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Proposed Southland Water and Land Plan: Technical advice for mediation

1 Background

My name is Michael Greer. I am employed as a Senior Scientist (Freshwater) by Aquanet Consulting Limited. I have worked for local government, the Department of Conservation and NIWA and have over 9 years of work experience in freshwater ecology and water quality. I hold the qualifications of a PhD degree in Ecology (2014) and a Bachelor of Science in Zoology from the University of Otago (2010).

I have significant experience conducting research into the effects of drain maintenance (vegetation and sediment removal in modified watercourses) on water quality and freshwater fish. My PhD project was focused exclusively on the topic of drain maintenance in the Southland and Waikato regions. I have published three peer reviewed journal articles on the effects of drain maintenance and have contributed to the Department of Conservation's and Environment Canterbury's internal guidance documents for managing the effects of this activity. I have acted on behalf of Greater Wellington Regional Council during the hearing and appeals processes for the Proposed Natural Resources Plan (PNRP), and as part of that work I have:

- Produced written evidence and engaged in expert conferencing on the effects of vegetation and sediment removal;
- Developed protocols for applying the watercourse classification definitions in the PNRP – *How to determine whether a watercourse is a river, ephemeral flow path, highly modified river or stream or artificial watercourse: A guidance note for Greater Wellington Regional Council officers*;
- Written the Council's guidance documents on implementing the vegetation clearance permitted activity rules – *Guide for landowners & excavator operators: Good Practices for the Mechanical Management of Highly Modified Waterways*; and
- Mapped the highly modified rivers and streams in the Wellington Region in those parts of the region where they occur in high densities[1].

[1] https://www.arcgis.com/apps/webappviewer/index.html?id=87a85d0ad2a3493fbeccb789eac79773

The purpose of this memorandum is to provide technical advice to inform Environment Court mediation on Rule 70 of the Proposed Southland Water and Land Plan (PSWLP). Specifically, it addresses the following questions:

1. Are there threatened native fish/protected taonga species/non-migratory galaxiids in Southlands modified watercourses?
2. If so, does drainage maintenance affect them and can that be reduced?
3. What is the relative impact of vegetation and sediment removal on non-migratory galaxiids in modified watercourses compared to trout?
4. Is there a commonly accepted definition or grain size for gravel and sediment?

Due to time constraints a large portion of the text in this memorandum is drawn from evidence, reports and guidance documents that I have authored previously.

2 Occurrence of taonga fish species, threatened native fish and non-migratory galaxias in modified watercourses

2.1 General value of modified watercourses to fish

The modified watercourses that make up drainage networks are often thought to be of no ecological value because of their "unappealing" aesthetics, the often intensively developed state of the landscapes they flow through, and the fact that they are perceived as infrastructure rather than natural watercourses. However, these waterways, commonly called drains, are important aquatic habitats. Drains increase connectivity within landscapes and provide important habitat for aquatic fauna (Colvin *et al.*, 2009; Herzon and Helenius, 2008). Drains often have fish assemblages comparable to nearby natural streams, and in some cases they have been found to contain more diverse animal communities than unmodified waterways (Armitage *et al.*, 1994; Simon and Travis, 2011). Drains are also used as refuges by fish that are declining or absent in natural water courses (Armitage *et al.*, 2003; Gómez and Araujo, 2008; Painter, 1998).

The majority of New Zealand's migratory fish species (a number of which are listed in Appendix M of the PSWLP) use drains as corridors for movement between other important freshwater habitats and the sea, and these watercourses likely provide particularly important temporary habitats for eels and members of the whitebait (Galaxiid) family (Hudson and Harding, 2004). Drains also provide permanent fish habitat, particular where more natural habitats have been lost or degraded (Hudson and Harding, 2004). More than 20 native fish species have been found to utilise drains (Hudson and Harding, 2004) and they are particularly important to 'at risk' (Dunn *et al.*, 2017) wetland species like the giant kokopu, as they often represent the only aquatic habitat available in catchments where wetlands have been extensively drained and converted to pasture.

2.2 Methods for assessing use of modified watercourses by taonga fish species, threatened fish species and non-migratory galaxiids in the Southland Region

In order to assess the occurrence of taonga fish species, threatened native fish[2] and non-migratory galaxiids in modified watercourses in the Southland Region, I have drawn on previous work done by Hudson and Harding (2004) who identified all fish species found to use modified watercourses in New Zealand up until 2004. I also interrogated the New Zealand Freshwater Fish database (NZFD) via QGIS (v3.0), to identify those species that have been found in modified watercourses[3] in the Southland Region. The results of this analysis are presented in Table 1.

2.3 Results

The vast majority of taonga fish species, non-migratory galaxias and threatened fish species present in the Southland Region can be found in modified watercourses (Table 1). Specifically:

- The only taonga species (listed in Appendix M of the PSWLP) not found in modified watercourses are koaro, shortjaw kokopu, bluegill bully, alpine galaxias and the Southern flathead galaxias (of which there is no record in the Southland Region);
- Two of the four non-migratory galaxiids found in the Southland region (Gollum galaxias and Pomahaka galaxias) are likely to occur in modified water courses; and
- The only threatened fish species in the region that is not likely to be found in the modified watercourses is the alpine galaxias.

[2] Based on *Conservation status of New Zealand freshwater fishes, 2017* (Dunn et al., 2017)

[3] Modified watercourses were identified using the Topo50 map series drains layer

Table 1: The taonga fish species, threatened native fish species and non-migratory galaxiids found in modified watercourses in the Southland Region. Presence in modified watercourses has either been confirmed by interrogating the NZFFD or Hudson and Harding (2004).

Common name	Scientific name	Found in modified watercourses	Non migratory galaxias	Non migratory galaxias	Taonga species (Appendix M)	Threatened (Dunn et al, 2017)	Additional information: Listed in Hudson & Harding (2004)	Additional information: Confirmed in Southland	Additional information: Notes
Inanga	*Galaxias maculatus*	✓	×	×	✓	×	✓	✓	
Banded kokopu	*Galaxias fasciatus*	✓	×	×	✓	×	✓	✓	
Koaro	*Galaxias brevipinnis*	×	×	×	✓	×	×	×	One record in lower Kingswell Creek
Shortjaw kokopu	*Galaxias postvectis*	×	×	×	✓	×	×	×	
Giant kokopu	*Galaxias argenteus*	✓	×	×	✓	×	✓	✓	Primarily in Waituna catchment
Upland bully	*Gobiomorphus breviceps*	✓	×	×	✓	×	✓	✓	
Bluegill bully	*Gobiomorphus hubbsi*	×	×	×	✓	×	×	×	
Giant bully	*Gobiomorphus gobioides*	✓	×	×	✓	×	✓	✓	
Common bully	*Gobiomorphus cotidianus*	✓	×	×	✓	×	✓	✓	
Redfin bully	*Gobiomorphus huttoni*	✓	×	×	✓	×	×	✓	
Longfin eel	*Anguilla dieffenbachii*	✓	×	×	✓	×	✓	✓	
Shortfin eel	*Anguilla australis*	✓	×	×	✓	×	✓	✓	
Lamprey	*Geotria australis*	✓	×	×	✓	✓	×	✓	
Alpine galaxias	*Galaxias paucispondylus*	×	✓	✓	✓	✓	×	×	
Gollum galaxias	*Galaxias gollumoides*	✓	✓	✓	✓	✓	×	✓	
Southern flathead galaxias	*Galaxias depressiceps*	×	✓	✓	✓	×	×	×	No records for this species in Southland
Pomahaka galaxias	*Galaxias "Pomahaka"*	✓	✓	✓	×	✓	×	×	There are records of this species in modified streams in Otago but not Southland
Torrentfish	*Cheimarrichthys fosteri*	×	×	×	✓	×	×	×	
Common smelt	*Retropinna retropinna*	✓	×	×	✓	×	✓	×	
Black flounder	*Rhombosolea retiaria*	✓	×	×	✓	×	✓	✓	

3 Impact of drain clearing on taonga fish species, threatened fish species and non-migratory galaxiids, and practices for minimising effects

New Zealand studies have demonstrated that mechanical excavation of aquatic plants and sediment significantly reduces native fish abundance, and that the reasons for this are complex (Greer, 2014). It is generally believed that the removal of individuals with vegetation is the primary mechanism through which drain clearing effects fish populations. However, equally important is habitat loss and reduced water quality (increased sediment suspension and reduced dissolved oxygen concentrations). The sections below briefly summarise the specific effects of drain clearing on fish, and the mitigations that can be employed to reduce those effects. They do not describe the effects on anyone specific species, and are relevant to all taonga fish species, threatened fish species and non-migratory galaxias that encounter excavators removing vegetation and sediment from modified watercourses (see Table 1).

It is important to note that while the practices set out below can minimise the impacts of vegetation and sediment removal on fish, when carried out over long distances the adverse effects can still be significant. Put simply, waterway clearance is an intentionally destructive activity; it is not possible to fully mitigate the effects of using an excavator in a modified watercourse. Accordingly, the best method of minimising the effects of waterway clearing is to reduce its frequency and extent (i.e., length of stream) (see Section 3.5).

3.1 Fish stranding

3.1.1 Background

During excavation of aquatic plants and sediment large numbers of fish are removed with the vegetation (Figure 1), and international studies indicate up to 20 percent of the resident fish population can be removed from the impacted reach (Serafy *et al.*, 1994). Without human intervention the majority of stranded individuals die (Young *et al.*, 2004).

Figure 1: A stranded eel attempting to make its own way back to the water.

3.1.2 Practices to reduce effects

3.1.2.1 *<u>Conduct fish recovery</u>*

To minimise the adverse effects of fish stranding during and after drain clearance, it is good practice to conduct fish salvage in the following manner:

1. Search the spoil for fish as soon as it is removed from the waterway;
2. If recovered fish are not immediately being returned to the waterway above the upstream extent of the drainage works; place them in a bucket or fish bin containing clear water sourced from the waterway being cleared;
3. Keep water in the bucket/fish bin well aerated and below 18°C by;
   a. Using an aquarium bubbler; or
   b. Providing manual aeration by frequently stirring up the water or pouring new water in from a height of at least one metre; and
   c. Placing the bucket/fish bin in the shade and replacing the water as often as necessary.
4. Hold fish for no more than one hour before returning them to the drain above the upstream extent of the drainage works; and
5. Periodically re-examine the spoil throughout the day, at the end of the day and the next morning for any remaining fish. Store and return recovered aquatic life to the drain using the process described above.

3.1.2.2 *<u>Use a weed rake in hard-bottomed drains</u>*

Weed rakes (rake type excavator buckets) allow fish caught in the spoil to escape back into the channel (Figure 2). The use of these rakes is especially useful in waterways known to contain species like longfin eels that utilise plants for cover, or in areas where rare or threatened species are present. However, weed rakes are inefficient at removing sediment and are not appropriate for use in operations where silt removal is a primary objective. Indeed, if large amounts of fine sediment are present in the channel, the use of a weed rake may actually increase the adverse effects of drain clearing by stirring up the silt without removing it from the channel. Consequently, the use of weed rakes should be limited to gravel bed streams or drains with very little deposited fine sediment on the bed.

Figure 2: An example of a weed rake: Fish are able to swim through the large gaps and are less likely to be caught than if a standard bucket was used.

3.1.2.3 Leave the bucket submerged at the end of each scoop

Fish are often able to swim out of the bucket of the excavator while it is still in the water. In instances where large numbers of native fish are being removed with the spoil, operators should ensure that bucket is submerged long enough at the end of each scoop that fish are able to escape.

3.1.2.4 Distribute spoil so that eels can return to the water

Eels are often able to make their own way back to the waterway from the spoil provided it is deposited in the correct manner. Spoil should be spread evenly along the bank, not placed in discrete built up mounds. To increase the chances of stranded eels returning to the waterway spoil should be placed the minimum distance from the waterway required to ensure it does not re-enter the channel during heavy rain (see Section 3.2.2.1 below). Eels can travel long distances on wet grass but tend to move downhill. If the bank is built up and sloped on both sides, spoil should be placed on the 'ridgeline' to encourage eels to move towards the waterway rather than adjacent dry areas.

3.2 Increased suspended sediment concentrations.

3.2.1 Background

Increased suspended sediment is also a major source of environmental damage following drain clearing (Greer, 2014; Greer *et al.*, 2017). Until recently, it was thought that any increases in suspended sediment following drain clearing were temporary and the effects on aquatic ecosystems were minor (Brookes, 1988; Wilcock *et al.*, 1998; Young *et al.*, 2004). However, recent research conducted by myself and others (Greer *et al.*, 2017) showed that this is not always the case. In that study, large amounts of fine sediment were suspended during drain clearing in the Waituna catchment, resulting in a 120,000 percent increase in suspended sediment concentration (Greer *et al.*, 2017) (Figure 3). Furthermore, without plants to trap the sediment, suspended sediment concentrations remained elevated for more than two months (Greer *et al.*, 2017).

Suspended sediment has a multitude of direct and indirect undesirable effects on freshwater fish populations. Feeding performance is impaired by reduced visibility (Greer *et al.*, 2015); the availability of key food sources (invertebrates and plants) are reduced (Davies-Colley *et al.*, 1992; Quinn *et al.*, 1992); and gill function is impaired (Lake and Hinch, 1999; Sutherland and Meyer, 2007). Sediment released during drain clearing can also have significant effects on downstream receiving environments. Fish and invertebrate habitat suitability may be reduced by re-suspended sediment settling out on the bed, and benthic fish and invertebrates may be smothered by the sediment and die (Ryan, 1991).

Figure 3: Very high suspended sediment concentrations after drain cleaning in Mahr Creek (Waituna catchment).

A major harmful effect of sediment suspension after drain clearing is de-oxygenation of the water. If sediment suspended by mechanical excavation contains a large amount of organic material, dissolved oxygen in the water column may be depleted and large fish kills can occur (Figure 4). In a previous study I recorded significant reductions in dissolved oxygen concentrations following drain clearing in Waikato Streams (Greer, 2014). This de-oxygenation was severe and persistent enough to kill most New Zealand fish species. In that study I also noted large numbers of dying fish after drain clearing in streams in both the Waikato and Southland regions (Carrans Creek in the Waituna catchment). The risk of deoxygenation during drain clearing is likely to exist wherever bed sediments have a large organic component.

Figure 4: An eel suffocating in a recently cleared drain.

3.2.2 Practices to reduce effects

3.2.2.1 Place spoil away from the waterway.

It is good practice to place spoil in a way that prevents the sediment removed by the excavator falling back into the channel during floods or re-entering through surface run-off. This will be dependent on bank gradient, maximum water height etc. and will need to be determined on a case by case basis. It is important to note, however, that spoil should not be placed further from the waterway than is necessary to prevent re-entry, since this may reduce the number of stranded eels and other fish that are able to return themselves to the channel.

3.2.2.2 Minimise downstream sediment transport

To minimise the risk of sediment impacting fish and invertebrates downstream of the excavator, it is good practice to trap and retain as much disturbed sediment as possible before it moves out of the reach being cleared. There are several methods of doing this:

- **Install permanent sediment traps** – Sediment traps are wide, short and deep excavated pools. As water flows into these pools, velocity reduces, allowing fine sediment disturbed by the excavator to settle out on to the stream bed. After drain clearance the fine sediment that has accumulated in the trap is excavated. Permanent sediment traps also have the benefit of controlling sediment transport even when drain clearance is not occurring, and this may decrease the frequency at which clearance is needed.

- **Install temporary sediment retention devices** – Sediment retention devices are commonly made by stretching filter cloth across the channel to form a silt fence, or by placing hay-bales on the bed and securing them with waratahs (steel stakes). When placed at the downstream end of the cleared reach these devices may provide some level of sediment control in small waterways. While these devices, are cheap and easy to install, in some instances they may "blow out" and wash away without frequent monitoring and maintenance. Accordingly, they are ill-suited to large clearance operations in fast flowing drains.
- **Maintain an uncleared section downstream of the excavated area** – Leaving an uncleared section of aquatic plant material downstream of the excavator will trap and retain some of the sediment released during drain clearance. The uncleared section of aquatic plants can then be excavated to prevent the sediment retained within it from moving downstream.

3.2.2.3 Use a conventional bucket in heavily silted drains

The removal of aquatic plants reduces bed stability allowing sediment to be continually re-suspended until it is transported out of the cleared reaches or re-emerging plants reconsolidate it. Using a conventional bucket rather than a weed rake in heavily silted drains will remove a significant proportion of the sediment, thereby limiting the potential for sediment suspension and its effects in the following weeks and months. The downside is that the rate of fish stranding will be greater than if a weed rake was used. However, this can be mitigated by thorough fish recovery.

Recover distressed fish from the waterway.

Fish mortality resulting from de-oxygenation caused by sediment suspension can be reduced by recovering and relocating fish exhibiting obvious signs of stress (gasping for breath at the surface, floating belly up etc.) within the waterway. This should be conducted in all heavily silted waterways containing healthy fish populations.

3.2.2.4 Do not remove vegetation from the dry banks and stabilise soil exposed on the bank during weed control

Scraping the banks with the excavator bucket during drain clearing significantly increases the risk of erosion by removing the vegetation holding the bank together and exposing soils that are prone to surface wash. Such bank erosion can have a significant impact on habitat structure, sediment transport, channel shape and hydrology.

To minimise the adverse effects of drain clearing on bank erosion it is good practice to retain vegetation cover on the banks of the channel by avoiding contact between the cutting edge of the excavator bucket and the dry bank, especially when working in deeply incised steeply banked channels. It is also good practice to re-seed or replant areas of bare earth on the bank.

3.3 Habitat loss

3.3.1 Background

Habitat loss after drain clearing reduces the number and diversity of fish species (Figure 5). Aquatic plants play an important role in increasing habitat complexity in streams, and are used by fish for cover and spawning habitat (Greer *et al.*, 2012; McDowall, 1990). Aquatic plants also increase the availability of invertebrate prey for fish (Collier *et al.*, 1999). Excavation removes almost all of the plants from the waterway (Greer, 2014; Greer *et al.*, 2012; Kaenel, 1998), causing native fish to leave excavated waterways (Greer *et al.*, 2012). Drain clearing also smooths the sides and floor of the drain further reducing the range of available habitats.

Figure 5: In stream cover for fish and invertebrates is usually removed by drain clearing.

3.3.2 Practices to reduce effects

3.3.2.1 Partially clear plants from the waterway

Plants provide important habitat for invertebrates and fish in soft-bottomed streams, and it is good practice to maintain at least some vegetation to minimise the impacts of drain clearing on aquatic fauna. This can be achieved in one of two ways:

- **Retain sections of intact aquatic vegetation at regular intervals** – Where high value species are present and full restoration of hydraulic capacity is not required, a staggered approach to clearing should be undertaken whereby short, uncleared sections of aquatic plants are retained at regular intervals along the length of the cleared reach.
- **Clear one side of the drain at a time** – Where restoration of hydraulic capacity is of the utmost importance and leaving entire sections of the waterway undisturbed is not an option, limit plant removal to one side of the drain at a time, leaving a strip of vegetation along the opposite bank to provide refuge habitat for fish.

3.3.2.2 Installing artificial fish refuges

If partial clearance is simply not an option, fish habitat lost during drain clearance can potentially be replaced with artificial refuge structures made of PVC piping, concrete masonry units or wood. Cover-loving species like giant kokopu and eels (all taonga species) have been found to use such structures in the Waituna catchment and their presence after drain clearance is likely to reduce the number of fish leaving in search of habitat. Artificial refuge structures have the benefit of being permanent installations, meaning that unlike partial clearance, they represent a one off investment. However, this form of mitigation is expensive, largely untested and may require resource consent depending on the design. Thus, in most cases, partial clearance is likely to be the best method of maintaining habitat after drain clearance. Indeed, improperly designed refuge structures may not provide appropriate habitat and may result in bank erosion. Thus, expert ecological and engineering advice should be sought if considering this option. A series of case studies trialling various types of artificial habitat can be found here[4] (see Case Studies 5 through 7).

3.3.2.3 Avoid clearing all waterways on a property at once

Aquatic ecosystems recover from disturbances like drain clearing quicker when there is undisturbed habitat in close proximity for fauna to move into and recolonise from. Where possible, avoid excavating all the waterways on a property or in a catchment in any one year. If the waterways require clearing every five years, clear one fifth annually.

3.3.2.4 Do not alter the width or depth of the channel

To minimise the adverse effects of drain clearing on aquatic habitat and bank erosion it is good practice to maintain the channel profile by only removing unconsolidated fine sediment that has been deposited on the bed since it was last cleared. In most instances an experienced excavator operator should be able to differentiate between deposited fine sediment and the underlying original bed. Even in soft bottomed streams the sediments that make up the "original" bed are generally more consolidated than those deposited on top of it.

3.3.2.5 Preserve specific habitats

Before undertaking the works, inspect the targeted section of the waterway, identify and mark features, such as pools, riffles, woody debris or threatened species habitats or sections of channel that should not be disturbed during excavation and ensure the operator knows to preserve these features. It is especially important when working in tidal areas to identify potential inanga spawning habitat (riparian grasses that are covered by water during spring tides) and avoid either removing it with the excavator or destroying it when dumping spoil.

[4] https://www.doc.govt.nz/nature/habitats/freshwater/habitat-restoration/

3.3.2.6 Avoid removing gravel

Where gravel is present it provides valuable habitat for fish and has the added benefit of being a poor rooting environment for recolonising plants. Where possible only remove fine sediment from the channel.

3.3.2.7 Maintain variability in stream bed profile.

Small variations in stream bed profile have minimal effect on hydraulic efficiency and provide important habitat diversity. To preserve these features, avoid excessive levelling of the stream bed.

3.4 Effects on inanga spawning

3.4.1 Background

Inanga (a key whitebait species and a taonga species listed in Appendix M of the PSWLP) spawn along banks of tidal reaches of creeks and drains. Eggs are deposited in vegetation on a spring tide and develop out of the water. Removal of vegetation immediately prior to spawning limits availability of suitable habitat for the deposition of eggs. If excavation is conducted while eggs are developing they may be crushed or removed from the tidal zone.

3.4.2 Practices to reduce effects

3.4.2.1 Avoid clearing inanga spawning habitat during the spawning season

To minimise the risk of adverse effects on inanga and trout spawning it is good practice to avoid clearing waterways identified as inanga spawning habitat between January and May inclusive.

3.4.2.2 Delay works if large numbers of inanga are being stranded during the spawning season

Inanga spawning habitat is concentrated in tidal areas, and during the spawning season the adult fish form large shoals as they migrate towards the coast to spawn. If an excavator intercepts one of these shoals there is a risk of a lot of fish becoming stranded. Thus, if a lot of inanga are found in the spoil between March and May (the peak spawning season) drain clearance should be postponed. Inanga only spawn on two nights of the month (new and full moon) and migrating fish will generally pass by fairly quickly. Thus, drain clearance can generally be resumed the following day.

3.5 Reducing the frequency and extent of clearing the most effective method of minimising effects on taonga fish species, threatened fish species and non-migratory galaxiids

While the good management practices described in Sections 3.1 to 3.33.4 will provide some level of protection to fish during and after drain clearance, when carried out over long distances the adverse effects on taonga fish species, threatened fish species and non-migratory galaxiids that are present are still likely to be significant. Put simply, drain clearance is an intentionally destructive activity; it is not possible to fully mitigate the effects of using an excavator in a stream. Accordingly, the best method of minimising the effects of drain clearing is to reduce the frequency at which it is conducted.

The frequency at which drain clearing is conducted can be reduced by:

- Only carrying out drain clearing when there is an obvious need (e.g., surface flooding during small rain events, submerged tile drain outlets, raised water table etc.), rather than carrying it out at regular intervals or when an excavator is on site for another job;
- Avoid clearing in the growing season when plants are likely to rapidly re-establish;
- Extend the time between clearings by spraying plants that grow through or on top of the water; and
- Progressively reduce plant growth and sedimentation through land and riparian management practices that decrease the amount of sediment, nutrients and light reaching the water (guidance on how to achieve this can be found on industry group websites[5]).

4 Relative effects of drain clearing on non-migratory galaxiids compared to the presence of trout

To my knowledge there has been no specific studies quantifying the relative effects of trout presence and drain clearing on non-migratory galaxias, it is simply too niche a topic of research. However, we know that trout do have a significant impact on non-migratory galaxiids (McIntosh *et al.*, 2010) and that the environmental impacts of drain clearing are such that it is also likely to cause a significant effect on those fish, especially when undertaken frequently over large stretches of river (Greer, 2014). Thus, it is safe to assume that while trout may impact non-migratory galaxiids over a greater part of the landscape compared to drain clearing, drain clearing will still have significant adverse effects on galaxias when it occurs in modified watercourses that support those fish, regardless of the presence of trout.

5 Grain size definition for fine sediment and gravel

In New Zealand, the bed substrates of rivers are commonly classified using the Wentworth scale (Wentworth, 1922), or a modified version of it (Clapcott *et al.*, 2011). This scale is set out below in Table 2. Briefly, fine sediment includes mud, silt and sand less than 2 mm in diameter (also consistent with NPS-FM 2020), while gravel includes inorganic particles between 2 mm and 64 mm (Wentworth, 1922).

[5] https://www.dairynz.co.nz/environment/waterways/planting-waterways
https://www.dairynz.co.nz/media/1569773/riparian-mgmt-wellington.pdf
https://www.dairynz.co.nz/environment/waterways/riparian-planner
https://beeflambnz.com/knowledge-hub/PDF/industry-agreed-good-management-practices-relating-water-quality
https://beeflambnz.com/knowledge-hub/PDF/stock-exclusion-managing-stock-around-waterways

Table 2: Wentworth scale (Wentworth, 1922) for classifying substrate by size. Classes that constitute fine sediment (<2 mm) are shaded in blue, while classes that are gravel (2 mm - 64 mm) are shaded green

Particle size class	Size (mm)	Description
Clay/silt	<0.06 mm	Not gritty between fingers and hard to pick up but visible as particles
Sand	>0.06-2 mm	Gritty between fingers Smaller than a match head
Small gravel	>2-8 mm	Match head to little finger nail size
Small-Med Gravel	>8-16 mm	Little finger nail to thumb nail size
Med-Large Gravel	>16-32 mm	Thumb nail to golf ball size (or circle when thumb and index finger meet)
Large Gravel	>32-64 mm	Golf ball to tennis ball size (or fist)
Small Cobble	>64-128 mm	Tennis ball to softball size (or circle when thumb and index fingers of two hands meet)
Large Cobble)	>128-256 mm	Softball to basketball size
Boulders	>256 mm	Basketball or greater
Bedrock		Continuous layer of solid rock

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