 requires regional councils to establish targets for mandatory freshwater attributes, called target attribute states. These targets must be set at a state that is no worse than attribute state was in 2017 (baseline attribute state). Where the baseline attribute state is below the NBL, measures need to be put in place to bring it above this line over a defined period of time. Councils must monitor current attribute state to track progress towards achieving targets.

Attribute bands can be thought of as a bit like a report card where A is the highest and D/E the lowest. However, a lower grade for a particular attribute does not always mean a river is in poor health. In some cases, a river's natural characteristics, such as geology, may mean that band A may be an unrealistic and unnecessary target. The NPS-FM also doesn't include bands for everything that may be monitored in rivers and streams. Examples are metal concentrations and stream habitat quality. In these cases, national guidelines (e.g. ANZG 2018, Clapcott 2015) can be used to interpret monitoring results. Guidelines are just that and exceeding them does not necessarily translate to an adverse environmental effect. Only standards have regulatory force and must be met.

In late 2024 the Government passed legislation that required regional councils to press 'pause' on notifying changes to regional plans to give effect to the NPS-FM 2020. Subsequent Government announcements have indicated that we can expect significant changes to the NPS-FM in 2026 as part of wider resource management reform. While this will result in changes to at least some future water quality targets at both the national and regional level, the targets, guidelines and standards used to interpret information in this section represent the most relevant currently available and allow the various data available to be assessed in a similar manner to the Otago Regional Council's existing river monitoring data.

4.1 River water quality and ecological health

4.1.1 Sediment

Fine sediment is a 'master' stressor on stream health

Fine sediment:

- reduces water clarity when suspended in the water column, reducing aesthetic values, light penetration for plant growth and the ability of fish to see their prey,
- can smother the bed which, particularly in naturally cobble and gravel bedded rivers and streams, reduces the diversity and quality of the streambed habitat for aquatic life with flow-on impacts (e.g. reduced diversity of aquatic life, loss of fish spawning habitat), and
- carries contaminants that readily attach to it, most commonly phosphorus, pathogens and metals, with flow-on effects for ecosystem health and reduced water quality for recreational and other uses.

The river typically runs clear

Although visual clarity is not measured by the ORC, turbidity and suspended fine sediment data from monthly sampling across all three sites indicates that the river runs clear most of the time. Based on a national equation that converts turbidity measurements to estimates of horizontal visual clarity (Franklin et al. 2020), the median visual clarity varies from 5.4 m at Goodwood Pump to 9.5 m in the upper reaches at SH85 (Table 1). While there is uncertainty around these estimates, there is little doubt that median visual clarity sits in band A of the NPS-FM across all sites[9]. This is supported by historical black disc visual clarity measurements made ~two-monthly at Craig Road (median=4.13 m, Aug 2001–Feb 2005) and Goodwood Pump (median=3.74 m, Aug 1997–Feb 2005).

Median turbidity values primarily represent base flow conditions so low median values do not necessary mean that sediment is not a problem at other times. During and immediately following heavy rainfall, overland flow and bank erosion can cause sharp increases in suspended sediment concentrations that are not captured by median statistics. Monthly 'spot' sampling rarely coincides with significant rain events when suspended sediment (SS) concentrations are highest.

The highest SS concentration recorded by the ORC to date is 135 mg/L on 19 December 2018 (at Craig Road), coinciding with a turbidity measurement value of 115 FNU. Stoneburn rainfall records indicate that 47 mm of rain had fallen in the 24 hours prior to sample collection, suggesting that there was significant sediment running off the land and into the river. In addition, because the river had experienced its fifth-largest flood flow just a month earlier (417 m^3/s on 20 November), its banks were likely already weakened or freshly eroded and continuing to release large amounts of sediment into the river. Although no water quality data are available for that flood event, more than 2,100 tonnes of sediment will have likely exited the river into the estuary that day[10], equating to over 6% of the estimated total annual sediment load (see section 4.2.2).

[9] Visual clarity is used to assess the suspended fine sediment attribute in the NPS-FM. Visual clarity can be directly measured or estimated from turbidity using a national equation developed by Franklin et al. (2020) from the relationship between visual clarity and turbidity measurements at hundreds of river sites across the country. However, there is considerable scatter around the straight-line relationship used in the national equation. This is a source of uncertainty in the estimate.

[10] A conservative estimate calculated using the mean daily flow at Craig Road (232.3 m^3/s) and the TSS measurement of 106 mg/L recorded at Goodwood Pump on 18 December (the actual peak TSS concentration on 20 November was likely much higher).

Table 1: Summary of sediment-related water quality indicators for the Waihemo/Shag River at ORC's three SOE sites, based on monthly data for the five-year period ending June 2025 (n=58-60). The median values (shaded) summarise current water quality state or condition. Visual clarity estimated from turbidity. Statistics calculated from data supplied by the ORC.

	Turbidity (FNU)	Visual clarity (m)	Total suspended solids (mg/L)
Upper Shag at SH85 culvert			
Min	0.09	1.0	<1
Median	0.24	9.5	<1
95^{th} percentile	3.1	16.1	4.5
Max	5.1	19.0	15
Shag River at Craig Rd			
Min	0.13	0.4	<1
Median	0.44	6.1	0.7
95^{th} percentile	3.56	11.6	3.6
Max	22	14.6	19.4
Shag River at Goodwood Pump			
Min	0.23	0.3	<1
Median	0.52	5.4	0.7
95^{th} percentile	3.22	8.8	2.4
Max	24	9.7	22

Fine sediment is deposited on the bed of some tributaries

Fine sediment suspended in the water column often settles out on the riverbed where it can infill the spaces in the cobbles and gravels that are important to invertebrates and fish. This is commonly seen adjacent to, or downstream of, actively eroding banks or where there are quiet backwaters that allow fine sediments to accumulate. Based on ORC's observations at its Goodwood Pump SOE site and visual assessments made by the author during a drive through the catchment in October 2025, coverage of the streambed with fine sediment is low. This suggests that most sediment is rapidly flushed through the river system during high flow events.

Most of the information available for tributaries of the Waihemo/Shag comes from water and ecological sampling carried out in the Deepdell Creek subcatchment by OceanaGold. Multiple monitoring reports (e.g. Ryder 2019, SLR 2024) indicate that the beds of some of these tributaries have significant deposits of fine sediment. Most sediment deposits are found in pools and other low velocity areas along creek edges, but pugging caused by stock is also reported (Ryder 2019).

4.1.2 Nutrients

Nitrogen and phosphorus exist in different forms

The nutrient forms readily taken up by algae (periphyton) and aquatic plants (macrophytes) for growth are dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP). When these forms of nutrients are in plentiful supply and combine with high light and water temperatures and stable or low river flows, thick growths or 'blooms' of algae can occur. These growths reduce the quality of the streambed habitat for some aquatic life, look unsightly and can be a nuisance, spoiling recreational activities such as swimming and fishing, and clogging water intakes and filters.

DIN is made up of three forms of nitrogen (N): ammoniacal-N, nitrite-N and nitrate-N. In very high concentrations – much higher than those that can cause algal blooms – these forms are toxic to aquatic life (see section 4.1.4). It is also unsafe to drink water with very high concentrations of nitrate.

Note: A mixture of nitrate-N and nitrite-nitrate nitrogen (NNN) are used in this section, reflecting differences in what forms of nitrogen were tested or reported across different reports and time-periods. In essence these two forms of plant-available N are broadly equivalent because nitrite-N concentrations are typically very low in surface waters. Ammoniacal-N concentrations are also usually very low (i.e. nitrate-N makes up most of DIN).

Nitrogen concentrations increase down the catchment

Nitrogen, especially plant-available nitrogen (DIN) concentrations, are very low in the headwaters of the Waihemo/Shag River but are significantly higher at Craig Road, and higher again at Goodwood Pump in the lower catchment (Table 2). Results from the ORC's year-long catchment water quality investigation in 2012/13 indicate plant-available concentrations remain low (relative to concentrations at Craig Road) as far as downstream as The Grange, with the highest concentrations recorded at Horse Range Road and Goodwood Pump (Figure 8).

The increasing DIN concentration with distance downstream is consistent with the more intensive land use in the lower catchment where nitrogen will be leached as nitrate through farmed soils into the underlying shallow groundwater aquifer. The ORC's investigations of connections between the aquifer and river identified river reaches near Glenpark, the gravel pits off Switchback Road and downstream of Horse Range Road where nutrient-enriched groundwater enters (refer Figure 4). In other locations, river water is lost to groundwater, such as upstream of the Palmerston Wastewater Treatment Plant ponds.

Overall, current median DIN concentrations could be broadly described as 'very low' in the upper reaches, 'low' in the mid reaches and 'moderate' in the lower reaches of the river. When the median concentrations at the ORC's three SOE sites are compared with those for other monitored river sites in New Zealand on the Land Air Water Aotearoa (LAWA) website[11]:

- Upper Shag River at SH85 culvert and Craig Road both sit within the top (best) 25% of monitored rural sites for all forms of nitrogen, and
- Goodwood Pump sits in the best 50% of lowland rural sites across all forms of nitrogen.

[11] Comparison based on median values on LAWA (accessed in December 2025), generated from five years of monthly monitoring ending June 2024. The comparison for Craig Road and Goodwood Pump was made against other lowland rural sites. Note: LAWA's statistics are updated annually.

Table 2: Summary of nutrient concentrations (mg/L) recorded in the Waihemo/Shag River at ORC's three SOE sites, based on monthly data for the five-year period ending June 2025 (n=57-60). The median values (shaded) summarise current water quality state or condition. Calculated from data supplied by the ORC.

	Ammoniacal-N	Nitrate-N	Dissolved inorganic N	Total N	Dissolved Reactive P	Total P
Upper Shag at SH85 culvert						
Min	<0.005	0.002	0.006	0.045	<0.001	0.002
Median	<0.005	0.008	0.010	0.068	0.002	0.003
95th percentile	<0.005	0.101	0.105	0.295	0.005	0.017
Max	<0.005	0.590	0.400	0.620	0.019	0.040
Shag River at Craig Rd						
Min	<0.005	0.008	0.010	0.107	<0.001	0.002
Median	<0.005	0.073	0.077	0.245	0.003	0.007
95th percentile	0.008	0.556	0.556	0.916	0.008	0.023
Max	0.011	1.11	1.12	1.60	0.019	0.054
Shag River at Goodwood Pump						
Min	<0.005	0.007	0.010	0.157	<0.001	0.004
Median	0.007	0.200	0.210	0.410	0.004	0.008
95th percentile	0.015	0.894	0.898	1.11	0.009	0.023
Max	0.018	1.22	0.600	0.860	0.020	0.027

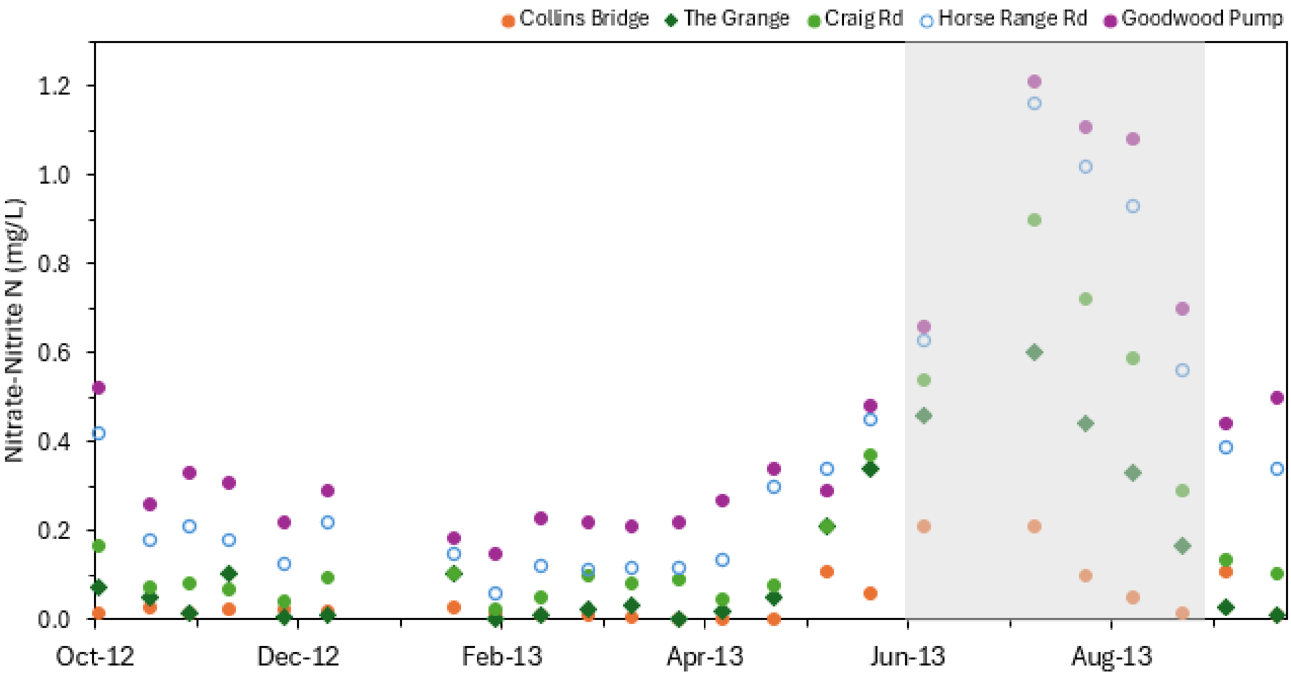

Figure 8: Nitrate-nitrite nitrogen (NNN) concentrations (the main component of plant-available DIN) recorded at Waihemo/Shag River sites between October 2012 and September 2013. Concentrations increase with distance downstream from Collins Bridge (Peddies Rd, inland of Waihemo Downs) to Goodwood Pump, and peak in winter (shaded panel). ORC data, with one outlier for The Grange removed.

As is common in many river systems, nitrate-N shows a strong seasonal cycle, with peak concentrations early in winter and the lowest concentrations recorded in late summer/early autumn (Figure 8, Figure 9). The peak likely reflects a 'first flush' of nitrate through the soil profile after the drier summer period followed by higher wintertime 'throughflow' through the soil to the waterways. In the case of Goodwood Pump, nitrate-N concentrations peak in late winter and dominate the pool of total nitrogen available through until December (Figure 9). This site is in a river reach fed from groundwater that is richer in nitrate-N (median of ~2.5 mg/L (ORC data[12]) compared with 0.2 mg/L in the river). Lower nitrate-N concentrations in summer – across all sites – likely reflect uptake by algae and aquatic plants.

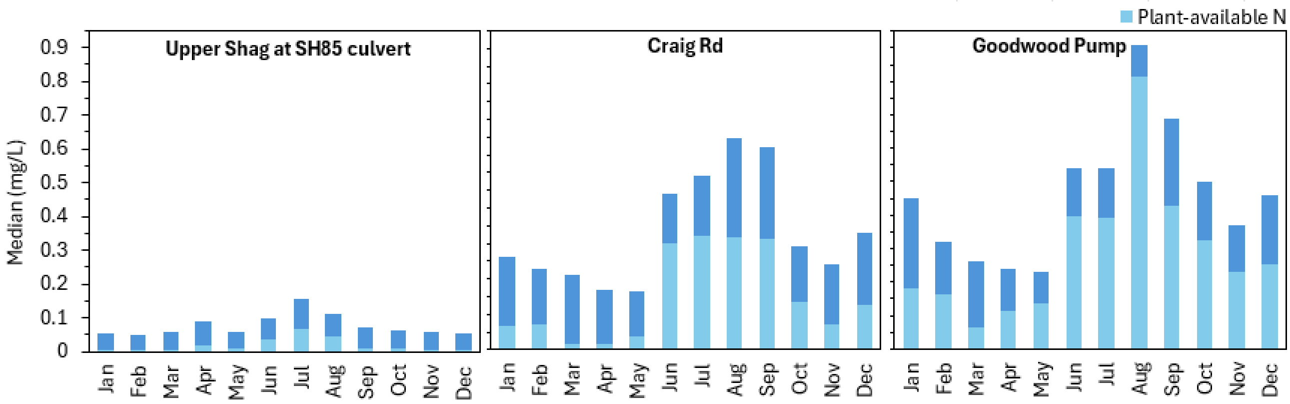

Figure 9: Median monthly concentrations of nitrogen in the Waihemo/Shag River at each of ORC's SOE sites for the five years ending June 2025). The total height of each bar represents the total nitrogen concentration, with the dissolved inorganic (plant-available) component – primarily comprising nitrate-N – shown in light blue.

A comparison of median DIN versus total nitrogen concentrations for the three SOE sites shows that, on average, DIN concentrations make up only 7% of the total nitrogen present in the water column in the upper reaches but this rises to 50% at Goodwood Pump upstream of the estuary (Figure 10). This means a significant portion of nitrogen is 'locked up' in organic matter, sediments or particles where it is not immediately available to plants. However, these nitrogen stores can become available under the right conditions, especially downstream in the estuary where decomposition is faster and oxygen conditions differ.

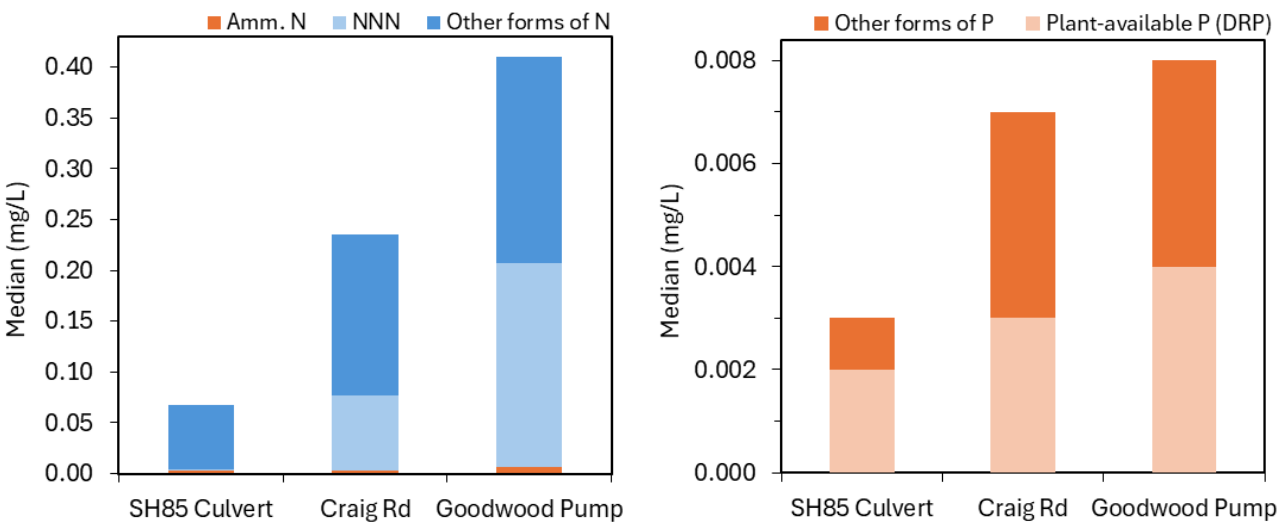

Figure 10: Left: Median concentrations of ammoniacal-N (Amm. N) and NNN (together representing the plant-available component or DIN) recorded at the ORC's three Waihemo/Shag River SOE sites over the five years ending June 2025. The height of each bar represents the total nitrogen concentration. **Right: Median concentrations of DRP (the plant-available component of P) relative to other forms of phosphorus (P).** The height of each bar represents the total P concentration.

[12] Based on all available data for ORC's shallow groundwater SOE wells J41/0019 (SH85, just east of Switchback Rd) and J41/0021 (Blacks Rd).

Phosphorus concentrations are low

River water quality monitoring by all organisations to date points to low concentrations of plant-available phosphorus (DRP) and total phosphorus across the catchment. Concentrations of both measures of phosphorus are at times below detection in the upper reaches (SH85 culvert) of the river and although they increase with distance down the catchment, they remain low at Goodwood Pump relative to both guideline values and other monitored rural rivers in New Zealand. For example, a comparison of median DRP and total P concentrations for the ORC's Waihemo/Shag River SOE sites with those for other river sites on the LAWA website shows that all three SOE sites fall in the best 25% of monitored rural streams in New Zealand.

Although DRP makes up, on average, around half of the total phosphorus concentrations recorded at Craig Road and Goodwood Pump (Figure 10), the median concentrations are very low across most months (Figure 11). As such, phosphorus is the primary nutrient that limits (i.e. controls) plant growth in the catchment (Ryder 2024).

The proportion of phosphorus delivered to the river will be much higher in wet weather, with most of this attached to sediment (McDowell et al. 2009, Peryer-Fursdon et al. 2015). For example, the results of sampling at Craig Road following 47 mm of rainfall on 19 December 2018 returned the highest phosphorus concentrations in 20+ years of monitoring to date (DRP of 0.016 mg/L, and total P ten times higher at 0.178 mg/L). Therefore, even in a low phosphorus catchment like the Waihemo/Shag, sediment-bound phosphorus pulses during wet events can substantially increase the load of phosphorus delivered to rivers. Much of this will be flushed downstream into the estuary where sediment and other particles more readily settle and can accumulate in sheltered areas.

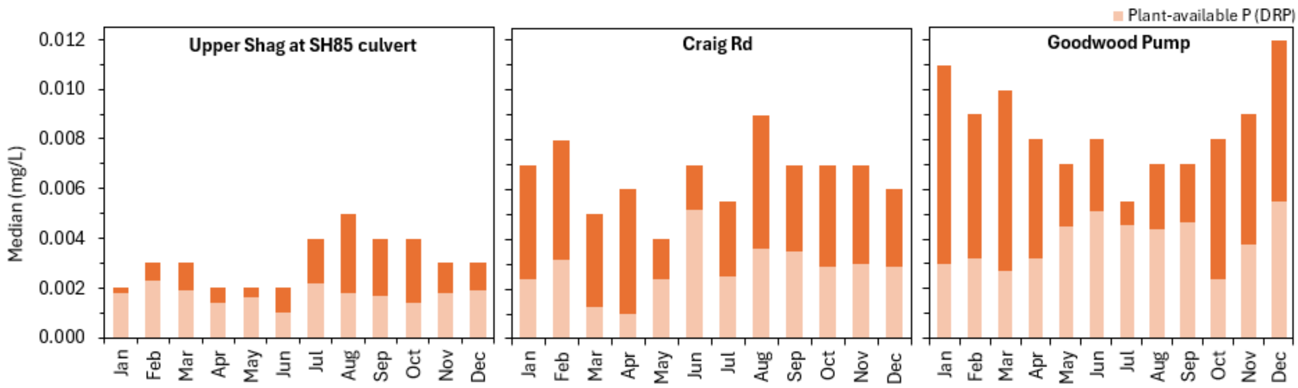

Figure 11: Median monthly concentrations of phosphorus in the Waihemo/Shag River at each of the ORC's SOE sites for the five years ending June 2025. The total height of each bar represents the total phosphorus (P) concentration, which is lowest in autumn and winter.

4.1.3 Pathogens

E. coli is used to indicate the risk to human health from faecally-sourced pathogens

Escherichia coli (E. coli) is a long-established and accepted, but imperfect, indicator of the risk to human health from faecally-sourced pathogens that are much more expensive to test for. The presence of *E. coli* may indicate the presence of harmful pathogens (e.g. campylobacter, giardia) that can cause eye, ear, nose and throat infections, skin diseases, and gastrointestinal disorders. Some pathogens in contaminated water can also be transmitted to livestock and affect their health. *E. coli* is nearly always found in high numbers in the gut of humans (so is present in wastewater discharges) and other warm-blooded animals, including sheep, cattle and birds.

The current NPS-FM *E. coli* attribute bands are based on the national microbiological water quality guidelines for recreational areas (MfE/MoH 2003). Like all guidelines that manage risks to human health, the MfE/MoH (2003) guidelines are set conservatively. A key statistic used to determine risk is the 95th percentile value in a five-year dataset, which represents the near-maximum value. On one hand, this is helpful because if it is low, then the public can be confident that the water is nearly always suitable for recreational activities. On the other hand, in many waterways, the highest *E. coli* counts coincide with rainfall or high and often 'dirty' river flows when most people are much less likely to be in the water.

Monthly year-round water quality monitoring across the ORC's three SOE sites indicates that, most of the time, *E. coli* indicator bacteria are below levels that pose a significant risk to human health from contact recreation activities such as swimming and fishing, or to stock health if the river is used as a stock drinking water supply (Table 3). Based on five years of monthly *E. coli* monitoring to June 2025, the ORC's SOE sites at Craig Road and Goodwood Pump fall into bands B and C of the NPS-FM, respectively. These bands are determined from the worst of four metrics used to assess the *E. coli* attribute under Table 9 of the current NPS-FM. Despite generally lower *E. coli* concentrations in the upper Shag at SH85 culvert, the available data indicate this site would, overall, fall into band B based on its 95th percentile value.

Table 3: Summary of *E. coli* concentrations (MPN/100mL) recorded in the Waihemo/Shag River at ORC's three SOE sites, based on monthly data for the five-year period ending June 2025 (n=57-59). The median values (shaded) summarise the current water quality state or condition; all fall into band A of the NPS-FM and meet the ANZG (2023) livestock drinking water guideline. Calculated from data supplied by the ORC.

Site	Median	95th percentile	Max	Results >260 MPN/100mL	Results >540 MPN/100mL
Upper Shag at SH85 culvert	50	770	1,120	20.4%	6.8%
Shag River at Craig Rd	57	599	11,870	15.5%	8.6%
Shag River at Goodwood Pump	91	1,125	4,040	35.1%	22.8%

The river is suitable for swimming most of the time

No sites on the Waihemo/Shag River are monitored as part of the ORC's weekly summer recreational water quality monitoring programme. However, monthly SOE *E. coli* results for the November to March period provide some insights into likely suitability for swimming. Based on the ten summer periods ending 31 March 2025, *E. coli* concentrations at Craig Road and Goodwood Pump exceeded the red/action threshold of the national swimming guidelines (540 *E. coli*/100mL, equating to an unacceptable risk to human health) on six (10%) and ten (18.5%) occasions, respectively (Figure 12). Most of these occasions coincided with heavy rainfall during or prior to sampling, when swimming would have been unlikely. Only one occasion did not follow any rainfall; this was on 29 March 2021 when the Goodwood site recorded 613 *E. coli*/100mL.

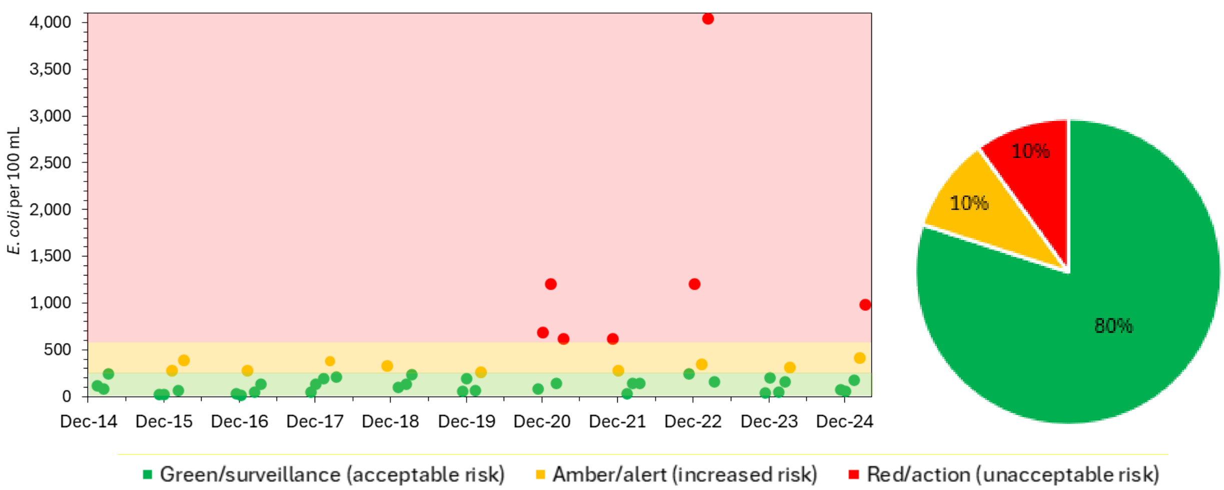

Figure 12: Left: *E. coli* concentrations recorded in the Waihemo/Shag River at Goodwood Pump from monthly sampling over last the ten 'summertime' periods to March 2025. Results are categorised according to MfE/MoH (2003) human health risk. **Right: Summary of monthly results for the last ten summers at Craig Road.** ORC data. Note that, for readability, the highest result (72,700 *E. coli*/100mL during heavy rain in December 2018) has been omitted from the main graph.

Overall, the strong link between *E. coli* and rainfall points to overland runoff as the primary source of significant faecal contamination in the Waihemo/Shag River. Low level contamination (equating with the amber/alert level) does occur at times in dry weather, likely from low densities of stock access (Olsen 2014) and wildfowl. Overall, though, summertime *E. coli* concentrations in fine weather don't appear to pose any significant risk to human health.

Microbial water quality, while critical for informing the risk to human health from pathogens, is only one measure of a river's suitability for contact recreation. Water clarity, depth and temperature, current strength and the amount of nuisance weeds or algae and rubbish are also relevant (Milne et al. 2017). Based on estimates from turbidity measurements, visual clarity at the baseflows when people would be swimming easily meets the long-established minimum guideline of 1.6 m (MfE 1994) but algae cover exceeds recreational use guidelines at times in the lower river reaches (see section 4.1.6).

4.1.4 Toxicants

Ammonia, nitrate and range of metals, pesticides and other compounds can be toxic to aquatic life. Concentrations of toxicants in surface waters are usually low unless the waterbody is impacted by industrial or other wastewater discharges.

There is a low risk of contaminants causing toxic impacts on aquatic life

Both ammonia and nitrate can be toxic to aquatic life but ammonia concentrations in the Waihemo/Shag River are seldom above detection and nitrate is also below levels that would cause toxicity effects on sensitive aquatic species such as trout. Based on the last five years of ORC's monitoring (refer to Table 2), all three of SOE sites fall within band A of the NPS-FM for both ammonia and nitrate toxicity.

Annual monitoring by WDC of (total) metal concentrations in the raw water intake adjacent to the Waihemo/Shag River at Goodwood over the last three years has not detected arsenic, cadmium, chromium, copper or zinc.[13] Total lead and nickel were detected in low concentrations once in October 2022.

Recent monitoring by OceanaGold in the Deepdell Creek subcatchment and the Waihemo/Shag River at Loop Road and McCormicks Creek points to low concentrations of dissolved (i.e. bioavailable) copper, cyanide, lead and zinc. Arsenic is consistently found in measurable concentrations, with the median concentration of 0.0124 mg/L at the most downstream site in Deepdell Creek (DC08) in 2024/25 around ten times higher than that measured at the control site upstream (0.0011 mg/L) and sites downstream in the Waihemo/Shag River at Loop Road (0.0018 mg/L) and McCormicks (0.0016 mg/L). While arsenic is elevated at DC08, the median concentration recorded during 2024/25 was just below the ANZ (2018) guideline value for the protection of aquatic ecosystem health[14] and no individual measurements exceeded the OceanaGold's resource consent compliance limit of 0.15 mg/L.

Although not a toxicant, monitoring indicates that sulphate is found in elevated concentrations in Deepdell Creek downstream of the mine's influence, relative to background levels (Ryder 2025). It is well established that high sulphate water is discharged from some parts of Macraes Mine but this is actively managed through consent conditions and current in-stream concentrations are well below those that might potentially impact use of the water (e.g. for stock or irrigation purposes).

Historical monitoring at the (now closed) Palmerston Landfill found boron-rich leachate from part of the site was entering a modified tributary of the lower Waihemo/Shag River (Sycamore 2007). However, leachate collection systems were subsequently installed, with leachate high in boron separated from the balance of the landfill leachate and disposed offsite. Recent WDC monitoring reports (Clarke 2023, 2024) suggest that the

[13] Note that some of these metals may be present; the lab test method detection limits are coarser than those used by OceanaGold and the ORC.

[14] 0.024 mg/L as arsenic V (arsenate), typically compared against the 95th percentile (rather than median) value of a dataset. Arsenic can exist in different oxidation states but arsenic V is usually the most dominant form in well-oxygenated surface waters (Smedley and Kinniburgh 2002).

works have been successful, with boron concentrations – when there was sufficient flow for water sample collection – significantly reduced and below the ANZ (2018) guideline value.

4.1.5 Trends over time

Understanding trend assessments

Assessment of trends over time complements information on current state by providing information on whether water quality is getting *better or worse* over time. State and trend results therefore need to be considered together to understand river health.

Trend assessment methods applied to river water quality (and ecological) data in New Zealand are statistically based and have evolved over time, resulting in differences in interpretation and reporting. The current recommended approach (Snelder et al. 2021) has been used in national and most regional SOE reporting for at least five years. This approach is based on the view that a trend always exists, but often there is not enough precision in the dataset to confidently say if the trend is increasing or decreasing. Previously, trend results falling into this category were classified as "no trend" and where trends were detected, they were only reported if they had a very high of level of statistical significance.

Trend assessments are now reported based on bands of statistical confidence and associated descriptions, ranging from a low confidence of 33-66% ("as likely increasing as decreasing") to >99% confidence ("virtually certain"). The same bands and descriptions are not always universally applied.

Trend direction is sometimes reported on its own (e.g. LAWA, Ozanne et al. 2023) but this only provides a part of the picture. The trend *magnitude* or size is also important as this indicates the *rate of change* (increase or decrease) in water quality over the time period assessed. There may be a virtually certain increase in nitrate-N concentrations at a site over a 10-year period, indicating a deterioration in water quality, but the environmental significance of that increase depends on:

- what the current state of water quality is (e.g. is it above, below or approaching a critical guideline or standard?), and
- how quickly it is increasing (i.e., the rate of change).

Trend assessments also require the data analyst to make decisions about what data to include or exclude to ensure a robust assessment. Some of these 'data filtering' decisions are subjective, meaning two sets of assessments may not produce exactly the same results (Snelder et al. 2021). This is often the case when multiple sites and long timeframes are being assessed (e.g. regional or national reporting) because of changes in the measurement frequency or methods that, if not accounted for, would prevent a robust comparison between sites. This applies to the ORC's SOE data and effectively means that sometimes not all of the data available for an individual site are used in regionwide trend assessments.

Some aspects of water quality may have improved over time

The most recent publicly available assessment of trends in water quality over time in the Waihemo/Shag catchment was carried out as part of an Otago-wide assessment of river, lake and ground water quality completed by LWP Ltd (Fraser et al. 2023a, 2023b) and reported in Ozanne et al. (2023). This assessment looked at river water quality data collected over 10- and 20-year periods ending 30 June 2022.

Over the 10-year period ending 30 June 2022, both the Craig Road and Goodwood Pump monitoring sites showed decreasing (improving) trends in concentrations of turbidity and nutrients (N and P) (Ozanne et al. 2023). This contrasts with the 20-year period between July 2002 and June 2022 where both sites recorded deteriorating trends in these same water quality indicators. Overall, the only improving or deteriorating trends reported with a very high level of confidence were:

- the increasing turbidity, nitrate-nitrate-N (NNN) and total N concentrations (i.e. deteriorating water quality) at Craig Road over the 20-year period ending 30 June 2022, and
- the decreasing turbidity and concentrations of NNN, total N, DRP and total P (i.e. improving water quality) at Goodwood Pump over the 10-year period ending 30 June 2022 (Table 4).

Table 4: Summary of key trends in water quality at river SOE monitoring sites within the Waihemo/Shag catchment for the 10-year period ending June 2022. Simplified from the results reported by Ozanne et al. (2023) – green cells indicate improving trends; yellow cells indicate the trend direction was unclear (note there were no deteriorating trends). Black arrows indicate both high confidence in the trend direction and a trend rate that was able to be quantified (presented as percentage change per year, extracted from LWP data files provided by the ORC). Amm. N is ammoniacal-N; NNN is nitrate-nitrite N; DRP is dissolved reactive P.

	Turbidity	Amm.-N	NNN	Total N	DRP	Total P	*E. coli*
Craig Rd							
Goodwood Pump	↓ -3.9%		↓ -8.2%	↓ -4.1%	↓ -6.9%	↓ -4.6%	

More recent trend information available on LAWA (for the 10 years ending June 2024) reports deteriorating (i.e. increasing) trends in NNN and total N at both Goodwood Pump and Craig Road. Although the statistical confidence in the direction of these trends is low, more sophisticated trend analysis carried out by the ORC for the Craig Road site also identified deteriorating trends in total N concentrations for all time periods analysed between 2000 and 2025 (H. Trotter, ORC, pers. comm. 2026). The analytical method used in this recent analysis indicates these deteriorating trends are likely to be associated with human activities.[15]

No information was available on LAWA for trends in groundwater nitrate-N concentrations so the ORC's historical record for former SOE groundwater well J43/0006 (located adjacent to Mill Road) was assessed for this report using the same methods as Fraser et al. 2023a, 2023b). This identified an 'extremely likely' decreasing (i.e. improving) trend of 4.4% per year (for the 15-year period ending October 2023) and would explain the improving trend over the ten-year period to 2022 for the groundwater-influenced Goodwood Pump site (Table 4).

4.1.6 Ecological health

Periphyton cover reaches nuisance levels in the lower river reaches

The amount (biomass) of periphyton present on the bed of the Waihemo/Shag River has been monitored at ORC's Goodwood Pump site since February 2019. Biomass routinely exceeds the Ministry for the Environment's (2000) national guideline for the protection of biodiversity (50 mg/m^3 as chlorophyll *a*) and often exceeds guidelines set to protect aesthetics/recreation (120 mg/m^3) and trout habitat and angling (120–200 mg/m^3) values (Table 5). Based on the last five years of monitoring, this site would fall into band D of the NPS-FM, below the national bottom line or minimum acceptable state. A lack of shade, in combination with sufficient nutrient concentrations, high water temperatures and stable flows for extended periods in summer, collectively provide ideal conditions for periphyton to proliferate at the Goodwood Pump site (Figure 13).

Table 5: Summary of periphyton biomass (as chlorophyll a, mg/m^3) measured on the bed of the Waihemo/Shag River at Goodwood Pump between February 2019 and September 2025. Source: ORC.

Five years to June 2025				All results		
No. of results	Median	92nd percentile*	Max	No of. results	%<50 mg/m^3	% >200 mg/m^3
40	114	346	675	59	33.9	15.3

* The 92nd percentile statistic is used to assess attribute state under NPS-FM. The NPS-FM sets a minimum acceptable state of no more than 200 mg/ m^3.

[15] The ORC recently ran the Weighted Regression on Time, Discharge and Season (WRTDS) model for all river SOE water quality sites with available flow data (i.e. Craig Rd but not SH85 culvert or Goodwood Pump). Unlike the Mann Kendall method used in traditional SOE and LAWA trend assessments, this model attempts to control for variation in climate over the trend assessment period (e.g. by separating wet years vs. dry years, which are known to significantly influence water quality), increasing confidence that any detected change in water quality is driven by human activity (Ausseil et al. 2025).

Figure 13: Filamentous periphyton growth in the Waihemo/Shag River at Goodwood Pump. Left: *Cladophora* bloom during drought conditions on 8 February 1999 (source: ORC 2000). Right: In winter (July) 2020 (source: ORC). Monitoring records show a mix of long filamentous and mat periphyton are usually recorded.

Cladophora dominated periphyton taxa identified from rock scrapings collected annually by the ORC between 2001 and 2008 at The Grange. In contrast, a wide range of taxa dominated in annual samples from Craig Road between 2001 and 2013, including the filamentous cyanobacterium *Oscillatoria* and diatoms such as *Encyonema* sp. (Olsen 2014). Further downstream at Goodwood Pump, *Oscillatoria* and the stalked diatom *Gomphoneis* were often abundant. The potentially toxic cyanobacterium *Microcoleus* (formerly *Phormidium*) has also been recorded at this site and macrophytes (i.e. aquatic plants such as watercress) are often present (Figure 14). Overall, the more common periphyton taxa that were recorded from monitoring at the ORC's SOE sites are associated with a wide range of water quality conditions.

Figure 14: *Phormidium* mats (left), extensive aquatic plant cover at OceanaGold's Northern Gully site (middle, SLR 2004) and bankside plant cover at Deepdell Creek in 2023 (SLR 2024).

Some of the Waihemo/Shag River tributaries monitored by OceanaGold also have a significant portion of their beds covered with periphyton. Overall, aquatic plant cover is often higher (Figure 14), particularly in Camp Creek, Tipperary Creek, Northern Gully and site DC05 on Deepdell Creek; during 2023 cover across the channel ranged between around 70 and 90% (SLR 2024), much higher than when monitoring began in 2012 (SLR 2024) and well above the recommended provisional national guideline (Matheson et al. 2012) of 50%. Moss cover is also high at some sites at warmer times of the year (SLR 2024).

Invertebrate community health varies across the catchment

Macroinvertebrates are a direct measure of stream health

Aquatic macroinvertebrates include insects, crustaceans, snails, worms and other small critters that are large enough to see by the naked eye. They are an important part of the stream food web and good indicators of overall stream ecological health or condition. This is because as well as good water quality, a diverse macroinvertebrate community needs a range of microhabitats within the stream, including variation in streambed materials (substrate such as cobbles and gravel) and the types and amount of water flow (e.g. riffles, runs and pools).

Macroinvertebrate sampling results are commonly reported as a series of **community health measures:**

Taxa richness – the number of different species (taxa) of invertebrates present in a sample. Generally, high taxa richness is considered good, but some streams with mild nutrient enrichment can support higher numbers of taxa than pristine streams. Taxa richness is therefore a very coarse indicator of stream health.

Macroinvertebrate Community Index (MCI) – the most widely used indicator of stream ecological health, based on the tolerance or sensitivity of the different species (taxa) present in a sample to organic pollution and nutrient enrichment. Most invertebrate taxa have been assigned a tolerance value ranging from 1 (very tolerant) to 10 (very sensitive). The MCI score is derived from the average tolerance value of all taxa present at a site, multiplied by 20. Higher MCI scores indicate better stream conditions at the sampled site.

The MCI and its variant, the QMCI (below), were designed originally for stony bed streams with riffle flow. This means caution is needed when interpreting scores for other stream types.

Quantitative Macroinvertebrate Community Index (QMCI) – a variation of the MCI that considers the relative abundance of each invertebrate taxa found in the sample. The QMCI is generally more sensitive to subtle changes in water quality and stream health because it responds to changes in the relative of proportions of different species rather than changes in what species are present or absent. A QMCI score ranges from 0 to 10.

Ephemeroptera (mayflies), Plecoptera (stoneflies) Trichoptera (caddisflies) (EPT) – aquatic insects that are sensitive to water pollution and degraded stream habitat (e.g. silted streambeds). A stream macroinvertebrate community that has a high abundance or percentage of EPT taxa generally indicates good stream health.

The NPS-FM 2020 also includes the **Average Score Per Metric (ASPM)**, calculated by combining information from the MCI and two measures of EPT.

Common measures of aquatic invertebrate community health indicate ecological health declines from 'very good-excellent' in the upper reaches (at SH85 culvert) to 'fair-good' at Craig Road and 'poor-fair' at Goodwood Pump (Table 6). Median values from annual macroinvertebrate sampling by the ORC over the last three to five summers ending in March 2024 return macroinvertebrate community index (MCI) and quantitative MCI (QMCI) scores for Goodwood Pump of just 85 and 3.5, respectively. These scores are similar to those calculated from the entire 20-year+ monitoring record. A key driver of the low scores at this site is that the riverbed is characterised by very high coverage of algae (see previous subsection) with pockets of fine sediment: conditions that are more favourable to snails, worms and midges (Figure 15). Despite this, taxa lists provided in Olsen (2014) indicate that the site still regularly supports large numbers of some pollution-sensitive taxa, in particular *Deleatidium* mayfly larvae and a wide range of caddisfly larvae.

Deleatidium mayfly larvae also numerically dominate the macroinvertebrate community at both the Craig Road and SH85 monitoring sites but multiple other pollution-sensitive taxa are also common, especially at SH85, driving significantly higher MCI, QMCI and other metric scores at this upper site. These taxa include *Stenoperla* and *Zelandoperla* stonefly, *Coloburiscus* and *Nesameletus* mayfly, and *Helicopsyche* caddisfly larvae (Figure 15). As well as excellent water quality, the quality of the physical habitat at this site is also much higher, characterised by faster flowing water and a bed free of significant algal growth.

Table 6: Median (and range) of common macroinvertebrate community health measures for the ORC's three SOE monitoring sites on the Waihemo/Shag River. Source: ORC annual kick-net monitoring carried out in the five years to June 2025.

Monitoring site	Date range	MCI	QMCI	%EPT	ASPM
SH85 culvert	2022–2025 (4 samples)	126 (123–133)	6.9 (6.1–7.4)	52 (50–61)[2]	0.62 (0.54–0.74)
Craig Rd	2022–2025 (4 samples)	96 (93–98)	5.5 (5.0–6.6)	39 (32–45)[2]	0.48 (0.37–0.52)
Goodwood Pump	2021–2025 (5 samples)	85 (80–89)	3.8 (3.5–5.1)[1]	32 (19–33)[2]	0.33 (0.32–0.42)

[1] QMCI value only available for last 4 sample results.

[2] No EPT values provided for 2025 sample results.

Figure 15: Some of the invertebrate taxa found in high numbers in annual sampling of the Waihemo/Shag River by the ORC. Top row (abundant at all three sites), left to right: *Deleatidium* mayfly larvae, *Pycnocentrodes* caddisfly larvae and *Potamopyrgus* snail, Middle row (abundant in upper Shag at SH85), left to right: *Stenoperla* (green) stonefly, *Nesameletus* (swimming) mayfly and *Helicopsyche* (spiral-cased) caddisfly larvae. Bottom row (most abundant at Goodwood Pump), left to right: Elmidae riffle beetle, Orthocladiinae chironomid midge and *Austrosimulium* (black or sand fly) larvae. Photos: Stephen Moore, Landcare.

The median MCI and QMCI scores at Goodwood Pump equate to 'fair' and 'poor' under the long-established Stark and Maxted (2007) guidelines and 'band D' (i.e. poor and below the minimum acceptable standard) under the current NPS-FM macroinvertebrate attribute bands. However, the site fares better under the ASPM attribute (band C). This is because ASPM includes EPT measures, which were 'moderate' for EPT abundance (32%) and associated EPT richness.

'Excellent' for the Upper Shag (SH85) and 'good' for the Craig Road sites under the Stark and Maxted (2007) 'quality classes' probably better describe MCI scores than assignment to NPS-FM bands B and C, respectively.

The NPS-FM MCI bands are set higher than the Stark and Maxted (2007) quality classes and many very high quality river sites across the country cannot meet band A (MCI >130). Based on both QMCI and ASPM scores, the Upper Shag would fall into band A, and Craig Road would fall into band B, aligning with overall descriptions of 'excellent' and 'good'.

Other invertebrate data for the Waihemo/Shag River confirms that MCI and other invertebrate community health metric scores are higher upstream of Craig Road and lower downstream of this site. For example:

- the median MCI score from annual monitoring by the ORC at The Grange between 2001 and 2008 was 98, with a score of 106 in April 2008 when both Craig Road and Goodwood Pump scored <100, and
- the ORC's 2012/13 catchment investigation returned MCI and %EPT taxa scores of 133 and 61% at Collins Bridge, 108 and 50% at The Grange, 92 and 40% at Craig Road, 92 and 37% at Horse Range Rd, and 88 and 39% at Goodwood Pump (Olsen 2014).

Outside of the Waihemo/Shag River mainstem, invertebrate data are available for Deepdell Creek and sites on several of its tributaries, as well for Cranky Jims Creek and Tipperary Creek as part of OceanaGold's consent monitoring. MCI scores are generally consistent across Deepdell Creek sites and seasons, and have typically remained indicative of 'fair' quality conditions using the narrative terminology of Stark and Maxted (2007). However, the QMCI scores (which are probably more robust given they reflect both the diversity and abundance of taxa at a site) point to a difference upstream and downstream of mining activities; recent monitoring shows the three control sites were generally indicative of 'fair' and 'good' quality whereas downstream impact sites were typically 'poor' (SLR 2024) (Figure 16).

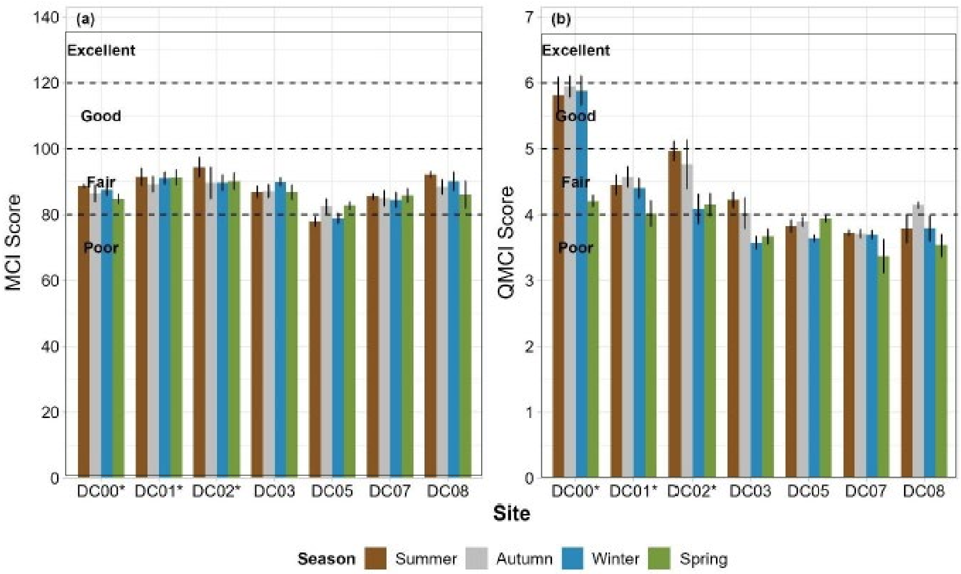

Figure 16: Average (± standard error) MCI (left) and QMCI (right) scores from Deepdell Creek sites sampled quarterly in 2023 as part of OceanaGold's resource consent monitoring requirements. Sites DC00 to DC02 represent control sites, unimpacted by mining operations. The thresholds are based on guidance from Stark and Maxted (2007). Reproduced from Figure 6 in SLR (2024).

The ORC's 2012/13 catchment investigation included macroinvertebrate sampling on the lower reaches of McCormicks Creek at SH85. This returned MCI and semi-quantitative MCI scores indicative of 'good' and 'excellent' quality, respectively, with EPT taxa comprising half of the 16 taxa present (Olsen 2014).

Overall, the Stark and Maxted (2007) quality classes appear to better describe macroinvertebrate community health in the Waihemo/Shag catchment than the current NPS-FM bands. However, both 'frameworks' present a 'one size fits all' set of numbers and a better approach is to compare the macroinvertebrate metrics against a national dataset that groups measurements made at hundreds of river sites according to their environmental 'type' (Clapcott et al. 2013). Type is determined using the climate (e.g. warm-wet vs warm-dry) and source of flow (e.g. mountain-fed vs lowland) classes of the River Environment Classification (Snelder and Biggs 2003). This comparison shows that the current median MCI scores for the Waihemo/Shag River at Craig

Road (96) and Goodwood Pump (85), both classified under the REC as 'cool-dry upland', are below the average MCI (106.4) measured across river sites of the same type. This suggests that there is room for improvement.

Freshwater fish diversity is high

ORC monitoring confirms the Waihemo/Shag River supports a high diversity of native freshwater fish, equating to band A (high biological integrity, indicating good habitat and access to the sea) of the NPS-FM. Over the 14 occasions that the ORC has carried out electric fishing at Craig Road since 2008, īnanga, longfin eel, shortfin eel, pouched lamprey, redfin bully, bluegill bully, common bully, upland bully, brown trout, torrentfish, Canterbury galaxias and Taieri flathead galaxias have all been recorded (Figure 17). Of these, upland bully is consistently found in the highest numbers. Similar fish were recorded in the lower river reaches, along with black flounder and common smelt in 2013 (Olsen 2014).

Figure 17: Clockwise from top left – redfin bully (photo: Stella McQueen), Taieri flathead galaxias (photo: © Rod Morris), kōura/freshwater crayfish (photo: DOC) and longfin eel (photo: Rohan Wells, NIWA) are all regularly recorded in the Waihemo/Shag River catchment. Kōura, often found in Deepdell, Highlay, Cranky Jims and Tipperary creeks near Macraes, are classified as 'at risk – declining' (Grainger et al. 2018).

Electric fishing of the upper tributaries of the Waihemo/Shag River near OceanaGold's mine at Macraes has most commonly found Taieri flathead galaxias in Tipperary and Highlay creeks and kōura/freshwater crayfish (Figure 17) at most sites (e.g. Ryder 2024, SLR 2024). At some sites water levels are often insufficient for electric fishing (SLR 2025) and SLR (2024) note that increasing macrophyte cover and sediment loads at some sites (e.g. in Highlay Creek) will likely further degrade habitat for macroinvertebrates and fish.

As of December 2025, around 30 eDNA test results were publicly available on the Wilderlab website for stream sites in Waihemo/Shag River catchment, including for sites on a few tributaries such as Pig Root Creek, Siberia Creek and Shingly Creek and Green Valley Stream in the upper catchment. In general, the fish species detected align with electric fishing records although eDNA tests for Goodwood Pump have also detected giant bully and banded kokopu on occasion. Consistent with electric fishing, upland bully dominate the test signal at most sites.

The river can get very warm and flows very low at times

River water temperature, at least for short periods in summer, can get uncomfortably warm for some aquatic life. High frequency measurements at the ORC's SOE site on the Waihemo/Shag River at Craig Road indicates that water temperature at this location regularly exceeds 21°C for short periods during summer (Figure 18). The highest water temperature recorded to date is 25.3°C early on the evening of 5 February 2023, following an extended period (starting in late December 2022) when peak daily water temperatures were almost always above 20°C.

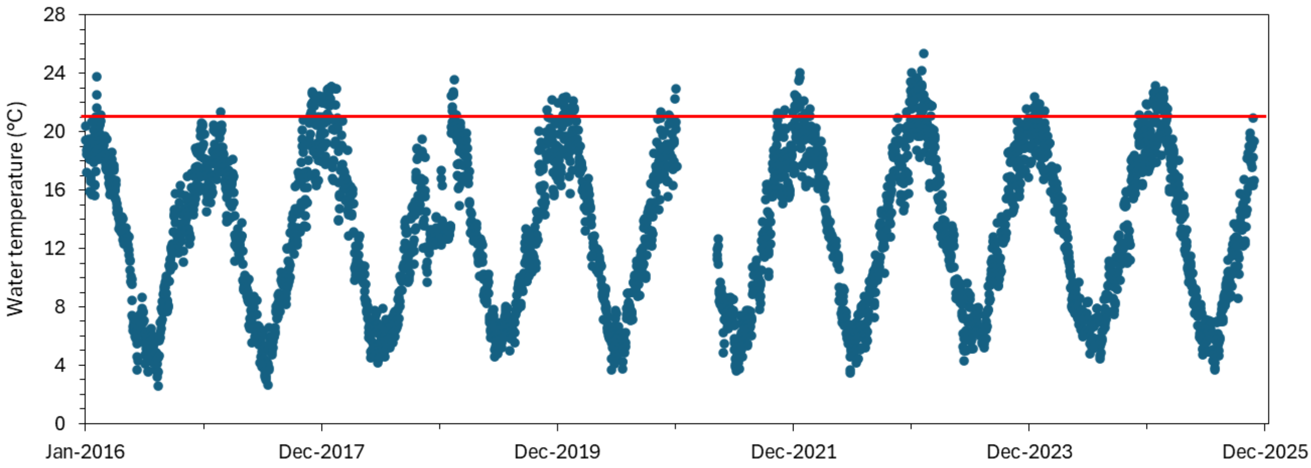

Figure 18: Maximum daily water temperature in the Waihemo/Shag River between January 2016 and November 2025, based on high frequency data from the ORC's Environmental Data Portal. The horizontal red line indicates a commonly accepted threshold of 21°C, above which acute thermal stress has been associated with mayflies (Olsen et al. 2012)[16].

In New Zealand, the Cox Rutherford Index (CRI) is commonly used to characterise summertime water temperatures and can be used to interpret the potential effects of water temperature on aquatic ecosystems. The CRI is the midpoint between the daily average and daily maximum temperatures and can be averaged over the five hottest days of a summer from a continuous water temperature record (Davies-Colley et al. 2013). For the five warmest days recorded from monitoring to date, during early February 2023, the CRI was calculated to be 21.9°C. This placed the Craig Road site within a water temperature range Davies-Colley et al. (2013) describe as causing *"some thermal stress on occasion, with loss of certain sensitive insects and absence of certain sensitive fish."*[17] A scan of the remaining data records suggests that, in most summers, water temperatures would only cause *"minor thermal stress on occasion"*.

The ORC also collected high frequency water temperature measurements at Collins Bridge and lower McCormicks Creek between October 2011 and May 2012. Collins Bridge remained below 20°C throughout this period while McCormicks Creek recorded a weekly average over 21°C and a maximum temperature of 24.7°C (Olsen 2014). No high frequency temperature data exist for the less shaded lower reaches of the Waihemo/Shag River but a spot measurement of 20.9°C was recorded around midday on 4 February 1998 at Goodwood Pump and a measurement of 29°C was recorded at the same site late in the day on 8 February 1999 amidst a significant drought in Otago (Caruso 2002).

One consequence of elevated stream temperatures can be lower levels of dissolved oxygen (DO) in the river (as warm water holds less oxygen). Continuous measurements taken by ORC at Craig Road since May 2021 indicate DO seldom drops below critical minima (Figure 19) despite high water temperatures at times. The main exception occurred in early December 2024 when the DO concentration dropped to a minimum of just 1.7 mg/L and averaged only 2.6 mg/L over the course of a full week. Concentrations this low over successive

[16] Thresholds for acute thermal stress vary across invertebrate and fish species and life stage. *Deleatidium* mayflies and brown trout are among the most sensitive invertebrates and fish, respectively.

[17] Davies-Colley et al. (2013) established recommended NPS-FM bands of A to D based for water temperature based on the CRI, but water temperature was not adopted as an attribute in the NPS-FM. A CRI of 21.9°C would equate to 'band C'.

days would likely have caused significant stress on sensitive aquatic life, in particular trout, and placed Craig Road into band D of the NPS-FM for the DO attribute.

The period of very low DO concentrations was unusual being in early December, outside of the peak water temperatures. However, it did coincide with a period of low river flow (Figure 19) and water temperatures reached a maximum of 21.1°C at this time.

Continuous flow records for the Waihemo/Shag River at Craig Road indicate that river flows can be low for extended periods in some summer/autumn periods (Table 7). One of the most significant low flow periods in the >32-year monitoring record occurred during drought conditions in early 1999 (Figure 20). Extended low flow periods can increase water temperatures and accelerate periphyton growth (refer section 4.1.6).

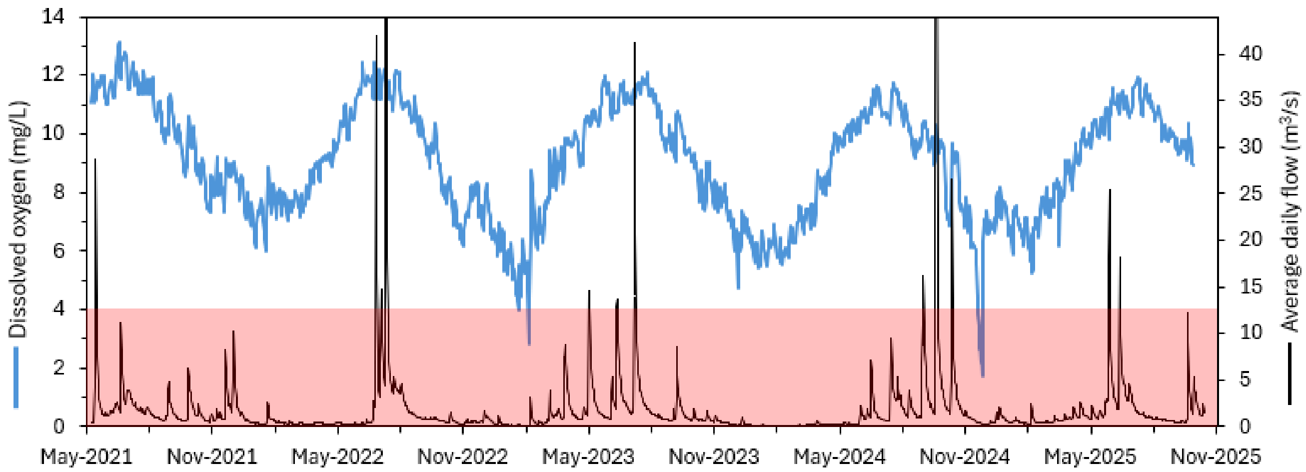

Figure 19: Minimum daily dissolved oxygen (DO) concentrations and average daily flow in the Waihemo/Shag River at Craig Road from high frequency monitoring between May 2021 and October 2025. The red area aligns with NPS-FM band D and indicates a DO range at which concentrations can be detrimental to aquatic life, particularly some fish. ORC data.

Table 7: Summary statistics of monthly mean flows (m^3/s) at The Grange and Craig Road, based on monitoring by the ORC. Calculated from data sourced from the ORC's Environmental Data Portal, December 2025.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
The Grange (Dec 1989–Nov 2025)												
Median	0.45	0.32	0.30	0.50	0.72	0.95	1.66	1.54	1.03	1.02	0.61	0.53
Minimum	0.05	0.03	0.05	0.10	0.17	0.23	0.35	0.25	0.45	0.33	0.27	0.16
Mean	1.13	0.70	0.82	1.14	1.65	1.91	2.81	2.92	1.96	1.80	1.33	1.22
Max	7.39	5.22	11.8	12.3	14.5	21.1	15.7	14.1	11.5	8.7	14.4	17.2
Craig Road (Oct 1993–Nov 2025)												
Median	0.52	0.38	0.34	0.64	0.89	1.25	1.88	2.15	1.14	1.12	0.69	0.58
Minimum	0.05	0.03	0.09	0.11	0.19	0.23	0.45	0.36	0.53	0.35	0.30	0.15
Mean	1.64	0.98	1.37	1.65	2.31	2.72	4.11	3.29	2.00	1.87	1.85	1.22
Max	12.4	6.94	22.1	20.4	24.5	31.4	26.3	19.7	13.1	12.4	26.3	11.8

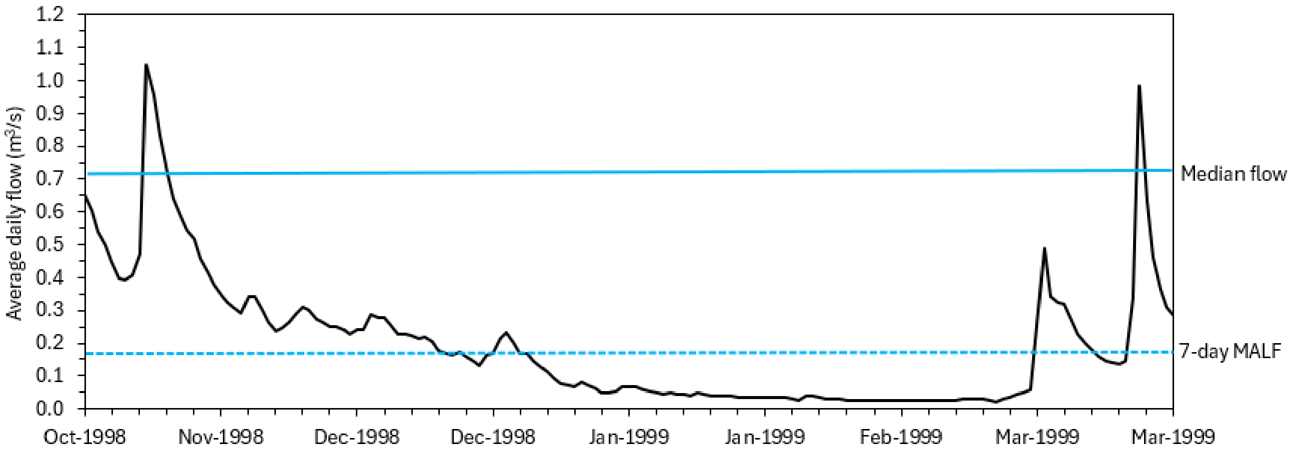

Figure 20: Average daily flows recorded by the ORC in the Waihemo/Shag River at Craig Road during summer 1998/99. Median flow and mean annual low flow (MALF) calculated for the period Sept 1993 to May 2014, from Olsen (2014).

Information on trends in ecological health is limited

The most recently documented information on trends in ecological monitoring indicators at ORC sites is for the Shag River at Goodwood Pump, which was reported with an "unlikely improving" trend in MCI scores over the 10-year period ending 31 August 2020 (ORC 2021). The more recent assessment for this site available on LAWA (for the 10-year period ending in June 2024) is a "likely degrading" trend based on the quantitative MCI (QMCI). Neither "unlikely" nor "likely" trends are associated with high statistical confidence.

Analysis of trends over time of OceanaGold data from tributary streams in the Macraes area indicates that macroinvertebrate community health has declined over time across all Deepdell Creek sites, but especially at impact sites DC05 and DC07. SLR (2024) suggest that a combination of habitat degradation and mining activities are likely driving the decline. Recent declines in QMCI scores have also been recorded in Cranky Jims Creek and Tipperary Creek. Several factors are suggested as contributing causes, including sedimentation, increasing coverage of aquatic macrophytes (plants) and altered flow regimes. SLR (2024) state that while mining activities may be having an impact on stream invertebrate communities, it is difficult to isolate this from the effects of intermittent stream drying and farming (e.g. stock access).

4.2 Estuary water quality and ecological health

4.2.1 Information on water quality in the estuary is limited

No information was found on the microbiological water quality of the Waihemo/Shag Estuary to assess the potential risks to human health from swimming or shellfish harvest. The greatest risk of exposure to harmful waterborne pathogens will be following heavy rainfall, particularly in the upper estuary where there is less tidal flushing compared with near the estuary mouth.

One-off monitoring of the water column in December 2016 identified that the upper estuarine reaches were eutrophic (enriched), with very high chlorophyll *a*, ammoniacal nitrogen and total nitrogen concentrations in the bottom waters relative to the surface (Robertson et al. 2017). This indicated that stratification was present, whereby the river water was sitting above the denser estuarine water. This suggests poorly flushed bottom water is intermittently present in the estuary. While this increases the risk of water column algal (phytoplankton) blooms, the estuary's very high flushing rate (0.7 days) limits this risk (Plew 2021). Should blooms occur, these would be mostly likely in the upper estuary channel or in the main estuary channel if the flow at the estuary mouth becomes constricted.

4.2.2 Ecological health is under pressure from fine sediment

The most recent ecological survey, completed in November 2023, identified that the primary pressure on the health of the Waihemo/Shag Estuary is fine sediment. Sediments comprising more than 25% mud covered

15.6 ha (41% of the available intertidal habitat), an increase of around 7 ha compared with the November 2016 baseline survey (O'Connell et al. 2024). As well as greater coverage of muddy sediments across the intertidal flats, sediment plate monitoring undertaken in parallel shows the annual sediment accumulation rate between December 2016 and November 2023 averaged 2.6 mm/year in the mid-estuary and 1.1 mm/year in the lower estuary (Rabel 2024). While this could indicate an increase in sediment inputs from the upstream catchment, significant year-to-year variation in sediment depth has been recorded, suggesting that patterns of erosion and deposition driven by hydrodynamic processes are likely the dominant influence on sediment distribution (Forrest 2023).

Muddy sediments are often poorly oxygenated, resulting in an unbalanced macroinvertebrate community in the Waihemo/Shag Estuary dominated by crustaceans and polychaetes, with very few bivalves (e.g. cockles) and gastropods (e.g. mudflat whelks). The presence of muddy, poorly oxygenated intertidal sediments near the estuary mouth in December 2016 was considered atypical compared with other New Zealand estuaries of a similar type (Robertson et al. 2017).

Outside of fine sediment and its impact on the macroinvertebrate community, most other estuarine indicators were in a 'good' or 'very good' state in 2023. Similar to 2016/17, saltmarsh cover is high (54% of the intertidal area) and surface sediments sampled at representative intertidal locations returned low organic, nutrient and heavy metal concentrations. The cover of potentially nuisance macroalgae did increase slightly between surveys but is limited to 8% of the intertidal habitat area (O'Connell et al. 2024).

Catchment sediment inputs pose the greatest risk to estuary health

With evidence of an increase in mud content in parts of the Waihemo/Shag Estuary, limiting further significant sediment inputs from the upstream catchment should be a priority. National modelling by Hicks et al. (2019) estimated that 33,537 tonnes of sediment enters the estuary annually. However, sediment delivery is not even, with very high pulses of sediment entering in wet weather (refer section 4.1.1), which can rapidly smother benthic habitats and organisms and have disproportionate ecological effects compared to average annual loads.

While water column sampling in 2016 suggests that the water is nitrogen-rich, which has the potential to fuel phytoplankton blooms if other conditions permit, overall, the risk of these blooms appears to be limited by the estuary's very short flushing time. Work by Plew (2021) indicates that macroalgae blooms on the sediment pose a greater risk. Total nitrogen inputs to the estuary have been estimated at 118.6 tonnes per year, compared with 3.4 tonnes per year for total phosphorus (Snelder and Fraser 2023). The small deterioration in macroalgae condition rating between the 2016 and 2023 surveys suggests nutrient enrichment is a potential issue requiring ongoing monitoring (O'Connell et al. 2024).

4.3 Summary

Assessment of available monitoring and other information indicates that water quality in the Waihemo/Shag River is 'excellent' in the upper reaches and 'fair' in the lower reaches. Overall, water quality compares favourably with current NPS-FM attribute bands (Table 8) and trend assessments indicate that nutrient concentrations decreased (i.e. improved) in the lower river reaches over the 10-year period to June 2022 (and in the shallow groundwater over a 15-year period).

Visual clarity is high most of time and only one very low oxygen episode has been captured in the four years of high frequency dissolved oxygen monitoring at Craig Road to date. Significant faecal contamination is also infrequent and limited to very wet weather when recreational activities are less likely to be occurring. While concentrations of toxicants and plant-available phosphorus are low across the catchment, plant-available nitrogen concentrations increase from the upper to lower catchment, reflecting an increase in land use intensity and inputs to the river of nitrate-enriched groundwater from the Shag Alluvium Aquifer.

Table 8: Summary of overall* NPS-FM 2020 attribute grades (bands) assigned to selected attributes (indicators) at ORC SOE sites in the Waihemo/Shag catchment, based on the five-year period ending June 2025 (June 2024 for macroinvertebrate attributes). Letters in brackets are estimates based on fewer data points than specified in the NPS-FM. Suspended fine sediment is visual clarity, estimated from measurements of turbidity. Chl-*a* is periphyton biomass measured as chlorophyll *a*.

Site	Fine sediment		Ammonia toxicity	Nitrate toxicity	DRP	*E. coli*	Chl-*a*	MCI	QMCI	ASPM
	Suspended	Deposited								
SH85 culvert	A	-	A	A	A	B	-	(B)	(A)	(A)
Craig Road	A	-	A	A	A	B	-	C	B	B
Goodwood Pump	A	A	A	A	A	C	(D)	D	D	C

* For many NPS-FM attributes, more than one metric (e.g. median, 95th percentile) is graded but the metric with the poorest grade determines the overall grade.

The plentiful supply of nitrogen, together with stable flows over extended periods and high sunlight, contributes to significant year-round periphyton growth in the lower river reaches (NPS-FM band D at Goodwood Pump). Periphyton cover reaches nuisance levels during summer/autumn low flows, reducing streambed habitat quality and favouring a poorer quality invertebrate community more tolerant of these conditions. Brown trout are nevertheless routinely observed in the lower river reaches. While their presence is likely supported in part by access to downstream estuarine food resources, it also indicates that invertebrates important in their diet (e.g. mayflies, caddisflies and snails) remain sufficiently available and that some localised areas of cover and/or cooler water persist during summer. Native fish diversity is also high in the lower reaches, reflecting good access to the sea, which many species need to complete their lifecycle[18].

Despite elevated water column nitrogen concentrations, the Waihemo/Shag Estuary is in a moderate ecological condition, with muddy, poorly oxygenated sediments the primary issue limiting the health of the macroinvertebrate community. The most recent estuary surveys in late 2023 indicate that both the extent and depth of mud-enriched sediments have increased since monitoring began in late 2016.

[18] Some freshwater native fish, including whitebait and eels, are diadromous, meaning that they need to migrate between fresh water and the ocean to complete their lifecycle.

5 Management considerations and information gaps

Sediment, nutrients and pathogens are the primary contaminants that need managing to maintain or improve water quality in rural catchments (PCE 2012). In this section, the sources of these contaminants in the Waihemo/Shag River catchment are briefly discussed, building on the key findings from section 4.

5.1 Sediment sources

No specific work appears to have been carried out on the sources of sediment entering the Waihemo/Shag River. Suspended fine sediment concentrations are consistently low at base flows, with localised bank erosion and stock access the likely primary contributors to occasional small spikes. Most of the sediment enters the river in wet weather, through both overland flow and bank erosion. While much of the overland flow will come from erosion-prone land, ORC (2025) reported that some floods have also removed topsoil from paddocks. Although the number of heavy rain days per year is not expected to change much with climate change, the severity of these heavy rain events (i.e. the amount of rain that falls during these events) is likely to increase (Macara et al. 2019).

Plantation forestry cover has increased in some areas of the catchment in the last decade. When more of the longer-established forest undergoes harvest, this will need careful management to minimise sediment loss to surface water.

5.2 Nutrient sources

Nutrient losses from land in the Waihemo/Shag catchment were modelled in 2022/23 by Ravensdown using a combination of OverseerFM and LUCU-Ag (Crawford et al. 2023). This identified:

- the highest nitrogen load (Figure 21) was under winter grazed crops, and
- the highest phosphorus load was under productive land on steeper slopes, underlain by poorly draining Pallic soils.

Mitigations on 14 case study farms, further fencing and planting of riparian zones on low slope land, increased irrigation/intensification and additional exotic forestry on ~8% of the catchment's steeper land were also modelled to assess their effects on stream nutrient concentrations. Most of these scenarios had limited impact on the overall instream nitrogen (N) and phosphorus (P) concentrations predicted at the river's exit to the estuary, although at the farm scale, riparian plantings saw average reductions in N and P concentrations of 13% and 50%, respectively, in localised streams leaving the farms. Overall, additional forestry was predicted to reduce N and P concentrations the most at the river's exit (by 9 and 14%, respectively). However, the modelling did not consider other effects of forestry, such as reductions in stream flow, and sediment and nutrient losses associated with harvest (Crawford et al. 2023).

Another important consideration when assessing nutrient losses, particularly nitrogen in the lower catchment, is how the river interacts with the underlying shallow groundwater aquifer. Investigations by the ORC in 2017 and 2018 included age dating of groundwater in shallow bores in the Shag Alluvium Aquifer at base river flows. This identified that the groundwater with the highest connection to the river was associated with more recent alluvial sediments close to the river and, on average, is only two years old (Mourot et al. 2022). In contrast, groundwater at the outer margins of the aquifer was found to be less well-connected to the river and associated with older/more weathered/clayey alluvial sediments and more mineralised, older groundwater (20 years on average). This means that shallow groundwater near the river represents a 'fast pathway' (short lag time), with river nitrate-N concentrations in groundwater-fed reaches reflecting the effects of recent land use. This has implications for land management, with mitigation measures in the riparian zones and adjacent river flats a high priority (Figure 22) and likely to yield faster 'wins' for water quality. As groundwater at the margins of the aquifer effectively store two decades of historical nitrate-N, this can be expected to continue to leak slowly into the system with potential legacy effects.

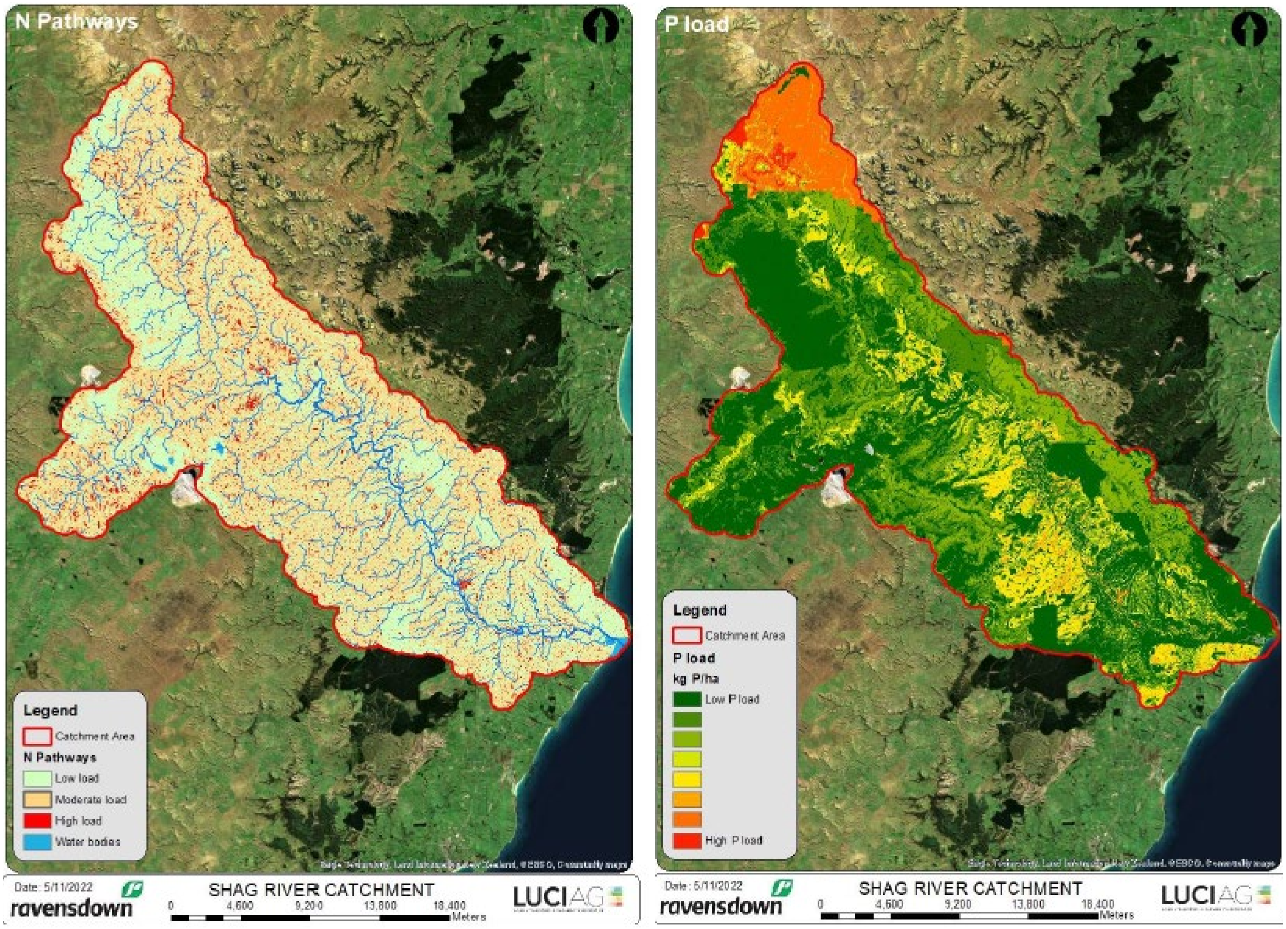

Figure 21: Nitrogen (left) and phosphorus load (kg ha/yr) in the Waihemo/Shag River catchment modelled in LUCI-Ag. Load is categorised from high to low based on the catchment data only and is not related to either average or expected regional or national nutrient loss values. Source: Reproduced from Crawford et al. (2023).

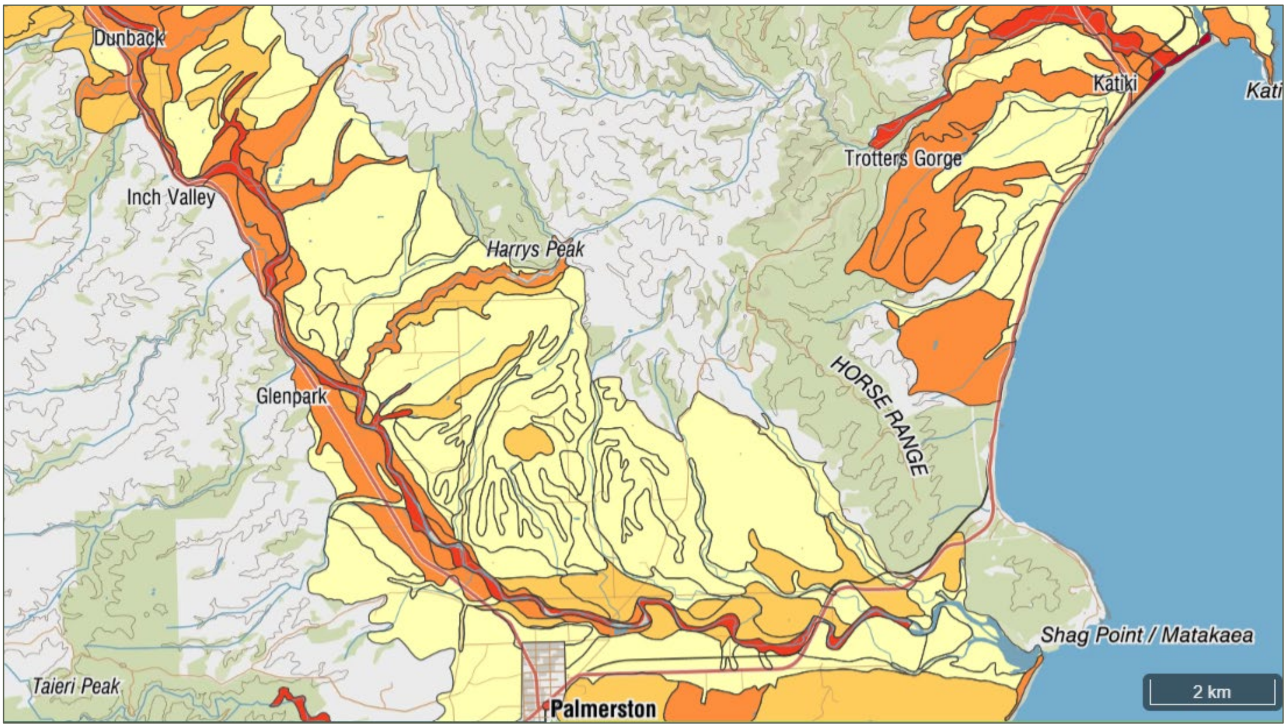

Figure 22: Nitrogen leaching susceptibility in the Waihemo/Shag River. Light yellow areas represent the lowest leaching risk and dark red the highest. Source: S-MAP (accessed 23 December 2025). The map highlights that great care is needed when cultivating, fertilising or grazing land along the river margins (see Figure 21).

High frequency nitrate monitoring by the ORC during 2017/18 identified pulses of nitrate-N entering groundwater and, from there, the river in reaches fed by groundwater (Mourot et al. 2022). Seasonal effects are also seen in the monthly river SOE monitoring, with peak nitrate-N concentrations occurring in the lower Waihemo/Shag River in winter, reflecting a flush of nitrate once soil moisture levels, depleted over the summer, are restored. The bulk of phosphorus inputs likely occur in rain events, via overland flow and bank erosion.

There is some potential for nitrogen inputs to increase in the catchment if, for example, farming was to intensify (Crawford et al. 2023). The proposed expansion of OceanaGold's mine at Macraes is also predicted to increase instream nitrogen concentrations (Ryder 2024) and forestry harvest is an activity that has been linked with pulses of nitrogen loss to groundwater and connected streams (Wilkins et al. 2024, Davis 2014). Sediment loss from forestry harvest will also provide a source of additional phosphorus to the river, particularly in wet weather.

The Palmerston Wastewater Treatment Plant discharges to land adjacent to the Waihemo/Shag River either side of Horse Range Road. While this discharge once occurred over a small area and led to significant nutrient leaching into the river (Sycamore 2007), recent water quality monitoring results do not show any increase in river nutrients downstream of the land treatment area. Current monitoring is limited to annual sampling in summer so if nitrate is reaching the river, it is possible that it is rapidly taken up by periphyton (no periphyton cover or biomass monitoring is required by the consent).

5.3 Faecal contaminant sources

The primary sources of faecal contamination in the catchment are stock (e.g. in the upper tributaries of the Waihemo, as reported by SLR 2024, 2025) and, based on faecal source tracking investigations in rural catchments in Southland (Moriarty et al. 2019a to d), waterfowl.[19] Septic tanks represent another potential source, although the effects of any contamination from septic tanks are likely to be localised.

The ORC's monitoring data for its three SOE river sites suggest that faecal contamination – as assessed by concentrations of *E. coli* indicator bacteria – only poses an unacceptable risk to human health in very wet weather. This suggests that most faecal inputs enter the river from overland flow and are carried down into the estuary. It is also not uncommon in estuaries like the Waihemo/Shag for strong winds to resuspend pathogens entrained in the bottom sediments, increasing concentrations in the overlying water (Stott and Wood 2024).

Evidence of the influence of heavy rainfall on *E. coli* concentrations is also sometimes seen in the WDC's source water monitoring results for the Palmerston water supply. While the source water is drawn from below the river where the overlying gravels act as a pathogen filter (*E. coli* is typically <1 MPN/100mL), the river loses water to groundwater at this point (refer Figure 3). As such, high river water *E. coli* concentrations observed as flows increase during wet weather sometimes result in low concentrations of *E. coli* in the groundwater. For example, the WDC recorded 16 *E. coli*/100mL in a source water sample on 7 October 2024, following over 80 mm of rainfall in the week prior (and a peak river flow at Craig Road of over 173 m^3/s), and 14 *E. coli*/100mL on 30 June 2025, following over 30 mm of rainfall in the two days prior to sampling (and a peak river flow of 38 m^3/s).

5.4 Information gaps

The water quality of the Waihemo/Shag River looks to be well characterised owing to the ORC's network of long-term monitoring sites in the upper, middle and lower reaches, together with monitoring of the underlying shallow groundwater aquifer. Some targeted sampling of sediment and nutrient loads under heavy rainfall could be beneficial but a greater gain would come from completing LiDAR mapping of the catchment.

[19] Based on eDNA data from the Wilderlab website, both grey and mallard duck have been frequently detected in water samples from the catchment (although this does necessarily indicate if they are a significant source faecal contamination). Red deer and possum have also been picked up in some eDNA samples.

Currently only a portion of the lower catchment has been mapped. High-resolution data on terrain and drainage pathways across the entire catchment would allow erosion hotspots and sediment source areas to be precisely identified, enabling mitigation efforts to be targeted where they will deliver the greatest reduction in sediment loss. As noted earlier, sediment loss may be significant in very heavy rain events and this poses a risk to the health of the estuary downstream.

The possibility that land-use change in the Macraes area has altered the surface water balance in the upper catchment (e.g. SLR 2024), and consequently the hydrology of tributary streams, also warrants further investigation. While these changes may not represent a direct water quality impact, alterations to the flow regime, such as increased storm runoff and reduced baseflows, can promote higher sediment delivery and channel instability, with flow-on effects for stream habitat and aquatic ecosystem health (Larned et al. 2018).

6 Conclusions

Water quality in the Waihemo/Shag River is ‘excellent’ in its upper reaches but declines with distance downstream to ‘fair’ in its lower reaches. This is a pattern common in many river systems and reflects the cumulative influence of increasing catchment area, tributary inputs, and land-use pressures with distance downstream, as well as natural changes in flow regime, sediment dynamics and channel form along a river’s length.

Overall, water quality compares favourably with current NPS-FM requirements and trend assessments indicate that nutrient concentrations decreased (i.e. improved) in the lower river reaches over the 10-year period to June 2022. A decrease in nitrate-N concentrations was also found in a shallow groundwater well over the 15-years to October 2023 (when monitoring of the well ceased).

Visual clarity is high most of time and only one very low oxygen episode has been captured in the four years of high frequency dissolved oxygen monitoring at the ORC’s Craig Road site to date. Significant faecal contamination is also infrequent and limited to very wet weather when water-based recreational activities are not likely to occur. While concentrations of toxicants and plant-available phosphorus are low across the catchment, plant-available nitrogen concentrations increase from the upper to lower catchment, reflecting an increase in land use intensity and inputs to the river of nitrate-enriched groundwater from the Shag Alluvium Aquifer.

The plentiful supply of nitrogen, in combination with stable flows for extended periods of time and good sunlight levels, contributes to significant year-round periphyton growth in the lower river reaches (NPS-FM band D at Goodwood Pump). Periphyton is at nuisance levels in summer/autumn low flows, reducing streambed habitat quality and favouring a poorer quality invertebrate community more tolerant of these conditions. Despite this, brown trout are present in these reaches; while they are likely supported in part by access to downstream estuarine food sources, their presence suggests that invertebrates important in their diet remain sufficiently abundant, and that some localised areas of cover and/or cooler water persist during summer. Native fish diversity is also high in the lower reaches, reflecting good access to the sea, which many species need to complete their lifecycle.

Recent ecological data for the Deepdell Creek subcatchment and other tributaries monitored by OceanaGold show Taieri flathead galaxias are regularly recorded in Tipperary and Highlay creeks and kōura/freshwater crayfish are found at most sites. However, low stream flows and an apparent increase in streambed sedimentation and macrophyte (i.e. aquatic plant) cover over time are degrading stream habitat, particularly at sites located downstream of the mine operation where invertebrate community health is typically rated only ‘poor’ to ‘fair’. Low intensity farming in the area is likely a contributing factor to habitat degradation (e.g. via stock access to streams).

The Waihemo/Shag Estuary is in a ‘moderate’ ecological condition. Although elevated water column nitrogen concentrations have been recorded, the estuary’s very high flushing rate reduces the risk of water column algal blooms. Muddy, poorly oxygenated sediments are the primary issue limiting the health of the macroinvertebrate community, with few bivalves (e.g. cockles) or gastropods (e.g. mudflat whelks) recorded in routine ecological surveys to date. The most recent estuary surveys in 2023 indicate that both the extent and depth of mud-enriched sediments have increased since monitoring began in 2016, reinforcing that muddy sediments are a key pressure on ecological health.

Most of the sediment, phosphorus and pathogen (as indicated by *E. coli*) load enters the Waihemo/Shag River in wet weather, most likely through overland flow and bank erosion. While some targeted sampling under heavy rainfall could be beneficial to better estimate the sediment load entering the estuary, a greater gain would come from completing LiDAR mapping of the catchment. This would allow erosion hotspots and sediment source areas to be precisely identified, enabling mitigation efforts to be targeted where they will deliver the greatest reduction in sediment loss.

Significant amounts of nitrogen are lost from leaching through the soil profile in the lower catchment where the most intensive farming and cropping land use occurs. The fertile, porous soils along the river flats are prone to the highest nitrate leaching and require careful management.

Lastly, the Waihemo/Shag River is fully allocated under the ORC's Regional Plan Water and drains a naturally water-short catchment, with potential evapotranspiration exceeding rainfall for multiple months of the year. During very low flows in warm, dry summers, river water temperatures can rise to levels than can cause acute thermal stress for sensitive aquatic insects and fish. Any land-use changes that significantly reduce catchment water yield have the potential to exacerbate these conditions.

Acknowledgements

Steph Scott of the East Otago Catchment Group initiated this project and, along with Nicola McGrouther (Creekside Consulting) provided valuable background information. Many other people also contributed data and information. Thanks to:

- Zoe Flockton and Angela Findlay (ORC), for resource consent-related information and monitoring reports
- Ruth Topless, Rachel Ozanne, Helen Trotter, Sam Thomas, Erik Button and Amir Levy (ORC) for monitoring data and reports
- Cara Wilkinson (Waitaki District Council) for Waihemo raw water supply intake monitoring data
- Scott Mossman (Oceana Gold) for providing recent water quality data and ecological monitoring reports
- Rod Philip for providing copies of early ORC and consultant reports on the catchment that were not available in electronic format and comments on a draft version of this report.

Carys Marulli de Barletta (Traverse) produced the GIS maps and Dimitrios Rados (Traverse) carried out the groundwater trend analysis.

References

ANZG. (2018) Australian and New Zealand guidelines for fresh and marine water quality. Online platform: https://www.waterquality.gov.au/anz-guidelines

ANZG. (2023) Livestock drinking water guidelines. Australian & New Zealand Guidelines for fresh & marine water quality. Draft, November 2023. https://www.waterquality.gov.au/sites/default/files/documents/livestock-drinking-water-guidelines-draft.pdf

Ausseil O, Snelder T, Milne J, McDowell R. (2025) Freshwater Plan effectiveness monitoring: How do we measured the success of our freshwater plans. Report prepared for Otago Regional Council by Traverse Environmental. 54 p.

Black A, Craw D, Youngson JH, Karubaba J. (2004) Natural recovery rates of a river system impacted by mine tailing discharge: Shag River, East Otago, New Zealand. *Journal of Geochemical Exploration*, 84(1): 21-34.

Blake F, Grant K, MacKenzie D, Scott, J, Craw D. (2019) Surficial arsenic redistribution above gold-mineralised zones in East Otago, New Zealand. *New Zealand Journal of Geology and Geophysics,* 62: 573-587.

Cameron S, Forsyth PJ, Turnbull IM, Tait TM. (2003) Groundwater of the lower Shag Valley, North Otago: Phase 2 investigations. GNS Client Report 2005/48 prepared for Waitaki District Council. 36 p.

Caruso BS. (2002) Temporal and spatial patterns of extreme low flows and effects on stream ecosystems in Otago, New Zealand. *Journal of Hydrology*, 257: 115-133.

Clapcott J. (2015) National rapid habitat assessment protocol development for streams and rivers. Cawthron Report No. 2649 prepared for Northland Regional Council. 29 p. plus appendices.

Clapcott J, Goodwin E, Snelder T. (2013) Predictive models of benthic macroinvertebrate metrics. Cawthron Report No. 2301, prepared for Ministry for the Environment. 35 p. plus appendices.

Clarke S. (2023) Palmerston Landfill inspections and monitoring report: November 2023. Waitaki District Council report prepared for Otago Regional Council. 14 p.

Clarke S. (2024) Palmerston Landfill inspections and monitoring report: November 2024. Waitaki District Council report prepared for Otago Regional Council. 22 p.

Craw D. (1985) The metamorphic geology of the Otago Schist Belt, South Island, New Zealand. *New Zealand Journal of Geology and Geophysics*, 28(3), 383–394.

Crawford M, Metherell A, Talbot W. (2023) LUCI-Ag report: Shag River catchment. Report prepared for Otago Regional Council by Ravensdown Environmental. 27 p.

Craw D, Pope J. (2017) Time-series monitoring of water–rock interactions in mine wastes, Macraes gold mine, New Zealand. *New Zealand Journal of Geology and Geophysics*, 60(3), 159–175.

Davies-Colley R, Franklin P, Wilcock B, Clearwater SJ, Hickey CW. (2013) National Objectives Framework – temperature, dissolved oxygen and pH. NIWA Client Report No. HAM2013-056 prepared for Ministry for the Environment.

Davis M. (2014) Nitrogen leaching losses from forests in New Zealand. *New Zealand Journal of Forestry Science.* 44:2.

Forrest B. (2023) Shag Estuary intertidal fine-scale monitoring data summary. Salt Ecology Short Report 129 prepared for Otago Regional Council. 2 p.

Forsyth PJ. (Compiler). (2001) *Geology of the Waitaki Area* (Institute of Geological and Nuclear Sciences 1:250 000 Geological Map 19). GNS Science, Lower Hutt. 1 sheet and 64 p.

Franklin P, Booker D, Stoffels R. (2019) Contract 23184: Task 2 – turbidity and visual clarity threshold conversion. NIWA technical memorandum prepared for Ministry for the Environment. 10 p.

Franklin P, Stoffels R, Clapcott J, Booker D, Wagenhoff A, Hickey C. (2019) Deriving potential fine sediment attribute thresholds for the National Objectives Framework. NIWA Client Report No. 2019039HN prepared for the Ministry for the Environment. 290 p.

Fraser C, Snelder T. (2023a) State of lake and river water quality in the Otago Region: For records up to 30 June 2022. Report prepared for Otago Regional Council by LWP.

Fraser C, Snelder T. (2023b). ORC river, groundwater and lake water quality trend analysis: For 10 and 20-year periods up to September 2022. Report prepared for Otago Regional Council by LWP.

GNS Science. (2020) *Digital QMAP – Geological Map of New Zealand, 1:250 000 Series (Waitaki/ Waikouaiti Sheet).* GNS Science Data Service.

Grainger N, Harding J, Drinan T, Collier K, Smith B, Death R, Makan T, Rolfe J. (2018) Conservation status of New Zealand freshwater invertebrates, 2018. New Zealand Threat Classification Series 28. 25 p.

Hicks M, Semadeni-Davies A, Haddadchi A, Shankar U, Plew D. (2019) Updated sediment load estimator for New Zealand. NIWA Client Report No. 2018341CH prepared or the Ministry for the Environment. 190 p.

Kilroy C, Unwin M. (2011) The arrival and spread of the bloom-forming, freshwater diatom *Didymosphenia geminata* in New Zealand. *Aquatic Invasion*s 6(3): 249–262.

Larned S, Booker D, Dudley B, Moores J, Monaghan R, Baillie B, Schallenberg S, Moriarty E, Zeldis J, Short K. (2018) Land-use impacts on freshwater and marine environments in New Zealand. NIWA Client Report No. 20181276CH prepared for the Ministry for the Environment. 291 p.

Macara G, Woolley J-M, Zammit C, Pearce P, Stuart S, Wadhwa S, Sood A, Collins D. (2019) Climate change projections for the Otago Region. NIWA Client Report 2019281WN prepared for Otago Regional Council. 136 p.

Matheson F, Quinn J, Hickey C. (2012) Review of the New Zealand instream plant and nutrient guidelines and development of an extended decision making framework: Phases 1 and 2 final report. NIWA Client Report HAM2012-08 prepared for MBIE Envirolink. 127 p.

McDowell RW, Larned ST, Houlbrooke DJ. (2009) Nitrogen and phosphorus in New Zealand streams and rivers: Control and impact of eutrophication and the influence of land management. *New Zealand Journal of Marine and Freshwater Research*, 43(4), 985–995.

McDowell RW, Noble A, Kittridge M, Ausseil O, Doscher C, Hamilton DP. (2024) Monitoring to detect changes in water quality to meet policy objectives. *Nature Scientific Reports* (2024):14: 1914.

Milne JR, Madarasz-Smith A, Davies T. (2017) Recreational water quality monitoring and reporting in New Zealand: A discussion paper for Regional and Unitary Councils. NIWA Science and Technology Series Report No. 82. 34 p.

Milne J, Valois A, Robbins J. (2023) Make your stream monitoring data count! A national quality assurance framework for community-based monitoring in Aotearoa New Zealand. Part 1: Guidance for community and catchment group coordinators. NIWA Client Report No. 2023346WN prepared for MBIE Envirolink. Version 1.0.

Ministry for the Environment. (1994) Water quality guidelines No 2. Guidelines for the management of water colour and clarity. Ministry for the Environment, Wellington.

Ministry for the Environment. (2000) New Zealand periphyton guideline: Detecting, monitoring and managing enrichment of streams. Report prepared for the Ministry for the Environment by NIWA, Christchurch.

Ministry for the Environment and Ministry of Health. (2003) Microbiological water quality guidelines for marine and freshwater recreational areas. Ministry for the Environment, Wellington.

Mourot F, Coble MA, Moreau M, Herpe M. (2022) Synthesis of the groundwater investigations in the Lower Waihemo/Shag River Valley. GNS Science Consultancy report 2022/91 prepared for Otago Regional Council. 80 p.

Moriarty EM, Pantos O, Coxon S. (2019a) Sources of pollution in the Aparima Freshwater Management Unit. ESR Client Report No. CSC 19008 prepared for Environment Southland. 133 p.

Moriarty EM, Pantos O, Coxon S. (2019b) Sources of pollution in the Mataura Freshwater Management Unit. ESR Client Report No. CSC 19007 prepared for Environment Southland. 134 p.

Moriarty EM, Pantos O, Coxon S. (2019c) Sources of pollution in the Oreti Freshwater Management Unit. ESR Client Report No. CSC 19005 prepared for Environment Southland. 126 p.

Moriarty EM, Pantos O, Coxon S. (2019d) Sources of pollution in the Waiau Freshwater Management Unit. ESR Client Report No. CSC 19006 prepared for Environment Southland. 77 p.

Mortimer N. (2003) The Median Batholith and the evolution of the New Zealand continental crust. *New Zealand Journal of Geology and Geophysics*, 46(2), 233–253.

New Zealand Government. (2024) National Policy Statement for Freshwater Management 2020. Updated October 2024.

New Zealand Land Resource Inventory (NZLRI). (2020). *Land Resource Information System Spatial Layers*. Manaaki Whenua–Landcare Research.

OceanaGold (2025) Macraes phase 4 project. Resource consent application and assessment of environmental effects. 28 March 2024 (updated 18 February 2025). OceanaGold (New Zealand) Ltd. 279 p.

O'Connell-Milne S, Forrest BM, Roberts KL, Stevens LM. (2024) Synoptic broad scale ecological assessment of Shag Estuary. Salt Ecology Report 134, prepared for Otago Regional Council. 72 p.

Olsen D. (2014) Shag River/Waihemo catchment: Water quality and ecosystem. Technical report, Otago Regional Council, Dunedin. 77 p.

Olsen DA, Tremblay L, Clapcott J, Holmes R. (2012) Water temperature criteria for native aquatic biota. Auckland Council Technical Report 2012/036 prepared by the Cawthron Institute. 80 p.

Otago Regional Council (ORC). (2000) The effects of the 1999 drought on Otago's rivers. Report No. 99/767, Otago Regional Council, Dunedin. 69 p. plus appendices.

Otago Regional Council (ORC). (1991) Shag River catchment: Resource description, issues and options for management. An expanded companion document to the ORC Discussion Paper ISSN 1170-6422, Otago Regional Council, Dunedin. 88 p. plus appendices.

Otago Regional Council (ORC). (2025) Flood hazard Waitaki District: Review of Waitaki District Plan: Natural hazards. Otago Regional Council. 39 p.

Ozanne R, Levy A, Borges H. (2023) State and trends of rivers, lakes, and groundwater in Otago: 2017–2022. Otago Regional Council science report. 159 p.

PCE. (2012) Water quality in New Zealand: Understanding the science. Parliamentary Commissioner for the Environment, Wellington. 93 p.

Peryer-Fursdon J, Abell JM, Clarke D, Özkundakci D, Hamilton DP, Pearson L. (2015) Spatial variability in sediment phosphorus characteristics along a hydrological gradient upstream of Lake Rotorua, New Zealand. *Environmental Earth Sciences*. Vol. 73(4): 1,573–1,585.

Plew D. (2021) Proposed nutrient load limits for Otago estuaries. NIWA Client Report No. 2021256CH prepared for Otago Regional Council. 62 p.

Rabel H. (2024) Shag Estuary: 2023/24 intertidal sediment monitoring summary. Salt Ecology Short Report 044 prepared for Otago Regional Council. 2 p.

Robertson BM, Gillespie PA, Asher RA, Frisk S, Keeley NB, Hopkins GA, Thompson SJ, Tuckey BJ. (2002) Estuarine environmental assessment and monitoring: A national protocol. Part A. Development, Part B. Appendices, and Part C. Application. Prepared for supporting councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A. 93 p. Part B. 159p. Part C. 40 p plus field sheets.

Robertson B, Robertson B, Stevens L. (2017) Shag Estuary fine scale monitoring 2016/17. Report prepared for Otago Regional Council by Wriggle Coastal Management. 33 p.

Ryder G. (2024) Macraes Gold Mine: Macraes phase four project: Stage III – cumulative effects on surface water ecology – updated. August 2024. Report prepared for OceanaGold (NZ) Ltd by Greg Ryder Consulting Ltd. 39 p.

Ryder G. (2019) Oceana Gold (New Zealand) Ltd Deepdell North Stage III project: Gold Mine: Aquatic ecology assessment. Report prepared for OceanaGold (NZ) Ltd by Ryder Environmental Ltd. 64 p.

SLR (2024) Annual surface water biological monitoring 2023: Macraes gold mine. Report prepared for Oceana Gold (NZ) Limited by SLR Consulting New Zealand. 108 p plus appendices.

SLR (2025) Annual surface water biological monitoring 2024: Macraes gold mine. Report prepared for Oceana Gold (NZ) Limited by SLR Consulting New Zealand. 96 p.

Smedley PL, Kinniburgh DG. (2002) A review of the source, behaviour and distribution of arsenic in natural waters. *Applied Geochemistry,* 17:517–568.

Snelder TH, Biggs BJ. (2002) Multiscale river environment classification for water resources management 1. *Journal of the American Water Resources Association*, 38(5): 1225–1239.

Snelder T, Fraser C. (2023) Assessments of nutrient load reductions to achieve target attribute states in the rivers, lakes and estuaries of Otago: Using revised periphyton nutrient criteria. LWP Client Report No. 2023-13 prepared for Otago Regional Council. 147 p.

Snelder T, Fraser C, Larned S, Whitehead A. (2021) Guidance for the analysis of temporal trends in environmental data. NIWA Client Report No. 2021017 prepared for Horizons Regional Council and MBIE Envirolink. 99 p.

Stark JD, Maxted JR. (2007) A user guide for the Macroinvertebrate Community Index. Cawthron Institute Report No. 1166 prepared for the Ministry for the Environment. 58 p.

Stevens L, Robertson B. (2017) Shag Estuary broad scale habitat mapping 2016/17. Report prepared for Otago Regional Council by Wriggle Coastal Management. 34 p.

Stewart B. (2007) Mapping of the Waikouaiti and Shag river estuaries: Otago Regional Council state of the environment report. Prepared for Otago Regional Council by Ryder Consulting Ltd. 54 p.

Stewart D. (2003) Shag River catchment water resources. Prepared for Waitaki District Council.

Sycamore D. (2007) Applications 2007.315, 2007.317 and 2007.318 by Waitaki District Council for the ongoing management of the Palmerston Landfill, Palmerston. ORC Consent Hearing Panel Report, Otago Regional Council, Dunedin. 48 p.

Taumata Arowai. (2022) Drinking water quality assurance rules 2022. Taumata Arowai. 87 p.

Turnbull IM, Fraser HL. (2005) Groundwater of the lower Shag Valley, North Otago: Phase 2 investigations. GNS Client Report 2005/48 prepared for Waitaki District Council.

Weightman E. (2020) Environmental geochemistry of mine waste and waters at Macraes gold mine, Otago. MSc thesis, University of Otago. 168 p. excl. appendices.

Wilkins B, Johns T, Mager S. (2024) Nitrate-nitrogen dynamics in response to forestry harvesting and climate variability: Four years of UV nitrate sensor data in a shallow, gravel aquifer. *EGUsphere,* 2024-694.

Williams J. (2014) Channel morphology of the Shag River, North Otago. Technical report, Otago Regional Council, Dunedin. 54 p.

Williams J, Hornblow S, Gore E, Bloor H. (2018) Waihemo/Shag River morphology and riparian management strategy. Technical report, Otago Regional Council technical, Dunedin. 108 p.

Appendix A Stoneburn monthly rainfall summary

Monthly rainfall (mm) for ORC's Stoneburn rain gauge, January 1998 to October 2025 inclusive. Calculated from data downloaded from the ORC's Environmental Data Portal (December 2025) based on days starting at 0000 hr NZ Standard Time. Values rounded to nearest 1 mm.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
1998	3	29	24	35	28	17	16	9	35	67	17	36	316
1999	23	11	63	43	6	50	68	9	25	22	38	51	408
2000	130	24	93	83	30	29	13	215	83	50	60	82	893
2001	52	37	6	16	43	39	144	17	9	60	44	37	507
2002	227	36	16	111	33	52	32	29	28	31	36	21	655
2003	39	38	25	32	32	55	9	23	84	59	30	5	433
2004	34	68	20	14	60	23	7	81	30	53	61	97	550
2005	52	106	60	20	20	16	38	8	21	34	23	93	494
2006	55	45	22	145	17	31	14	21	6	23	65	116	562
2007	34	15	28	26	10	59	160	19	48	57	18	75	550
2008	36	27	31	39	39	21	145	39	44	41	12	96	566
2009	47	161	48	29	106	18	74	9	64	33	13	39	638
2010	36	22	18	62	328	48	26	76	30	32	21	107	804
2011	29	110	58	31	72	3	12	34	16	117	77	16	572
2012	113	98	51	13	15	19	84	160	34	86	53	48	772
2013	122	21	34	85	117	245	12	31	28	67	24	110	894
2014	55	48	59	220	88	18	23	14	28	28	35	17	630
2015	23	64	45	52	17	103	9	34	23	42	44	27	481
2016	90	14	25	18	115	43	48	60	26	76	94	41	649
2017	81	50	65	152	27	24	136	27	54	40	14	56	724
2018	25	204	66	114	29	13	37	39	42	48	253	86	953
2019	82	17	26	28	57	10	51	67	29	87	48	59	558
2020	17	66	30	42	5	15	21	14	25	38	48	58	376
2021	207	18	25	22	76	39	40	20	39	51	69	98	701
2022	25	69	33	22	12	25	252	21	19	39	47	51	610
2023	14	69	69	76	98	45	69	8	58	24	60	58	646
2024	20	3	38	22	13	74	84	32	75	161	31	57	607
2025	49	50	48	48	30	129	23	8	23	66	-	-	-
Average (all years)	**61**	**54**	**40**	**57**	**54**	**45**	**59**	**40**	**37**	**55**	**49**	**60**	**613**
Average (last 10 yr)	**57**	**56**	**43**	**54**	**43**	**47**	**70**	**30**	**37**	**61**	**71**	**59**	**630**