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Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Investigations and Monitoring Group

Fine sediment removal from streams: environmental effects, protocols and a proposed rule

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Executive summary

Fine sediment removal from the bed of waterways, particularly in lowland areas, may be a critical step in ecosystem health restoration. Lowland, and especially spring-fed waterways, often don't have sufficient flow velocities to flush fine sediments. Therefore, the legacy of fine sediment additions to waterways may impair aquatic communities in perpetuity. However, a recently developed method can remove fine sediment using a water pumping system. This report details the removal method, the method's efficacy and potential effects, as well as proposing protocols to minimise its environmental effects.

Two trial assessments of the method (detailed in the appendices) suggest that the technique is effective at fine sediment removal, that its negative environmental effects can be mitigated and that they aren't long lasting. In both trial waterways, the mobilisation of sediment and suspended sediment in return water remained acceptable during the activity. However, practitioners must take care to minimise any impacts. Both trials found a significant impact on benthic invertebrates within the cleaned reach so stream-scale mitigation should be applied in the future to allow invertebrate populations to recover more rapidly. The method doesn't necessarily put adult fish at risk of death, but sensitive life stages such as eggs and larvae within gravel are vulnerable. Where particular species are present, especially salmonids and kanakana/lamprey, we recommend seasonal timing and habitat specific mitigations. Similarly, practitioners should avoid specific habitats at sites known to contain koura and kākahi, and should consider trapping and removing individuals.

We recommend that every application to use this method includes a stream-specific plan that details the salient characteristics of the stream and proposed strategies to protect environmental, cultural and social values. The application should also include detail on: the sediment disposal strategy, general characteristics of the stream, location and length of the stream to be cleaned, the presence of sensitive communities or species, and consultation with affected parties.

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1 Introduction

This report compiles the information available in New Zealand on the fine sediment removal from waterways using suction technology. It includes a summary of two completed trials and an assessment of environmental effects. Based on the apparent environmental effects found during trials and a general understanding of waterway ecosystem processes, we discuss a range of protocols to mitigate effects on the environment. Finally, the report assesses fine sediment removal against rules in Environment Canterbury’s proposed Land and Water Regional Plan (pLWRP) to identify potential conflicts and compose a suitable plan rule that enables waterway rehabilitation using this method.

The document provides:

- useful information to any groups or individuals considering waterway rehabilitation through fine sediment removal
- guidance to applicants seeking resource consent for fine sediment removal
- guidance for regulatory authorities to assess those applications.

2 Fine sediment removal

Fine sediment (<2 mm) is a significant contaminant in Canterbury waterways. Its accumulation has the potential to alter the quantity and quality of physical habitat to the detriment of invertebrate and fish communities. Specifically, sediment smothers invertebrates and the stream bed and may clog the gills of fish (Clapcott *et al.,* 2011). Infilling of spaces between stream bed gravels reduces the availability of habitat for invertebrates and prevents the movement of oxygenated water through the stream bed to support larval fish. In addition, substantial fine sediment cover reduces the aesthetic appeal of waterways. Accordingly, managers have suggested fine sediment removal from the bed of lowland streams as a critical step in rehabilitating stream ecosystem health. Some streams naturally have a sand/silt bed and fine sediment removal may not be appropriate in such waterways. However, that is not to say that the addition of further sand and silt from bank erosion and surface runoff into those waterways is acceptable. Naturally, soft-bottomed streams occur in the Waikato and Northland regions, but Canterbury streams are predominantly hard-bottom in their natural state.

Lowland farm waterways, drains and spring-fed streams may not experience floods of sufficient magnitude to flush fine sediments, unlike many braided rivers. The legacy of fine sediment deposits may impair these stream communities in perpetuity. The Sand Wand™ is a recently developed tool for removing fine sediment using a water pumping system (Figure 2-1). It is manufactured and distributed by Streamside Environmental, Ohio USA, and has been trialled in Canterbury with good results (Appendix 1 & 2). This report assesses the effects of fine sediment removal based on two trials, summarised below. In addition, the report offers protocols and mitigations to reduce the environmental impact of fine sediment removal and presents a draft rule to be potentially included in the Selwyn Te Waihora sub-regional plan.

Figure 2-1: Fine sediment removal. Panel A shows the Sand WandTM and pump apparatus deployed at a stream restoration site. Panel B shows the Sand WandTM intake, which is dragged across the stream bed. Panels C and D show the stream bed before and after fine sediment removal, respectively. (Photographs courtesy of Assoc. Prof. Jon Harding, University of Canterbury)

The Sand Wand™ uses a combination of water jet and suction to mobilise and transport (suck up) fine sediments beneath an enclosed hood (Figure 2-1). Practitioners manually move the equipment across the stream bed using a rocking motion moving parallel to flow. The arrangement of pumps relative to the hood depends on the topography of the stream. Slurry can be discharged to land or into sediment separating equipment (Figure 2-2).

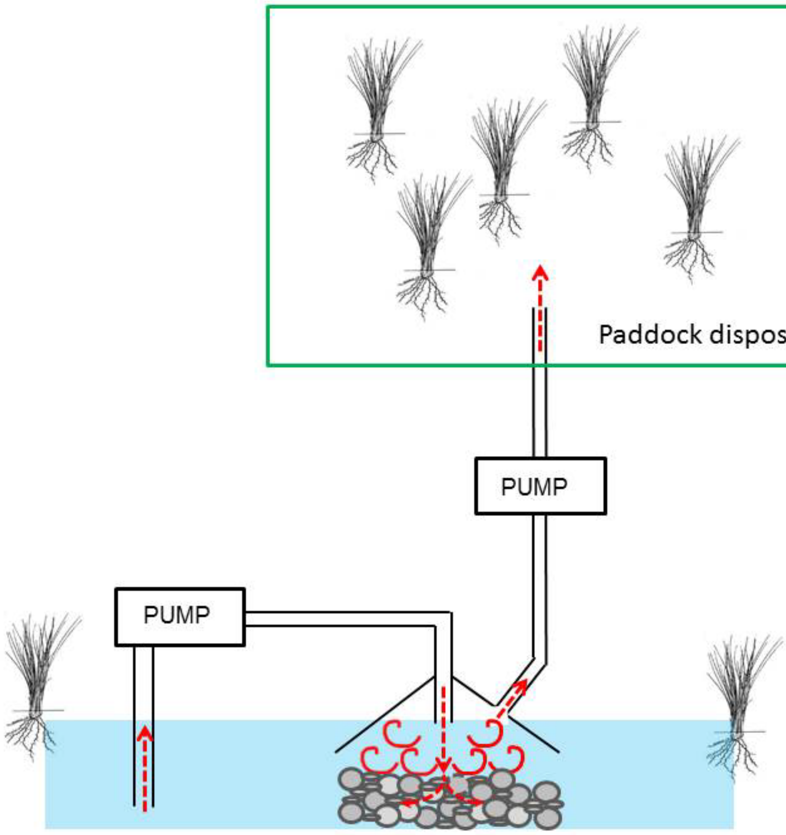

Figure 2-2: Schematic showing the arrangement of pumps for the Sand Wand^{TM}

2.1 Fine sediment trials

To date, there have been two trials in New Zealand on the efficacy and environmental impacts of fine sediment removal using suction technology (Sand Wand^{TM}). Aquatic Ecology Limited (AEL, 2013) undertook an initial trial in the urban Wairarapa Stream, Christchurch (Appendix 1). That trial considered the efficacy of the method for remediating trout spawning gravels impacted by earthquake liquefaction. They used a high-performance baffle tank called a SiltBuster to separate silt into a collecting skip and discharge clean water back to the stream. A total of 1360 kg of silt was removed from a 14 m reach, equal to 22 kg of wet fines per square metre of stream bed. The cleaning process caused some downstream reduction in water clarity, largely because the operator's feet disturbed the bed. However, 500 m downstream (or less) water clarity returned to upstream levels. The AEL before-and-after assessment of the fish population indicated an increase in fish biodiversity from one to three species. Abundance of the predominant species, the upland bully, had decreased, but this trend might have been seasonal, representing the natural demise of young fry between the assessments. It was also evident that some sediment was settling in the reach from upstream sources.

The report also considered results from flocculant tests (HaloKlear™) (Appendix 1). Flocculants are compounds that can facilitate the deposition of very fine sediment from dirty water, and potentially be used to treat slurry entering the SiltBuster™. Used in this way, flocculants could improve the SiltBuster™'s performance, trapping more silt in the skip for disposal, and reducing the turbidity of the water returning to the stream channel. The report concluded that, with training and some equipment modifications, this equipment could be used by a team of three people to remove significant amounts of sediment from lowland waterways.

A second trial occurred in the Otukaikino Creek, Christchurch. The research team assessed the efficacy of fine sediment removal using suction technology, effects on downstream water quality, and effects on the invertebrate community (Gray *et al.,* 2013, Appendix 2). The Sand Wand^{TW} appeared highly effective at removing fine sediment from the surface of the stream bed, but had limited penetration depth into the substrate. Despite an unusually high flow event between assessments, the trial reach remained less sedimented than before the trial. Sediment laden water was discharged into an adjacent paddock ~ 30 m from the stream bank to allow water to infiltrate and sediment to be entrained in vegetation. Water did eventually return to the stream and had an acceptably low suspended sediment concentration. Elevated water turbidity was found 50 m downstream from the trial during the removal, but it returned rapidly to background levels once people and equipment left the waterway. The trial had no observable effect on turbidity 200 m downstream. Invertebrate communities within the sediment removal reach were initially reduced in richness and density by the activity (after three days), but recovered fully to pre-sediment community richness and density after six weeks. The post re-colonisation invertebrate community contained a greater proportion of mayflies than pre-trial but we also observed a similar pattern in the upstream control reach. Because this trial was limited to a short stretch of stream bed, it may have underestimated the impact on invertebrate communities of cleaning longer reaches.

3 Potential environmental effects

3.1 Introduction

The suction technique for fine sediment removal disturbs stream bed substrates, to a depth of ~ 15 cm, across the area of stream cleaned (Gray *et al.,* 2013). Water containing sediment is pumped out of the stream channel and, depending upon the location of the stream reach, either discharged to land or through a sediment settling system before the sediment-free residual water is returned to the stream. The process has various impacts on the in-stream environment.

3.2 Volume of water pumped

The volume of water pumped from the stream during fine sediment removal will vary with the pumping equipment used. The existing trials have used a pump with a maximum capacity of 16 L/s. The actual rate may also be dictated by the discharge location. If water and sediment are discharged to land (e.g. Appendix 2) the rate of water extraction will be dictated by subsequent infiltration to ground and the consequent turbidity of any return water. If water and sediment are discharged into a separating apparatus (Appendix 1), the pumping rate will be determined by the capacity of that apparatus. The maximum permitted extraction of water from any river in the proposed Land and Water Regional Plan for Canterbury (pLWRP) is 5 L/s and 10 m^3 per day. Abstraction at quantities above those values would require specific authorisation via resource consent.

3.3 Volume of sediment

The volume of sediment pumped from a stream reach depends on the area of bed cleaned and the amount of sediment in the stream. During the Wairarapa Stream trial, a total of 1360 kg of silt and sand were removed from 14 m of stream (~22 kg/m^2). Before the trial, the Wairarapa Stream was impacted by high levels of sand derived partially from earthquake liquefaction (AEL, 2013). Because the fine sediment levels observed in the Wairarapa Stream are typical for many agricultural streams it's likely that the volume of sediment removed from other sites would be similar.

3.4 In-stream sediment suspension

The majority of sediment disturbed during fine sediment removal is pumped out of the stream, but some mobilised sediment is washed downstream. Though this is not a discharge as such, the sediment suspension does constitute an effect under the RMA and should be considered for its impacts on aquatic life, water clarity and water quality for stock consumption. The potential effects of sediment suspension will depend on the nature of the sediment and the flow characteristics of the downstream reach.

A fine sediment removal trial in the Otukaikino Creek, near Christchurch (Appendix 2), found 19 g/m^3 mean total suspended solids (TSS) in the water column directly downstream of the operation. The pLWRP states that the concentration of suspended solids discharged to a spring-fed river shall not exceed 50 g/m³. The pLWRP also defines a mixing zone for discharges (extending a maximum extent of 200 m) although mixing zones are not entirely appropriate for contaminants such as sediment, which fall out of suspension on to the stream bed rather than dissipating. During the Otukaikino Creek trial, researchers monitored turbidity (NTU) continuously at 50 m and 200 m downstream. At 50 m downstream, water turbidity was affected, with peaks reaching ~38 NTU. However, at 200 m downstream, maximum turbidity was ~ 1.5 NTU and the effects from the activity were barely detectable. Researchers made comparisons during the Wairarapa Stream field trial (Appendix 1) using a clarity tube. At 40 m downstream, clarity was reduced to 38% of upstream clarity. However, 500 m downstream clarity returned to 93% of upstream clarity.

Based on observations during the Otukaikino Creek trial, collateral activities associated with accessing the stream and site preparation generated a significant proportion of the suspended sediment washed downstream. In particular, peaks in turbidity caused by eroded and mobilised bank and near-bank sediments (with high organic content) were not associated with the actual fine sediment removal process itself. This effect could be mitigated with simple protocols addressing stream bank access and movement around the removal site.

3.5 Return water

At rural sites, water and sediment can be discharged to a paddock, but may return to the river via surface flow. In urban settings, water and sediment must be separated before the water is discharged directly back to the stream. In either case, the quality of return water is subject to rules 5.76 and 5.77 in the pLWRP. Suspended sediments must be sufficiently low in return water so the environmental effect is acceptable. During the Otukaikino Creek trial, we returned discharged water to the stream along a shallow groove from the discharge area after flowing ~30 m through rough grazed grass. Return water had a mean suspended sediment concentration of 13 g/m³ (n=3). During the Wairarapa Stream trial, water discharged to the stream from the sediment capture equipment had a clarity of ~9 cm, 12% of the upstream clarity. Further trials have indicated that using flocculants to bind together fine particles (Appendix 1) can provide a substantial gain in discharge clarity.

3.6 Macrophyte beds

Streams with stable flows and fine bed materials such as spring-fed lowland streams are often home to aquatic plants, or macrophytes. Macrophytes provide habitat for invertebrates and fish, and entrain fine sediment. However, excessive growths of macrophytes can have a negative impact upon streams by depleting oxygen, channel choking and binding fine sediments in root mats. Macrophytes are often managed through mechanical removal to alleviate channel choking and flood hazard, but less often for the benefit of in-stream communities. It is likely that, with a little extra effort, both objectives can be achieved by selectively removing macrophyte beds to maximise habitat diversity within a stream reach.

Fine sediment removal suction apparatuses may be clogged by macrophytes, so practitioners have to remove growths before they clean the substrate. This report gives guidance on ecologically and environmentally sensitive macrophyte removal below.

3.7 Invertebrates including koura and kākahi

Because benthic invertebrates live in and on the stream bed substrate, improving benthic habitat for these taxa is one of the primary goals of fine sediment removal. However, invertebrates are disturbed during sediment removal and may be captured by the suction pumps and discharged with sediment either onto paddocks or into sediment capture equipment. Those invertebrates that are able swim or cling to large substrates escape the pumping and remain in the stream (Appendix 2). During the Otukaikino Creek trial, the research team observed invertebrates captured by suction alive in paddock ponding, but these individuals were unlikely to survive as the ponded water soaked away. Although benthic invertebrate communities may be quick to recover from this disturbance, it does represent a significant mortality event for affected populations in the stream reach and should be mitigated as much as possible.

Koura (freshwater crayfish) and kākahi (freshwater mussel) are larger and likely to suffer some damage if passed through the pump apparatus. Kākahi, in particular, are vulnerable because they live buried in fine sediments deposited on stream beds. Koura and kākahi are rare in Canterbury lowland streams (EOS, 2011), although the specific sampling techniques researchers routinely use to sample streams may partly account for this status (Hannah Rainforth, Massey University. pers. comm). The Department of Conservation classified both koura and kākahi as "At Risk – Declining" in 2013 (Grainger *et al.,* in press) although isolated populations of both species exist in Canterbury. We recommend that practitioners try to identify koura and kākahi presence before sediment removal. If they find either species, we recommend taking steps to reduce the impact of removal on these species (see mitigations and protocols below).

3.8 Fish

The majority of adult fish species will be able to evade suction and few fish have been observed in discharge water (Mark Taylor, AEL, pers. comm.). Eggs and larvae that reside within the stream bed are vulnerable and individuals may become entrained against the water intake grill. Native and exotic fish species possess a range of spawning strategies that make them more or less vulnerable to impacts from fine sediment removal. We grouped New Zealand fish species with similar spawning characteristics and predicted their vulnerability to fine sediment removal (Table 2-1). Salmonids and some species of native fish (bully and non-migratory galaxiids) that may spawn in the habitats targeted for fine sediment removal are the groups of primary concern. However, excessive fine sediment precludes salmonid spawning and a primary motive for sediment removal is to improve spawning habitat. Kanakana/lamprey may also be vulnerable during the juvenile ammocoete stage when they burrow in fine sediments accumulated in shallow marginal areas.

Table 2-1: Vulnerability of New Zealand fish groups to fine sediment removal based on spawning location and season and larval habitat (McDowall, 2000)

Fish species	Spawning location	Spawning season	Larval habitat	Predicted Vulnerability
Tuna/Eel	Ocean	Winter-spring	Ocean	Low
Kana kana/Lamprey	Small streams	Spring-summer	Burrows in stream margins sands; gentle flow	Medium
Paraki/Smelt	Lower reaches of rivers and estuaries	Summer-autumn	Ocean	Low
Kokopu including koaro	Mostly unknown or marginal gravels and vegetation during high flow	Autumn-winter	Ocean	Low
Inanga	Estuarine riparian vegetation	Autumn	Ocean	Low
Non migratory galaxiidae[1]	Various, predominantly on the underside of boulders, in loose riffle substrate or spring-heads	Spring	Stream margins	Medium
Mudfish	Amongst aquatic vegetation, debris or in burrows[2]	Late winter-spring	Weedy, overgrown streams, drains or wetlands, or in open water then under cover	Medium
Trout and salmon	Swift flowing, shallow, gravelly runs and riffles	Autumn-spring depending on species	Buried within natal gravels, later stream margins	High

[1] This group lives in a diverse range of habitats and the requirements of each species in each stream should be assessed individually.
[2] Brown mudfish only.

Papanoko/Torrentfish	Mostly unknown, some in lower reaches of larger rivers	Summer-autumn	Ocean	Low
Bullies	Beneath large rocks in-stream with eggs in a cluster	Spring-summer	Natal stream margins or ocean	Medium

3.9 Summary of effects

Based on trials in the Wairarapa Stream and Otukaikino Creek, the primary negative impact of fine sediment removal is benthic invertebrate (including koura and kākahi) mortality. The eggs and larvae of salmonid fish and kana kana/lamprey may also be vulnerable at certain times of year. Bed sediment mobilisation and return water may contribute to suspended sediment concentrations in the water column. However, during the sediment removal trials, suspended sediment levels were acceptably low and could be further reduced by modifying the sediment removal method. The activity might also require specific authorisation with respect to regulations governing the quantity of water and material removed from rivers. However, any short-term or localised impacts of the activity should be balanced against the benefits that sediment removal offers for habitat rehabilitation.

4 Mitigation and protocols

This section offers proposed mitigations and protocols to reduce the environmental impact of fine sediment removal using suction techniques. These recommendations are based on ecological knowledge and lessons learned during the two trials completed to date. To validate and inform this protocol, monitoring should accompany application of the technique.

4.1 Suspended sediment

Based on the Otukaikino Creek and Wairarapa Stream trials, concentrations of suspended sediment resulting from fine sediment removal met acceptable levels directly downstream. Beyond 200 m downstream, researchers found reduced turbidity and increased clarity. However, practitioners could likely minimise sediment suspension by using good operating practices. We recommend these good operating practices:

- Minimise the number of people operating within the stream at any one time
- Minimise the number of trips to and from the stream bank
- Disturb only the stream bed beneath and immediately upstream of the Sand Wand^{TM}
- Allow the apparatus to remove the majority of fine sediment before moving on
- Minimise collateral suspension by using selected entry and exit points to the stream, placing a plank over areas containing fine and/or organic sediments
- When cutting or pulling on macrophyte beds, minimise sediment suspension by slow movements and consider leaving some weed beds to provide habitat for fish and invertebrates
- When cutting or lifting woody debris in the stream, minimise sediment suspension by slow movements and consider leaving or replacing debris to provide habitat for fish and invertebrates
- Do not damage or disturb riparian vegetation.

4.2 Return water

Return water should be of an acceptable quality before it re-enters the stream. Water discharged to paddocks should be directed so the majority infiltrates the ground. Based on trials to date, suspended sediment concentrations in return water were acceptably low (13 g/m^3). However, practitioners could likely improve return water clarity by using good operating practices and potentially by using flocculants. We recommend these good operating practices:

- To avoid any paddock or bank material erosion, do not allow high velocity/volume sheet or channelised flow to return to the stream
- Because vegetation encourages infiltration and strains out sediments, direct discharge should be done into an area with vegetation growth
- Regularly move the discharge point to prevent large fine sediment accumulations from killing paddock vegetation and consider seeding with suitable paddock species and raking to spread sediment
- Consider creating an infiltration pit that can be grassed over once the water drains
- Construct sediment retention fencing or bunds where the topography is likely to directly and rapidly return water back to the stream
- Retain fencing or bunds if there is a possible rainfall event that would wash material back into the stream
- Spread or retain sediment so that it becomes entrained into paddock soils.

In an urban setting or any location where discharge to land is not acceptable, sediment capture equipment should be used (Appendix 1). Sediment capture apparatuses are commonly available for controlling sediment discharges from construction sites or road works. They must be configured specifically, accounting for the stream's sediment grade (coarse or fine), to effectively remove sediments. In addition, some patented sediment capture equipment can accommodate flocculants and coagulants to bind suspended sediment and increase settling. Trials of two commonly used flocculants are detailed in Appendix 1. Trial results suggest that clarity of discharged water can be improved considerably when there are fine clay particles in the water column.

4.3 Invertebrates including koura and kākahi

Koura, kākahi and other benthic invertebrates are likely to be sucked up by pumps during sediment removal, discharged to land or sediment settling equipment and/or damaged by the pumping apparatus. Practitioners could potentially rescue entrained individuals, but it would be very labour intensive. Rather, we recommend protocols and mitigations that involve stream-scale planning and avoid particular habitats. Many benthic invertebrates (excluding koura and kākahi) are quite mobile within the stream, have a terrestrial life stage (often aerial), and can reproduce quickly. These characteristics allow species to re-colonize areas quickly following a disturbance. However, rapid recovery characteristics tend to be more prevalent in communities inhabiting disturbance-prone streams. Invertebrate communities in less disturbed systems, such as spring-fed streams, tend to take longer to recover and may be less resilient to sediment removal disturbance (Death & Winterbourn 1994, Scarsbrook 2002). Accordingly, if practitioners expect re-colonists from within the stream, it is important <u>not</u> to remove sediment from the entire upper length of a stream. In fact, it is critical that lengths of habitat are left temporarily untouched to provide colonists. These lengths of habitat should represent areas least impacted by sedimentation or at least areas that will provide the greatest number and variety of re-colonists. Following a suitable period for invertebrates to disburse, practitioners can complete fine sediment removal in the refuge areas. Some colonists will arrive from downstream reaches via crawling and flying if there is suitable downstream habitat for them to occupy.

Researchers haven't documented invertebrate recovery rates from sediment disturbance in lowland streams, but experimental manipulations do provide some information. During the Otukaikino trial, benthic invertebrate richness (as number of taxa) and density was significantly reduced three days after the sediment removal, but after six weeks, the richness and abundance had recovered to pre-trial levels (Appendix 2). In a selection of spring-fed, high country streams, invertebrate community metrics typically recovered 20–40 days after water blasting (Pete McHugh, University of Canterbury, pers. comm.). In both high country stream studies, the impacted reach was relatively short compared to the refuge area. Fine sediment removal is envisaged to take place over the majority of a stream reach with only short areas left as refugia. To avoid problems with source populations for re-colonisation, we recommend that sediment removal be staged into rounds at six week intervals with no more than 75% of an area cleared at a time. The number of removal rounds can be increased if the area is large and the habitat needs to be divided into smaller sections.

In situations where the invertebrate community of a stream is severely degraded and no colonists are present, refuge areas will serve little purpose. In those cases, practitioners will have to collect and move re-colonists from adjacent streams with better habitat or more distant sites.

Koura are rare in lowland streams impacted by siltation, but there are remnant populations in Canterbury. Their preferred daylight habitat tends to be under cover, close to banks and in-stream debris (Jowett *et al.,* 2008). Koura are not likely to be found on or amongst midstream substrates with high fine sediment components. Thus, to reduce the chances of koura mortality, those who remove fine sediment should avoid the extreme stream edge and substantial debris deposits. Practitioners can assess the presence of koura in an area by referring to the New Zealand Freshwater Fish database[3] or any available ecological survey data, by obtaining local knowledge, or running a survey to assess the potential impacts of fine sediment removal. At locations where koura are present, practitioners might remove them through trapping, electric fishing or spotlighting to mitigate impacts and ensure the population survives.

Kākahi or freshwater mussels are similarly quite rare in lowland streams affected by excessive sedimentation, although few researchers have conducted surveys targeting mussels in Canterbury. Like koura, remnant populations do exist. Kākahi are at risk and declining nationally (Grainger *et al.,* in press). This is attributed to habitat loss, eutrophication, other types of pollution, and possibly loss of host fish species that kākahi depend on to complete their life cycle. Healthy kākahi populations form abundant beds that may contain individuals from a range of size-classes. The species was historically common and widespread throughout New Zealand, in habitats ranging from small, fast flowing streams to lakes. Unfortunately, to date few researchers have studied the environmental characteristics that influence kākahi in streams (Rainforth, 2008) and there are very few available data on their distribution within individual streams in Canterbury (EOS, 2011). Local runanga are probably the best source of information about whether kākahi occur in a stream. If kākahi are present or discovered before or during fine sediment removal, all activity should cease. A suitably qualified ecologist should assess kākahi populations before anyone continues further sediment removal. We recommend further research on kākahi distribution and the potential impact of fine sediment removal on remaining populations.

4.4 Macrophytes

Though macrophytes provide habitat for invertebrates and fish, and entrain fine sediment, excessive macrophyte growths can deplete oxygen, cause channel choking or bind fine sediments in their root mats. They can be mechanically removed to alleviate channel choking, but with a little extra effort, selective removal could also maximise habitat diversity within a stream reach.

Macrophytes can block the fine sediment removal apparatus so vegetation has to be removed before the sediment removal can begin. Practitioners should do this carefully to prevent fine sediment entrained in the plant beds from mobilising within the water column. Some mid-stream beds will need to be retained to increase the diversity of flow and depth in the reach, allowing the stream to self-clean fine sediment from higher velocity areas. Thus, practitioners should also consider the number and location of macrophyte beds that need to be retained within the reach. In streams previously accessed by stock, the channel may be excessively broad for the flow and the edges may contain large quantities of fine sediment bound by macrophytes. If left undisturbed, this matrix will eventually consolidate, binding the sediment and constraining the channel such that depths and velocity increase, further helping to flush fine sediment.

4.5 Fish

The majority of adult fish can detect and avoid the fine sediment removal apparatus, particularly because the suction unit is preceded by the passage of human feet. However, spawning and larval habitat of some species would be vulnerable to impacts from fine sediment removal (Table 2-1). Thus, practitioners should take account of the species likely to be present and the time of year before undertaking fine sediment removal. Practitioners can assess the presence of fish species in an area by referring to the New Zealand Freshwater Fish database[4], to any available ecological survey data, or by obtaining local knowledge. Because the majority of freshwater fish spawn in autumn and winter, we recommend avoiding fine sediment removal from streams containing fish species during these times of years. The larvae of some species, particularly salmonids and kana kana/lamprey, live within the stream bed for some time. Therefore, we recommend avoiding obvious spawning locations and

[3] http://fwdb.niwa.co.nz/
[4] http://fwdb.niwa.co.nz/

larval habitat, and delaying sediment removal until larvae have left the substrate, if salmonids and kanakana/lamprey are present.

4.6 Summary of impact mitigation and protocols

The characteristics of an individual stream will determine the impact mitigation and protocols for fine sediment removal in that stream. We recommend addressing these questions before undertaking sediment removal:

1. Where and how will sediment be discharged and disposed?
2. Are there any special features of this stream reach that preclude the activity (e.g. high naturalness or ecological value, potable water abstraction, stock drinking water supply, a downstream impoundment or site of high cultural or recreational value)?
3. Is aquatic weed management an issue and what consideration should be given to the removal or otherwise of weeds and woody debris from a waterway?
4. Are there invertebrate populations in the stream that should be protected by leaving refugia for re-colonisation of the cleaned stream reach?
5. Are there any vulnerable fish species or sensitive life stages that should be considered?
6. If koura or kākahi are present, which areas shall be left untouched to protect the population?
7. What approach will minimise disturbance of the banks, stream bed and riparian vegetation?

Local landowners, runanga, Fish & Game, local stream care groups or other organisations often hold valuable local knowledge about a stream's values and should be consulted during the planning stage.

5 Relevant legislation and rules

There are no specific requirements in the legislation or planning documents pertaining to fine sediment removal using suction technology for waterway rehabilitation. Accordingly, we've assessed this method under the general provisions of the RMA and proposed Land and Water Regional Plan for Canterbury (pLWRP). The pLWRP provides several rules relevant to fine sediment removal using suction technology. We've listed the rules as "permissive" of the activity or "manageable", as rules that "clearly conflict" with the activity, or as rules that have "potential to conflict" with the activity (Table 4-1).

Table 4-1: Rules in the pLWRP that pertain to fine sediment removal using suction technology (rule numbers based on current iteration of the plan)

Status	Rule	Number
Permissive or manageable	Structures Refuelling in lake and river beds Gravel from lake and riverbeds Vegetation from lake and river beds Small and community water takes	5.119, 1 5.120, 1, 2, 3 5.125, 1 5.144, 1, 2 5.88, 5
Clear conflict	Structures Gravel from lake and river beds Small and community water takes	5.114, 6 5.125, 2, 5.14, 1(a, b)
Potential conflict	Other minor contaminant discharges Other minor contaminant discharges Structures Structures Gravel from lake and riverbeds Vegetation in lake and river beds Small and community water takes Small and community water takes	5.76, 1, 3, 6, 8 5.77, 2, 3, 4 5.114, 1, 3, 5.119, 2, 3 5.125,1, 4 (a, b, c,), 6, 8, 9 5.143, 6, 7 5.14, 2, 3, 4, 5, 6 5.99, 1, 2, 3, 4

Most pLWRP rules relating to fine sediment removal can be addressed using revised protocols and operating practices, but there is a clear conflict with rules about structures within a riverbed, water abstraction and gravel extraction from a riverbed. Structures rule 5.114, 6 and gravel from riverbeds rule 5.125, 2 state that works shall not occur within flowing water. While fine sediment removal doesn't strictly involve in-stream structures or gravel extraction, the rules are intended to prevent the mobilisation of bed substrates. In addition, the maximum water abstraction rate during fine sediment removal trials was 16 L/s, whereas under the pLWRP, the maximum permissible rate is 5 L/s for any waterway, beyond which a consent is required.

We recommend a rule specific to the activity of fine sediment removal using suction technology to facilitate the restoration of impacted streams in Canterbury. In particular, this rule must identify the conditions under which the activity is permissible under existing rules and articulate CRC and other stakeholders' roles in overseeing the activity. We recommend that this activity be classified as "restricted discretionary" until researchers complete further trials of the suction pump method on a range of streams.

A restricted discretionary activity requires a resource consent before it can be carried out. The consent authority can decide whether to grant consent or to impose conditions, but only respecting the activity's discretionary restriction in the plan, or respecting activities that have restricted discretion in national environmental standards or other regulations (section 104C). The activity must also comply with any requirements, conditions and permissions specified in the RMA, regulations or relevant plan (section 87A(3)(b)).

We recommend that each application to use this method include a stream-specific plan that details the salient characteristics of the stream and proposed strategies to protect environmental, cultural and social values. The application should also include detail on: the sediment disposal strategy, general characteristics of the stream, location and length of the stream to be cleaned, the presence of sensitive communities or species, and consultation with affected parties.

A Draft Rule

Fine sediment removal from rivers and streams

These following Rules prevail over Regional Rules 5.123 to 5.125 (Take and Use of Surface Water). The associated discharge is addressed under Rules 5.98 and 5.99 (Other Minor Discharges of Contaminants).

Article I. The taking and use of water from a river and the disturbance of the bed of a river to remove fine sediment less than 2 mm in diameter for the sole purpose of habitat restoration is a restricted discretionary activity providing the following conditions are met:

1. A Management Plan has been prepared and submitted to the CRC that includes the location and method of sediment removal and disposal, an inventory of sensitive ecological habitats and species, and an assessment of the environmental risks and how potential adverse effects will be avoided or mitigated; and
2. The activity ceases when the river is at or below the minimum flow in Table 11(c); or
3. Any abstracted water is returned to the river not more than 250 m from the point of take following removal of fine sediment; and
4. The maximum instantaneous rate of water abstraction shall not exceed 50% of the flow in the stream at the site being remediated; and
5. The activity does not take place on a site listed as an archaeological site; and
6. The activity is not undertaken within a Group or Community Drinking Water Protection Zone as listed in Schedule 1; and
7. The activity is undertaken more than 50 m from any lawfully established surface water intake.

The exercise of discretion is restricted to the following matters:

1. The location, method and timing of sediment removal with respect to the life stage and habitat of sensitive ecological communities including fish and invertebrates; and
2. The potential adverse effects of the activity on downstream water quality, flows and significant habitats of indigenous fauna and flora; and
3. The effect of the activity on reliability for any authorised surface water take; and
4. The volume and rate at which water is abstracted and returned to the river; and

5. The potential adverse effects of the activity on sites used for freshwater bathing in Schedule 6 and, cultural landscapes or mahinga kai areas in Table 11(p); and
6. The potential benefits of the activity to the applicant, community and the environment.

11.5.1 The taking and use of water from a river and the disturbance of the bed of a river to remove fine sediment less than 2 mm in diameter for the sole purpose of habitat restoration that does not meet one or more of the conditions in Rule 11.4.21 is a discretionary activity.

Note:
In addition to the provisions of this Plan and any relevant district plan, any activity which may modify, damage or destroy any pre 1900 archaeological sites is subject to the archaeological authority process under the Historic Places Act 1993. An archaeological authority is required from the NZHPT to modify, damage or destroy any archaeological site, whether recorded or not in the NZAA Site Recording Scheme website.

6 Acknowledgments

Thanks go to Alistair Picken and Tami Woods who assisted in the compilation of this report and draft rule composition. Tim Davie and Ken Taylor provided useful comments on earlier drafts.

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Appendix 1: Wairarapa Stream silt wand trial

Environment Canterbury
Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Investigations and Monitoring Group

Silt removal trial from Wairarapa Stream; 12 April 2013

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Report prepared for Environment Canterbury by

Mark Taylor
Winsome Marshall
Aquatic Ecology Ltd

November 2013

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Silt Removal trial from Wairarapa Stream; 12 April 2013

Prepared for:
Environment Canterbury

AEL Report No. 104

Mark Taylor
Winsome Marshall

Final Report

November 2013

Cleaned stream habitat in Wairarapa Stream

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Contents

1 Executive Summary

Following the Canterbury earthquakes, many stony reaches in the upper Avon River have become clogged with fines. Where the fines thinly coat the stream gravels, dredging techniques are not considered appropriate, without damaging or removing the natural gravels which form the bed.

To remediate silted stony rivers, the University of Canterbury and the North Canterbury Fish and Game Council purchased and imported a SandWand, a simple mechanical device which is designed to cleanse stony rivers of settled silt, regardless of its source.

The report describes the use and operation of the SandWand in the Wairarapa Stream, a small spring-fed tributary of the Avon River. The reach was primarily selected because of its importance for brown trout spawning, and that the stream gravels were half buried in earthquake fines. The SandWand functions by causing the silt on the stream bed to be pumped from the bed as a slurry. This slurry entered a high-performance baffle tank called a SiltBuster™ which concentrates the silt before it is discharged into a roadside skip.

A total weight of 1360 kg of silt was removed from a 14 m reach, which equates to 22 kg of wet fines per square metre of stream bed. The SandWand is not heavy, and can be used effectively by one operator, with two others on the stream bank manipulating the hoses and monitoring the silt discharge. Some reduction in water clarity was caused during the cleaning process, largely by foot pressure by the operator. However, 500 m downstream, and possibly over a shorter distance, water clarity had returned to nearly that of the normal upstream level.

A before-and-after assessment of the fish population in the study reach indicated an increase in fish biodiversity from one to three species. The numbers of the predominant species, the upland bully, had decreased, but this trend may be complicated by seasonal effects representing the natural demise of young fry between the assessments, and it was also evident that some sediment was settling into the reach from upstream sources. The colonisation of eels into the reach after cleaning was encouraging.

This report also presents results from tests using flocculants (HaloKlear™) in a trial using samples of Otukaikino River water. Flocculants are bio-degradable compounds which can be used to facilitate the sedimentation of very fine sediment from dirty water, and can be potentially used to treat the slurry entering the SiltBuster™. Used in this way, flocculants improve the performance of the SiltBuster™, allowing more silt to be trapped in the skip for disposal, but also reducing the turbidity of the supernatant and filtrate water returning to the stream channel.

With training and some equipment modifications, this equipment could be used by a team of 3 people to remove significant amounts of sediment from lowland streams.

2 Introduction

The seismic activity commencing from September 2010 has deposited fines in Christchurch rivers, including in reaches which had a predominantly gravel substrate. Fines have a numbers of deleterious impacts on invertebrate and fish values (Death 2000; Jowett & Boustead 2001; Maret *et al.* 1993).

The SandWand™ (Figs. 1a,b) is a mechanical device which can remove fines from stream gravels, and potentially a useful device for the removal of fines from waterway reaches affected by earthquake. However, more generally, and further afield from Christchurch, then SandWand™ could potentially be used for the removal of fines from waterbodies where fines have become deposited over time from erosion processes.

It works by driving clean pumpwater into the stream bed, agitating the gravels, and releasing the fine sediments as a slurry. At the same time, a second pump sucks the slurry into a sediment collection device. The filtered pumpwater returns back into the watercourse via the roadside kerb and channel.

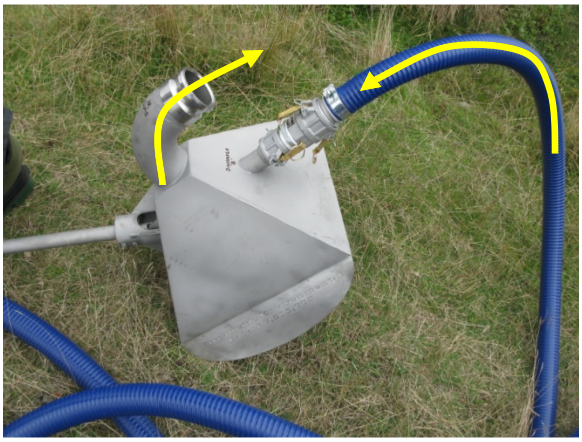

Figure 1a. Top-side view of the SandWand's stainless steel shroud. Water flow direction is indicated.

Figure 1b. The underside of the SandWand shroud. Flow direction indicated.

One SandWand™ unit was recently purchased by the University of Canterbury and the North Canterbury Fish and Game Council. In 2012, the unit was used in two trials in the Otukaikino River to test its effectiveness under New Zealand conditions; refine cleaning technique, and to test sediment containment measures appropriate in an urban setting. In addition, an assessment was made on the influence of silt removal on the invertebrate fauna, but it was considered that spatial variance in cleaning technique detracted from an adequate assessment of the SandWand™'s operation on the invertebrate community.

Following these early Otukaikino River trials, it was proposed to undertake a further trial in a tributary of the Avon River, the upper reaches of the Wairarapa Stream (Fig. 2). This trial would encompass silt removal and silt containment techniques practised in the Otukaikino River, but in an urban setting with conditions typical of a seismically-affected urban reach. Cleaning technique would be further standardised, with fish values assessed before and after the silt-removal trial to quantify ecological remediation. During the silt-removal process, a number of water clarity measures will be measured to determine the level of disruption caused by the cleaning process, and to evaluate the efficiency of the removal of fines.

Figure 2. The location of the silt removal trial at the end of Wai-iti Terrace, 11th April 2013.

3 Objectives

The objectives of this study were to:

- Use the SandWand, and associated equipment, to remove interstitial silt from a reach of Wairarapa Stream. Monitor the effectiveness of the cleaning operation.

- Monitor the reduction in water clarity, and the increase in Total Suspended Solids (TSS), as a result of the cleaning operation.

- Assess the changes in fish community as a result of silt removal.

4 Methods

4.1 Physical habitat and electric fishing

A physical habitat survey preceded both fishing surveys, and considered overall substrate composition, as by its appearance at the surface. A semi-quantitative estimate was made of fish refuge, and nature of the banks (measured vegetation and bank overhang). These assessments were made 'blind' without recourse to the data from the previous assessment. The semi-quantitative assessment of fish cover deserves some explanation, and this is provided in App. I. The surveyed section was divided into several 3 segments, and the average amount of vegetation overhang is measured directly with a measuring stick, as is the degree of bank overhang, and the extent of emergent macrophytes. Over several transects, a measuring stick is also used to estimate mean flow depth, sediment depth, the height of macrophytes above the stream bed, and 'free-flowing' water above the macrophytes.

A more global assessment is made to assess the proportion of overall aquatic macrophyte cover and overall substrate embeddedness. Global assessments are facilitated by partitioning the wetted area into zones of different macrophyte cover/embeddedness and calculating a weighted average based on zone-weighted areas.

Prior to silt removal (on the 28/3/13), a defined reach was electric-fished using a standard Kainga pack-set electric fishing machine set at 300 V. A downstream stopnet was set across the stream to catch fish fleeing downstream, and all fish captured were measured and returned to their resident habitat. The reach was fished twice, and the 'removal method' used to estimate the fish population. The site, over exactly the same location was re-surveyed for fish life on 10/6/13, 60 days after sediment removal, and 74 days after the first fishing survey.

4.2 Silt Removal

Silt Removal, similar to earlier trials, used a device called a SandWand™ to extract a slurry of sand and silt from the streambed. The slurry enters a device called a SiltBuster™ which serves to facilitate the sedimentation of fines. The fines can be discharged from the SiltBuster to a gantry skip for disposal.

This trial revealed the design minimum water depth in which the SandWand would operate, which is limited by the design of the shroud. This depth is about 23 cm, the distance between the bottom edge of the shroud and the point where the towing handle enters the shroud enclosure. The depth of most of the stream bed was much less than this (c. 13 cm), therefore a temporary weir was constructed with sandbags to increase the channel depth above 23 cm (Fig. 3).

During the operation of the SandWand™, clarity tube data was collected from upstream of the working area, 40 m downstream of the downstream boundary of the working area, and the discharges entering the SiltBuster (pumped slurry from SandWand), the supernatant from the SiltBuster (i.e. the clear water after the fines have fallen out of suspension), and the gantry skip drainage (filtrate). The use of the clarity tube is provided in (Kilroy & Biggs 2002), and involves obtaining a paired reading from the one water sample. The operation of the SiltBuster and Gantry skip is explained below.

Figure 3. Sandbags were used to create a temporary weir to increase water depth to a level where the SandWand could be used. The weir was removed after the stream cleaning exercise.

4.2.1 SandWand™ operation

During previous trials on the Otukaikino River, the effective operation of the SandWand™ has been determined. It has been found that the unit is easier to use by pulling it upstream over the bed by its handle, in contrast to trying to push it across the bed (Fig. 4). In addition, the operator's feet tend to re-suspend fines on the bed, and this is partly remediated by having the SandWand™ shroud always downstream of the operator's feet. With this orientation, a proportion of the disturbance caused by the operator's movements is entrained by the SandWand™.

Figure 4. The use of the SandWand by one operator (11/4/13). River flow direction is indicated. Note the pump operator on the bank who assists with moving the heavy hoses, and SandWand shroud.

The stream bed was cleaned in lanes along the stream channel, and parallel to the banks. During cleaning, the shroud was pulled upstream slowly in 0.5 m steps, then held stationery for several seconds to develop a negative pressure over the bed. This was visually confirmed, as suspended fines around the edges of the shroud could be observed to be drawn under the shroud edge when effective suction was occurring. The shroud was then screwed from side to side (a yawing action), and pitched gently forward and back, by moving the handle, such that the shroud edges bit into the substrate by several centimetres. The bodily rocking of the shroud from side to side, used on the 2nd day of the Otukaikino River trial was avoided, as this action was associated with poor silt removal, possibly because of loss of a low pressure "suction" zone under the shroud.

Once at the upstream margin of the cleaned section, the SandWand was carried by two operators to the downstream margin of the section. At the upstream end of the 15 m cleaning run, another person was required to assist in carrying the SandWand downstream into its new position. Each lane run took approximately 30 min, and 6 cleaning lanes were achieved.

4.2.2 SiltBuster and Container setup

The discharge from the SandWand entered the SiltBuster at the full rate achievable by the large pump at full throttle (c. 16 L/s). The SiltBuster is a sedimentation tank with multiple baffles which facilitates the settlement of suspended fines from the pumped SandWand slurry (App. II), with the fines then discharged to waste (Fig. 4). During this trial, no flocculent was added to the slurry to facilitated sedimentation. Settled fines were accumulated in the SiltBuster chutes for 5 minutes before the sluice gates were opened, and the slurry discharged to a Bidim™-lined skip container (Fig. 5). A layer of Cordrain™, which resembles a sheet of plastic waffleboard, was placed between the steel sides and the Bidim to facilitate drainage. The water drained through the Bidim and Cordrain™, then through a hole in the bottom of the container, and finally discharged into a stormwater sump leading directly back to Wairarapa Stream.

Supernatant water from the SiltBuster, the relatively silt-free water at the top of the unit where the coarser fines have fallen out of suspension, was directed back into the Wairarapa Stream channel via a large plastic sheet (Fig. 6). After 48 hrs to drain, the collected fines in the skip (Fig. 7) were weighed, and disposed to landfill.

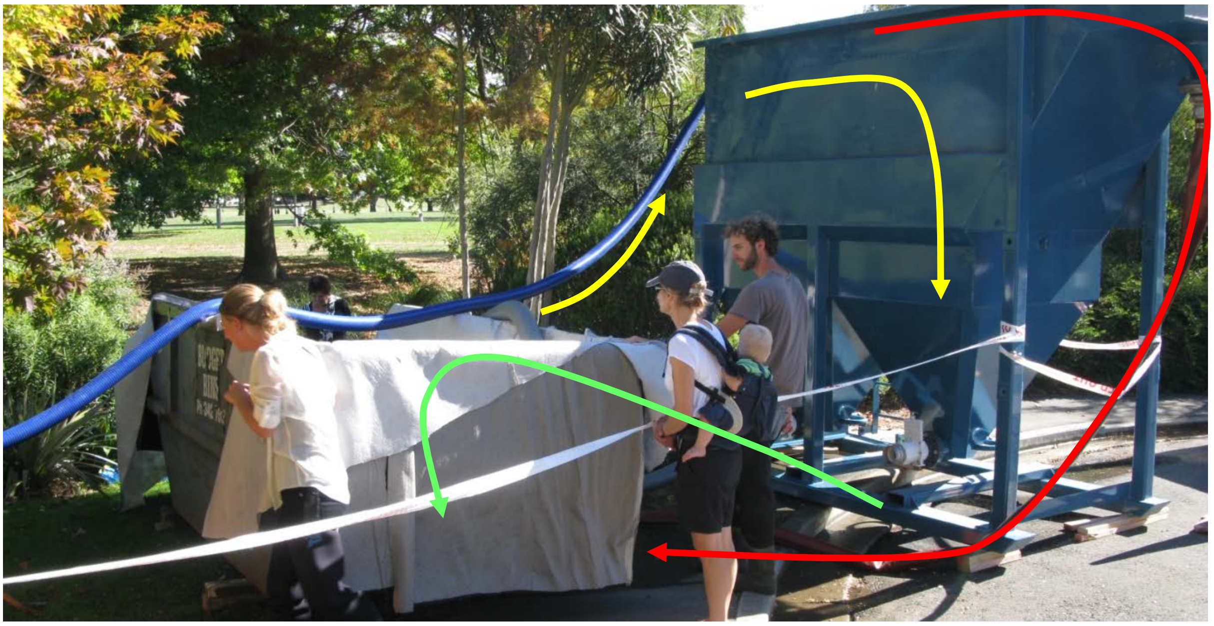

Figure 5. The placement of the SiltBuster and the lined container at the end of Wai-iti Terrace. The supernatant (red arrow) from the SiltBuster was discharged onto a large nylon sheet that also discharged back into the stream channel (Fig. 6). The silt sludge (green arrow) was drawn from the bottom of the SiltBuster to the Bidim-lined skip (Fig. 7), with the filtrate returning to the river via a stormwater sump.

Figure 6. Supernatant water from the SiltBuster discharging back into the stream channel.

Figure 7. Collected fines from Wairarapa Stream. A total of 1360 kg of silt and sand was removed from 14 m of Wairarapa Stream channel (c. 22 kg/m^2).

5 Results

5.1 Physical habitat of fishing site

The initial survey (28/3/13) recorded high levels of sand (substrate < 2 mm), and low levels of large cobbles (substrate from 100-260 mm) (Fig. 8). After the use of the SandWand (on 11/4/13), and during the reassessment (10/6/13, 60 days after silt removal), the observed proportion of sand was substantially decreased, with a significant increase in the area of large cobbles. However, there was little change in the proportion of fine gravel, coarse gravel, or small cobbles at the site. Further, embeddedness had decreased only slightly after comparison with site before the silt had been removed, and the situation two months after removal.

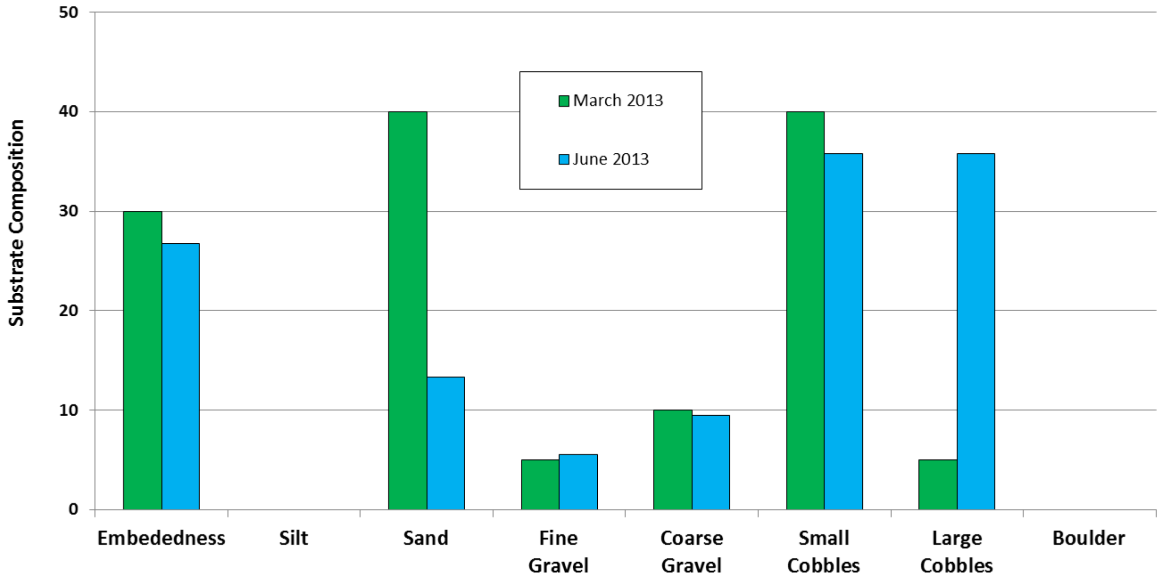

Figure 8. Change in habitat substrate composition as assessed before (28/3/13) and after (10/6/13) the SandWand was applied (11/4/13).

In respect to fish cover, total fish cover had increased, from 130 fish cover points to 145.8 fish cover points. Most of this change was due to the increase in substrate cover particularly large cobbles, although overhanging vegetation has decreased slightly while overhanging banks had remained unchanged (Fig. 9). Neither the pre-impact or post-impact assessment recorded fish refuge in the form of submerged aquatic plants or instream debris. Notably, between habitat assessments, the study reach had been subject to low-level maintenance by the river workers a week before the SandWand was used. This maintenance was limited to bank trimming, and the removal of small amounts of aquatic vegetation, and this was manifested as loss of overhanging bank vegetation cover.

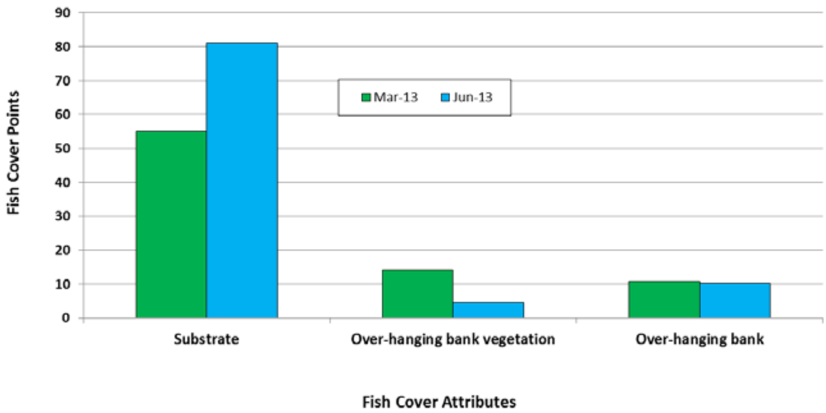

Figure 9. Change in fish cover with habitat assessments (28/3/13, 10/6/13).

5.2 Sediment removal and physical appearance of site

Comparable photograph sets are available at the time of the initial assessment before silt removal, immediately after silt removal, and the time of habitat reassessment two months later (App. III, Figs.i (a-f)). What was apparent that the substrate had become noticeably more silted between the time when the silt had just been removed, and the same reach two months later. Further, a degree of shrub canopy trimming had taken place, including native ferns on the grassed true right bank and *Carex* on the right bank. Before-impact underwater photographs of the reach had been taken from staked locations, but the stakes were stolen overnight precluding a rigorous comparison of the same locations before and after cleaning. However, before-and-after underwater photographs are provided for the SandWand's use in a recent (24/5/13) Otukaikino River trial (App. IV). There were obtained from exactly the same physical location by staking the downstream margin of the photographs with a metal stake.

After draining over the weekend, the removed fines (Fig. 6) were weighed by Waste Management (TransPacific Ltd). The total weight was reported as 1360 kg, removed from a measured wetted area of 61.4 m^2, or 22.2 kg/m^2.

5.3 Water clarity reduction induced by the SandWand operation

During silt removal, reduction of water clarity, as measured with a Clarity Tube, was quite marked 40 m downstream of the worked area (reduced to 38 % of upstream clarity), but recovered to 93% of the upstream clarity at Clyde Road, about 500 m downstream (Fig. 10). Visually, the impact was less apparent due to the shallow depth of the stream (c. 8-30 cm).

The turbidity of sand/silt slurry entering the SiltBuster was highly turbid, with clarity of a few centimetres, with the removal of fines in the SiltBuster, the supernatant water had an overall 37% increase in clarity, although the improvement was variable. When the SiltBuster's trapped slurry was retained on the Bidim cloth, the Gantry bin filtrate water had clarity 117% better than SiltBuster input. The combined flow volume was considered equal to the large pump when on full throttle, or approximately 16 L/s. This indicates that much of the coarser fines drawn from substrate, and captured by the SiltBuster/Bidim assembly do not contribute significantly to water clarity.

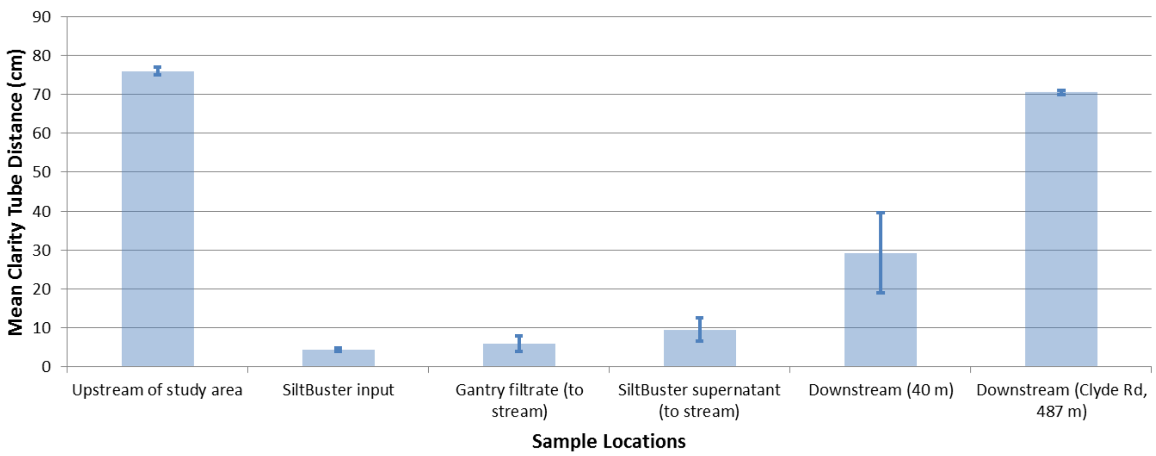

Figure 10. Mean clarity tube readings from the study area (Wairarapa Stream) reflecting the significant reduction in clarity tube readings downstream of the study area. Bars are based on the mean of 2 replicate paired readings by the same observer, except for the upstream location, and at Clyde Road. Error bars = range of readings.

5.4 Fish Values

The resident fish community, at the time of the pre-impact survey (28/3/13) was composed of a sparse population of upland bullies. No other species were identified. The estimated population was 30 fish, based on the capture of 30 fish over two electric fishing runs (27 fish 1st run, 3 fish 2nd run), with a standard error of 0 ($p_{capture}$ = 0.9). Over a fished streambed area of 34.7 m2, this equates to a population density of 86 fish per 100 m^2 (Figure 11). The size distribution was multi-modal, with cohorts of young fry less than 20 mm in length, larger fish around 35 mm, 50mm, and 65-70 mm (Fig. 12).

The second survey (10/6/13) produced significantly different results in the fish population (Figs. 11, 12). A total of 14 upland bullies were caught (8 in the 1st run and 6 in the 2nd), which gave a 'removal method' population estimate of 17 (standard error = 3.24 probability of capture 0.5). There was also a significant change in the mean length of upland bullies (U=196, $p < 0.05$), probably due to the loss of very young fry from the population, and growth of the survivors.

Low numbers of shortfin eels (n=3) and longfin eels (n=1) were recorded during the second survey, but numbers were too low to provide a meaningful population estimate. Brown trout parr were observed in adjacent deeper reaches of the stream which were netted off from the study section.

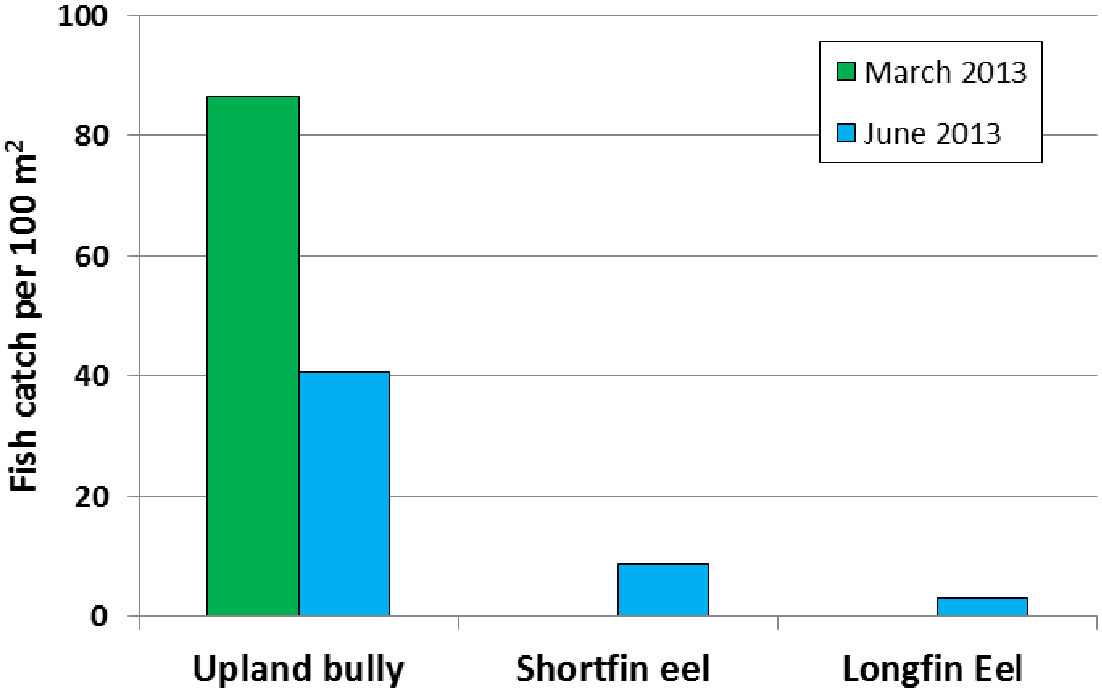

Figure 11. Species composition from the two fishing surveys.

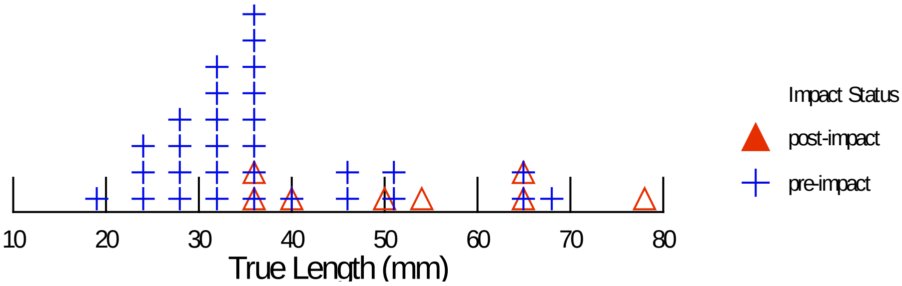

Figure 12. Length frequency dit plot for measured upland bully.

6 Discussion

6.1 Changes in physical habitat

Immediately after the silt was removed with the SandWand, there was a marked increase in substrate coarseness over the study reach. Not only had much of fines been removed, but the remaining substrate felt loose underfoot, and it appeared that some of the periphyton appeared to have been lost, as the substrate was materially lighter and more reflective (Fig. 13). The change in substrate was reflected in the visual substrate composition assessment 2 months afterwards.

Figure 13. The cleaned section of Wairarapa Stream immediately after silt removal (11/4/13). The yellow line demarcates the downstream margin of the cleaned section.

However, substrate did appear to accumulate fines over the 2 months after SandWand use (see App II, Fig. i(c-f)), presumably transported from upstream sources. Upstream of the cleaned reach, there are reaches with accumulated silt, and this is suspected to be a principal source of sediment, and it was evident that the middle reaches of the Avon River recorded several freshes, between the time when the reach was cleaned, and the final assessment (esp. 20/4/13, 7/5/13, Fig. 14), and these are likely to represent peaks of sediment transport. However, the upstream true right bank, which borders Cobham School, is largely unvegetated, and is eroding in thinly grassed sections. This erosion is probably facilitated by groups of school children who gravitate to the bank edge during play periods. Upstream of Ilam Road, within the grounds of Jellie Park, the true left bank is unstable in places, and soft sediment is also present. Along the cleaned section, the true right bank had been planted out in native vegetation, whereas the true left bank was a vertical basalt rock wall, both of which appear stable and are unlikely sources of sediment.

During baseflow, Wairarapa Stream is quite clear with a clarity tube reading in the order of 76 cm. This is not quite as clear as the Styx River which has a summer baseflow which has readings close to the instrument maximum of 100 cm (Taylor & Bray 2008). However, sediment transport is likely to occur during high flow events, and there were two significant high-flow events in the Avon River catchment after the substrate was cleaned on the 11th April. These high flows were on the 20th April, and the 7th May (Fig. 14). A number of small freshes also occurred over the 8 weeks between the habitat cleaning and habitat assessment. While flow elevation in the upper catchment would be much less than at the flow recorder at Gloucester Street, the freshes were evidently sufficient to transport some fines in the cleaned reach.

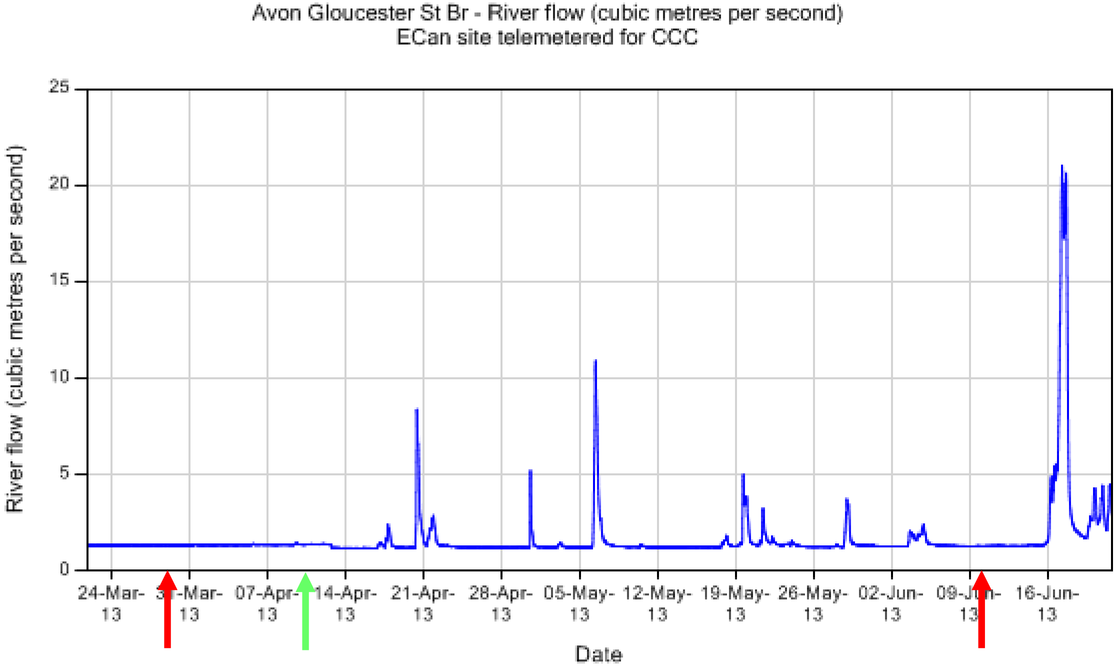

Figure 14. The Avon River CBD hydrograph illustrating the two habitat assessments (red arrows) and the date of silt removal (green arrow).

6.2 Operation-induced reduction in water clarity

The process of removing silt from the substrate clearly caused a significant reduction in water clarity in Wairarapa Stream, as graphically illustrated above (see Fig. 10). The sources of this clarity reduction are caused by the manipulation of the SandWand™ assembly, the operator's disturbance of the bed, and the 16 L/s of slightly turbid return water discharging back into the river. This turbid water is composed of filtrate water after it has passed through the geotextile lining the skip, and the supernatant water from the top of the SiltBuster. The return water clarity was less for the Wairarapa Stream than in similar silt removal trials in the Otukaikino River (c.f. 15.8cm Otukaikino supernatant, 16.8 cm Otukaikino filtrate). Given that the operating equipment and settings were identical during both trials, this would suggest that the proportion of very fine material in the Wairarapa Stream pump slurry was higher in the Otukaikino River.

The operational water clarity reduction figures for the Wairarapa Stream are broadly similar to those obtained from the Otukaikino River, given than the upstream uninfluenced Otukaikino River water is a little clearer than that in the Wairarapa Stream (Fig. 15).

6.3 Water clarity and sediment flocculant trials from the Otukaikino River

The SiltBuster™ can accommodate chemicals that cause flocculation and coagulation of very fine suspended particles like loess (clay) particles. These particles are the least successful to settle within the SiltBuster without the use of flocculants, chemicals that make clay particles bind together facilitating sedimentation. Trials on sampled pumpwater from the Otukaikino River (24 May 2013) took place with a chitin-based coagulant (HaloKlear™) which is biodegradable. These small water samples were disposed of to waste, and not returned to the river. This trial demonstrated accelerated sedimentation in clearing 1 L of SandWand pumpwater using a small volume of added flocculant. (Fig. 16).

Two approaches were used to determine the most suitable flocculent and concentration; one using just the HaloKlear Classic™ flocculent (normal strength), and the second using a combination of the HaloKlear Classic and LBP- 2101™ compounds. A 1:1 combination of the two compounds rendered the best clarification, with 8 drops each of HaloKlear Classic™ and LBP- 2101™ mixed into 1 L of pumpwater. Increasing dosage to 10 drops of each product produced very little net improvement in clarity. Photographs of the pumpwater clarification is provided in Figs. 17a, b.

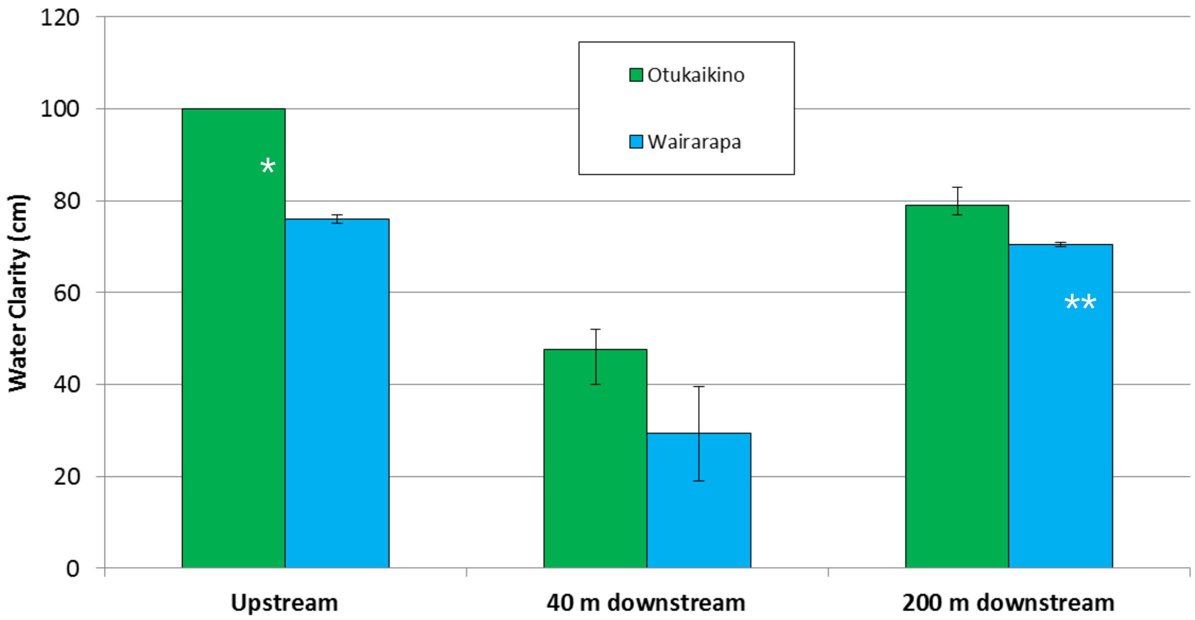

Figure 15. Clarity tube readings in the Otukaikino and Wairarapa Streams.*Upstream Otukaikino was greater than 100 cm.**Wairarapa 200 m downstream is actually 487 m downstream.

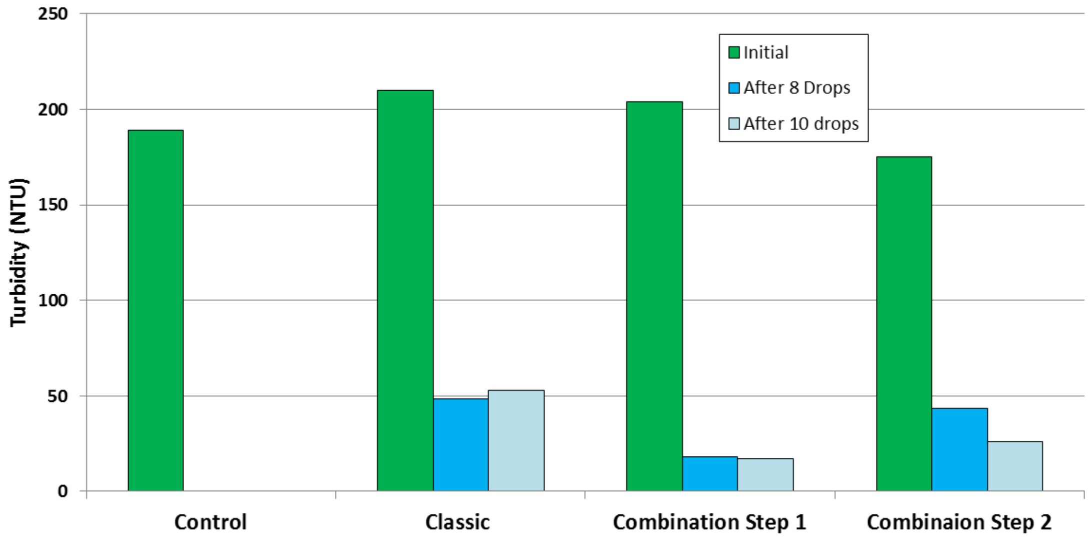

Figure 16. The effect of HaloKlear™ flocculant dosages on turbidity of 1 L SandWand pumpwater samples.

Figure 17a. Plan view of HaloKlear Classic™, HaloKlear™ dual step one, HaloKlear™ dual step two and control.

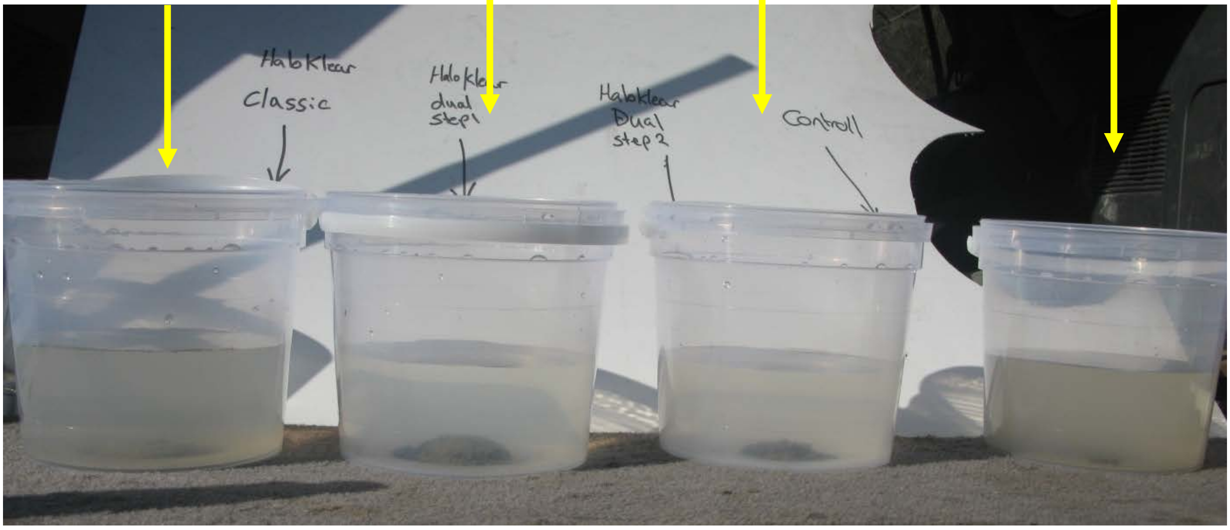

Figure 17b. Field-based demonstration at the clarity achieved by using HaloKlear flocculants, water sample is 1 L. Arrows link the plan and side-on view of each of the 4 treatments. The control container has had no flocculant added.

6.4 Ecological impacts on fish

The lower upland bully count surprised us; we were expecting an improved number of upland bullies after cleaning. Upland bully abundance has been experimentally demonstrated to decrease with increased sedimentation, and conversely increase with removal of sediment (Jowett & Boustead 2001).

However, other factors are involved here. The pre-impact assessment occurred in late March, and it was clear that many fry of the year were present from spawning over the summer and autumn. The site was re-fished in the winter (June) when spawning had finished, and many of the fry would have naturally dispersed or had died. This may be the main reason why the mean size of bullies had increased, but with few numbers caught

Secondly, 8 weeks after cleaning, it was apparent that the cleaned reach was becoming more sedimented, at least on the surface. The habitat reassessment indicated a coarser substrate, but with embeddedness at much the same level as prior to the cleaning. Therefore, the upland bullies population may be reflecting a combination of seasonal effects, perturbation from the cleaning exercise (along with their invertebrate prey), and increasing sedimentation. This observation of siltation emphasises the importance of cleaning rivers from the source to the sea, or at least ensuring that downstream transport of silt is prevented by the incorporation of silt traps or otherwise. In a recent investigation of seismic remediation of Wairarapa Stream, it was recommended that silt transport could be mitigated by the use of instream sediment traps (Hayward *et al.* 2013), possibly by mechanically excavating a deeper reach to facilitate sedimentation. These sediment traps could be located along the stream course on public land to make servicing easy, and upstream of sensitive ecological area (e.g. upstream of trout spawning reaches).

Ideally, without the benefit of a temporal control site (omitted due to cost), it would be advisable to re-survey the same site during the same season, even possibly a year after the site was cleaned, to allow for invertebrate recolonisation. However, we were surprised at the speed in which sediment re-entered the reach, and felt that re-surveying sooner rather than in the same season would be non-ideal but necessary given the circumstances. The small number of small eels (4) present in the cleaned reach may reflect an increase in the quality of habitat since the silt was removed. Eels less than 30 cm use gravels for habitat (Glova & Duncan 1985; McDowall 1990), and cleaning stream gravels may provide a significant benefit for eels, especially where alternative cover is scarce.

It was also evident that between surveys, some habitat perturbation took place from channel maintenance carried out by river maintenance workers. This involved the trimming of vegetation overhanging the banks (e.g. *Carex secta* and ferns Fig. 18). Overhanging *Carex,* in particular, is invaluable for refuge for spawning trout, but also larger eels and bullies. We recommend that trimming of overhanging vegetation, particularly *Carex*, be avoided through trout spawning reaches.

Figure 18. *Carex secta* at the end of Wai-iti Terrace recently trimmed by river care workers.

7 Logistic assessment of the silt removal operation

From this study, and the earlier trials, we consider that 3 field assistants are required to run the silt removal operation. In the Wairarapa Stream trial, we obtained a high level of silt removal with just one operator on the SandWand, and manipulating this device is not heavy work. Below is a discussion of work division and recommended efficiencies.

We consider that a ‘slow-but-sure’ approach is best for the SandWand, using a single pass technique. On the Wairarapa Stream we took about 30 minutes to cover 14 m of channel in a single cleaning lane, and using a method outlined in Sec 4.2.1. The effective cleaned width is somewhat narrower than the SandWand shroud, and is approximately 0.3 m in width. Thus, overlapping the shroud by 10 cm into the adjacent cleaned lane would provide a more uniform cleaning result.

A second operator on the bank provides Health and Safety Support, and services the pumps (petrol refills etc). The length of the cleaning lane, and therefore overall cleaning efficiency, could be improved by loading the pumps onto a heavy-duty braked trolley with pneumatic tyres, facilitating their transport along the bank by one operator. The elevation of the pumps would also assist in ensuring the hoses clear riparian vegetation near the water edge. Both the pump operator and the SandWand operator require earmuffs due to the noise from the two 4-stroke motors.

The SiltBuster requires frequent (5 minute) maintenance to dispatch accumulating fines from the settlement chutes into the disposal chute. This involves opening the sluice valve for a 2 minute period (every 5 minutes), or until it runs clear of silt. This is best handled by a third person, who can also check that the SiltBuster is getting the full water discharge, as airlocks in the hoses are common.

One problem we did face on Wairarapa Stream is lack of visibility due to working in the plume from the supernatant and filtrate discharge a short distance upstream. This was necessary because we were working downstream of the road, and therefore the SiltBuster and Gantry skips, and their associated discharges. However, it could be possible in those circumstances, to divert these discharges well downstream, if additional Cam-lock hoses were available. Notwithstanding site limitations, the graphic below suggests the best-practice arrangement of equipment, with the cleaning zone upstream of discharges (Fig. 19).

Another problem was the slow release of filtrate water from the gantry skip during the Wairarapa Stream trial. This meant the extraction process had to be stopped before the skip overtopped with dirty pumpwater, and effectively limited by the speed in which the Bidim-lined gantry skip would discharge through the 5 cm hole in the bottom. The filtration discharge also slowed as the skip filled, probably due to the weight of material pressing down on the geotextile, despite the waffle underlay liner. On the day of the Wairarapa Stream trial, this doubled the time of silt extraction.

An alternative to the lined gantry skip is discharging the SiltBuster discharge into a filter bag called a small GeoTube, which is small enough to fit into a gantry skip, and has a volume capacity of 2 m^3. This could accommodate a silt weight which should be under the maximum capacity of a gantry crane lift (i.e. max lift weight of 3.5 tonnes). Trials on the Otukaikino River with a larger product made of a similar material produced a higher filtrate water clarity (mean clarity tube distance = 16.8 cm).

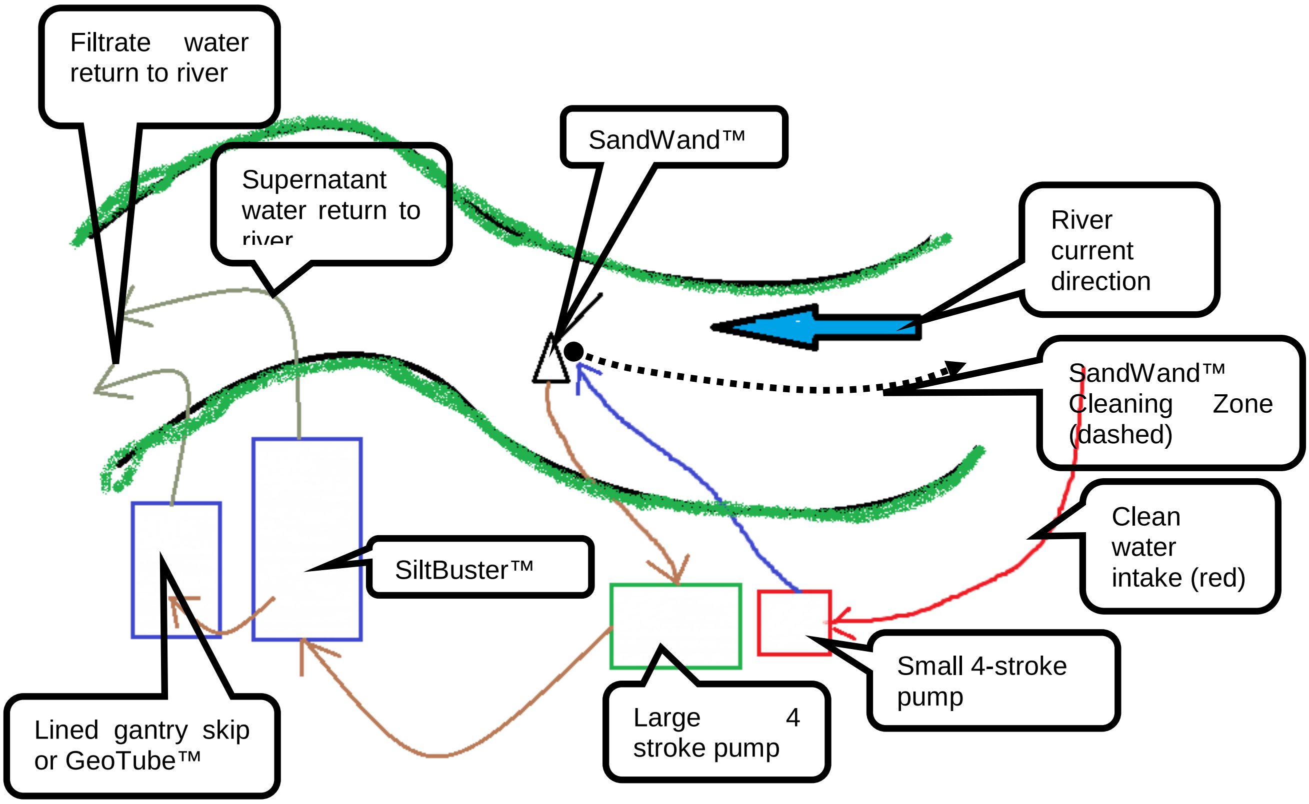

Figure 19. Schematic illustrating best practice layout for river silt cleaning with the SandWand, SiltBuster assembly. Lines indicate pumpwater flow direction.

8 Preliminary Cost Analysis

The estimated costs are as follows:

Technical issues aside, working efficiently, we consider that a 1.5 hrs is sufficient to clean an area 14 m long by 4 m width. With the current hose lengths, this is about the length of river reach which can be cleaned without materially changing the operation. However, with pumps mounted on a trolley, and longer hoses, the reach could be extended significantly. The pumps have a significant design head, and could accommodate longer hoses, and the CamLock hoses are inexpensive to hire (Emily Arthur, pers. comm.).

Based on this survey, we consider a 60 m x 4 m reach could be undertaken in a day, which would take an extraction time of 6.4 hrs, and a labour cost of $290. The rest of the day would be taken up with setting up, and priming the system, so with setting up, essentially the labour cost would be around $432 for an 8 hr day (@ $18/hr for 3 workers). The weight of fines from a reach of this nature (interstitial silt), based on the 0.022 tonne/m2, would be 5.3 tonnes, when the limit of the gantry bin lift is 3.5 tonnes. This could be achieved with the removal of one bin, and a replacement with another. If the gantry bin contains the new smaller Geo tube, the labour cost saving in not requiring lining would be about $165 (due to the expensive under-liner more than the labour cost). Alternatively, the Geotube alternative costs $207 (excl. GST), but appears to drain more efficiently and has a higher filtration performance.

9 Acknowledgements

We thank Mr and Mrs Perry for providing access to their property, and for their interest and support for silt removal from Wairarapa Stream, and Teneille Barwick and John Cooper for field assistance. Environment Canterbury staff also provided assistance, especially Michele Stevenson, as did Emily Arthur (North Canterbury Fish and Game Council).

Rob Grant (CRS Industrial Water Treatment Systems (NZ) Ltd) provided the SiltBuster, valuable advice about its use, and organised its transit to and from the site. Kate Lewis of Maccaferri provided technical advice on the use of silt removal with geotextiles, and Matt Darnbrough (Waste Management) organised the testing and safe disposal of the removed fines.

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11 Appendix I. Fish Cover semi-quantitative assessment

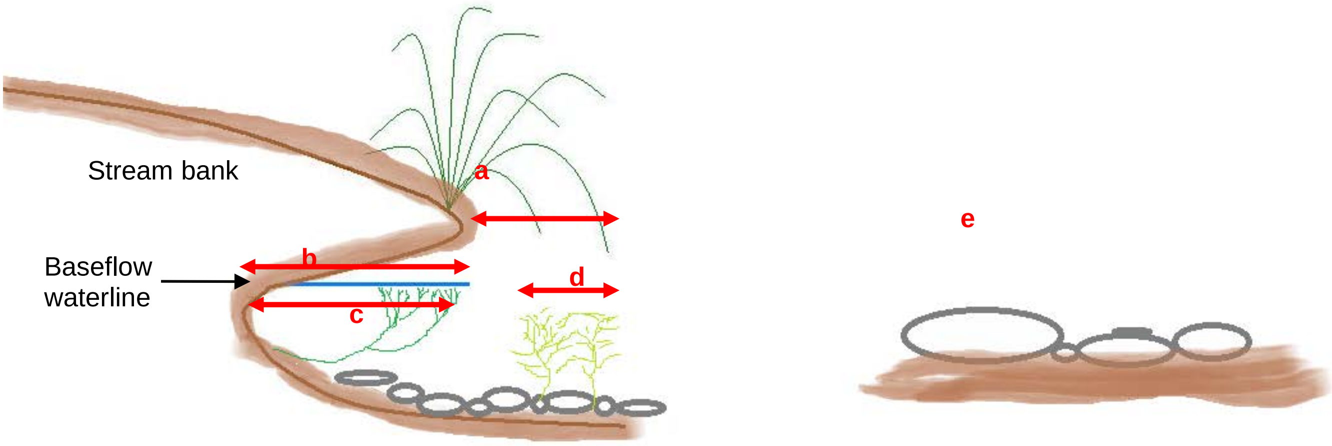

Fig. i. From (Taylor & Blair 2012)**,** Bank profile schematic depicting field measurements of (a) = vegetation overhang distance, (b) = bank overhang distance, (c) = width of bank-rooted emergent vegetation, (d) = area of bed-rooted aquatic macrophytes (width x length). (e)= Expansion of bed profile depicting how the coarse substrate is partially buried into surrounding fines. With approximately a third of the vertical axis of the cobbles buried, this equates to an embeddedness of approximately 30%.

12 Appendix II. Diagram of SiltBuster

Figure i. Diagram illustrating the SiltBuster internal function.

13 Appendix III. Comparison of pre- and post-impact silt levels

Figure i(a): Looking upstream at the fishing site pre-impact (28/3/13).

Figure i(b): Pre-impact. Looking downstream at the fishing site (28/3/13).

Figure i(c): Looking upstream at the same location immediately post-impact (11/4/13).

Figure i(d): Immediately post-impact looking downstream at the same section (11/4/13).

Figure i(e): The same section two months later, note the increase in siltation that has occurred (10/6/13).

Figure i(f): The same section re-photographed two months later showing an increase in siltation (10/6/13).

14 Appendix IV. Underwater photographs of the cleansing action of the SandWand (Otukaikino River, 24/5/13)

Figure i. Pre-cleaned substrate from the Otukaikino River (electronically stitched photograph).

Figure ii. Substrate after cleaning with the SandWand (electronically stitched photograph).

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Appendix 2: Otukaikino Sand Wand^{TM} trial 2013

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TECHNICAL REPORT Investigations and Monitoring Group

A trial of fine sediment removal using the Sand Wand^{TM}: efficacy and impacts

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October 2013

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Executive Summary

Fine sediment (<2 mm) is a significant contaminant in Canterbury streams. Fine sediment accumulation in streams has the potential to alter the quantity and quality of physical habitat to the detriment of invertebrate and fish communities. This report details an assessment of the efficacy and ecological impacts of fine sediment removal using a suction technique; the Sand Wand^{TM}. Overall, fine sediment removal using the Sand Wand^{TM} appears to be highly effective in removing sediment from the top 10 cm of the stream bed. When fine sediment is composed primarily of sand and fine sand the majority of sediment suspended by the activity and not removed from the stream drops rapidly out of suspension such that downstream water quality is maintained. Invertebrate communities within the sediment-removal reach were initially reduced in richness and density by the activity, but recovered fully to pre-trial community richness and density after six weeks. There was some indication that the post recolonisation invertebrate community contained a greater proportion of mayflies than pre-trial. However, a similar pattern was also observed in the upstream control reach. The trial was limited to a short stretch of stream bed and may underestimate the degree of impact on invertebrate communities resulting from the cleaning of longer stretches of stream. Overall, the method appears to hold considerable promise for the rehabilitation of stream impacted by fine sediment accumulation.

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List of figures

1 Introduction

Fine sediment (<2 mm) is a significant contaminant in Canterbury streams. Fine sediment accumulation in streams has the potential to alter the quantity and quality of physical habitat to the detriment of invertebrate and fish communities. Specifically, sediment smothers invertebrates and the stream bed and may clog the gills of fish. Infilling of spaces between stream bed gravels reduces the availability of habitat for invertebrates and prevents the movement of oxygenated water through the stream bed to support larval fish and hyporheic invertebrates. In addition, a high cover of fine sediment reduces the aesthetic appeal of waterways. Accordingly, fine sediment removal from the bed of lowland streams has been suggested as a critical step in the rehabilitation of stream ecosystem health.

Unlike many larger hill-fed and alpine rivers, lowland waterways and spring-fed streams typically do not experience floods of sufficient magnitude to flush fine sediments. Therefore, the legacy of fine sediment deposits may impair these stream communities in perpetuity. However, a recently developed tool (called a "Sand Wand^{TM}") to remove fine sediment using a water pumping system has been developed. This report provides a quantitative assessment of a trial of the effectiveness of the sand wand for fine sediment removal from the Otukaikino Creek, Christchurch.

The objectives of the trial were to:

(i) assess the efficacy of this tool for removing sediment from the stream bed

(ii) assess the effect of the fine sediment removal process on downstream water clarity

(iii) assess the recovery of invertebrate communities post treatment.

This assessment forms part of a larger project to assess the efficacy of fine sediment removal using suction technology and the potential benefits for ecological rehabilitation. Further trials are planned. The project is a collaborative undertaking between Fish and Game North Canterbury, Environment Canterbury and the University of Canterbury, Freshwater Ecology Research Group. The Sand Wand^{TM} is manufactured and distributed by Streamside Environmental, Ohio U.S.

2 Methods

On the 24th May 2013 fine sediment was removed from a single reach of the Otukaikino Creek over a period of approximately four hours. Technical issues with the pumps and training of volunteers resulted in greater time spent at the stream than would be required for sediment removal operations. The impact on stream habitat and invertebrate fauna of fine sediment removal was assessed using a 'before after control impact (BACI) design (Figure 2-1). Three equivalent reaches, each approximately 10 m wide by 15 m long, and adjoined along the stream length were chosen and designated as 'upstream, downstream and trial'. Data and observations of the stream were collected on three occasions: once immediately before sediment removal, three days post-removal, and six weeks post-removal. The survey design allowed the impact of fine sediment removal in the trial reach to be assessed while controlling for changes resulting from natural variation in stream conditions over time.

Fine sediment cover and quantity were assessed using standard techniques. Fine sediment cover was estimated using a stream bed viewer (Clapcott *et al.* 2011). In each reach and on each sampling occasion the viewer was placed randomly along four transects perpendicular to flow. The view was subdivided into four areas and percentage fine sediment cover estimated by eye for each area. Twenty observations were made along each transect resulting in a total of 80 observations for each reach and sampling occasion. Fine sediment quantity within the stream bed was estimated using the Quorer technique (Clappcott *et al.* 2011). A cylinder of known dimension was inserted into the stream bed and the bed agitated to mobilise sediments. A single grab sample of the water and sediment was collected and analysed for total suspended solids (TSS) at Hills Laboratory, Christchurch. Embeddedness of the stream bed due to fine sediments was assessed using a blunt rod insertion depth examination (BRIDE) test. A consistent force was applied to the rod and penetration depth measured. In each reach and sampling occasion, five BRIDE tests were undertaken along each of five transects for a total of 25 per sampling occasion.

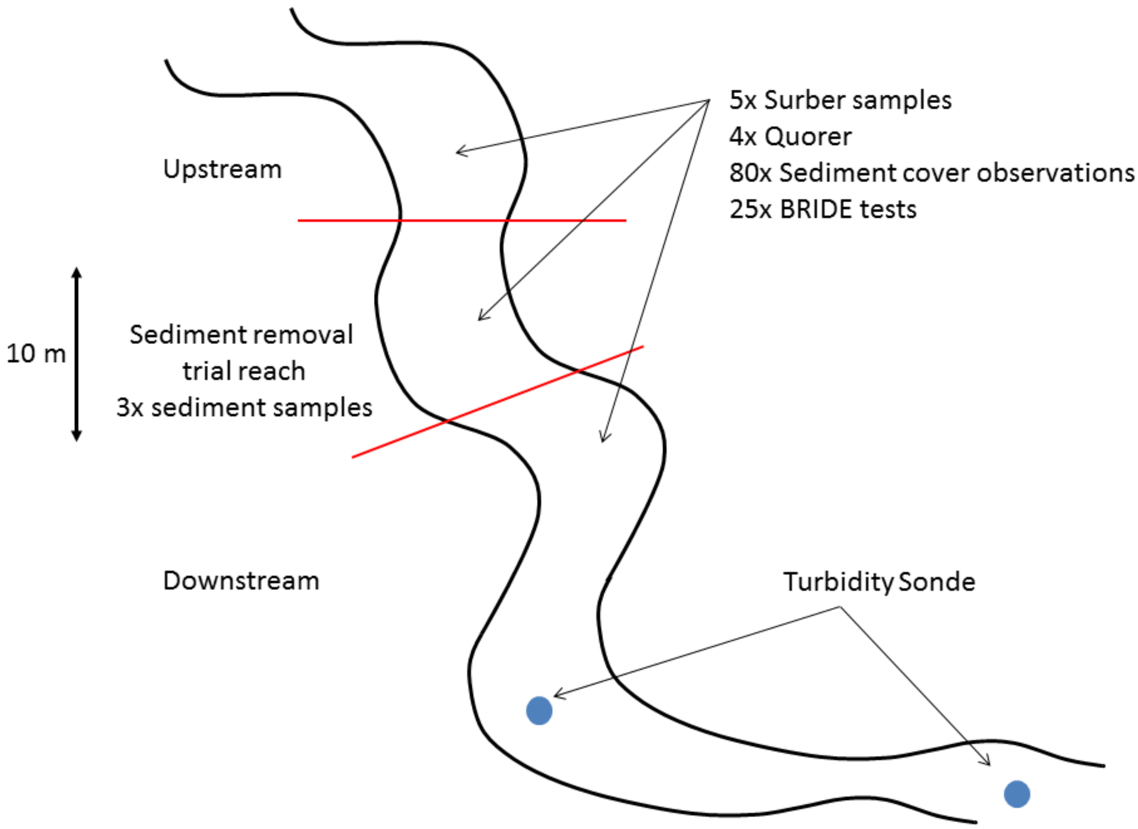

Figure 2-1: Study design for the Otukaikino Creek fine sediment removal trial

Three replicate sediment samples from within the trial reach were collected using a trowel and pottle. Sediments were graded through Endecotts sieves and ashed at 500 °C for four hours. During suction three replicate grab samples of water (up and downstream of the trial reach) and in return water flowing back to the stream from the discharge site were collected and analysed for TSS by Hills Laboratory, Christchurch. Turbidity downstream of the fine sediment removal trial was measured using two turbidity sondes, collecting data at 20 second intervals. Sondes were located ~ 50 m and 200 m downstream of the treatment reach. The upper sonde was a YSI 6600 multi-parameter water quality monitor, while the lower sonde was a GreenspanTS300. Both sondes were calibrated prior to deployment. Stage height in the fine sediment removal reach was recorded using a TruTrack WT-HR water level and temperature logger. Background water quality data was derived from the YSI 6600 multi-parameter sonde deployed at 50 m below the trial using data recorded after the trial had ceased and turbidity had returned to back-ground levels three days later. Finally, nitrate and phosphorus concentration was measured from filtered (0.45 µm) water samples by the University of Canterbury, School of Biological Sciences using a Systea, EasyChem Plus, version 1.9.6 e. Phosphorus was measured using the ortho-phosphate discrete analysis EASY PO4- 365.1 rev 0, colorimetric, automated, ascorbic acid method. Nitrate was measured using the EASY nitrate discrete 353.2 rev 0, colorimetric, automated, cadmium reaction method. The EasyChem machine was calibrated prior to each analysis.

In each of the three reaches and sampling occasions invertebrate communities were sampled using five replicate Surber samples. A Surber sampler allows a defined area of stream bed to be contained and sampled for invertebrates. Samples were preserved in ethanol and sorted using the standard protocols of Stark *et al.* (2001). All invertebrates were identified to the lowest practical levels (mostly genus) and counted using the keys of Winterbourn *et al.* (2006), Chapman *et al.* (2011) and NIWA guides.

3 Statistical analyses

Differences between groups or occasions in the BACI design were tested using one and two way ANOVA and Holm-Sidak post hoc tests for normally distributed or ranked data, but a Kruskal-Wallis test was used for non-normal data. TSS in water, TSS in quorer samples and invertebrate richness data were analysed using un-transformed data. Invertebrate density was $\log^{10}$ transformed, while sediment cover data were ranked. Finally, embeddedness data could not be made to approximate a normal distribution and so were analysed using the raw data and a Kruskal- Wallis test.

4 Fine sediment removal

The sand wand uses a combination of water jet and suction to mobilise and transport fine sediments beneath an enclosed hood (Figure 4-1). The equipment is manually moved across the stream bed using a rocking motion moving parallel to flow.

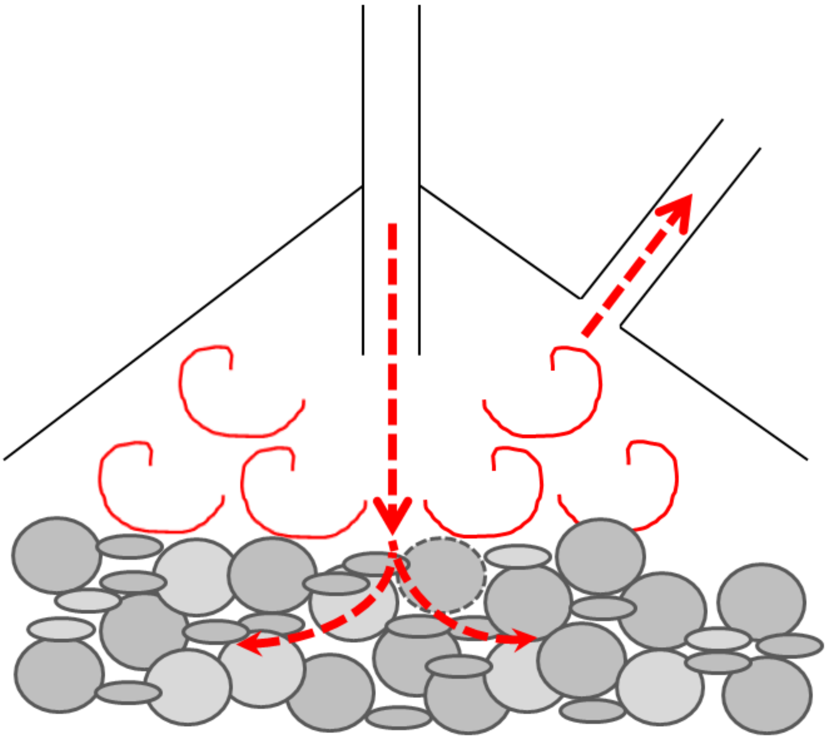

Figure 4-1: Schematic of the sand wand hood and flow paths of water. Pressurised water is forced into the stream bed mobilising fine sediments to a maximum size of ~ 2 mm. The slurry mix of water and sediment is then pumped away for disposal

The arrangement of pumps relative to the sand wand hood is dependent on the topography of the stream. Slurry may be discharged to land (Figure 4-2) or into sediment separating equipment. Figure 4-3 provides further detail on the equipment deployed streamside and the visual effect of fine sediment removal.

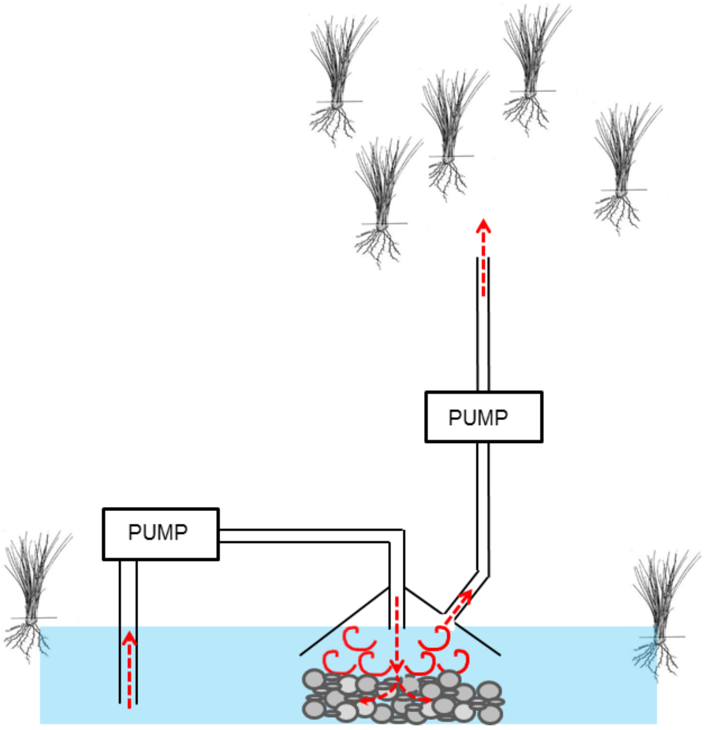

Figure 4-2: Schematic showing the arrangement of pumps for the sand wand. Slurry can either be discharged to land or into sediment separating equipment

Figure 4-3: Fine sediment removal. Panel A shows the sand wand and pump apparatus deployed at a stream restoration site. Panel B shows the intake of the sand wand which is dragged across the stream bed. Panel C and D show the stream bed before and after fine sediment removal. Photographs courtesy of Assoc. Prof. Jon Harding, University of Canterbury

5 Results

Water temperature was consistently cool with an average value of 10.9°C (SE ±1.7). Conductivity was relatively low for a lowland stream, 60.2 µS/cm (SE ±0.89), while dissolved oxygen concentrations and saturation were high, 12.4 mg/L (SE ±0.22) and 113 % (SE ±1.99) respectively. pH was slightly acidic typical of groundwater fed streams close to the point of upwelling. Nitrate concentrations were low (0.3 mg\L SE 0.008) and phosphorus was slightly elevated (0.012 mg/L SE 0.63), although typical of a spring-fed lowland stream (Hayward *et al.*, 2009)

Flow

Stage height was measured at the fine sediment removal sites for approximately six weeks following the fine sediment removal. Figure 5-1 indicates a significant high flow event after ~ three weeks and elevated, although declining, flows thereafter. The local landowner commented that the observed flows were the highest he had ever seen in the stream and that it had been running dirty for several days (David Shipley pers. Comm.). This flow event is likely to have mobilised a significant amount of sediment in the stream, some of which will have been deposited within the trial reach.

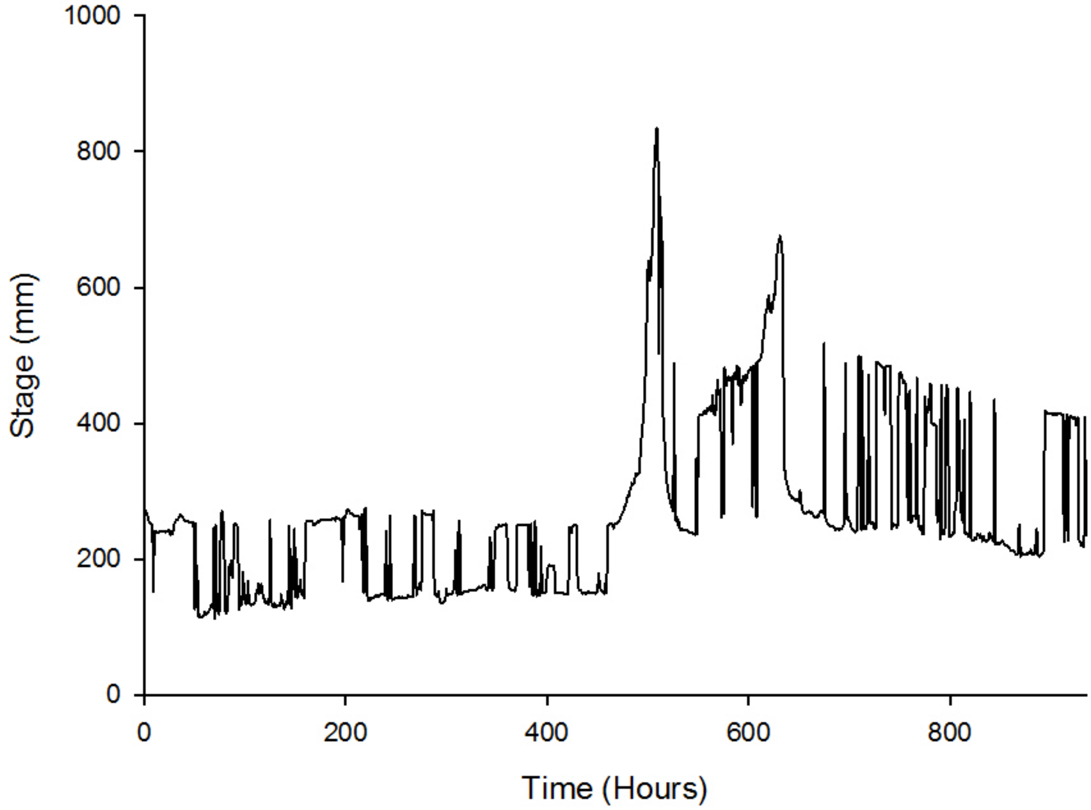

Figure 5-1: Stage height at the fine sediment removal site during the six week period subsequent to the remediation trial

6 Sediment characterisation

Three replicate sediment samples were collected from the trial reach prior to sediment removal. The three samples had dry weights of 255, 432 and 373 grams. The samples were ashed and found to contain a low proportion of organic materials, being 1, 0.9 and 0.9 % of sample dry weights, respectively. Figure 6-1 shows the proportions of each sediment sample which fall into classes specified by the Udden-Wentworth scale after sediments were passed through Endecotts sieves (Wentworth 1922). On average the majority of sediment (67 %) was classified as being fine and very fine sand and only 9.4 % was less than 63 µm in diameter and considered as silt.

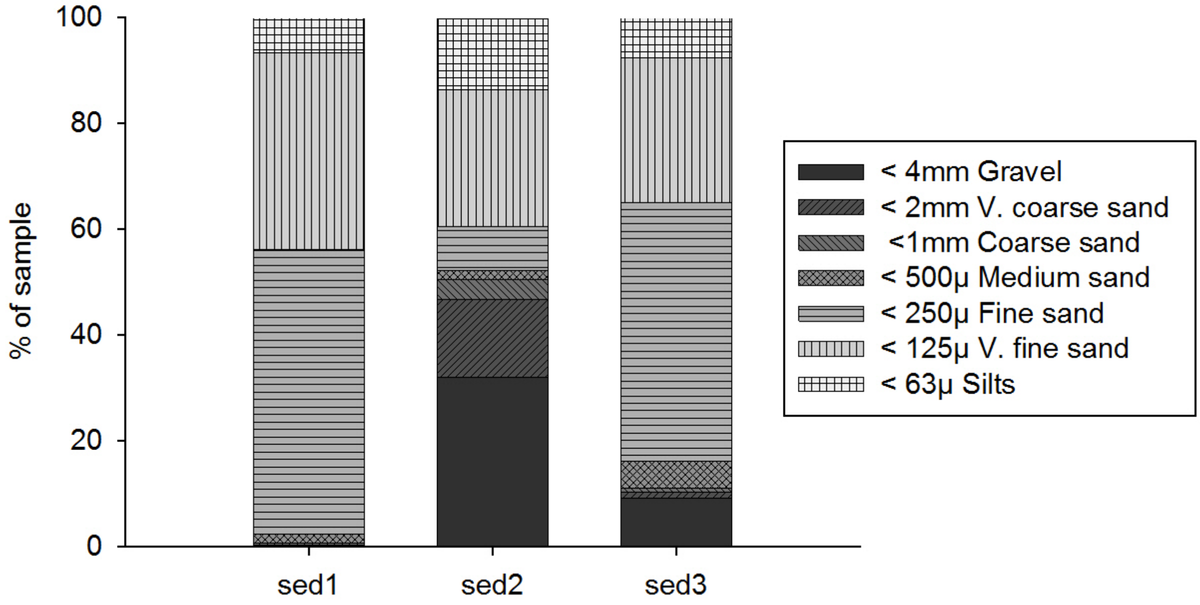

Figure 6-1: Composition of three sediment grab samples collected from the treatment reach of the Otukaikino Stream prior to the fine sediment removal trial. Sediment fractions were separated using Endecotts sieves

7 Downstream turbidity

We measured turbidity (NTU) during the sediment removal trial at 50 and 200 m downstream (Figure 7-1). At 50 m distinct spikes in turbidity were recorded during the trial with a maximum value of ~38 NTU. At 200 m downstream the turbidity did not increase by more than ~1.5 NTU above the background value (as derived from stable measurements taken downstream three days after the trial).

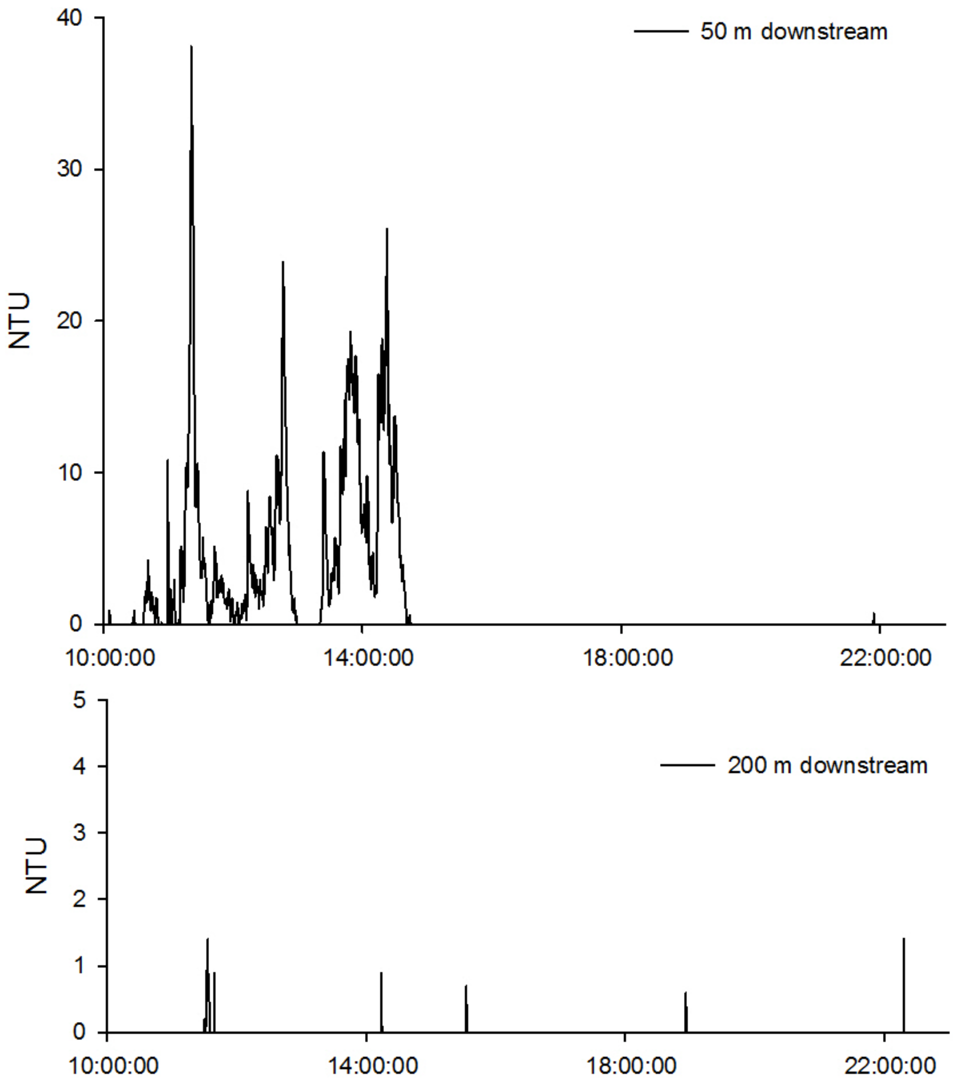

Figure 7-1: Turbidity (NTU) 50 and 200 m downstream of the trial. The trial occurred from 10:15 am to 2:30 pm. Note the different scales between the 50 and 200 m plots

8 Total Suspended Solids (TSS)

TSS was measured in three replicate water grab samples upstream and directly downstream of the sediment removal reach during the trial and in the return water flowing back across the paddock from the discharge site. Return water had pooled in the adjacent paddock and was flowing back to the stream via a shallow grassy depression ~ 30 m in length. One way ANOVA indicated significant differences between TSS in different areas of the stream (df 2, 6 F = 155.6, $p < 0.001$). Significant pairwise differences were assessed using Holm-Sidak tests. TSS levels upstream of the trial were very low and recorded as half the default detection limit (2 g/m³) (Figure 8-1). Directly downstream, during active sediment removal TSS was elevated with an average value of 19 g/m³ and maximum of 21 g/m³. Return water, prior to discharge and subsequent dilution, had an intermediate concentration of TSS with an average value of 13 g/m³.

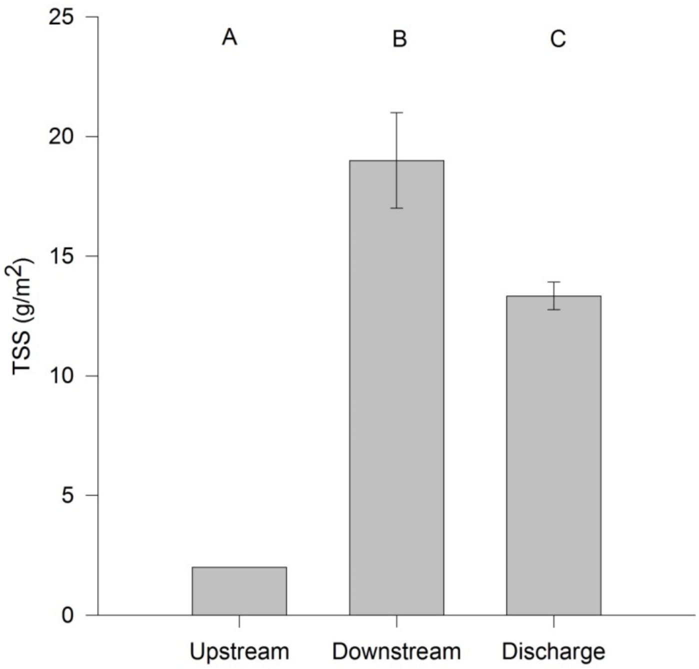

Figure 8-1: Mean (± 1SE) total suspended solids (TSS) in water from the upstream and downstream reaches of the fine sediment removal trial and in return water, n = 3. Differences ($p < 0.05$) derived from ANOVA are denoted by letters

9 Fine sediment cover

Sediment cover remained relatively constant at the upstream and downstream sites (Figure 9-1). However, in the trial reach cover dropped dramatically after the removal trial, although levels increased again after six weeks. A significant interaction effect was detected by two way ANOVA on ranked values, df 4, 715, $F = 42.2$, $p<0.001$. Pairwise multiple comparisons were made using the Holm-Sidak test and significant ($p<0.05$) differences found between occasions within the trial reach (Figure 9-1). This result was due to the lesser levels of sediment cover recorded in the trial reach three days and six weeks after the trial. In the upstream reach sediment cover remained constant throughout, whereas in the downstream reach sediment cover remained the same before and three days after the trial, but declined slightly after six weeks.

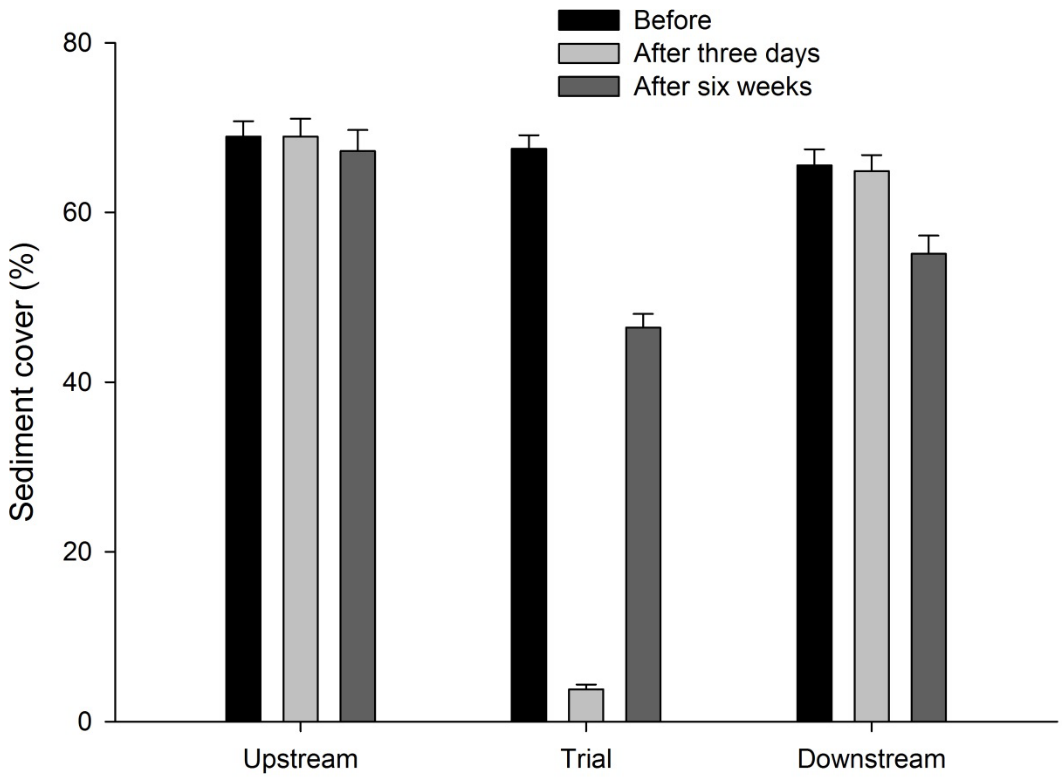

Figure 9-1: Mean (± 1SE) sediment cover within, upstream and downstream of the trial reach. Sediment cover was estimated using a stream bed viewer, n = 80. Differences ($p < 0.05$) between groups and occasions were derived from a two way ANOVA on ranked values

The initial removal of fine sediment, at least on the surface of the stream bed, was very successful with a significant removal of fine sediment. However, over time fine sediment has returned and deposited on the bed, almost reaching pre-trial levels of cover. The source of new sediment to the treatment reach may be deeper deposits within the reach itself or upstream reaches. The latter source appears more likely, particularly given the unusually high flows in the stream between sampling periods. However, despite the migration of fine sediment into the trial reach, sediment cover remained at a lower level than prior to the trial.

10 Bed sediment volume

Bed sediment volume was assessed using the Quorer technique (Clapcott *et al.* 2011). Pre-trial results indicated variable, although not significantly different quantities of TSS in the stream bed between the three stream reaches (Figure 10-1). After fine sediment removal TSS levels from the Quorer were observed to be unchanged which contrasted sharply with observations of sediment cover. TSS remained constant both within reaches (df 2, 23 $F=0.128$, $p = 0.128$) and between occasions (df 1, 23 $F=0.09$, $p = 0.765$). The quorer method was discontinued after the three days post assessment.

This result is considered to be due to a two factors.

1. Inadequate replication. Clapcott *et al.* (2011) recommend a minimum of 6 replicate samples.
2. Non-standardised bed agitation. Because the upper layers of sediment had been removed it was possible to mobilise deeper layers with a similar degree of effort. Standardisation of stirring depth might overcome this issue.

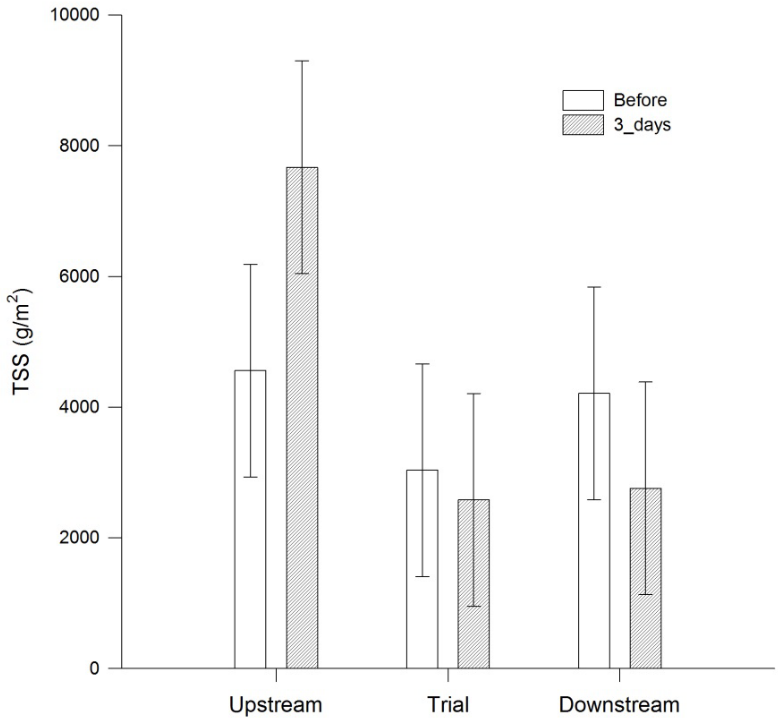

Figure 10-1: Mean (± 1SE) Total suspended solids (TSS) from Quorer samples (n=4) upstream, within and downstream of the trial reach before and after three days. Differences were assessed using ANOVA

11 Embeddedness

As well as smothering the surface of large stream substrates, fine sediment may also fill the gaps between substrates. The degree of embeddedness affects the space available for biota to inhabit and the flow of water through the stream bed. Embeddedness was assessed using BRIDE testing of the stream bed under consistent pressure (Figure 11-1). In the upstream and downstream reaches, after six weeks, penetration had an average value of 2.8 and 3.5 cm, respectively. However, in the sediment removal reach the average penetration was 6.4 cm and significantly different from the upstream and downstream reaches (Kruskal-Wallis $p<0.001$, $n = 25$). Thus, although at six weeks fine sediment cover had increased and deep sediment deposits remained present, interstitial sediments in the upper 10 cm of the stream bed remained at lower levels than in the control reaches.

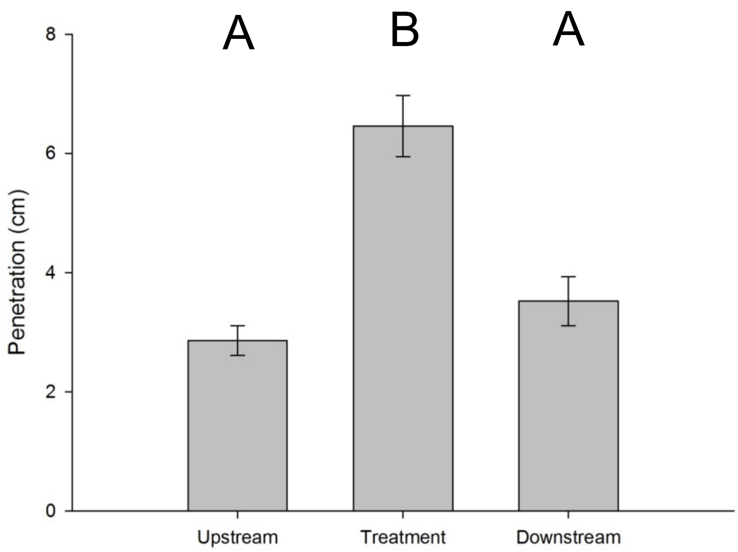

Figure 11-1: Mean (± 1SE) penetration, n=20, upstream, within and downstream of the remediation trial reach after six weeks. Differences were assessed using Kruskal-Wallis test and are indicated by letters

12 Invertebrates communities

Prior to fine sediment removal invertebrate richness was the same within each stream reach, suggesting that the study reaches were acceptable comparisons (Figure 12-1). However, three days after fine sediment removal richness in the trial reach was significantly less than either upstream or downstream sites, having four fewer taxa (occasion df 2 44, F=8.467, p=<0.001). However, after six weeks, richness in the trial reach had returned to similar levels as that found in the up- and downstream reaches before and after the trial. A similar pattern was observed in invertebrate richness at the downstream site although the differences between occasions were not significant.

Invertebrate density showed the same pattern being unchanged within the up and downstream sites, but significantly lower in the trial reach after three days and returning to background values after six weeks.

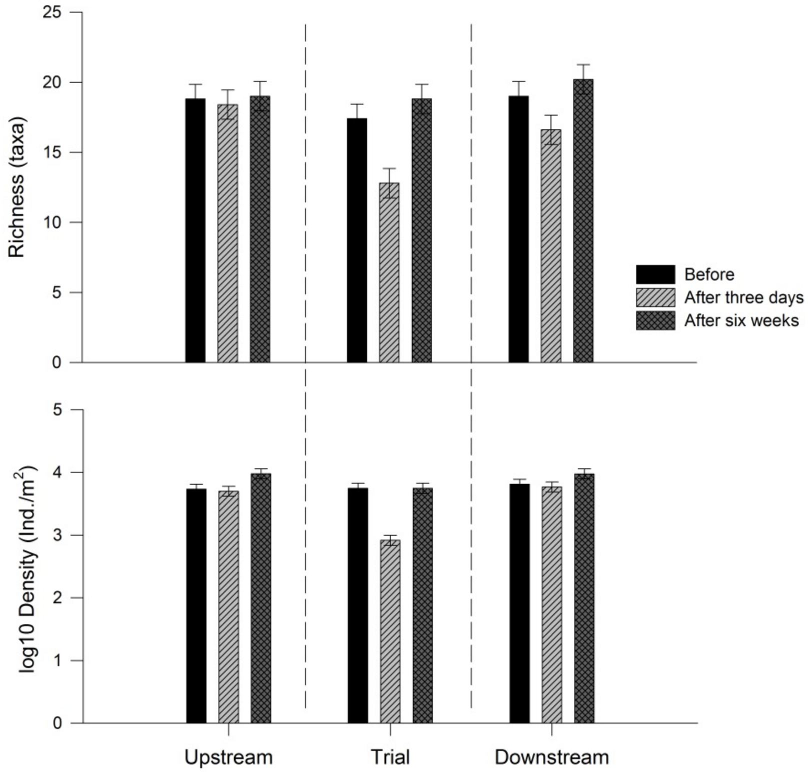

Figure 12-1: Invertebrate richness (top) and density (bottom) from 5 replicate surber samples upstream, within and downstream of the fine sediment removal trial prior, three days and six weeks after the trial. Differences ($p<0.05$) between sites and occasion were identified using two-way ANOVA

Percent EPT abundance, or the proportion of the community comprising sensitive mayfly, caddisfly and stonefly species, showed significant differences across the sites and sampling occasions (occasion x reach df 4 44, $F=4.842$ $p=0.003$, Figure 12-2). At the upstream site prior and three days after the trial %EPT abundance was less than 15 % of the community (1077 and 976 individuals respectively), but increased dramatically (34 %) after six weeks (2600 individuals). In the downstream site %EPT showed no significant differences between occasions. In the trial reach, three days after the trial, there was a significant decrease in %EPT (1375 down to 168 individuals). However after six weeks %EPT had increased to a significantly greater proportion than before the trial (1621 individuals). This result suggests that the fine sediment removal increased the proportion of sensitive taxa, although the conclusion is made equivocal by the increase in %EPT seen in the upstream control reach and the variability seen in the downstream reach.

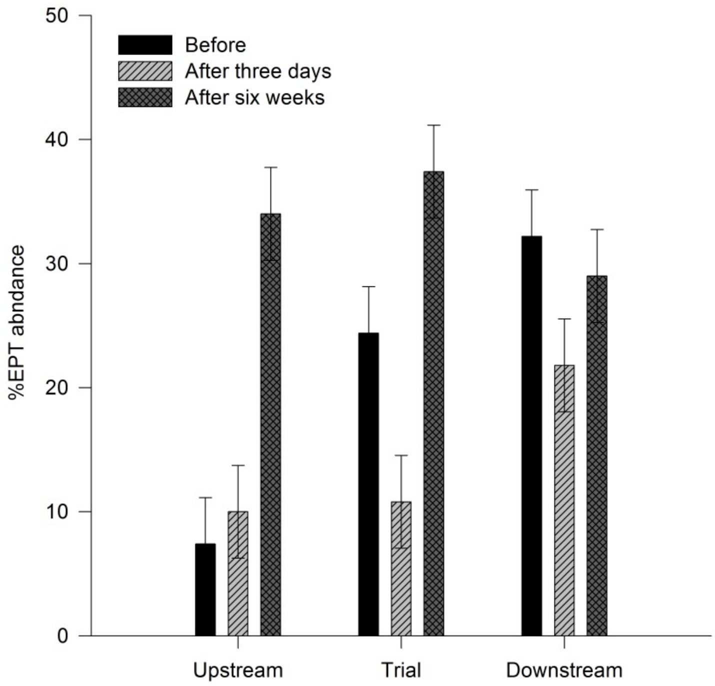

Figure 12-2: %EPT abundance upstream, within and downstream of the fine sediment removal trial prior, three days and six weeks after the trial. Differences ($p<0.05$) between sites and occasion were identified using two-way ANOVA on ranked values

Invertebrate community composition within the trial reach is shown in Figure 12-3. Prior to fine sediment removal the community was dominated by caddisflies and snails. Caddisflies were predominantly cased *Pycnocentria, Pycnocentrodes* and *Hudsonema*., although free living hydrobiosid taxa were also present. Snail taxa were dominated by *Potamopyrgus antipodarum*, while mayflies were represented primarily by *Deleatidium* and Oligochaete taxa dominated the “other” category.

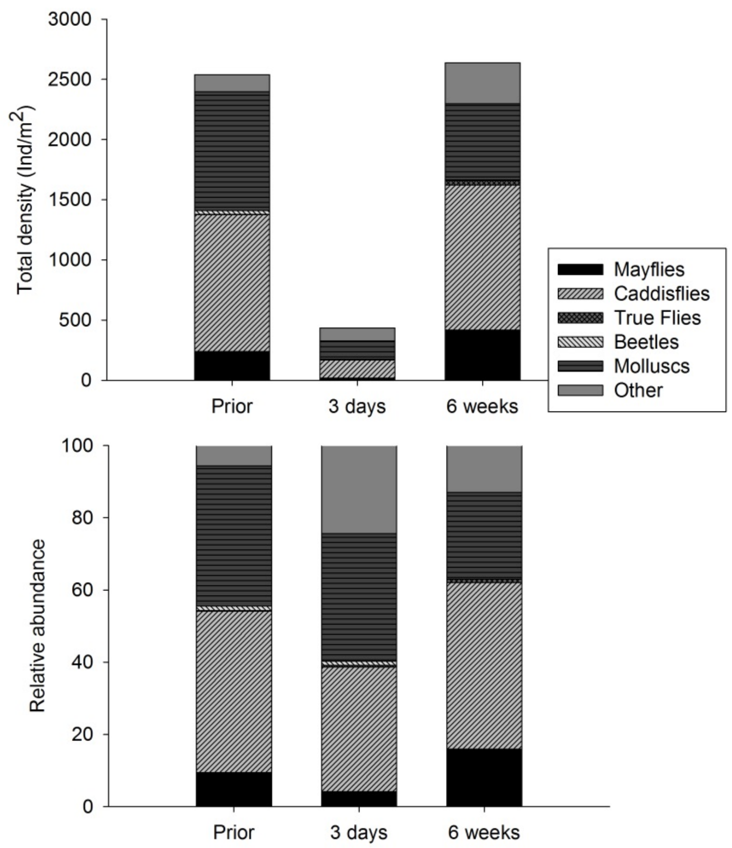

Figure 12-3: Invertebrate community composition in the trial reach prior, three days and six weeks after fine sediment removal

After fine sediment removal total density in the trial reach was much reduced although the approximate proportions of each taxa group were similar. Mayflies appeared to have been more impacted by fine sediment removal, whereas Oligochaetes (worms) appeared less affected. After six weeks total density had recovered to pre-trial levels and community composition had shifted towards an increased number of the mayfly *Deleatidium* (239 to 417) and the amphipod *Paracalliope* (11 to 62) and a reduction of snails (986 to 634).

13 Discussion

A trial to remove fine sediment from a short reach of the spring-fed Otukaikino Creek, Canterbury, resulted in the effective removal of surface deposited fine sediment and reduced substrate embeddedness with limited impacts on water clarity downstream. Elevated turbidity was detectable 50 m downstream for the duration of the trial, but ceased once people and equipment were removed from the stream. At 200 m downstream the impacts of fine sediment removal on water turbidity were negligible. Total suspended solids (TSS) in water were elevated directly below the fine sediment trial but not to an extent likely to breach discharge limits in the proposed Land and Water Regional Plan (pLWRP) of 50 g/m^3. Return water had elevated TSS and care should be taken to ensure return water is of suitable quality before discharge to the stream. It should be noted that these results are likely to be highly dependent on the composition of fine sediment within a stream. Fine sediment in the Otukaikino Creek was predominantly sand which falls out of suspension relatively rapidly. In streams where there is a greater quantity of finer sediments, downstream turbidity effects may extend over a greater distance and return water concentrations of TSS could exceed guideline values.

Due to inadequate replication it is not possible to definitively state the reason why sediment levels within the stream bed did not change before and after fine sediment removal. However, given the long period of agricultural activity in the catchment it is likely that there are considerable quantities of fine sediment contained deeper in the stream bed. These sediments are readily accessed by the Quorer method when overlying sediments are removed. The degree to which these sediments are naturally present within the deeper strata of the stream bed and the impact of deeper fine sediment deposits on biota are unknown. However, a limitation of the suction method as it is currently configured may be an inability to mobilise deeper sediment deposits.

This trial occurred over a short reach of the Otukaikino Creek, which had a substantial supply of fine sediment directly upstream. Therefore, the migration of fine sediment into the trial reach, particularly given post trial high flow events, is unsurprising. Otukaikino Creek was observed to be running turbid for at least 3 days during high flow events (David Shipley pers. Comm.) and substantial sediment suspension is likely. However, despite this, sediment cover after six weeks had not reached levels observed prior to fine sediment removal. In addition BRIDE testing suggested that although fine sediment had migrated into the reach, increasing benthic sediment cover, the substrate matrix remained open and less embedded. Thus, despite the supply of fine sediment from upstream reaches, fine sediment removal from this small, discrete reach endured for the duration of this study and resulted in a positive effect on benthic habitat. The fine sediment removal technology utilised during this trial had a penetration depth of ~10 cm. However, fine sediment was present in considerable quantities at greater depths. The degree to which this is a natural feature of the Otukaikino Creek bed is unknown. However, the saturated interstices of stream beds, referred to as the hyporheic zone, are known to play an important role in some streams (Collier & Scarsbrook 2000). The hyporheic zone may contain a diverse assemblage of species which are occasional visitors, sheltering from predators, floods or drought, or species which spend all or part of their lifecycles beneath the surface of the substrate (Gibert *et al.* 1994). Although the number and richness of invertebrates in the hyporheic zone is typically less than amongst the bed surface substrates Wright-Stow *et al.* (2006) showed that 96 % of annual secondary production of a common cased caddis, *Olinga feredayi*, occurred within the hyporheic zone >10 cm below the surface. Potential improvements to stream restoration techniques which involve the removal of fine sediment from deeper substrates would be a suitable topic of further investigation.

Invertebrate communities in the trial reach had reduced richness and density three days after fine sediment removal although broad community composition was similar. After six weeks, invertebrate communities had recovered to pre-trial richness and density, while community composition had shifted in favour of mayflies, and the amphipod *Paracalliope* at the expense of snails. This is an encouraging result as the fine sediment removal does appear to have resulted in a slight positive shift in the invertebrate community. These results are partially equivocal due to the same pattern being observed in the upstream reach and variability in the downstream reach. As such conclusions drawn about the impact of fine sediment removal on post recolonisation invertebrate communities must be cautious and further trials are warranted.

The primary source of colonists for the trial reach during the study period is likely to have been from upstream. Thus, those taxa which drift in the current and are generally more mobile were better able to recolonise the trial reach. Presumably, the greater the upstream length of stream which is cleared of fine sediment the greater the time required for re-colonisation and establishment of benthic communities within the newly exposed, larger substrates. The fact that no species groups were completely removed from the trial reach (sampled three days post-removal) suggests that some individuals of each species escaped the pump apparatus. However, if a substantial reach of stream, particularly upper reaches with no upstream habitat, is to be cleaned steps should be taken to preserve populations of invertebrates within that reach for re-colonisation. This might take the form of short sections of stream which are not cleaned and left to serve as refugia from fine sediment removal.

Overall, fine sediment removal using the Sand Wand^{TM} appears to be highly effective in removing sediment from the top 10 cm of the stream bed. When fine sediment is composed primarily of sand and fine sand the majority of sediment suspended by the activity and not removed from the stream drops rapidly out of suspension such that downstream water quality is maintained. Invertebrate communities within the sediment-removal reach were initially reduced in richness and density by the activity, but recovered fully to pre-sediment community richness and density after six weeks. There was some indication that the post recolonisation invertebrate community contained a greater proportion of mayflies than pre-trial. However, a similar pattern was also observed in the upstream control reach. This trial was limited to a short stretch of stream bed and may underestimate the degree of impact on invertebrate communities resulting from the cleaning of longer stretches of stream. The lack of a clear shift in the invertebrate community of the trial reach from that in the control reaches may be due to a number of reasons.

1. Monitoring of the invertebrate community did not continue for an adequate period of time to allow full recovery of the community from sediment removal.
2. High flow-driven fine sediment migration from upstream may have suppressed sensitive taxa.
3. High flows and seasonal variation in invertebrate communities may have masked the effects of fine sediment removal.

Further trials to assess the efficacy of fine sediment removal using suction technology would benefit from using a longer stream reach, ideally working from the headwaters down. Provided sediment inputs to the stream are prevented cleaned substrates would likely remain free of fine sediment and the benefits for invertebrate and fish communities could be more fully realised. Such trials are currently being planned and undertaken by the University of Canterbury, Freshwater Ecology Research Group.

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