NIWA
Taihoro Nukurangi

Instream sediment remediation feasibility assessment

Prepared for Christchurch City Council

April 2024

Prepared by:
Michelle Greenwood, Kristy Hogsden, Richard Measures, Jo Bind, Clare Wilkinson, Amy Whitehead

For any information regarding this report please contact:

Kristy Hogsden
Freshwater Ecologist
Freshwater Ecology Group
+64 3 343 7861
kristy.hogsden@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 8602
Riccarton
Christchurch 8440

Phone +64 3 348 8987

NIWA CLIENT REPORT No: 2024012CH
Report date: April 2024
NIWA Project: CCC21503

Revision	Description	Date
Version 1.0	Draft report sent to client	25 January 2024
Version 1.1	Final report sent to client	9 April 2024

Quality Assurance Statement		
	Reviewed by:	Elizabeth Graham
	Formatting checked by:	Rachel Wright
	Approved for release by:	Phillip Jellyman

Contents

Tables

Figures

Executive summary

The Christchurch City Council (CCC) manages waterways in Ōtautahi/ Christchurch and Banks Peninsula with an emphasis on six core values: ecology, drainage, culture, heritage, landscape and recreation. The waterways throughout the five main city catchments (Ōpāwaho/ Heathcote, Ōtākaro/ Avon, Pūharakekenui/ Styx, Ōtūkaikino, Huritini/ Halswell) and on Banks Peninsula have been historically valued as important sources of mahinga kai.

Residential, rural and industrial development has led to inputs of fine sediment and contaminants such as copper, zinc, lead and polycyclic aromatic hydrocarbons entering the waterways from various sources including stormwater discharges, soil and stream bank erosion, and industrial, pastoral and agricultural land uses.

The ecological and cultural values of the waterways are impacted by high levels of deposited sediment cover on the streambed and by contaminated sediment. The low gradient of most of the waterways means that mechanical removal of the deposited fine sediment is likely to be the most effective way to reduce streambed cover and contamination.

The CCC asked NIWA to undertake an assessment of the feasibility of sediment removal and mitigation within Ōtautahi/ Christchurch waterways by identifying priority locations for trials of potential methods of sediment removal. The catchments were prioritised by the CCC in the following order: Ōpāwaho/ Heathcote, Ōtākaro/ Avon, Pūharakekenui/ Styx, Ōtūkaikino, Huritini/ Halswell) and Banks Peninsula. The assessment was undertaken in two steps. First, data compilation and assessment of potential trial sites and, second, an assessment of the feasibility of removing or mitigating deposited sediment in Ōtautahi/ Christchurch waterways.

Data compilation and assessment of potential trial sites

We undertook the following steps to compile and assess the data available and to identify potential sites for trials:

1. Collating recent CCC data on deposited sediment cover, contaminants and ecological and cultural values within Ōtautahi/ Christchurch waterways.
2. Assessing available data on channel geomorphology, water velocity and stormwater infrastructure to determine if we can identify key fine sediment sources and depositional zones.
3. Developing a) a rationale to prioritise potential sites for trials of sediment mitigation/removal methods and b) interactive maps to visualise key data that could be used to prioritise sites.
4. Developing a list of potential trial sites based on the available data and rationale during a workshop with key experts, and
5. Briefly assessing potential sediment removal and mitigation options for suitability within Ōtautahi waterways.

The CCC provided ecological data from the most recent five-yearly ecological survey of each of the focal catchments, annual ecological surveys of four sites and Christchurch River Environment Assessment System (CREAS) surveys. Data were collected between 2017 and 2022 and included assessments of a wide range of variables including macroinvertebrate and fish communities, periphyton and macrophytes, deposited fine sediment cover, deposited fine sediment contaminants and physical conditions in the stream, on the banks and in the riparian zone. Variables differed in the spatial coverage of data available. Additional ecological data were provided from trout and īnanga spawning surveys, kākahi surveys, assessments of fish barriers, sites of ecological significance from the Canterbury District Plan and a database of uncommon species (i.e., the Waterway Species Database). The ecological datasets from the separate surveys were compiled into aggregated datasets and the units of measurement, site names and locations were standardised where possible. These data have been provided separately to the CCC (see Appendix A). Indicative cultural values were extracted from State of the Takiwā surveys undertaken between 2007 and 2022.

The stormwater piping network was investigated as a method to determine locations of large potential inputs of fine sediment. However, this was not used for trial site selection because of the very high number of piped inputs, which were present in almost every reach, and because of the influence of other sources of fine sediment inputs not captured by the piped network including overland run-off, tributaries and bank erosion. The slope of the waterways' surface was generated from LiDAR data from 2021 and used to estimate the potential for reaches to mobilise fine sediment.

From the more than 100 variables available to help identify priority sites for sediment removal and mitigation trials, we identified six key variable groups. These were: the deposited fine sediment quantity (depth and percentage cover) and quality (concentrations of key contaminants), ecological values, mana whenua values, habitat condition and the potential for deposited fine sediment to recur at a site after mitigation efforts. Key variables to represent each group were selected based on data availability and relevance. For sediment quality and quantity these included fine deposited sediment depth, the percentage of the substrate matrix filled with silt and percentage cover of the streambed by deposited fine sediment (from CREAS surveys) and the concentration of copper, zinc, lead and total polycyclic aromatic hydrocarbons (PAHs) in the sediment (from ecological surveys). For mana whenua values we used the Takiwā Index and the stream health component of the Cultural Health Index (CHI) as broad indicators. For ecological values the variables used were fish taxa richness, presence of freshwater crayfish (kōura), lamprey (kanakana), freshwater mussels (kākahi) and longfin eel (tuna) as well as īnanga and trout spawning sites and select macroinvertebrate metric values. Habitat condition was indicated by macrophyte cover and depth and the potential for a site to remobilise fine sediment by the surface water slope.

Interactive GIS maps and a StoryMap including the key variables were developed and discussed in a workshop held with local ecology and stormwater experts and environmental advisors to identify potential sites to trial sediment mitigation and removal methods. The rationale developed and used to select sites was that sites should:

- Be in a range of different-sized waterways so that different removal and mitigation tools could be trialled.
- Have problematic sediment quality and/or quantity.
- Include either isolated or spatially extensive fine sediment deposits to enable trialling a range of tools.
- Show potential for improved ecological and cultural values if deposited fine sediment was removed. The benefits and potential risks to sensitive species both at the site of interest and downstream were considered.

- Be located where sediment removal is practical and may complement other remediation activities already completed or planned.
- Be from multiple focal catchments. No trial sites were selected on Banks Peninsula or in Huritini/ Halswell catchments due to limited data, fewer sediment issues and the lower priority for these catchments identified by the CCC.

Following the workshop, eight potential sites for sediment removal and remediation tools were identified in the Ōpāwaho/ Heathcote, Ōtākaro/ Avon and Pūharakekenui/ Styx catchments.

The feasibility of different potential methods to both remove deposited fine sediment and to prevent it recurring or accumulating were briefly assessed. These methods were then matched to the potential trial sites.

In this report, we provide a list of potential sites where a range of different sediment removal and mitigation methods could be trialled and the rationale used to identify the sites. In conjunction we provide the tidied and compiled CCC datasets and interactive maps of key variables created to support our decision-making. These maps and datasets can be used to prioritise additional or alternative trial sites, if required.

Feasibility assessment

A robust assessment of the feasibility of removing or mitigating fine deposited sediment in Ōtautahi/ Christchurch waterways requires a definition of the desired outcomes of such work and an understanding of 1) the likelihood of meeting those outcomes, 2) the logistical and financial considerations of undertaking the work 3) the maintenance requirements to support outcomes and 4) consideration of any shorter-term ecological impacts versus potential long-term ecological benefits. Because deposited fine sediment removal from Ōtautahi/ Christchurch waterways has historically been undertaken to reduce flood risk, much of the knowledge required to assess whether ecological gains are likely is currently lacking, and likely to be site-specific. We propose that further work is undertaken to address this uncertainty and fill some of these knowledge gaps. This will allow for more robust feasibility assessments prior to development of a future instream sediment mitigation programme.

Below we provide 1) general recommendations for factors to consider when undertaking sediment removal or mitigation trials, 2) two suggested approaches to help fill some of the key knowledge gaps and 3) two examples of potential trials of deposited fine sediment removal and mitigation from Ōtautahi/ Christchurch waterways.

Our general recommendations for factors for the CCC to consider when assessing the feasibility of undertaking trials at any of the suggested sites, are:

1. Development of carefully defined goals and indicators of success for any trials. For example, what is an appropriate spatial scale for mitigation? What are the key indicators of success, how will these be monitored and for how long? What level of on-going maintenance is acceptable?
2. Once the goals of the trials are determined, specific sites can be assessed for their suitability depending on the sediment issues (quantity and quality) and ecological and cultural values present, as well as practical considerations such as access to the site.

3. Co-development with mana whenua of the goals and indicators of success, as well as engaging with Rūnanga representatives for their mātauranga on the appropriateness of the identified sites and proposed methods.

4. Consideration of past, current and future restoration projects and whether sediment removal trials could be undertaken in conjunction with these.

5. Assessment of the financial cost, which will require decisions on the goals of the project, specific locations and methods, the spatial scale of removal, on-going maintenance and potential disposal fees for the removed (potentially contaminated) sediment.

Historically deposited fine sediment was removed from Ōtautahi/ Christchurch waterways to reduce flood risk. Relatively recently, removal has been undertaken with the goals of improving instream habitat and/or ecological values. However, there are several gaps in knowledge that limit our ability to assess the efficacy of different sediment removal or mitigation methods for improving ecological values. These include 1) limited understanding of the timescales and factors that influence re-sedimentation rates at different locations, 2) maintenance requirements, particularly for sediment traps, to maintain effectiveness and 3) factors that limit ecological responses to mitigation actions.

We recommend two approaches to collect data that can begin to address these gaps:

1. Monitoring deposited sediment levels in areas that have previously had deposited fine sediment removed. Ideally monitoring would be completed before and after sediment removal, but even a time series beginning after removal would provide information about potential re-sedimentation rates. Ecological data for targeted taxa that might be predicted to increase after deposited sediment removal could also be collected. This will incur additional costs. Collation of any existing temporal data on deposited fine sediment or ecological values from locations where deposited fine sediment has been removed is also recommended.

2. Proceeding with trials of selected deposited fine sediment removal and mitigation methods at representative sites as described herein.

To address point two above we provide priorities for trials of the efficacy of different methods below. To prioritise these trials, we made the following assumptions:

1. Trialling multiple sediment removal and mitigation methods would fill several knowledge gaps. We recommend trialling excavator dredging and a sediment trap.

2. The ecological benefits of deposited fine sediment removal in smaller, non-tidal waterway reaches are likely to be greater than in the lower tidal reaches of the larger rivers, which are commonly depositional zones.

3. Data on the efficacy and maintenance requirements of a sediment-trap in a non-tidal medium-sized mainstem site is lacking currently.

4. A smaller number of trials in representative locations is more economically viable than larger-scale replicate trials of different methods in different locations. We recommend one location for each method. We selected locations that are likely to be representative of other areas in the city where the method also could be used.

5. Key indicators of success of the sediment removal and mitigation trials will be a decrease in deposited fine sediment cover below the threshold of 20% cover and/or reduction in contaminant concentrations below relevant guidelines. Secondary indicators of success are improvements in biological communities. Mana whenua should be consulted for additional key indicators of success and metrics to include in monitoring plans.

Following these assumptions, we recommend:

Trialling excavator dredging to remove deposited fine sediment at the Curletts Stream site, where sediment contamination (i.e., elevated zinc, copper, lead) is the key issue. This site is relatively small and located high in the catchment. Ideally, on-going contaminant and sediment inputs to the site could be reduced through the upstream stormwater detention basins and by education and end-of-pipe treatment options from the industrial area into the waterway. Traffic management would need to be considered for Curletts Road to allow excavator access and ecological assessments as well as relocation of sensitive taxa from the area, as required. Relocation of kākahi should be avoided, however kākahi are not recorded in this site.

Trialling a sediment trap in the mainstem of the Heathcote River, perhaps in Centennial Park, Hunter Terrace or a similar location with good site access and localised high cover of deposited sediment (i.e., a 'natural' depositional zone). The trial location should not have high abundances of kākahi to reduce impacts on their populations. Ecological assessments of the taxa present at the site and potentially relocation of other sensitive taxa prior to instream works and construction would be required.

Other sites that meet criteria for good access, are non-tidal, small to medium sized and with either or both contaminant and deposited sediment quantity issues could replace the sites we have suggested above. Regardless of the exact sites chosen, a fundamental requirement for effective removal and remediation trials is on-going monitoring of key indicators of success (at a minimum deposited sediment cover and contaminant concentrations (if relevant)) both before and repeatedly after initiation of the trials. Longer-term monitoring (ideally multiple years after the trials) will enable collection of data to inform re-sedimentation rates, and the maintenance requirements for both sediment removal locations and sediment traps.

Overall commentary

Although a feasibility assessment was not possible given the data and knowledge available, our recommendations for collation of existing data, targeted collection of new data and two sediment removal/mitigation methods will assist in filling some of the knowledge gaps, providing for more robust future feasibility assessment. In addition, if trials of the methods are carefully designed and maintained we anticipate that they will provide good ecological and/or cultural outcomes as well as providing the data required to make more robust assessments of the feasibility of different methods of fine deposited sediment removal and mitigation meeting target outcomes.

We recommend an iterative approach to designing a broader programme of projects that aim to remove and/or mitigate impacts of deposited fine sediment in the city's waterways. As increasing knowledge is collected and compiled about the feasibility of different methods in different locations for meeting target outcomes, more effective future projects can be designed. Monitoring the success of existing and future projects in meeting target outcomes and identifying the maintenance requirements to keep meeting them is key to this process.

1 Introduction

The Christchurch City Council (CCC) manages waterways in Ōtautahi/ Christchurch and Banks Peninsula with an emphasis on six core values: ecology, drainage, culture, heritage, landscape and recreation. The network of waterways includes large lakes, rivers, small tributaries, and intermittently flowing drains.

The waterways throughout the five main city catchments (Ōpāwaho/ Heathcote, Ōtākaro/ Avon, Pūharakekenui/ Styx, Ōtūkaikino, Huritini/ Halswell) and on Banks Peninsula have been historically valued as important sources of mahinga kai including tuna (eel), kanakana (lamprey), kōura (freshwater crayfish), native plants, and waterbirds.

However, residential, rural and industrial development has led to inputs of fine sediment entering the waterways from various sources including stormwater discharges, soil and stream bank erosion, and industrial, pastoral and agricultural land uses. Furthermore, substantial additions of silt and sand to the city's waterways occurred following the Canterbury earthquakes in 2010 – 2011 and the Port Hills fire in 2017. As most Ōtautahi/ Christchurch waterways are low gradient (apart from those on the hillslopes), inputs of fine suspended sediment commonly become deposited on the streambed rather than being washed downstream to receiving waterbodies.

Deposited fine sediment in urban waterways is often contaminated by heavy metals (e.g., arsenic, copper, lead, zinc), polycyclic aromatic hydrocarbons (PAHs), asbestos and/or coal tar, through inputs from stormwater discharge, urban runoff and industrial activities. Such contaminants can adversely affect stream biota and may accumulate in the sediment over time or become resuspended in the water during high flows or if the bed substrate is disturbed (for example, during channel works). Interestingly, the earthquake liquefaction silt may result in decreased contaminant concentrations in some surface stream-bed sediments by covering more contaminated historic deposits. This effect has been reported in Ihutai/ Avon-Heathcote estuary (Zeldis et al. 2011) but has been harder to detect within the rivers (Gadd and Sykes 2014). Large deposits of fine sediment can also increase flood risk, and high deposited fine sediment cover on the streambed contributes to poor ecological and cultural health of the waterways by smothering habitat for macroinvertebrates and fish, including populations of nationally and locally uncommon kākahi (freshwater mussels), kōura (freshwater crayfish), kanakana (lamprey), longfin eels, īnanga and bluegill bullies.

Due to the low gradient of many of the city's waterways, physical removal of the fine deposited sediment is likely to be the most effective method to reduce deposited sediment cover and remove contaminated sediments. Efficient and effective sediment removal that improves existing and potential future ecological and cultural values would ideally result in 1) minimal impacts on current values, 2) maximised benefits for potential future values and 3) long-lasting improvements in deposited sediment conditions with minimal on-going maintenance. Consideration of priority areas for sediment removal and mitigation, the risk of sedimentation reoccurring at sites and the most appropriate fine sediment removal and mitigation methods for different locations will also be required.

The CCC is investigating these considerations as part of the Comprehensive Stormwater Network Discharge Consent (CSNDC) CRC190445 granted by the Canterbury Regional Council (CRC) to discharge water and contaminants to land and water from the stormwater network. Condition 37 of the CSNDC requires the CCC to investigate and implement methods to improve the management of stormwater quality and to assess and reduce stormwater effects on the receiving environment. In addition, Condition 39 requires the Council to undertake the actions set out in Schedule 3 for the investigations required by Condition 37. Specifically, Schedule 3(g) requires the CCC to:

Investigate the feasibility of techniques for ***remediating adverse effects of stormwater sediment discharges on receiving environments****. This shall include consideration of sediment cover of the bed, and copper, lead, zinc, PAHs contamination.*

The goal of this report was to fulfil this requirement by considering the feasibility of sediment removal and mitigation within Ōtautahi/ Christchurch waterways by identifying potential methods of sediment removal and identifying priority locations for trials of the methods. This information could be used by the CCC to consider whether they should proceed to Condition 3(h) of Schedule 3 ("*If the consent holder determines that it is feasible, instigate an instream sediment remediation programme*"). Specifically, this report covers:

1. Collation of recent data on ecological and cultural values and deposited sediment cover and contamination within waterways in Ōtautahi,
2. Assessment of the potential for stream reaches to receive inputs of fine sediment (using the stormwater pipe network) and to remobilise fine sediment (using channel gradient as an indicator),
3. Development of interactive maps to visualise key data that could be used to prioritise and identify potential sites for trials of sediment mitigation/removal methods,
4. Documentation of a rationale for selecting potential trial sites,
5. Provision of a preliminary list of potential trial sites based on the available data,
6. Provision of a brief assessment of potential sediment removal and mitigation options.

1.1 Approach and report structure

First, we note that removal of deposited fine sediment from Ōtautahi waterways has been a common occurrence historically, and more recently after the Christchurch Earthquakes, to reduce flood risk to the surrounding land and/or to improve ecological, cultural and social values. This report documents the compilation of recent CCC data for Ōtautahi waterways and an assessment of the feasibility of sediment removal methods and priority locations using that compiled data.

Second, this is a feasibility study investigating potential sites and methods. While we provide a list of potential sites, alternative site selection criteria may result in a different site list. We provide the rationale we used to select sites as well as the compiled datasets and interactive maps of key variables, which could be used to consider alternative priority sites.

Finally, we note that engagement and consultation with mana whenua is required to determine the appropriateness of the potential sites listed in this report and of the suggested sediment removal and mitigation methods.

The CCC requested that the main catchments were prioritised in the following order: Ōpāwaho/ Heathcote, Ōtākaro/ Avon, Pūharakekenui/ Styx, Ōtūkaikino, Huritini/ Halswell, Banks Peninsula.

The report is structured in the following way:

Section 2 outlines the sources and compilation of data provided by CCC on sediment cover and contamination and potential cultural and ecological values within the catchments.

Section 3 describes how key variables representing values and sediment issues were selected and mapped to assist in identification of potential sites for sediment removal trials.

Section 4 outlines the process and rationale used to prioritise potential trial sites and provides details on the selected sites.

Section 5 assesses different sediment mitigation options and discusses their appropriateness at the potential trial sites.

2 Data compilation

Data were provided by the CCC for the Ōpāwaho/ Heathcote, Ōtākaro/ Avon, Pūharakekenui/ Styx, Ōtūkaikino, Huritini/ Halswell and Banks Peninsula catchments from:

- Surface water elevations every metre along main watercourses from 2021 LiDAR (Light detection and ranging) remote sensor data.
- A shape file of the main stormwater pipe network.
- The most recent five-yearly ecological surveys of each catchment.
- The most recent Christchurch River Environment Assessment System (CREAS) surveys.
- Annual ecological surveys of two sites each in the Ōpāwaho/ Heathcote and Ōtūkaikino catchments.
- Monthly water quality data.
- Fish passage barrier prioritisation assessments.
- Īnanga and trout spawning surveys.
- Data from the waterway species database.
- Sites of ecological significance from the District Plan.

For repeat surveys (e.g., CREAS and annual and five-yearly ecological surveys) we compiled data from the most recent survey at each site. The dates of the five-yearly and annual ecological surveys and the CREAS surveys used in this report are listed in Table 2-1. Note that limited data for sites on Banks Peninsula were available/provided and therefore the report focuses on the other five catchments.

The 2010–2011 Christchurch earthquakes had major impacts on the deposited sediment cover and contaminant concentrations in many locations within the waterways. Deposited fine sediment cover and depth increased at many locations through liquefaction, bank slumping or run-off (e.g., EOS Ecology 2011, Harding and Jellyman 2015). In some locations, liquefaction silt may have decreased contaminant concentrations in surface stream-bed sediments by covering more contaminated historic deposits. We only utilised data collected after the earthquakes.

2.1 Potential sediment input and mobilisation

The slope of the streambed was used to indicate the ability for fine sediment to be mobilised from a reach. Steeper slopes generally result in faster water velocity and a greater ability to mobilise fine sediment downstream. LiDAR data from 2021, and a polyline layer of watercourse locations (vwOpenDataWCWaterCourse) provided by CCC, were used to calculate the slopes of waterways within Ōtautahi. The LiDAR data were collected using aerial laser returns and provide elevation of ground or water surface points with a minimum density of eight points per square metre and with a vertical accuracy specification of ± 0.2 m. Water surface elevations were extracted from the LiDAR at one metre intervals along the line of the watercourses. Local slope at each one metre point was calculated by comparing that point with the points 10, 20 and 50 m upstream of it. Any points which were higher than their upstream comparison points were removed to eliminate features like culverts/bridges, or spurious LiDAR returns from vegetation. We thinned the dense points to 100 metre spaced points and did a final filtering of outliers. The "slope" attribute represents the average local slope between the points. Since the elevation is extracted from the water surface, some spurious results may occur in near-coast tidal reaches of the waterways if the LiDAR data was collected at different stages in the tidal cycle. However, no obvious outliers were noted for these reaches.

Potential inputs of fine deposited sediment were investigated using the stormwater pipe network maps provided by CCC.

2.2 Five-yearly and annual ecological data

The most recent data from five-yearly surveys of each catchment and from annual ecological surveys were from between 2017 and 2022, depending on the catchment and dataset (Table 2-1). The five-yearly ecological datasets were provided as separate excel files for each catchment with a sheet for each variable set (i.e., bank and riparian habitat, water velocity, macrophytes and periphyton, instream habitat, water velocity, results from laboratory analyses of sediment, macroinvertebrate indices and fish data). The equivalent sheets for each catchment were compiled into data frames containing all the site information for each variable set. The most recent annual data for the two annually-monitored Ōpāwaho/ Heathcote and Ōtūkaikino sites were added where available. Site and catchment names were made consistent across all files. Not all variables were provided for all catchments/sites, and no sediment contaminant data were provided for the annual sites. Column names and units of measurement were matched and standardised across the spreadsheets where possible. Site coordinates were standardised to NZTM. Readings of pH from the 2017 Ōtūkaikino survey were removed as they ranged from 52.6 to 68.9 (the pH scale is 0–14).

Macroinvertebrate indices were provided by CCC and were not re-calculated. Not all indices were available for all time periods or sites. The macroinvertebrate indices provided were:

- MCI: Macroinvertebrate Community Index – an indicator of ecological condition of a waterway calculated based on assigned scores representing the tolerance of the taxa present to organic pollution (Stark and Maxted 2007).
- QMCI: the quantitative variant of the MCI – calculations include the abundance of taxa in addition to their presence.
- Percent EPT abundance – the percentage of individuals that were Ephemeroptera, Plecoptera or Trichoptera. EPT taxa are often sensitive to deposited sediment cover.
- Percent EPT richness – the number of taxa that were Ephemeroptera, Plecoptera or Trichoptera.
- ASPM: Average Score Per Metric – an average value calculated from standardised indices of MCI, EPT richness and percent EPT abundance (Collier 2008).

Hydroptilid caddisflies were excluded from EPT metrics as they are less sensitive to organic pollution, and MCI and QMCI calculations were calculated using tolerance values for hard-bottomed streams (Stark and Maxted 2007).

Fish data were reduced to presence/absence records of taxa at a site to limit the influence of variation in fishing effort or method between sites, catchments or years.

Key sediment contaminants were identified in conjunction with the CCC as: total polycyclic aromatic hydrocarbons (PAH), copper, zinc and lead concentrations. Data for these contaminants in the stream-bed sediment were supplied by the CCC for 44 sites in total from the Ōpāwaho/ Heathcote, Ōtākaro/ Avon, Pūharakekenui/ Styx, and Huritini/ Halswell catchments. Data for nine sites in the Ōtūkaikino catchment were extracted from the most recent five-yearly survey report (Boffa Miskell 2022) to give data for 53 sites in total. More than one contaminant concentration was occasionally entered for the same site. The mean value was taken when this occurred.

Table 2-1: Sampling year for five-yearly and annual ecological surveys and CREAS assessments for the catchments. *Indicates survey year for annual sites. Five sites in the Ōtākaro/ Avon catchment (McCarthy Drain) were surveyed using CREAS in 2021 while the rest of the catchment was surveyed in 2017.

Catchment	Five-yearly survey year	Five-yearly report	CREAS survey year	Number of CREAS sites
Ōtākaro/ Avon	2019	Instream Consulting Ltd (2019)	2017 (2021)	623 (5)
Ōpāwaho/ Heathcote	2020 (*2022)	Instream Consulting Ltd (2020c)	2020	980
Pūharakekenui/ Styx	2018	Instream Consulting Ltd (2018)	2018	827
Ōtūkaikino	2022 (*2021)	Boffa Miskell Ltd (2022)	2022	611
Huritini/ Halswell	2021	Instream Consulting Ltd (2021a)	2021	387

2.3 CREAS surveys

CREAS surveys map broad-scale habitat patterns every 50 metres along wadeable reaches of Christchurch waterways. Data are recorded for instream, bank and riparian variables such as bank height, stream-bed silt coverage, channel depth and riparian vegetation cover. The most recent CREAS survey data were compiled for the focal catchments (Table 2-1). Sites coded as 'other' (typically assessed for notable weeds or fish barriers) and '25m', which are historic sites, were excluded.

Many riparian variables are recorded for both banks at each location (e.g., lower bank vegetation on the true right and true left banks). Similarly, many instream variables are measured at multiple points across the channel (e.g., fine sediment depth mid-channel and near the true left and true right banks). Where multiple measurements were recorded for a sampling location the data were summarised as averages. Note that for the Pūharakekenui/ Styx catchment a data entry error meant that the cumulative and calculated soft-sediment depths were transposed in the raw data sheets. This was corrected before calculations.

2.4 Mana whenua values

Several indices have been developed in an attempt to quantify the current health of waterways as assessed by mana whenua. We included two key indices in this report: the Takiwā Index and the Cultural Health Index (CHI).

The State of the Takiwā is an environmental monitoring approach developed by Te Rūnanga o Ngāi Tahu and is a cultural values-based environmental monitoring and reporting system. Using this approach, mana whenua assess site cultural health based on multiple factors: pressure from external factors, degree of modification of a site, suitability for harvesting mahinga kai, access, willingness to return to the site, overall state/health of the site, abundance of native taxa, taonga plants and dominance of native/exotic species. These factors are rated from 1 (poor) to 5 (very good) with the average value indicating the overall Takiwā Index score.

The CHI was developed by Tipa and Tierney (2003). The methods are similar to the Takiwā Index but slightly different categories are assessed and the focus is on assessment at a particular site, rather than a larger area as in the Takiwā Index. The CHI has three components: an assessment of traditional significance of the site to mana whenua (yes/no codes) and five-point scale assessments of both the mahinga kai value and cultural stream health. Cultural stream health assessments are based on the surrounding land use, vegetation, riverbed condition, water clarity, habitat variety and river channel.

State of the Takiwā assessments using both CHI and the Takiwā Index were conducted on the waterways of Ōtautahi in 2007 (Ōtākaro/ Avon and Ōpāwaho/ Heathcote catchments; Pauling et al. 2007), 2012 (Pūharakekenui/ Styx, Ōtākaro/ Avon and Ōpāwaho/ Heathcote catchments; Orchard et al. 2012, Lang et al. 2012) and 2022 (Ōtūkaikino catchment; Mahaaunui Kurataiao Ltd. 2023). We extracted the stream health component of the CHI (Tipa and Tierney 2003) and the average Takiwā Index scores from tables and figures in these reports (while not all site location co-ordinates were available in the reports, the detailed site descriptions and maps in the reports allowed us to determine relatively accurate coordinates).

2.5 Additional ecological values

The presence of kākahi in the waterways were assessed using data provided as a collated dataset from rapid assessments, quantitative surveys and salvage surveys conducted between 2007 and 2021 (Instream Consulting Ltd 2020d). We processed these data to produce presence/absence records of kākahi in the surveyed sites and reaches.

Data from 150 reaches or sites where trout or īnanga spawning has been observed previously were provided as a shape file. Reaches and sites were classified according to whether evidence of spawning was present or absent in the latest survey.

Data from the waterways species database, which compiles locations of previous records of sensitive species or excellent macroinvertebrate metric scores from a range of reports and the New Zealand Freshwater Fish Database (NZFFD), were converted to a standard coordinate metric (NZTM) and the presence of species that are threatened, at-risk or locally uncommon was extracted. Threatened or at-risk species were the fishes kanakana, longfin eel, giant bully, īnanga, bluegill bully, canterbury mudfish, torrentfish and kōaro (Dunn et al. 2017) as well as the invertebrates kōura and kākahi. The presence of the locally uncommon fishes banded kōkopu, mullet, redfin bully and the macroinvertebrate *Neocurupira chiltoni* were also extracted. Collection records were classified as either ‘recent’ (within the last 10 years) or ‘older’.

The locations of sites of ecological importance from the Canterbury District Plan were provided as a shapefile. These were filtered to include only the polygons relevant to freshwater habitats within the catchments of interest.

Fish passage barrier data were provided as locations assessed as very high risk, high risk, medium risk, low risk, very low risk and not assessed. These data were plotted on a map. Instream Consulting Ltd (2021b) identified the Ōtūkaikino catchment as the priority catchment most heavily impacted by instream barriers, along with several key locations within the Ōtākaro/ Avon catchment.

Monthly water quality data between January 2007 and December 2020 were provided for 72 sites (not all sites were sampled in all months). These data were compiled with censored values, i.e., those less than a detection limit or greater than a value, reported as either the limit or maximum value.

These compiled and tidied datasets have been separately provided to the council, along with a html file documenting their creation (see Appendix A for details).

3 Identification of key variables

The available data were composed of over 100 variables with varying spatial coverage. To prioritise key variables that could assist in identifying and prioritising trial sites for sediment mitigation and removal techniques, we first identified relevant key variable types. Below we provide an explanation and a summary of the variables we considered important for selecting trial sites. We note that other potential variables could be considered, and we have provided compiled and tidied datasets (see Section 2 and Appendix A) of all potential variables to CCC, which could be used in alternative prioritisations of sites.

The desired outcomes for fine sediment mitigation projects commonly include improved in-stream habitat for taonga and threatened species, removal of contaminated sediment, improved cultural values and protection of areas that currently support ecological values (e.g., Christchurch City Council 2016).

Therefore, we considered high priority sites for sediment removal and mitigation trials to be those that:

1. Had high bed coverage and/or depth of fine sediment and/or poor sediment quality (i.e., high contamination by copper, zinc, lead or PAHs).
2. Were ecologically valuable or were near ecologically valuable locations (examples of ecological values include the presence or spawning locations of species of conservation interest and high macroinvertebrate metric scores). Note that the presence of high ecological values may also exclude a site from being selected as a potential trial site to protect vulnerable populations or habitats.
3. Were of cultural importance or higher cultural value, as assessed by mana whenua.
4. Had low potential for rapid re-sedimentation after sediment removal.

A summary of the key variables selected to reflect these factors is in Table 3-1, with further discussion in the text below.

3.1 Deposited fine sediment quantity and quality

Deposited fine sediment quantity is an issue in many Ōtautahi waterways, with locations where the bed substrate is predominantly fine sediment or where a layer of fine sediment covers stoney substrate. During the 2019 survey of the Ōtākaro/ Avon River, approximately one third of the wadeable sites surveyed exceeded 30% fine sediment cover on the streambed (Instream Consulting Ltd 2019), which has been identified as a threshold above which macroinvertebrate communities are impacted (Burdon et al. 2013). Likewise, Tonkin and Taylor (2020) reported that the three annual monitoring sites on Cashmere Stream exceeded the CSNDC consent target of 20% cover in 2020.

To represent deposited fine sediment quantity, we extracted variables that reported the percentage cover and depth of deposited fine sediment on the streambed from the CREAS survey data. Similar data were also collected during the five-yearly ecological surveys but at fewer locations. Because CREAS data is collected every 50 metres in accessible locations, the CREAS data were used in preference to increase spatial coverage.

The variables we used to assess **sediment quantity** were (Table 3-1):

- Soft sediment depth (measured in cm). An average of three depths taken in the mid channel and near the true right and true left banks.
- Siltmatrix (percent cover) – an estimation of how much the interstitial spaces have been filled with fine sediment. This is estimated within five percentage categories (0–5%, 5–25%, 25–50%, 50–75%, 75–100%).
- Mud silt clay (percent cover)– an estimate to the nearest 5% of mud, silt or clay coverage on the stream bed.

Deposited fine sediment quality is impacted by contaminants from industrial activities and run-off from roads and roofs. For example, sediment concentrations of contaminants exceeded consent targets at 14 of 18 sites in the Ōpāwaho/ Heathcote catchment in 2020 (Instream Consulting Ltd 2020c). Within a catchment, concentrations can also be highly spatially variable (Gadd 2015).

Lead, zinc, copper and PAHs have all been reported to exceed ANZECC sediment quality trigger values at various sites within Ōtautahi waterways (e.g., Tonkin and Taylor 2020, Instream Consulting Ltd 2020c) and are listed as the main contaminants of concern by Gadd (2015). Zinc is of particular concern in the Ōtākaro/ Avon, Ōpāwaho/ Heathcote and Pūharakekenui/ Styx catchments with some locations exceeding ANZECC 'high' guideline values (Instream Consulting Ltd 2018, 2019, 2020c).

Consequently, the variables we selected to represent sediment quality were concentrations of PAH, copper, zinc and lead in the deposited sediment. Concentrations of these contaminants in the streambed sediment were available for 53 sites across all catchments. Total PAHs were calculated by summing 16 individual PAH concentrations, which include the PAHS listed as priority pollutants by the USEPA (Instream Consulting Ltd 2019). As reported in Instream Consulting Ltd (2019): total PAHs were normalised to 1% total organic carbon, as recommended by ANZECC (2018) and where one or more PAH compound was below the detection limit, half the detection limit was used in the calculation.

3.2 Ecological values

The ecological values commonly reported for Ōtautahi waterways include the presence of both nationally 'At-Risk' and locally uncommon fishes. For example, in the Ōtākaro/Avon River these include longfin eel, īnanga, giant bully, bluegill bully and kanakana (Instream Consulting Ltd 2019). Kanakana have also been reported in the Styx Mill Conservation Reserve, with juveniles within the catchment suggesting a breeding population (Instream Consulting Ltd 2018). Redfin bully and kanakana have occasionally been reported in the Ōpāwaho/Heathcote (Tonkin and Taylor 2020) and Huritini/ Halswell catchments (Instream Consulting Ltd 2021b) and bluegill bully in the Ōpāwaho/ Heathcote catchment. While most fish prefer stoney bed substrate, fine sediment deposits may provide beneficial habitat for some life stages of particular species, for example, the ammocoete larval stage of kanakana (lamprey, *Geotria australis).*

Freshwater mussels, kākahi (*Echyridella menziesii*), are locally uncommon and have an 'At Risk – Declining' conservation status (Grainger et al. 2018) but occur in several sections of the waterways within Ōtautahi. A population in the lower Pūharakekenui/Styx is likely to be one of the largest within the city (Instream Consulting Ltd 2020a) and they are also found in the Ōpāwaho/ Heathcote catchment (particularly Cashmere Stream). Kākahi have not been reported at any of the monitoring sites within the Ōtākaro/ Avon but have been reported in other mainstem locations in low to moderate densities (Instream Consulting Ltd 2021c). Kākahi are more common in sandy or stony substrate than amongst loose fine deposited sediment (Instream Consulting Ltd 2020d).

Freshwater crayfish, kōura (*Paranephrops zealandicus*), have an 'At Risk – Declining' conservation status (Grainger et al. 2018), are mahinga kai and also locally uncommon. Kōura have been observed in the Ōpāwaho/Heathcote catchment (Instream Consulting Ltd 2020a), particularly near Barrington Street and in Cashmere Stream (Tonkin and Taylor 2020). In 2021 kōura were also caught in several tributaries of the Huritini/ Halswell River (Instream Consulting Ltd 2021a) and in the Styx river in 2018 (Instream Consulting Ltd 2018).

Trout spawning occurs in the Ōpāwaho/ Heathcote and Ōtākaro/ Avon among silt-free gravels and īnanga spawn in the lower reaches at the upper limit of the saltwater encroachment. Increased sedimentation of the stream-bed is a likely contributor to a decline in trout spawning in the Ōtākaro/Avon over the last 20-30 years (McMurtrie et al. 2013).

The macroinvertebrate community of the urbanised waterways are generally comprised of pollution tolerant taxa, however sections of the Pūharakekenui/ Styx and Ōtūkaikino catchments support pollution sensitive taxa, including mayflies (Ephemeroptera).

Potential ecological values were assessed using:

- Presence of freshwater species of conservation interest including kākahi and kōura.
- The diversity of fish present.
- Presence of spawning habitat for trout and īnanga.
- Macroinvertebrate metrics MCI and QMCI.
- Percentage macrophyte cover as an indicator of habitat condition.

The presence of species of conservation interest was extracted using the data from the five-yearly and annual ecological surveys. Fish data were available from seventy sites across the catchments (Table 3-1) and converted to presence/absence to account for differences in fishing effort and methods. Fish species that were included were bluegill bullies, kanakana, longfin eel and īnanga at each site, as well as kōura. Other fish species were only present at a few sites within the catchments and were not included in the current assessment. Fish taxa richness was also included. Although fish taxa richness is commonly greater near the coast due to upstream migration barriers and the natural life histories of some fishes, taxa richness may still give an indication of fish diversity across Ōtautahi waterways, where sites are commonly within 20 kilometres of the coast.

The five-yearly and annual fish data were used in place of the Waterways Species Database due to difficulties assigning precise locations to some of the sites (commonly where species presence was reported as a spatial extent rather than a specific location) and a lack of ability to separate sites with records of sensitive species from those without (see figure in Appendix A). When we plotted records for sites that had 1) site co-ordinates available, 2) records less than 10 years old and 3) which contained sensitive species (i.e., threatened or locally rare fishes, kōura, kākahi or excellent macroinvertebrate metric scores) a high proportion of reaches within the focal catchments contained sensitive taxa (see Figure B-1), which was not useful for prioritising specific locations. Although the Waterways Species database data were not used to prioritise sites in this report they have been provided to the council as a tidied dataset with co-ordinates converted to NZTM, any spatial coordinates that cover a spatial extent summarised to an average value (which may not directly align with the waterway) and with the presence of individual taxa assigned to separate columns. The CCC could add this tidied dataset as a layer to the GIS maps created to prioritise sites (see Section 4) if required.

Data from the kākahi surveys of 191 sites were included with the locations surveyed and presence/absence of kākahi considered (Table 3-1).

Spawning habitat for trout and īnanga were identified using the dataset of ~150 surveyed spawning reaches (Table 3-1). The macroinvertebrate metrics MCI, QMCI and %EPT abundance were also included to identify sites with good or excellent macroinvertebrate communities.

Macrophyte cover of the streambed and macrophyte bed depth were selected as indicators of instream habitat (Table 3-1), with the understanding that macrophyte cover on the sampling day may have been influenced by macrophyte management programmes in the waterways. However, macrophytes can provide an indication of cover for fish and, if present in abundance, the type of macroinvertebrate community present. We included macrophyte cover as it was recorded during the CREAS surveys and had good spatial coverage.

The sites of ecological significance polygons provided from the Canterbury District Plan covered almost the entire length of the main rivers and were not useful in differentiating reaches within the rivers. Further details of the variables included are in Table 3-1.

3.3 Mana whenua values

Assessment of the of cultural importance of the priority sites suggested for sediment remediation needs to be done by mana whenua once the feasibility study is complete and information on the potential sediment removal methods and impacts on taonga species can be considered. Therefore, for this report we used sites of ecological significance as identified on the public version of Ka huru manu Ngai Tahu cultural atlas[1] and sites with higher stream health values from the CHI and Takiwā Index overall scores as a preliminary method to identify several potential sites. Consultation with mana whenua is required to determine 1) whether the preliminary sites we have identified are appropriate sites, 2) if key sites of interest have been omitted and 3) whether the potential methods of remediation or mitigation identified in Section 5 are appropriate for those locations.

3.4 Potential for re-sedimentation

We assessed the potential for re-sedimentation of a site after mitigation by calculating the slope of the streambed. Steeper bed gradients generally result in faster water velocities making suspended fine sediment less likely to deposit on the streambed. Spot water velocity measurements recorded during ecological surveys were not included due to the influence of river flow at the time of sampling on water velocity.

Maps of the stormwater pipe network for Ōtautahi were assessed for their ability to indicate high input locations of fine sediment. However, due to the magnitude of stormwater inputs into the waterways, the difficulty of determining potential output volumes of fine sediment from the pipes and the likely other sources of fine sediment and contaminants to the waterways, such as overland flow or bank erosion, the pipe network was not included as a variable to consider when prioritising trial sites.

[1] Homepage | Cultural Mapping Project (kahurumanu.co.nz)

Table 3-1: Names, descriptions and the data source of the variables extracted to represent sediment quantity and quality, ecological and cultural values and habitat condition which were used to assess potential sites for fine deposited sediment mitigation/removal trials in Ōtautahi waterways. The number of sites with data available is included (No. sites). The value of variables were colour coded when mapped, where possible, according to different criteria (Map colour criteria), including NPS-FM attribute bands or other guidelines (e.g., ANZECC water quality thresholds). Where guidelines were not available, variables were colour coded in five to six evenly distributed value ranges. BP = Banks Peninsula sites. The number of sites is the total across the Ōtākaro/ Avon, Ōpāwaho/ Heathcote, Huritini/ Halswell, Ōtūkaikino and Pūharakekenui/ Styx catchments.

Variable name	Description	Data source	No. sites	Map colour criteria
Sediment quantity				
Sediment depth	Sediment depth (average of three measurements)	CREAS surveys (avgsseddepth)	3433	Sediment depth in cm
Matrix silt	% interstitial space filled with fine sediment	CREAS surveys (siltmatrix)	3433	5 categories
Percentage mud/silt/clay	% cover of streambed by mud, silt or clay	CREAS surveys (mudsiltclay)	3433	Percent cover categories
Sediment quality				
Copper	Cu concentration in the sediment	Five-yearly surveys	53	ANZECC (2000)
Zinc	Zn concentration in the sediment	Five-yearly surveys	53	ANZECC (2000)
Lead	Pb concentration in the sediment	Five-yearly surveys	53	ANZECC (2000)
Total PAH	Total PAH concentration in the sediment	Five-yearly surveys	53	ANZECC (2000)
Mana whenua values				
Takiwā overall health	Takiwā Index score	State of Takiwā (2007, 2012, 2022)	67 river sites	1 = poor to 5 = very good
Cultural stream health	The stream health component of the CHI	State of Takiwā (2007, 2012, 2022)	67 river sites	1 = poor to 5 = very good
Cultural sites	Locations identified within the catchments	Kā Huru Manu, public version		NA
Ecological values				
Fish taxa richness	Total fish taxa caught during survey	Five-yearly and annual surveys	70	Number of taxa
Kōura	Presence/absence at fished site	Five-yearly and annual surveys	70	Presence/absence

Variable name	Description	Data source	No. sites	Map colour criteria
Kanakana	Presence/absence at fished site	Five-yearly and annual surveys	70	Presence/absence
Longfin eel	Presence/absence at fished site	Five-yearly and annual surveys	70	Presence/absence
Īnanga spawning	Presence/absence of spawning during last spawning survey	Spawning surveys 2007 - 2021	63 sites (23 BP)	Presence/absence
Trout spawning	Presence/absence of spawning during last spawning survey	Spawning surveys 2007 - 2021	85 sites (9 BP)	Presence/absence
Kākahi	Presence/absence		191 sites	Presence/absence
Macroinvertebrates: QMCI	Quantitative Macroinvertebrate Community Index score (HB)	Five-yearly and annual surveys	70 sites (3 BP)	NPS-FM attribute bands
Macroinvertebrates: MCI	Macroinvertebrate Community Index score (HB)	Five-yearly and annual surveys	70 sites (3 BP)	NPS-FM attribute bands
Macroinvertebrates: %EPT	Percentage of EPT individuals	Five-yearly and annual surveys	70 sites (3 BP)	Percent categories
Habitat condition				
Macrophyte cover	% cover by macrophytes	CREAS surveys	3433	Percent categories
Macrophyte depth	Depth of macrophyte bed (average of three measurements)	CREAS surveys	3433	Macrophyte depth in cm
Potential for re-sedimentation				
Bed slope	Channel slope as an indicator of sediment mobility	Calculated from LiDAR	Every 100 m	% slope

4 Identifying potential trial sites

One of the goals of this feasibility assessment was to identify representative sites in which to trial different sediment mitigation and removal options. To fulfil this requirement, we considered that a useful list of potential trial sites would include locations:

- Where sediment quantity and/or sediment quality was an issue.
- That varied in physical channel size, to enable feasibility trials of a range of different methods. We aimed to include channel sizes that ranged from small headwater sites to larger main channels. We also considered accessibility of the site.
- Where sediment cover and/or contamination varied in spatial extent. The techniques required to effectively remove sediment from an isolated section compared to a long river reach will differ.
- With ecological or cultural values, or adjacent to such locations. Sediment feasibility trials have the potential to improve both ecological and cultural values and we aimed to prioritise sites where the impact is likely to be largest.
- Where sediment removal may complement other remediation activities already planned.
- That varied in the values present. Sites with nearby sensitive or at-risk taxa will require different considerations from those that do not.
- From sites across the focal catchments.

We excluded Banks Peninsula sites due to a lack of data and focussed on the Ōtākaro/Avon, Ōpāwaho/ Heathcote, Pūharakekenui/ Styx and Ōtūkaikino, as requested by the CCC (Figure 4-1). Huritini/Halswell catchment was excluded because common stormwater contaminants (metals and total PAHs) were generally within guidelines at most monitoring sites in 2021 (Instream Consulting Ltd 2021a). It was also the lowest priority catchment assigned by the CCC within the city. We excluded sites that were in tidal reaches as these are predominantly depositional areas where sediment removal would be harder to maintain (Figure 4-2).

To prioritise sites we:

1. Developed interactive maps of the key variables identified in Section 3. These maps were GIS-based and allowed us to make layers of different variables visible and to zoom into areas of interest.
2. Used the maps to develop a shortlist of locations that met the requirements of the list above, and
3. Held a workshop with experts in Ōtātutahi waterways from CCC, Environment Canterbury, EOS Ecology, Instream Consulting, SCO Consulting and Mahaanui Kurataio (MKT).

Details of these steps are provided in the sections below and the preliminary and final site lists are shown in Table 4-1.

4.1 Mapping key variables

We imported the .csv files containing each of the key variables in Table 3-1 into ArcGIS Pro (Version 3.1.3). Using the XY coordinates for each dataset, we created point or line feature classes. We then grouped the data into Group Layers to help visualise any differences in related variables across the catchments. Catchment outlines and the river network were also added as layers. Maps were exported to ArcGIS Online and also made available to workshop participants as an interactive StoryMap[2].

Variables were colour coded based on their value to aid in interpretation. See Table 3-1 for criteria for colours for each mapped variable. Where guidelines existed (e.g., NPS-FM attribute band thresholds for MCI and QMCI or ANZECC (2000) guidelines for copper, zinc, lead, and PAH sediment concentrations) these were used as thresholds for colour coding. Council consent conditions (CSNDC) were used to guide appropriate bands for visualising deposited sediment (i.e., <20% cover of fine sediment). Where no existing guidelines indicated 'good' or 'poor' conditions, we divided the distribution of values in to five to six evenly spaced bins (e.g., for percentage cover of macrophytes: 0–10%, 11–25%, 26–50%, 51–75%, 76–100%).

ANZECC (2000) ISQG-low and ISQG-high guideline values for sediment concentrations of heavy metals were:

- Copper: <65 (green), 65–270 (orange) and >270 (red) mg/kg dry weight.
- Zinc: <200 (green), 200–410 (orange) and >410 (red) mg/kg dry weight.
- Lead: <50 (green), 50–220 (orange) and >220 (red) mg/kg dry weight.

See Table 4-1 for details of other thresholds used. Screenshots of example maps from the StoryMap are provided for stream-bed slope (Figure 4-2), a sediment quantity variable - percentage cover deposited fine sediment (Figure 4-3), a sediment quality variable - zinc concentration in deposited fine sediment (Figure 4-4) and an ecological value - macroinvertebrate index QMCI (Figure 4-5).

[2] Available here: https://storymaps.arcgis.com/stories/e3f574911b6e4c56a415fbfc7b61fd5b

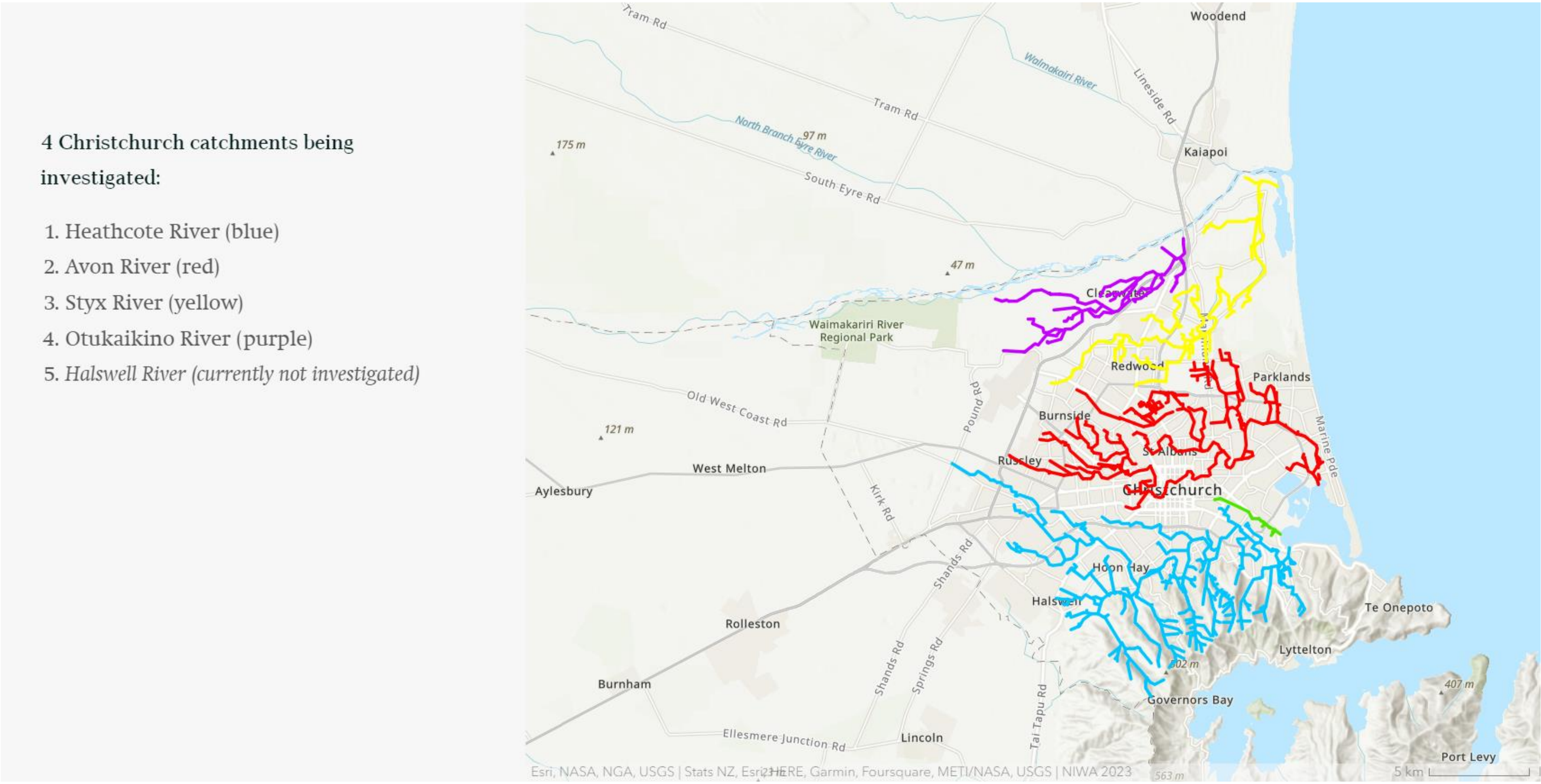

Figure 4-1: Screenshot of the StoryMap identifying the focal catchments. StoryMap available here: https://storymaps.arcgis.com/stories/e3f574911b6e4c56a415fbfc7b61fd5b. Green is the Linwood main drain, which was mapped but not directly assessed.

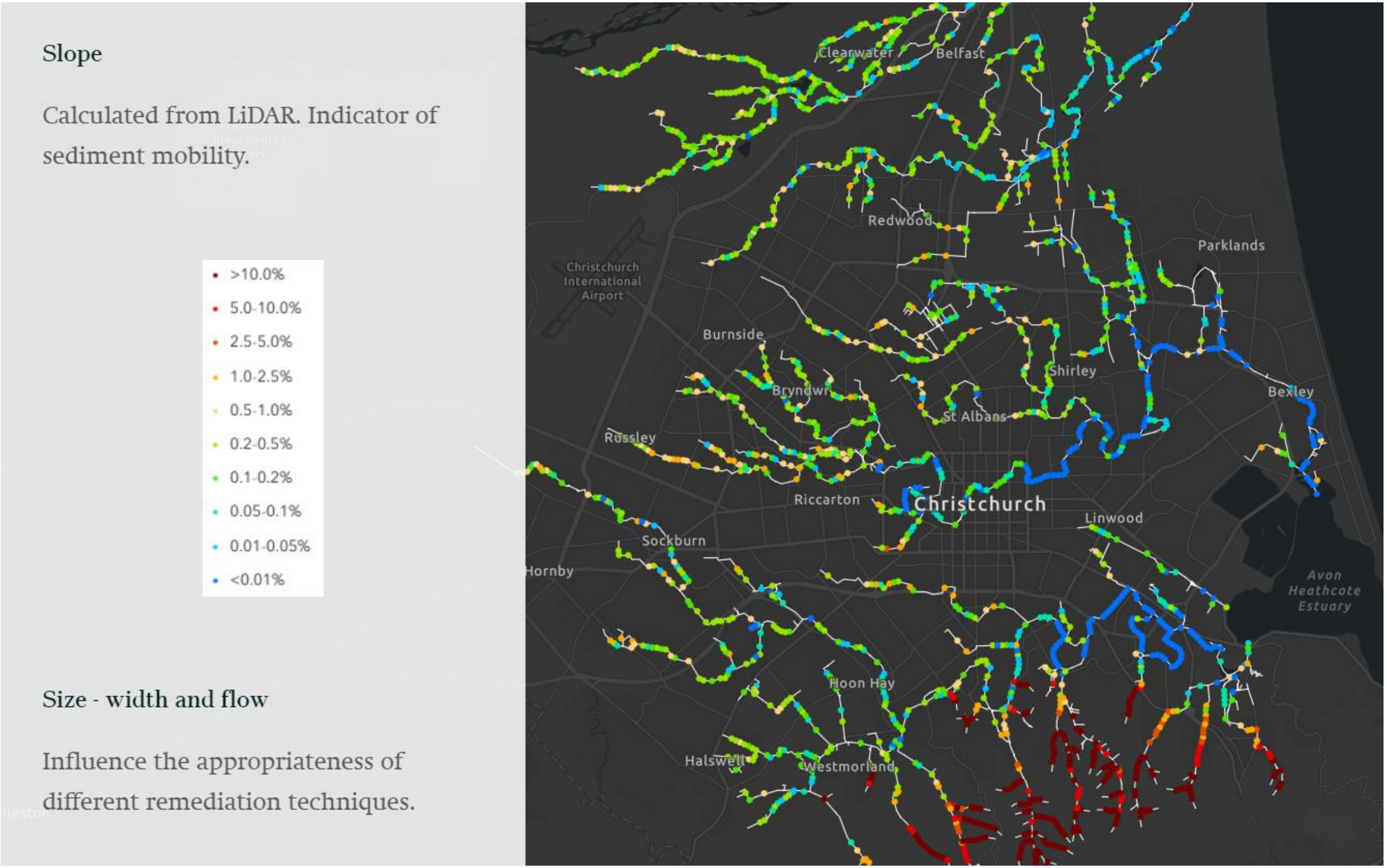

Figure 4-2: Stream slope as an indicator of ability to mobilise or prevent deposited fine sediment accumulations as visualised in the StoryMap. The map is interactive and can be zoomed to focus on individual reaches.

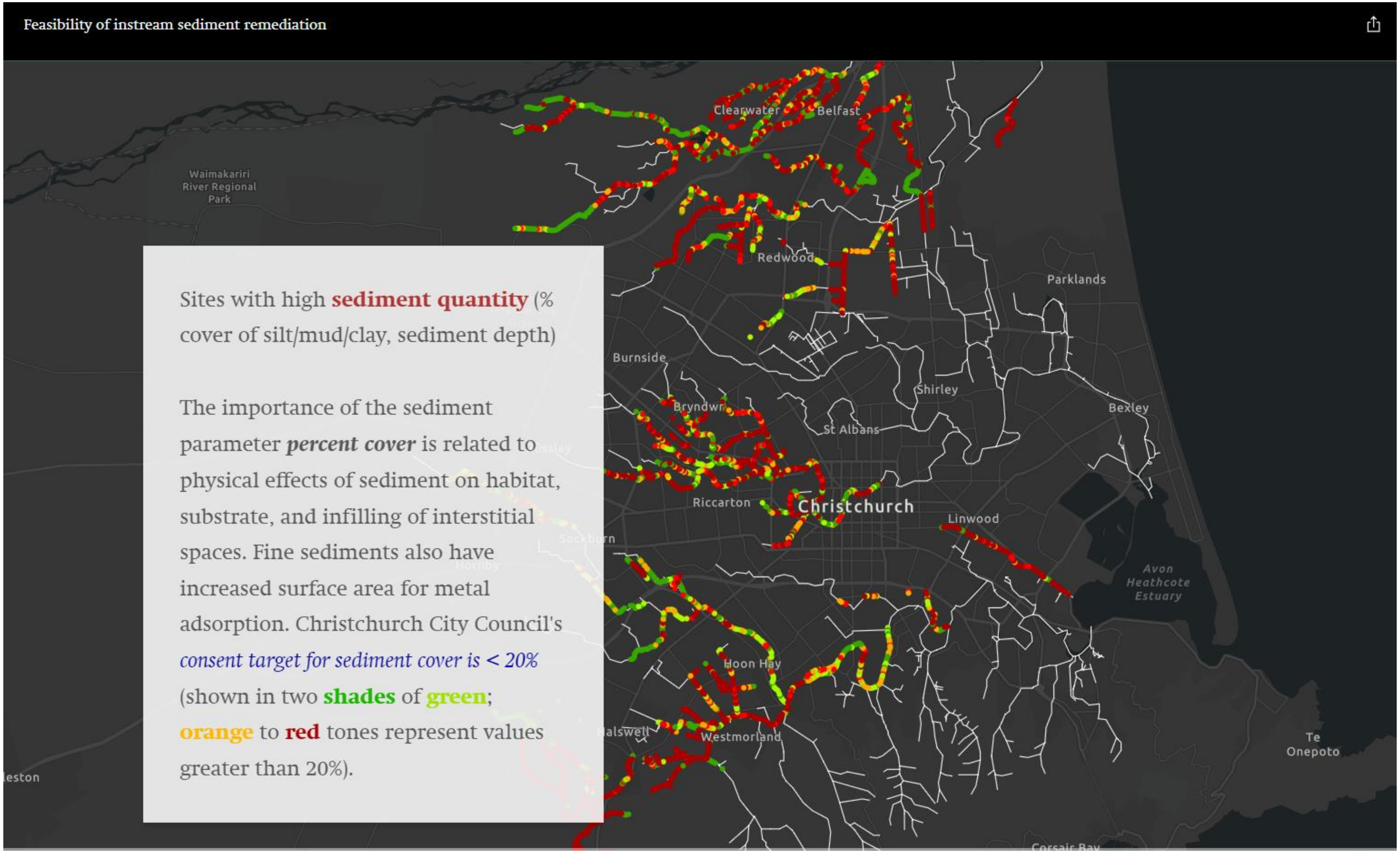

Figure 4-3: A sediment quantity variable (percentage cover of the streambed by silt, clay or mud) visualised in the StoryMap. The map is interactive and can be zoomed to focus on individual reaches.

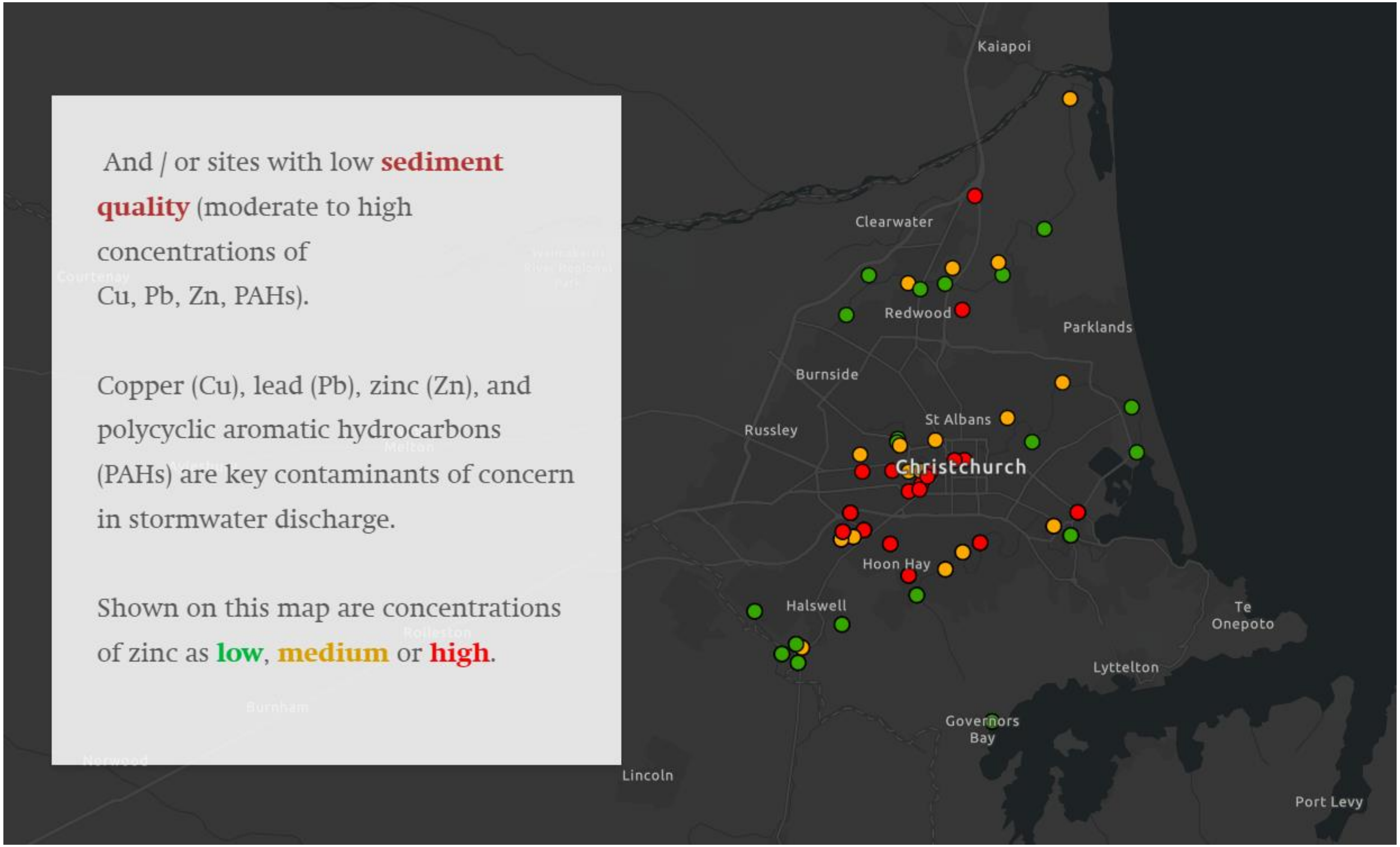

Figure 4-4: A sediment quality variable (zinc concentration in stream-bed sediment) visualised in the StoryMap. The map is interactive and can be zoomed to focus on individual reaches.

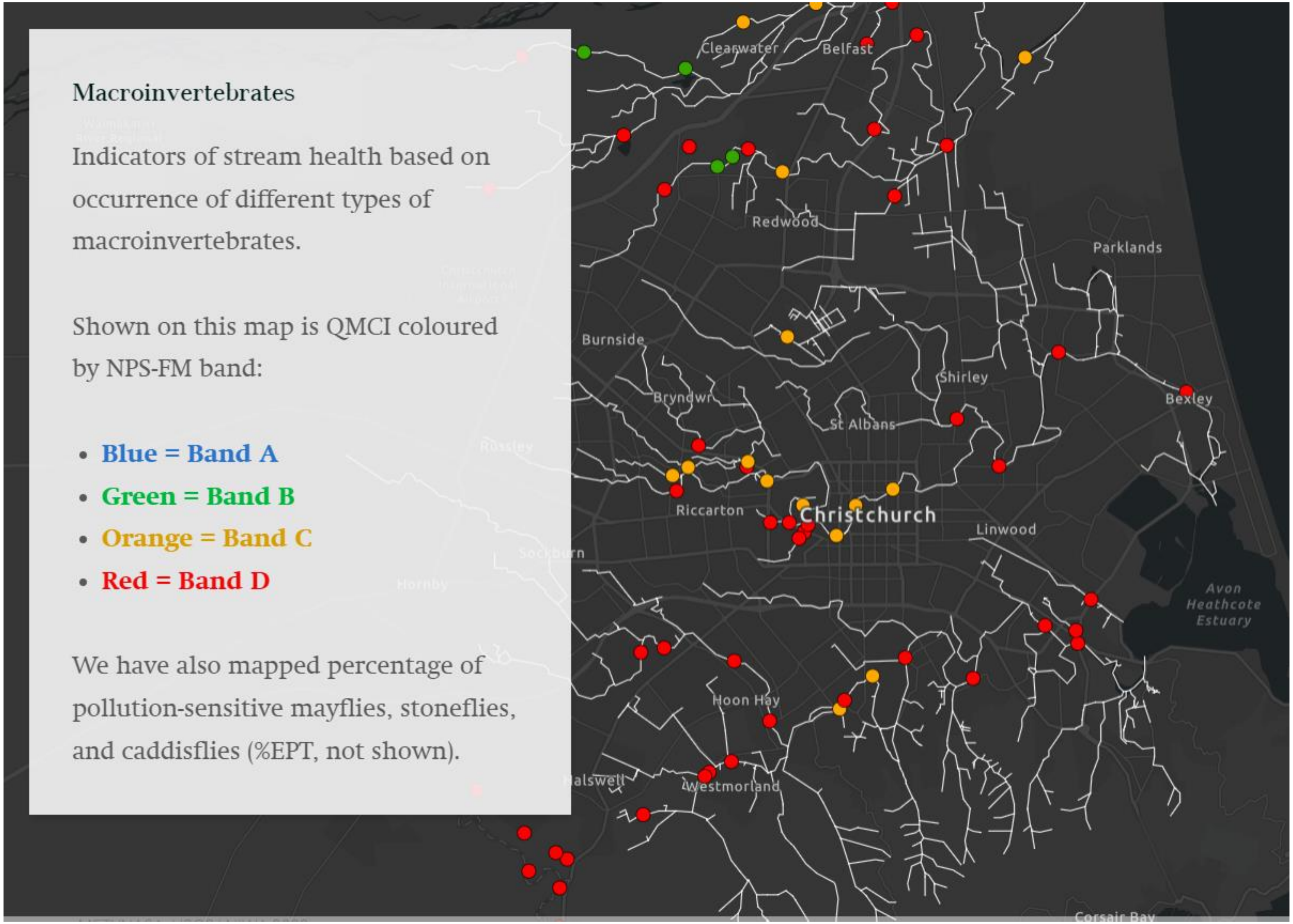

Figure 4-5: A ecological value variable (macroinvertebrate metric QMCI) visualised in the StoryMap. The map is interactive and can be zoomed to focus on individual reaches.

4.2 Workshop

The workshop was held on 11 October 2023 with participants from CCC (Florian Risse, Katie Noakes, Joe Harrison), Environment Canterbury (Michele Stevenson, Channell Thoms), Mahaanui Kurataiao Ltd (Donna Sutherland), EOS Ecology (Shelley McMurtrie), Instream Consulting (Greg Burrell), SCO Consulting (Clinton Cantrell) and NIWA (Michelle Greenwood, Richard Measures, Kristy Hogsden, Ruby McKenzie Sheat, Rose Kuru).

The data available and mapping methods were discussed. Participants were provided the link to the StoryMap to investigate the separate variable layers interactively during and after the workshop. A potential list of trial sites was proposed and discussed as well as a general discussion around how to prioritise sites and points of consideration.

The main topics discussed by the group were:

- The importance of developing the trial sites alongside mana whenua to ensure appropriate sites are selected and that any sediment mitigation or removal methods are appropriate for those sites. The goal of this report is not to provide a final list but to create a short-list of options that can then be assessed in more detail by mana whenua.
- That sites should be selected to present a range of different conditions to trial potential sediment removal and mitigation tools.
- The importance of also controlling upstream sources of sediment and contamination when undertaking removal trials to increase the long-term benefits. Such methods could include upstream bank stabilisation, filters on key inputs or in-stream sediment traps. More intensive options include, where possible, narrowing the channel or increasing the stream-bed slope to increase water velocity and reduce deposition. Previous trials without source control or methods to prevent redeposition have shown rapid return to pre-mitigation conditions (e.g., monitoring after sediment removal trials in Wairarapa Stream; Taylor and Marshall 2013).
- The benefit of doing trials in conjunction with other remediation efforts, such as bank stabilisation or channel alterations, which may minimise deposited sediment and contaminants returning to a site.
- The importance of good experimental design and on-going monitoring after trials to effectively quantify the short and long-term effects of the sediment removal.
- The importance of defining measures of success for the mitigation trials. What are the key indicators of success and what are appropriate temporal and spatial scales? Consider including key indicators of not only sediment changes but also ecological and cultural benefits. Is a goal for the mitigation be self-sustaining or will on-going maintenance to prevent re-sedimentation be required?
- Investigating contaminant types or sources in detail can inform the best mitigation options. For example, total PAHs can be interrogated to better understand the source and best mitigation options based on the concentrations of the individual PAHs present. Some PAHs can indicate roading and carpark pollution and sumps that are not well maintained or designed. If this is the main source, then options to control the

source include filter inserts for sumps draining high contamination areas. However, other PAHs can also indicate legacy coal tar contamination, where removal of the contaminated sediment may have long-term benefits without the need for source control.

- That the piped stormwater network may not be a good indicator of all sediment inputs.
- Some physical factors to consider when deciding on the appropriateness of a site, such as accessibility or areas to temporarily store removed sediment if required. These topics will need to be investigated once the potential trial sites and potential methods are proposed. We provide a list of considerations for this stage in Section 5.3.
- The presence of threatened species within the trial reach or downstream is a key consideration to both minimise ecological impacts on critical habitat for threatened species and also for consideration during consenting for the trials.
- That a matrix of interventions will be required depending on the site. Ideally these interventions will work together to provide long-term and self-sustaining (or minimal on-going maintenance) improved sediment quantity and quality. Many sites will need a combination of approaches to both sediment removal and source control. Sediment removal and source control solutions will need to be site-specific, depending on the size of the waterway, access ability and sources of sediment and contaminants.

Ten potential trial sites were proposed in the workshop with five sites each in the Ōpāwaho/ Heathcote and the Ōtākaro/ Avon catchments (Table 4-1). The Ōtūkaikino and Pūharakekenui/ Styx were proposed for trial sites, but exact locations were not confirmed before the workshop. The lists of the proposed trial sites before and after the workshop are in Table 4-1 (see Figure 4-6 for map of final proposed sites). The discussion of proposed sites at the workshop included that:

- The Ōpāwaho/ Heathcote River at Hunter Terrace may show a localised patch of high sediment cover due to remediation of the channel upstream (channel narrowing) causing deposited sediment to move downstream into this location. However, the deposited sediment data were from 2021, before the channel narrowing work, so this effect cannot be assessed. However, this highlights the importance of on-going monitoring of deposited sediment and contamination in the waterways, particularly as other remediation projects are undertaken.
- A proposed site on Cashmere Stream (Ōpāwaho/ Heathcote River catchment) was excluded from the list due to potential impacts of sediment removal on the resident kākahi populations. The risk of impacting this significant population was deemed to be too great. Also, this stream commonly has high suspended sediment loads, and may be likely to quickly return to high deposited sediment cover if upstream mitigation approaches to reduce sediment input are not undertaken. Reducing sediment inputs is likely to be complicated due to multiple sources of sediment, including run-off from the Port Hills (EOS Ecology 2008).
- A proposed site on the Ōtākaro/ Avon River at Cambridge Terrace is in a section of river that has previously had sediment removed. The reach from the Antigua boat

sheds to Barbadoes Street had sediment removed via various methods, apart from a section near Manchester Street where access was difficult.

- A proposed Curletts Drain site (Ōpāwaho/Heathcote River catchment) is a good location as there is contamination present but also an upstream stormwater basin that may reduce inputs if the area downstream is mitigated. The Haytons Drain site (Ōpāwaho/Heathcote River catchment) was similar to Curletts Drain but more difficult to control sediment inputs into and so was excluded in preference to the site on Curletts Drain. Ideally the Curletts Drain site would include monitoring both up stream and or downstream of the stormwater basin to assess its effectiveness in filtering deposited sediment and contaminants.
- Addington Brook (Ōtākaro/Avon catchment) is currently undergoing habitat enhancement work with stormwater flow mitigation work proposed. There could be benefit in working in conjunction with this work, or at least in monitoring fine sediment levels over time after the remediation work to see if the site becomes
- The proposed site on Addington Brook (Ōtākaro/ Avon catchment) above has Tranzlink stormwater retention ponds upstream that have very high zinc contamination. The ponds could be considered as a good location for removal of contaminated sediment that may improve downstream conditions.

- The importance of including a site on the Pūharakekenui/ Styx River. There are different processes operating in this catchment in comparison to the already more urbanised catchments.
- The Ōtūkaikino catchment is a lower priority for a trial site due to being a wai tapu site and having less urban development and stormwater infrastructure currently.
- The tidal reaches of the catchments are of lower priority than upstream reaches due to being naturally depositional.

4.3 Selected trial sites

The final list of potential sites for feasibility of sediment mitigation and removal trials is provided in Table 4-1. A brief discussion of the sites follows below, with a summary of key rationale in Table 4-2. Note that no sites in the Huritini/ Halswell catchment were included because this catchment was a low priority according to the council and because common stormwater contaminants are generally within guidelines at most monitoring sites in the catchment (Instream Consulting Ltd 2021a).

4.3.1 Curletts Stream

This small site is located high in the catchment with potential for upstream source control (Figure 4-6). The sediment quality at the site is poor, with high concentrations of zinc, copper and lead. However, sediment cover is relatively low, meaning that comparatively little overall material may need to be removed. The stream is a major source of zinc to the Ōpāwaho/ Heathcote (Instream Consulting Ltd 2020d). The basin is planted with wetland species and Curletts Stream has been realigned to flow through it. Sediment upstream of the stormwater facility has high metal concentrations, particularly zinc, and previous reports have suggested removing this contaminated sediment (Gadd 2015, Instream Consulting Ltd 2020d). There is a reach of approximately 500 metres between the stormwater basins and the confluence with the Ōpāwaho/ Heathcote.

Mitigation tools for this site could include small-scale methods (see Section 5.1.1) to remove the limited deposited sediment. The new sediment retention ponds near the motorway potentially provide good potential upstream source control if sediment removal is successful, the contaminated sediment in the retention basin is also removed and direct inputs into the reach can be reduced. Monitoring of sediment mitigation/removal trials could be paired with monitoring upstream and downstream of the new stormwater basins to assess their ability to filter contaminants and deposited sediment.

Figure 4-6: Photos of Curletts Stream taken from a reserve near 7 Mokihi Gardens. Photos are of the stream bed (left), looking downstream (middle) and looking upstream (right).

4.3.2 Ōpāwaho/ Heathcote River at Spreydon Domain

This site is a larger main river site, but within the upper catchment (Figure 4-7). The sediment quality is poor due to high concentrations of zinc, and moderate concentrations of copper, lead and PAHs. There is moderate to high sediment cover on the stream bed, but upstream and downstream areas have lower sediment cover. There are relatively low ecological values at the site (low macroinvertebrate metrics and limited sensitive fish species), however trout spawning habitat and moderate fish taxa richness occur downstream of this site. The location of the site within a public domain will likely facilitate access to the site and give public visibility to the project and any visual improvements to the site.

Figure 4-7: Photos of the Ōpāwaho/ Heathcote in Spreydon Domain. Images taken from foot bridge looking upstream (left) and downstream (right). Note the eel in bottom of the downstream image.

4.3.3 Hendersons Drain

The proposed site on Hendersons Drain (Figure 4-8) is downstream of an extensive wetland habitat and re-aligned and enhanced section of the drain. There is high sediment cover, but data on sediment quality (contaminants) were limited. Downstream of this site in Cashmere Stream there are records of kōura, kākahi, and longfin and shortfin eels. The removal of deposited sediment at this site would improve habitat quality and extend the channel improvements already undertaken upstream to include almost the full length of this small waterway. The upstream wetland likely provides good source control to prevent re-sedimentation, although this would need further assessment and quantification.

Figure 4-8: Photos of Hendersons Drain. Images taken from driveway bridge just upstream of Cashmere Road / Hendersons Road intersection looking upstream (left) and downstream (right).

4.3.4 Ōpāwaho/ Heathcote at Hunter Terrace

This relatively large mainstem river site has high deposited fine sediment cover on the stream bed and poor sediment quality, due to high contamination by PAHs (Figure 4-9). There are moderate ecological values (fish taxa richness and presence of longfin and shortfin eels) and trout spawning habitat upstream. This site is a larger river site where trials of more intensive mitigation and removal tools may be beneficial. The high deposited sediment cover at this site is relatively localised, with lower cover both upstream and downstream. This site may be a natural depositional zone, where a sediment trap could be considered, or may have higher cover due to historic reasons, in which case sediment removal would connect locations of low sediment cover both upstream and downstream. Dredging has been undertaken previously along this reach.

Figure 4-9: Photos of Ōpāwaho/ Heathcote on Hunter Terrace, just upstream of the Malcolm Avenue bridge. Images taken looking upstream (left) and downstream (right).

4.3.5 Addington Brook

This is a small waterway flowing through public land with good access to the channel (Figure 4-10). The site has high deposited fine sediment cover (in some locations) and poor sediment quality, predominately due to contamination by zinc. The site has low ecological value (poor macroinvertebrate metric scores) but there is moderate fish taxa richness downstream. Addington Brook is currently undergoing remediation works to the channel with the goal of enhancing in-stream habitat. These works could be paired with a sediment removal trial for increased overall benefit and cost-effectiveness. If channel works are already progressed and include sediment removal then long-term deposited sediment monitoring would be beneficial within the enhanced reach and downstream of it to investigate whether fine sediment returns. This site was one of the three sampled by Instream Consulting Ltd (2019) in the Ōtākaro/Avon catchment which exceeded the ANZECC high guideline for zinc contamination of the stream-bed sediments.

Figure 4-10: Addington Brook from the cycle way in South Hagley Park. Looking upstream (left) and downstream (right).

4.3.6 Ilam Stream

Ilam Stream has high deposited sediment cover and moderate sediment quality, due to contamination by copper, zinc and PAHs (Figure 4-11). There is moderate fish richness, including longfin and shortfin eels, and trout spawning occurs downstream. Site access may be possible on the University of Canterbury campus, although native riparian plantings would need to be protected or restored. The waterway is small to medium sized. Downstream of Clyde Road, after the confluence with the Avon River there is a historic weir that acts as a sediment trap.

Figure 4-11: Avon River just downstream of the Ilam Stream confluence from University Drive on the University of Canterbury campus. Photos taken from the footbridge to the recreation centre looking upstream (left) and downstream (right).

4.3.7 Waimairi Stream

Waimairi Stream has high deposited fine sediment cover on the stream bed and also sections of deep sediment (Figure 4-12). The sediment quality is moderate, with contamination by lead and PAHs. Kākahi and trout spawning sites are present downstream. The CCC is planning waterway enhancement work in this stream within the nest few months.

Figure 4-12: Waimairi Stream in Fendalton Park. Images taken from footbridge into the park looking upstream (left) and downstream (right).

4.3.8 Pūharakekenui/Styx

We propose a site on the Pūharakekenui/Styx River upstream of the Styx Mill Road and Gardiners Road intersection. This site currently has moderate urban development, which is likely to increase. The site has high deposited sediment cover but relatively good sediment quality (only moderate contamination by lead). Further downstream, the Styx Mill Reserve has good habitat quality and supports some of the best macroinvertebrate communities within Ōtautahi. Kanakana and kōura are present downstream as well as trout spawning habitat. The section upstream of the road intersection is on private land, site photos graphs were taken from Gardiners Road (Figure 4-13).

Figure 4-13: Pūharakekenui/Styx River at Gardiners Road. Images taken from footbridge into the park looking upstream (left) and downstream (right).

Table 4-1: Preliminary and final list of proposed trial sites for a feasibility assessment of sediment mitigation and removal tools. The full list is provided and grey shading indicates sites excluded during the workshop. See Section 3 for the list of key variables used to prioritise sites, Section 4 for overall rationale for site selection and Table 4-2 for rationale specific to the selected sites.

Catchment	Site type	Site description	Final list?	Reason excluded
Ōpāwaho/Heathcote	Tributary	Curletts Stream	Y	
Ōpāwaho/Heathcote	Mainstem	At Spreydon Domain	Y	
Ōpāwaho/Heathcote	Tributary	Hendersons Drain	Y	
Ōpāwaho/Heathcote	Mainstem	At Hunter Terrace	Y	

Catchment	Site type	Site description	Final list?	Reason excluded
Ōpāwaho/Heathcote	Tributary	Haytons Stream	N	Similar to Curletts Drain
Ōpāwaho/Heathcote	Tributary	Cashmere Stream	N	Sensitive kākahi population
Ōtākaro/Avon	Tributary	Addington Brook	Y	
Ōtākaro/Avon	Tributary	Ilam Stream	Y	
Ōtākaro/Avon	Tributary	Waimari Stream	Y	
Ōtākaro/Avon	Mainstem	At Cambridge Tce		Previous sediment removal, site of cultural significance
Pūharakekenui/Styx	Mainstem	Upstream Styx Mill / Gardiners Rd	Y	Added at the workshop

Table 4-2: Summary key variables used to assess the sites for criteria for including sites as trial sites. The variables are colour-coded according to the relevant thresholds (and matching the StoryMap criteria). For sediment quantity (percent cover fine sediment) green indicates <20% cover, bright red 40–70% and dark red 70–100% cover. Sediment quality is colour-coded according to ANZECC guidelines (orange = >low and < high, red = > high) with the relevant contaminant named. QMCI is colour coded according to NPS-FM attribute bands (Band D is below the national bottom line). Mana whenua values for the sites were considered using the data we had available (Takiwā Index and CHI), however, a more holistic consideration must be undertaken by mana whenua and so cultural values are not included in this table. Ds = downstream.

Catchment	Site	Size	Sed. quantity	Sed. quality	QMCI	Sensitive taxa
Ōpāwaho/Heathcote	Curletts Stream	Small		Zn, Cu		
Ōpāwaho/Heathcote	In Spreydon Domain	Medium	Localised	Zn	Band D	Trout spawn ds
Ōpāwaho/Heathcote	Hendersons Drain	Small				Kōura and kākahi ds
Ōpāwaho/Heathcote	At Hunter Tce	Large	Localised	PAH, Zn	Band C	Trout spawn us
Ōtākaro/Avon	Ilam Stream	Small		Pb, Zn, PAH	Band D	Trout spawn ds, mod-high fish richness
Ōtākaro/Avon	Waimari Stream	Small		PAH	Band C	Trout spawn ds, kākahi ds
Ōtākaro/Avon	Addington Brook	Small	Patchy	Zn	Band D	Kākahi ds (Ōtākaro/ Avon)
Pūharakekenui/Styx	Upstream Styx Mill/Gardiners Rd	Small		Pb	Band D	Trout spawning ds, QMCI band B ds in reserve

Figure 4-14: Map of potential trial sites finalised after a workshop with local experts. Screenshot from the StoryMap available here: https://storymaps.arcgis.com/stories/e3f574911b6e4c56a415fbfc7b61fd5b.

5 Assessment of sediment mitigation/removal options

In this section we discuss several potential methods for sediment removal or mitigation/source control. Several of these methods have been used previously within Ōtautahi waterways with examples provided below.

5.1 Potential removal tools

5.1.1 Small-scale vacuum pumps or hand removal

Small-scale removal methods can be appropriate for isolated small fine sediment deposits or for small waterways. Small-scale mechanical fine sediment removal techniques include high water pressure hoses to blast fine sediment out of interstitial spaces and wash it downstream, hand removal using shovels and small vacuum pumps such as the SandWand (

Figure 5-1 and 5-2). The SandWand works by pumping water onto the stream bed and then sucking up the slurry of water, silt and sand created through a second pipe (

Figure 5-1). The slurry can either be pumped onto the bank or into settling systems such as geotube bags. The SandWand is operated by one or two people in the stream.

A trial of the SandWand was undertaken in Wairarapa Stream in 2015 by North Canterbury Fish and Game. The SandWand and subsequent filtering of the output slurry through a geotube bag removed 19 tonnes of sediment (data provided by Emily Moore, Fish and Game). Waterblasting and an excavator also removed 43 tonnes. There was an initial strong decrease in deposited fine sediment cover of the streambed (from an average 94% fine sediment bed cover before to 23% coverage after). This indicates that the SandWand and other small-scale mechanical methods may be effective tools to remove fine deposited sediment in small waterways, particularly in localised patches. However, the removal effort was very labour intensive and after four years the deposited sediment cover had almost returned to pre-removal coverage, highlighting the importance of source control or other mitigations to prevent cleared areas becoming covered in fine sediment again.

Figure 5-1: The SandWand in use in Wairarapa Stream. Photo credit: North Canterbury Fish and Game.

Figure 5-2: Use of water blaster and vacuum hose to remove fine deposited sediment from Jarden's drain (left) and vacuum hose to remove sediment from St Albans Creek. Photos provided by CCC.

Feasibility in Ōtautahi/Christchurch waterways

The SandWand and other manual removal methods are highly labour intensive. They are likely only useful in very small-scale areas where access with mechanical excavators is limited and for sites that have localised values, for example a specific salmonid-spawning riffle. We do not recommend the SandWand and other manual removal techniques for larger-scale reaches, and for that reason did not prioritise them for inclusion in trials of deposited sediment removal and mitigation methods in Ōtautahi waterways.

5.1.2 Dredging

Dredging and sediment removal from larger waterways has been common practice historically in Ōtautahi, largely with the goal of improving drainage (Patten 2016). Dredging is more recently undertaken considering the six core CCC values of ecology, landscape, recreation, heritage, culture and drainage. Dredging is not recommended for reaches where kākahi are abundant due to potential long-term impacts on their populations (Instream Consulting Ltd 2021c).

Dredging has been undertaken in sections of the Ōtākaro/ Avon, Ōpāwaho/ Heathcote and Pūharakekenui/ Styx rivers after the earthquakes, largely to removal liquefaction silt and to reduce flood risk. Dredging is commonly done by an excavator situated either on the bank or on a floating barge. Smaller-scale vacuum dredges, such as the Dino-6 vacuum dredge (Figure 5-3), may also be used in smaller waterways or to access areas that excavators cannot reach (Patten 2016). The Dino-6 dredge was challenging to use effectively in Linwood Canal due to the channel geomorphology, however, has been used effectively to remove fine deposited sediment in larger waterways such as the Avon River loop (K. Patten, pers comm). The slurry removed by the Dino-6 dredge can be easily contained within geobags, reducing mobilisation of fine sediment downstream. Excavator and barge dredging is most suited to large river sections with deep and widespread fine sediment deposits. However, within these larger reaches it is challenging to remove fish and other sensitive species prior to works.

Examples of previous use

As part of the Watermark project the Avon River precinct (between the Antigua boatsheds and Barbadoes Street) was dredged by excavators to remove fine deposited sediment, largely liquefaction silt. Inflatable booms were installed to separate dredged areas from the main channel in an attempt to reduce suspended fine sediment washing downstream (James 2013). Embedded silt was also removed from interstitial spaces using an excavator with a bucket scoop drilled with holes, which was designed to act as a sieve (Figure 5-4). The fine sediment from the bucket scoop was washed downstream to floating bunds designed to capture it while the cleaned gravel was returned to the streambed. Each scoop was required to be rinsed multiple times with an ecologist on-site supervising the cleaning and redistribution of the material back into the river channel (James 2013). This work in the Avon River Precinct removed nearly 10,000 tonnes of silt and cleaned 15,000 m^2 of gravel (James 2013).

Dredging was undertaken in the Ōpāwaho/Heathcote River between 2018 and 2020 over a five kilometre reach upstream of the Woolston barrage, which removed approximately 70,000 tonnes of fine sediment from the river (Instream Consulting 2020b). The removed sediment was transported and disposed of in Burwood landfill. Attempts to use curtains or baffles to trap the mobilised suspended sediment were abandoned as they were difficult to implement effectively (Instream Consulting 2020b). Ecological impacts were instead minimised by use of periodic dredging with breaks between to allow turbidity to decrease and by limiting dredging during īnanga spawning periods. During dredging turbidity was very high downstream of the dredging site and the river was visibly turbid for several kilometres downstream. Incoming tides also pushed some turbid water upstream; however, turbidity generally declined within two to four tidal cycles (Instream Consulting 2020b).

Results from monitoring before and after dredging in the Ōpāwaho / Heathcote River indicated that fish species diversity was similar (Instream Consulting 2020c) with tagged eels species returning to dredged sections. However, recolonisation of kākahi into previously dredged reaches has been limited in reaches in the Ōpāwaho/Heathcote River and Cashmere stream up to two years after dredging (Instream Consulting 2021c). This may be because dispersal and re-establishment is slow for the mussels and/or that the new reaches were not suitable habitat (Instream Consulting 2021c). Survival of relocated kākahi within a reach in Cashmere Stream indicated either low survival of the moved mussels, or that they have left the relocation area (Instream Consulting 2021c). Dredging of areas with abundant kākahi is not recommended due to potential long-term consequences for their populations (Instream Consulting 2021c).

Approximately 4700 m^3 of fine deposited sediment was removed from the Pūharakekenui/ Styx River between Lower Styx Road and Spencerville Road in 2017 as part of the earthquake remediation. The sediment was checked for contamination by heavy metals, PAHs and asbestos and was above background levels but was assessed as suitable for disposal at Burwood landfill.

Potential costs

Cost estimates for removal methods are highly site-specific and dependent on the method, the particular machinery used and the scale of the removal and disposal of fine sediment. For these reasons we do not provide detailed cost estimates here. Some cost estimates for dredging projects were provided in a report by Patten (2016). These will have undoubtedly increased over the seven years since that report but are at least indicative. Costs are only for the work of sediment removal (and in some cases dumping fees). Many of the potential costs associated with resource consents, assessment of ecological effects and effectiveness and mitigation plans to prevent sediment return are not included. In particular, assessment of ecological effects is likely required prior to any remediation works and relocation and post-mitigation monitoring of sensitive species may also be required. Depending on the scale of the ecological work these costs could range from approximately $5000 to more than $100,000.

Examples costs from Patten (2016) include:

1. In 2013, a long-excavator on a barge removed fine deposited sediment from Ōtākaro/ Avon River and placed it onto a second barge, which was unloaded by another excavator. 10,000 m^3 sediment removed for $795,000 dredging cost and $240,000 dumping cost at Burwood landfill (~$1,035,000 total).
2. The Pūharakekenui/ Styx River was dredged in 2013 by an excavator on the bank or floating pontoon. 2812 m^3 sediment removed at a cost of $282,000 with $67,500 dump cost (total cost ~$350,000).

Figure 5-3: Dino-6 vacuum dredge. Images from https://geoforminternational.com/products/dino6/ and CCC.

Figure 5-4: Photos of bucket sieve for removing deposited fine sediment, addition of extra gravel and excavator dredging of deposited fine sediment removal during the Avon River precinct project. Photos from EOS Ecology report on river enhancement, available here: https://www.eosecology.co.nz/files/ARP-Enhancement-PPP.pdf.

Figure 5-5: Geobags are an option to contain fine sediment mobilised during removal operations or instream works. Using baffles and filters such as hay bales to contain fine sediment mobilised during excavator works can be challenging in larger waterways. In smaller reaches pumps can filter some slurry through geobags, where the water drains from the bag leaving the sediment inside. Dried bags can then be disposed of. However, in larger waterways or remediation works this method is challenging and checking for accidental capture of sensitive taxa is difficult.

Feasibility in Ōtautahi/Christchurch waterways

Dredging using an excavator is a relatively efficient way to remove large volumes of deposited fine sediment from the streambed and has historically been used extensively in Ōtautahi waterways for flood control. There is potential for dredging to also result in ecological benefits. This method is most suitable to larger waterways with good access and areas with deep and extensive deposits of fine sediment. Large areas of fine deposited sediment can be removed, potentially leading to ecological improvements along long reaches of waterways.

Potential ecological impacts include the difficulty in preventing sediment suspended during the dredging from washing downstream, which results in turbid water and in potential re-deposition downstream. In smaller reaches options such as pumping water through geobags may reduce turbidity (Figure 5-5) but this is commonly not practical in larger waterways or works projects. Turbid water after dredging is relatively short-lived and the longer-term benefits of less deposited fine sediment may outweigh short-term increases in turbidity in some situations. Contaminants present in the sediment can also be mobilised downstream and resettlement of fine sediment downstream may impact lower reaches.

The physical action of scooping up the stream-bed substrate can have major impacts on in-stream biota, particularly less mobile taxa such as kākahi. Removal and relocation of any sensitive taxa prior to dredging is recommended, as is checking the removed sediment for biota and monitoring post-dredging to assess for return of taxa (e.g., Instream Consulting 2020c, Boffa Miskell 2017). Note that relocation of kākahi has had limited success in Cashmere Stream and Ōpāwaho/Heathcote River and it is recommended that dredging is not undertaken in areas with high kākahi abundance (Instream Consulting 2021c).

The excavated fine sediment may be left onsite on the stream banks but is more commonly taken to an approved disposal facility such as Burwood landfill. Testing of the concentration of contaminants such as heavy metals and PAHs is required to assess whether the disposal site is appropriate (Patten 2016). Heavy contamination will require specialist treatment or disposal facilities and additional fees.

Trials of dredging as a tool to improve instream habitat are recommended, in particular trials designed to investigate both the spatial scale and temporal extent of any reductions in deposited fine sediment coverage and ecological improvements both at the site of the dredging and downstream.

5.2 Potential maintenance or source control tools

A key component of sediment removal projects is ensuring that effects are long-lasting. It is critical to identify whether any fine sediment deposits are a historical legacy, in which case removal alone may be sufficient, or whether source control is required to prevent re-sedimentation.

Solutions to preventing re-sedimentation of any sites where removal is undertaken will be situation specific, depending on the source of the sediment and whether it has an on-going supply or is a historical legacy.

Before the earthquakes, the Pūharakekenui/ Styx and Ōtākaro/ Avon received most sediment from bank erosion and overland runoff (Hicks 1993). In comparison, runoff from the Port Hills delivers sediment to the Ōpāwaho/ Heathcote through tributaries, stormwater pipes and through the riparian zone (Patten 2016). These sources of sediment are on-going. The earthquakes added additional fine material through liquefaction, run-off from upstream material and movement of the streambed and banks. This material was largely short-term input, but ongoing bank movement may be a source of some material and the fine sediment may continue to redistribute through the rivers. Once sediment is in many of the waterways, the low gradient means that heavier sediment settles and is not easily flushed out to sea (Patten 2016).

Several potential solutions to prevent re-sedimentation where on-going supply is an issue are listed below.

5.2.1 Reduce sediment inputs

The first step is to reduce inputs of fine sediment into the waterways. The method to reduce inputs will depend on the source. Areas of bank slumping or erosion can be stabilised and rock barriers or riparian vegetation used to stabilise banks. Vegetated swales can filter fine sediment from overland run-off following rain. Point-source discharges should be assessed and either on-site or end-of-pipe mitigations such as bunds or filters could be options. Good on-site sediment control on construction projects can also reduce sediment inputs into waterways.

Sediment traps

Sediment traps can reduce fine sediment entering waterways and can be installed instream or offline. In-stream traps can be comprised of a deeper, slower flowing or pool section of stream where sediment settles out and drop to the stream bed (Figure 5-6). Once the sediment trap is full the sediment is removed using an excavator. The size and shape of the sediment trap needs to be designed by experts based on the width of the stream, size and slope of the catchment, water velocity, severity of rainfall events and the size of the fine sediment entering the waterway. Sediment traps will not work for very fine material, which may remain in suspension. Ideally, traps would be designed to need only periodic clearing; i.e., annually or less often. Sediment traps can be installed in isolation or in series.

An example cost for a slow pool installation as a sediment trap in a small rural stream (~1 metre wide) with good digger access was listed on the Living water website[3] as:

1. Cost of an excavator to dig the trap was approximately $166 per metre @ $135 per hour.
2. Bank riparian planting was $33 per metre.
3. Not included was maintenance of the plantings until established or the costs to empty the trap (estimated on the website as annually).

Sediment traps can also be constructed in the riparian zone to settle out sediment from run-off or pipes before it enters the waterway. Stormwater detention ponds are a large-scale example, although smaller systems can also be installed.

Sediment traps can also incorporate material to act as filters such as wetland plants for offline traps or material such as hay bales for in-stream systems. However, ongoing maintenance and removal of deposited fine sediment is key to their effectiveness.

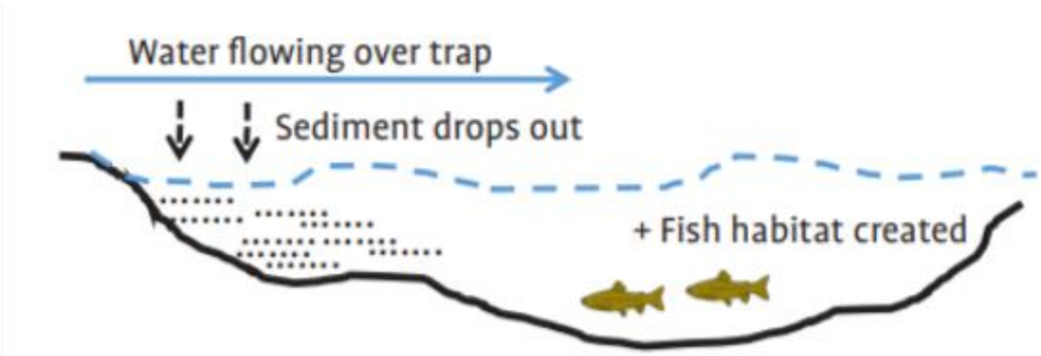

Figure 5-6: Example of a slow-flowing instream sediment trap. Diagram from University of Canterbury CAREX project (Canterbury Waterway Rehabilitation Experiment (CAREX) | University of Canterbury).

5.2.2 Reduce contaminant inputs

Potential source control options to reduce contaminant inputs include specific filters for point source discharges. Many contaminants enter urban waterways from stormwater pipes or sumps that capture contaminated run-off from roads or roofs. The main sources of zinc in the Ōpāwaho/ Heathcote catchment are unpainted or poorly maintained galvanised steel roofs, as well as run-off from roads because zinc is present in tyres (Gadd 2015). Examples of filters that remove contaminants include the "Storminator", designed by University of Canterbury engineers, which can be fitted to existing roofing downpipes and acts to remove heavy metals such as zinc (e.g., Skews 2021). Other options include filters that can be installed into road sumps that remove litter, suspended solids and oils from stormwater. However, the maintenance requirements, capacity and longevity of such filters would need to be investigated relative to the amount of run-off and contaminant load for any particular location. Good on-site treatment and control of contaminants in industrial areas will also reduce contaminant inputs into waterways.

5.2.3 Channel modifications

Channel modifications that increase bed slope and/or water velocity can assist in preventing fine sediment from settling in a location and may be beneficial when used in conjunction with deposited fine sediment removal. For example, in the Avon River Precinct project an excavator was used to

[3] https://www.livingwater.net.nz/catchment/ararira-lii-river-te-awa-o-araiara/in-stream-sediment-traps/

remove liquefaction silt and clean the gravels while areas of the channel were also narrowed to increase water velocity and the bed slope was increased (James and McMurtrie 2015). These changes maintained the low deposited sediment cover for at least 17 months after the sediment removal (James and McMurtrie 2015) and monitoring three and six years after restoration indicated that habitat diversity had been maintained as well as an increase in fish abundance and diversity (Boffa Miskell 2017 and 2020). Ongoing management of the rehabilitation work will be required to maintain these gains due to continued inputs of deposited fine sediment into the waterway (Boffa Miskell 2020).

Additional channel modifications include changes to the channel form such as a two-stage channel (Figure 5-7). These channels have a narrow channel in the centre that maintains a faster water velocity during base flow. When flows increase during floods the water spills into a water flood-plain, which is often vegetated, which acts to slow the water velocity and allow some of the suspended sediment to settle out.

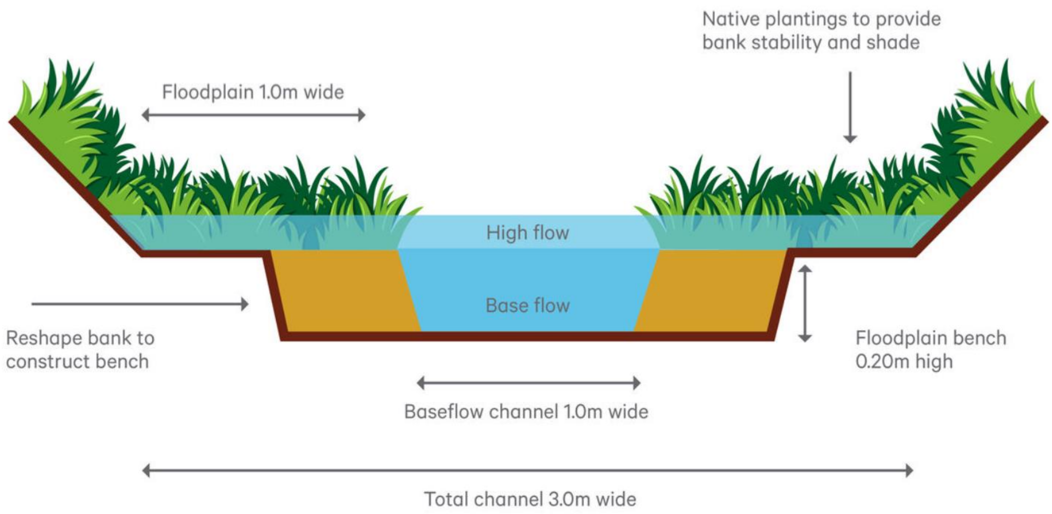

Figure 5-7: Example of a two-stage channel with a narrower central base flow channel and wider high flow channel that can filter or settle suspended fine sediment. Diagram from Living Water: https://www.livingwater.net.nz/catchment/ararira-lii-river-te-awa-o-araiara/two-stage-channel-flood-management-and-reducing/.

Feasibility in Ōtautahi/Christchurch waterways

Reducing inputs of fine deposited sediment and contaminants is challenging but likely to be feasible within some areas of Ōtautahi/Christchurch waterways if the right tools are used in the right locations and are maintained appropriately. Stormwater detention basins are installed and being installed in many locations, which should mitigate downstream movement of fine sediment and contaminants from upstream in the catchment. Very fine clay particles are likely to be difficult to settle in stormwater ponds during high flows, however. End-of-pipe contaminant treatments or filters may be applicable for some small-scale inputs and in-stream sediment traps may be useful if installed in appropriate locations and maintained. Further information is required for these methods to determine the most appropriate locations and the maintenance requirements associated with each method. Maintenance requirements for each method will likely also vary between locations depending on the rate of sediment or contaminant inputs.

5.3 Matching deposited fine sediment removal and mitigation tools to sites

We have matched potential sediment removal and mitigation tools to the list of potential trial sites in Table 5-1. Because ecologically effective removal of fine deposited sediment is likely to be highly site specific we discuss some of the factors to consider when determining the best approach to removing and/or preventing reoccurrence of deposited fine sediment for a particular site.

The factors to consider when choosing appropriate removal and mitigation tools include:

1. What is the goal of the sediment removal and what are the indicators of success? What level of sediment reduction is important and over what temporal and spatial scales? Should the project be self-sustaining or is on-going maintenance acceptable? What other values should be improved by the project e.g., better trout spawning habitat.

2. Is this the best restoration approach for this site? For example, Cashmere Stream is highly turbid after rainfall, however the suspended sediment is mostly small clay particles which are hard to settle out in detention basins (EOS Ecology 2008). Likewise, the lower Pūharakekenui/ Styx, Ōtākaro/ Avon and Ōpāwaho/ Heathcote Rivers are natural depositional zones due to the low gradient and tidal influence. The lower Pūharakekenui/ Styx River was assessed by Hicks and Duncan (1993) as being very difficult to prevent fine deposited sediment from reoccurring after dredging.

3. Is the cost of removal and any ongoing maintenance justified? For example, removal of 250,000 m^3 deposited fine sediment from the lower Pūharakekenui/ Styx was estimated to cost over $42 million, in addition to ongoing maintenance removal of 60,000 m^3 every 15 years at a cost $10.2 million. The goal of sediment removal will help identify whether this cost is justifiable. In this case, riparian planting and managed weed removal were recommended as a more cost-effective management approach (Patten 2016).

4. What are the ecological and cultural values at the site and downstream of it? How will different sediment mitigation tools impact these? Additional surveys to assess the ecological and cultural values present may be required prior to commencing sediment removal.

5. Co-development of appropriate methods and sites in conjunction with mana whenua. What methods are appropriate to the site given cultural and ecological values present?

6. What are the best methods to prevent sediment and contaminants being mobilised downstream during the removal process? Can sections of streambed be isolated from the main flow? How effective are sediment curtains or filters likely to be?

7. Assessment of the likelihood of sediment returning. Is this a historical legacy of sediment unlikely to return? Can we develop mitigation plans to reduce sources of sediment? Is this site a natural depositional zone that could be managed as a sediment trap to protect downstream locations? Or will the site become easily filled with sediment again? And what are the continued maintenance costs?

8. Assessment by ecologists of the likely ecological impacts of sediment removal on in-stream biota and whether any taxa require relocating prior to works. Also,

consideration of the best mitigation options to reduce impacts on in-stream biota during the remediation. This may include methods to contain sediment suspended by the sediment or not dredging during particular stages of sensitive species life cycles (e.g., īnanga spawning).

9. Potential re-location of sensitive taxa prior to dredging, monitoring of removed sediment to rescue biota (e.g., tuna/ eels).
10. Pre- and post-dredging monitoring of deposited sediment, biota and any other identified indicators of success to quantify project effectiveness.
11. Resource consents will be required for the sediment removal and mitigation works and may also be required for the disposal of the material.
12. Are there safe access locations to the channel? Developing these may include removing riparian vegetation or structures. Is the access on private or public land? Is there a location to temporarily store removed sediment if required?
13. Testing of contaminant levels prior to sediment disposal.
14. Fees for sediment disposal. These will be greater for highly contaminated sediment requiring specialist facilities or treatment.

Several of the points are discussed in further detail in the sections below.

5.3.1 Species present

The habitat requirements of native species and their current distribution needs to be considered when selecting sites for deposited sediment removal and when considering the best methods to use. For example, kākahi are found in sites with both stony and fine deposited sediment within the Ōpāwaho/ Heathcote River catchment (Instream Consulting Ltd 2020a). Kākahi are uncommon within Christchurch waterways and are likely to suffer high mortality if they cannot be removed from reaches undergoing remediation first. Therefore, sites with kākahi present are recommended to be low priority for deposited sediment removal (Instream Consulting 2020d). However, kākahi populations downstream of mitigation works are likely to be reasonably tolerant of short-term high suspended sediment and turbidity (Instream consulting 2020d). In some cases, the potential benefits to upstream habitat could outweigh potential impacts on kākahi populations downstream of the sediment removal zone.

Fine deposited sediment can also provide habitat for burrowing eels and juvenile kanakana and may create sinuosity and variations in water depth and velocity in modified and straightened waterways. Consideration should be given as to whether deposited sediment removal is the best improvement that can be undertaken at a particular site given the values present and the nature of the waterway.

5.3.2 Is this a legacy issue or ongoing contamination?

If a site can be confirmed as having a legacy of poor sediment quality or quantity with little current degradation, then removal without intensive source control options may be sufficient. For example, Instream Consulting Ltd (2020d) suggested that zinc concentrations in sediment samples collected from some locations in 2020 appeared to be predominantly in depositional areas that were not increasing in spatial extent or depth. Sites with ongoing inputs of deposited fine sediment or contaminants will need to be assessed for the best maintenance or source control option, such as those listed in Section 5.2. These may include riparian buffers, filters or treatments on piped inputs, and sediment traps or settling ponds.

For example, the Avon River Precinct project involved gravel cleaning and removal of fine deposited sediment (McMurtrie and James 2013). Methods to prevent the fine sediment deposits recurring included narrowing of riffles, addition of cobble habitat and native plantings in adjacent high flow plains.

5.3.3 Can removal of fine deposited sediment be done in conjunction with other restoration efforts?

The actions that prevent fine sediment deposits from recurring, such as channel narrowing and additional of floodplain plants can have additional ecological and cultural benefits. Undertaking sediment removal in conjunction with other restoration is likely to be more cost effective than doing the projects separately and may have synergistic benefits. For example, the addition of riparian vegetation in waterways near the tidal reaches may help reduce fine sediment inputs and provide spawning habitat for inanga. One of many example projects where fine sediment settlement and other restorations efforts are occurring together is the headwaters of Cashmere Stream, which has been restored by the Cashmere Stream Care Group, CCC and Environment Canterbury. The straight channel has been replaced with a meandering channel, woody debris and large rocks have been added as fish habitat and riparian plantings have been undertaken. Further downstream stormwater basins and wetlands have been added to reduce peak flows and allow sediment to settle prior to discharge.

5.3.4 Linking trial sites to methods

In Table 5-1 we link the potential trial sites to potential methods that could be used to remove deposited fine sediment and prevent it recurring. In linking the sites and methods, we firstly included sites with a range of different fine sediment issues (contamination and percentage cover of the streambed) and with a range of physical conditions such that different removal and mitigation methods could be trialled. Secondly, we considered whether removal of fine deposited sediment was the best restoration action for each particular site based on:

- The impacts to existing biota and cultural values of removing fine deposited sediment.
- The potential for fine sediment deposition and/or contamination to recur.
- Whether the removal will have long-term benefits for ecological and cultural values.

Further discussion of the specifics of the sites and methods, particularly with mana whenua, is required before any of the listed methods should be trialled at the suggested sites.

Table 5-1: Potential sediment removal and mitigation options for the identified trial sites and important considerations.

Site	Size	Sediment issues	Sediment removal options	Sediment mitigation options	Considerations
Curletts Stream	Small	Low sediment cover High zinc and copper	For a short reach consider the SandWand and manual removal. For a longer reach a small excavator.	Good source control of contaminants required. Filters on pipes and sumps and swales in industrial area, education to local businesses, investigate effectiveness and removal of contaminants in upstream stormwater basins.	Methods to prevent downstream movement of contaminated sediment. Limited ecological values in the drain but the Heathcote downstream supports kākahi, kōura and uncommon fish species. Traffic management required for busy roads. Opportunity to remediate entire reach from stormwater basins to the Ōpāwaho/Heathcote (~500 m)
Ōpāwaho/Heathcote in Spreydon Domain	Med.	Localised high sediment cover High zinc	Bankside excavator or mini vacuum dredge if deep enough	Investigate the potential for sediment trap. May already be a natural sediment trap and could be maintained as such.	Protect downstream trout spawning locations. Need to prevent contaminants moving downstream during removal
Hendersons Drain	Small	High sediment cover	Small bankside excavator	Continue riparian planting or channel modifications undertaken upstream to increase water velocity. Instream sediment traps and good source control.	Potential to link upstream restored sections to the Ōpāwaho/ Heathcote. Protect kōura and kākahi downstream
Ōpāwaho/Heathcote at Hunter Terrace	Large	Very high localised sediment cover Moderate zinc and PAH	Bankside or in-stream excavator	Investigate the potential for sediment trap. May already be a natural sediment trap and could be maintained as such.	Channel modifications have increased water velocity upstream. This may naturally be a depositional zone.
Ilam Stream	Small	Very high cover High lead, zinc and PAH	Bankside excavator	Filters on key road sumps or input pipes to reduce contaminant input if possible.	Protect trout spawning downstream. Contain contaminated sediment.

Site	Size	Sediment issues	Sediment removal options	Sediment mitigation options	Considerations
Waimari Stream	Small	High sediment cover High PAHs	Bankside excavator	Filters on key road sumps or input pipes to reduce contaminant input if possible.	Protect trout spawning and kākahi downstream. Contain contaminated sediment. Potentially dries in some locations.
Addington Brook	Small	Patchy sediment cover High zinc	Small bank-side excavator or SandWand if high cover reaches are short	Potential for channel modifications in conjunction with planned restoration. Consider a two-stage channel.	Good site for public education and signage about waterway health and reducing contaminant inputs.
Pūharakekenui/Styx upstream of Gardiners Road/Styx Mill Road intersection	Small	High sediment cover Moderate zinc	Small bank-side excavator	Consider mitigations that reduce run-off from construction as urbanisation proceeds in the catchment. Riparian planting and bank protection.	

6 Recommendations and future steps

In this report we provided a list of potential trial sites where a range of different sediment removal and mitigation methods could be trialled. In addition, we provided the 1) rationale used to identify sites, 2) tidied and compiled datasets of data provided by CCC and 3) interactive maps of key variables associated with fine deposited sediment quality and quantity, ecological and mana whenua values and indicators of the potential for a site to mobilise fine sediment.

Below we assess the feasibility of undertaking trials of different methods of deposited sediment removal to investigate their potential to improve instream habitat and ecological values and provide recommendations.

A robust assessment of the feasibility of removing or mitigating fine deposited sediment in Ōtautahi/ Christchurch waterways to enhance ecological outcomes requires a definition of the desired outcomes of such work and an understanding of 1) the likelihood of meeting those outcomes, 2) the logistical and financial considerations of undertaking the work 3) the maintenance requirements to maintain outcomes and 4) the balance of the long-term gains versus any shorter-term impacts. While some of the logistical and financial considerations are comparatively well understood from historical dredging projects, much of the other knowledge required to make such assessments is currently lacking for Ōtautahi/ Christchurch waterways and will be highly site-specific (see Section 5.3).

We propose that work is undertaken to fill some of these knowledge gaps to allow more robust assessments of the feasibility of undertaking efficient and effective mitigations of the ecological impact of fine deposited sediment depending on factors such as the size of the waterway and sediment issues present. Below we provide 1) general recommendations for the factors that need to be considered when undertaking trials of sediment removal or mitigation (Section 6.1) and 2) based on identified key knowledge gaps we provide recommendations for two methods to gather data to fill these gaps as well as details for two potential trials of deposited fine sediment removal and mitigation from Ōtautahi/ Christchurch waterways (Section 6.2).

6.1 General considerations

During our data compilation and identification of potential trial sites we note that our ability to determine key sources of inputs of fine sediment to the waterways and the ability for specific reaches to mobilise fine sediment was limited by:

1. Limited data available on the main sources of deposited fine sediment inputs and contaminants into the waterways, and
2. The fact that the slope of waterways across the non-hill slope regions of Christchurch is predominantly very low, making it difficult to distinguish potential depositional and mobilisation zones using the data that were available.

In addition, because the following factors impact the design of effective removal of fine deposited sediment, and will be site and project specific we recommend the following further steps are undertaken before undertaking trials at any of the suggested sites:

1. Development of carefully defined goals and indicators of success for any trials. For example, is the goal to trial one or multiple different methods? What is an appropriate spatial scale for mitigation? What are the key indicators of success and how will these

be monitored before and after the trial? What on-going maintenance of deposited fine sediment or contaminants is acceptable?

2. Once the goals of the trials are determined then specific sites can be assessed for their suitability depending on the sedimentation issues and ecological and cultural values present, as well as practical considerations such as access to the site and locations to store removed sediment, if required.
3. Co-development of the goals and indicators of success and in assessing the appropriateness of identified sites and proposed methods with mana whenua.
4. Consideration of current and future restoration or mitigation projects and whether sediment removal trials could be undertaken as part of these.
5. Assessment of the financial cost requires decisions on the goals of the project, specific locations and methods, the spatial scale of removal, on-going maintenance and potential disposal fees of the removed sediment.

6.2 Recommendations for feasibility assessments

In this section we make some assumptions for the questions listed above and provide our recommendations for the next steps in trials of deposited fine sediment removal and mitigation tools.

Fine sediment removal, particularly using dredging, has historically been used as a method of flood control rather than to improve instream habitat and ecological values. This results in key gaps in knowledge when determining if the methods lead to lasting ecological benefits. Such gaps include:

1. Can deposited fine sediment cover be reduced to levels likely to be ecologically meaningful (Burdon et al. 2013 identify a threshold of 20% cover over which ecological impacts are more likely)?
2. What are the rates of re-sedimentation following deposited fine sediment removal?
3. How variable are re-sedimentation rates in different locations and can any influential factors be readily identified? (such as channel size and slope, upstream sediment sources etc). Note, that identifying upstream sediment sources was difficult in this project due to the multitude of ways fine sediment could enter the waterways.
4. What are the maintenance requirements to sustain low or target deposited sediment levels and/or contaminant concentrations? Particularly for methods such as sediment traps. How much do these vary between locations?
5. Are any ecological improvements observable? If so, in which type of taxa and over what time scales?

Many of the answers to these questions are likely to be specific to the removal method and to the location in the waterway where the removal is undertaken, particularly the network location of the site (headwater or further downstream), channel slope and any upstream sediment sources and sources of potential recolonist taxa.

We recommend gathering data to inform these knowledge gaps and allow more robust site-specific feasibility assessments by:

1. Monitoring deposited sediment levels in areas that have previously had deposited fine sediment removed. Ideally data on deposited sediment cover, depth and/or particle size would be available prior to the removal activities. However, time series of deposited sediment cover depth and/or particle size beginning after removal would provide information about potential re-sedimentation rates. These data would complement data from any new removal trials, which may be limited in number by financial considerations. Ecological data for taxa that might be predicted to increase after deposited sediment removal could also be collected. However, this data collection will be more expensive than monitoring deposited fine sediment cover and/or contamination and should be targeted to taxa that are most likely to respond, such as mobile fish taxa or macroinvertebrates, if there are nearby sources of potential colonists of new or sensitive taxa. Initial collation of existing deposited fine sediment, contaminant and ecological values from sites where deposited fine sediment has been removed is also recommended.
2. Conducting deposited sediment removal trials specifically designed to answer some of the key knowledge gaps identified above. We provide further recommendations for these below.

In providing recommendations for preliminary sediment removal trials we make the following assumptions:

1. Trialling multiple sediment removal and mitigation methods would provide useful data. Due to limitations with small-scale removal techniques such as the SandWand we recommend trialling excavator dredging and a sediment trap. Further trials of the Dino-6 vacuum dredge could also be considered but are not explicitly discussed here.
2. Evidence from dredging trials in smaller, non-tidal waterway reaches would supplement the data available (or able to be collected) from historic dredging operations which were predominantly in the lower tidal reaches of the larger rivers, but also in the non-tidal reaches of the Ōpāwaho/Heathcote and Ōtākaro/ Avon Rivers. Data on the efficacy of a sediment trap in a non-tidal medium-sized mainstem site is also lacking currently.
3. A limited number of trials is more economically viable than larger-scale replicate trials of different methods in different locations. Conducting trials in a variety of locations that differ in their position in the catchment, in the magnitude of fine sediment inputs and contaminants, in channel size and in the types of taxa present as well as their proximity to a source of taxa to colonise a remediated area would assist in understanding the mechanisms leading to variable rates of re-sedimentation and ecological improvement following deposited fine sediment removal. However, if financial considerations limit the number of trials that can be conducted, then selecting widely applicable methods and locations that are likely to be representative of other areas where the method could be used would be beneficial.
4. Key indicators of success of sediment removal trials are a decrease in deposited fine sediment cover and/or contaminants. Secondary indicators of success are improvements in biological communities. Mana whenua should be consulted for additional key indicators of success and metrics that record these included in monitoring plans.

Following these assumptions we recommend:

Trialling excavator digging to remove deposited fine sediment at the Curletts Drain site (see 4.3.1), where sediment contamination is the key issue. This site is relatively small, high in the catchment and ideally contaminant and sediment inputs to the site could be reduced through the upstream stormwater detention basins and by education and end-of pipe treatment options from the industrial area into the waterway. Traffic management would need to be considered for Curletts Road to allow excavator access and ecological assessments and potentially relocation of sensitive taxa from the area also required.

Trialling a silt trap in the Heathcote River mainstem, perhaps in Centennial Park, Hunter Terrace (Section 4.3.2) or a similar location with good site access and localised high cover of deposited sediment (i.e., a natural depositional zone). The final location should not have high abundances of kākahi. Ecological assessments of the taxa present in the site and potentially relocation of sensitive taxa prior to construction would be required, if feasible.

Other sites that meet criteria for good access, non-tidal, small to medium size and with both contaminant and deposited sediment quantity issues could replace the sites we have identified above. The CCC may also consider different rationales when determining priority sites for trials of methods to remove or mitigate fine deposited sediment. The datasets and maps provided can be used to identify alternative trial sites, if required.

Regardless of the exact sites chosen, the key requirement that will improve the usefulness of any removal and remediation trials is monitoring of key indicators of success (at a minimum deposited sediment cover and contaminant concentrations (if relevant)) both before and repeatedly after initiation of the trials. Longer-term monitoring (up to multiple years after the trials) will enable collection of data to inform potential rates of re-sedimentation, and the maintenance requirements for both removal locations and sediment traps.

6.3 Overall commentary

The objective of this project was to undertake an assessment of the feasibility of techniques for mitigating the impacts of stormwater sediment discharges on receiving environments.

During the process of undertaking the project we identified several factors that created uncertainty in our feasibility assessment. These included knowledge gaps such as what is the required magnitude of reduction in fine deposited sediment cover or contamination to result in improvements in different target ecological or cultural outcomes, how quickly different locations are likely to have fine deposited sediment and contamination recur, and what maintenance is required to continue meeting target outcomes in different locations.

These gaps limited our ability to undertake a robust assessment of the feasibility of removing or mitigating fine deposited sediment in Ōtautahi/ Christchurch waterways to enhance ecological or cultural outcomes. Instead, we provide:

- Interactive maps that can be used to visualise overlap of ecological and cultural values with fine deposited sediment cover and contamination by the CCC to identify priority locations dependent on target values,
- A list of preliminary sites with problematic fine deposited sediment cover and/or contamination to trial different removal or mitigation tools in,

- A brief assessment of the feasibility of using different methods in Ōtautahi/ Christchurch waterways, with links to the sites identified above,
- A list of general considerations when assessing the feasibility and developing trials of fine deposited sediment removal and mitigation methods for specific target outcomes,
- Recommendations for approaches to fill some of the identified knowledge gaps preventing robust feasibility assessments,
- Recommendations for trials of one method each for deposited fine sediment mitigation and removal that will provide data to fill key knowledge gaps.

Our recommendations for collation of existing data from locations where deposited fine sediment removal has been undertaken, targeted collection of new data in both previous and future projects removing deposited fine sediment and the trials of dredging in a smaller, headwater site and sediment trap in a mainstem river sites will assist in filling some of these knowledge gaps. If trials of the methods are carefully designed, and maintained we hope that they will provide good ecological and/or cultural outcomes as well as providing the data required to make more robust assessments of the feasibility of different methods of fine deposited sediment removal and mitigation meeting target outcomes.

We recommend an iterative approach to designing a larger programme of projects that aim to remove or mitigate deposited fine sediment from the city's waterways. As increasing knowledge is collected and compiled about the feasibility of different methods in different locations for meeting different target outcomes, more effective future projects can be designed. Monitoring the success of existing and future projects in meeting target outcomes and identifying the maintenance requirements to keep meeting them is key to this process.

7 Acknowledgements

We would like to thank Rose Kuru and Ruby McKenzie Sheat for compiling mana whenua values data from relevant reports. Emily Moore from Fish and Game provided information on the SandWand trial in Wairarapa Stream. We are grateful for the very helpful discussions and wealth of local knowledge provided by the attendees at our workshop from CCC, EOS Ecology, Instream Consulting Ltd, Mahaanui Kurataiao Ltd, Environment Canterbury and SCO Consulting. We thank Katie Noakes, Florian Risse, Greg Burrell, Kirsty Patten and Dr Belinda Margetts (previously CCC) for helpful discussions and scoping of this work.

8 References

ANZECC (2000) Australian and New Zealand guidelines for fresh and marine water quality. Volume 1: The guidelines. Australian and New Zealand Environment and Conservation Council, ANZECC, and Agriculture and Resource Management Council of Australia and New Zealand, ARMCANZ, Artarmon, New South Wales.

Boffa Miskell (2017) Avon River Precinct aquatic ecology. Three years' post-rehabilitation activities. Report prepared by Boffa Miskell Limited for the Christchurch City Council.

Boffa Miskell (2020) Avon River Precinct aquatic ecology. Six-year post-rehabilitation activities. Prepared for Christchurch City Council.

Boffa Miskell Limited (2022) Ōtūkaikino and cashmere monitoring 2022: five yearly and annual aquatic ecology monitoring. Report prepared by Boffa Miskell Limited for Christchurch City Council.

Burdon, F.J., McIntosh, A.R., Harding, J.S. (2013) Habitat loss drives threshold response of benthic invertebrate communities to deposited sediment in agricultural streams. Ecological Applications. 23: 1036-1047.

Christchurch City Council (2016) Ōpāwaho/Heathcote River catchment tauākī wai pātua / visions and values. Prepared by Opus International Consultants Ltd.

Collier, K. J. (2008) Average score per metric: an alternative metric aggregation method for assessing wadeable stream health. New Zealand Journal of Marine and Freshwater Research, 42(4), 367- 378.

Dunn, N.R., Allibone, R.M., Closs, G.P., Crow, S.K., David, B.O., Goodman, J.M., Griffith, M., Jack, D.C., Ling, N., Waters, J.M., Rolfe, J.R. (2017) Conservation status of New Zealand freshwater fishes, 2017. New Zealand Threat Classification Series 24. Department of Conservation.

EOS Ecology (2008) Sources of sediment input into Cashmere stream. Prepared for Environment Canterbury. EOS Ecology Report No: 08031-ENV01-01.

EOS Ecology (2011) Christchurch February Earthquake: effect on aquatic invertebrates. Prepared for Environment Canterbury and Christchurch City Council. EOS Ecology Report No: 11010-CIV01-01.

EOS Ecology (2015) Dudley Creek flood remediation: ecological condition of lower Dudley Creek. Prepared for BECA. EOS Ecology Report No: BEC01-15015.

Gadd, J., Sykes, J. (2014) Avon River Sediment Survey. Prepared for Christchurch City Council. NIWA report no. AKL2014-004.

Gadd, J. (2015) Sediment quality survey for Heathcote River catchment, City Outfall drain and Estuary Drain. Prepared for Christchurch City Council. NIWA report no. AKL-2015-021.

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

Harding, J.S., Jellyman, P.J. (2015) Earthquakes, catastrophic sediment additions and the response of urban stream communities. New Zealand Journal of Marine and Freshwater Research. 49: 346-355.

Hicks, D.M., Duncan, M.J. (1993) Sedimentation in the Styx River catchment and Brooklands lagoon. NIWA. Miscellaneous report No. 128.

Hicks, D.M. (1993) Sedimentation and erosion in the Avon-Heathcote catchment and estuary. Prepared for Canterbury Regional Council and Christchurch City Council. NIWA. Miscellaneous report No. 27.

Instream Consulting Ltd (2018) Styx River catchment aquatic ecology 2018. Prepared for Christchurch City Council.

Instream Consulting Ltd (2019) Avon River catchment aquatic ecology 2019. Prepared for Christchurch City Council.

Instream Consulting Ltd. (2020a) Kākahi in Cashmere Stream: distribution and current state of the population. Prepared for Christchurch City Council. 19 p.

Instream Consulting Ltd. (2020b) Effects of Ōpāwaho / Heathcote River dredging on turbidity. Prepared for Christchurch City Council. 17 p.

Instream Consulting Ltd (2020c) Heathcote River, Linwood Canal and Banks Peninsula aquatic ecology 2020. Prepared for Christchurch City Council.

Instream Consulting Ltd (2020d) Kākahi (Freshwater mussels) in Christchurch waterways. Prepared for Christchurch City Council.

Instream Consulting Ltd (2021a) Christchurch aquatic ecology monitoring 2021. Prepared for Christchurch City Council.

Instream Consulting Ltd. (2021b) Prioritisation of fish barriers for remediation in Christchurch. Prepared for Christchurch City Council. 40 p.

Instream Consulting Ltd (2021c) Kākahi (Freshwater mussel) monitoring in Christchurch City. Prepared for Christchurch City Council. 30 p.

James, A. (2013) Memorandum – Aquatic assessment of environmental effects of liquefaction sand removal and gravel cleaning in the Avon River Precinct (ARP). EOS Ecology Job No. 13067-OPU01.

James, A., McMurtrie, S. (2015) River enhancement: is it possible to create self-sustaining clean gravel habitat? EOS Ecology. NZFSS Conference presentation. November 22 – 25. Wellington.

Lang, M., Orchard, S., Falwasser, T., Rupene, M., Williams, C., Tirikatene-Nash, N., Couch, C. (2012) Cultural health assessment of the Avon-Heathcote estuary and it's catchment. Mahaanui Kurataiao Ltd.

McMurtrie, S., James, A., Meurk, C. (2013) Avon River Precinct, North & East frames ecology report – turning aspiration into action. EOS Ecology, Christchurch, New Zealand. EOS Ecology Report No. 12033-OPU01-01. 86 p.

Mahaanui Kurataiao Ltd. (2023) Ōtūkaikino monitoring report. Mahaanui Kurataiao Ltd

Orchard, S., Sarson, R., Lang, M., Falwasser, T., Rupene, M., Williams, C., Tirikatene-Nash, N. (2012) State of the Takiwā 2012 Puharakekenui. Cultural health assessment of the Puharakekenui/Styx River, Te Riu o Te Aika Kawa/Brooklands Lagoon and catchment. Mahaanui Kurataiao Ltd.

Pauling, C., Lenihan, T.M., Rupene, M., Tirikatene-Nash, N., Couch, R. (2007) Te Āhuatanga of Te Ihutai: cultural health assessment of the Avon-Heathcote Estuary and it's catchment. Te Rūnanga o Ngāi Tahu. 72p.

Patten, K. (2016) Review of dredging past practice and current considerations. Christchurch City Council.

Skews, R.A. (2021) Mechanisms of dissolved Zn and Cu retention by mussel shells in a rapid-flow stormwater treatment system. Master of Water Resource Management thesis. University of Canterbury.

Stark, J.D., Maxted, J.R. (2007) A user guide for the Macroinvertebrate Community Index. Prepared for the Ministry for the Environment. Cawthron Report No. 1166.

Taylor, M., Marshall, W. (2013) Silt removal trial from Wairarapa Stream, 12 April 2013. Report prepared for Environment Canterbury. Aquatic Ecology Ltd. Report No. R13/117

Tipa, G., Tierney, L. (2003) A Cultural Health Index for streams and waterways: indicators for recognising and expressing Māori values. Ministry for the Environment, Wellington.

Tonkin and Taylor Ltd. (2020) Annual aquatic ecology monitoring: Styx River, Cashmere Stream and Balguerie Stream. Prepared for Christchurch City Council. Job Number 1013562. V1.

Zeldis, J., Skilton, J., South, P., Schiel, D. (2011) Effects of the Canterbury earthquakes on Avon-Heathcote Estuary / Ihutai ecology. Report No. U11/14. Report prepared for Environment Canterbury & Christchurch City Council. 27 p

Appendix A Compiled datasets provided to CCC

File name	File type	Data included	Notes
Ecology_data.xlsx	Excel file	Sheets for: ecology_sites, Instream_habitat, Wq_flow_habitat, Sediment_lab_results Macroinvertebrate indices Macroinvertebrates, bank_riparian_habitat, water_velocity, macrophytes_periphyton, Fish_data	Includes original file data was extracted from. Compiled from most recent five yearly and annual ecology sampling programme from data provided by CCC for Ōpāwaho/ Heathcote, Ōtākaro/ Avon, Pūharakekenui/ Styx, Ōtūkaikino, Huritini/ Halswell and Banks Peninsula catchments
Monthly_water_quality.xlsx	Excel file	Sheets for: wq_sites, monthly_wq	Site locations and tidied data from monthly water quality dataset provided by CCC
Monthly_water_quality	Shape file	Shape file to allow visualisation of locations of monthly water quality sites	
Ecology_data	Shape file	Shape file to allow visualisation of locations of ecology data sites	
Readme	Text file	Brief explanation of how to join the shape files to the data in the datasets.	The shape and data files were not joined as there were commonly multiple data rows associated with each site (e.g., sampling dates or transect points).
Collating_ccc_data_html	Internet file	Summarises the data tidying process and provides visualisations and tables of the resulting data.	

Appendix B Sites containing sensitive species: Waterway species database

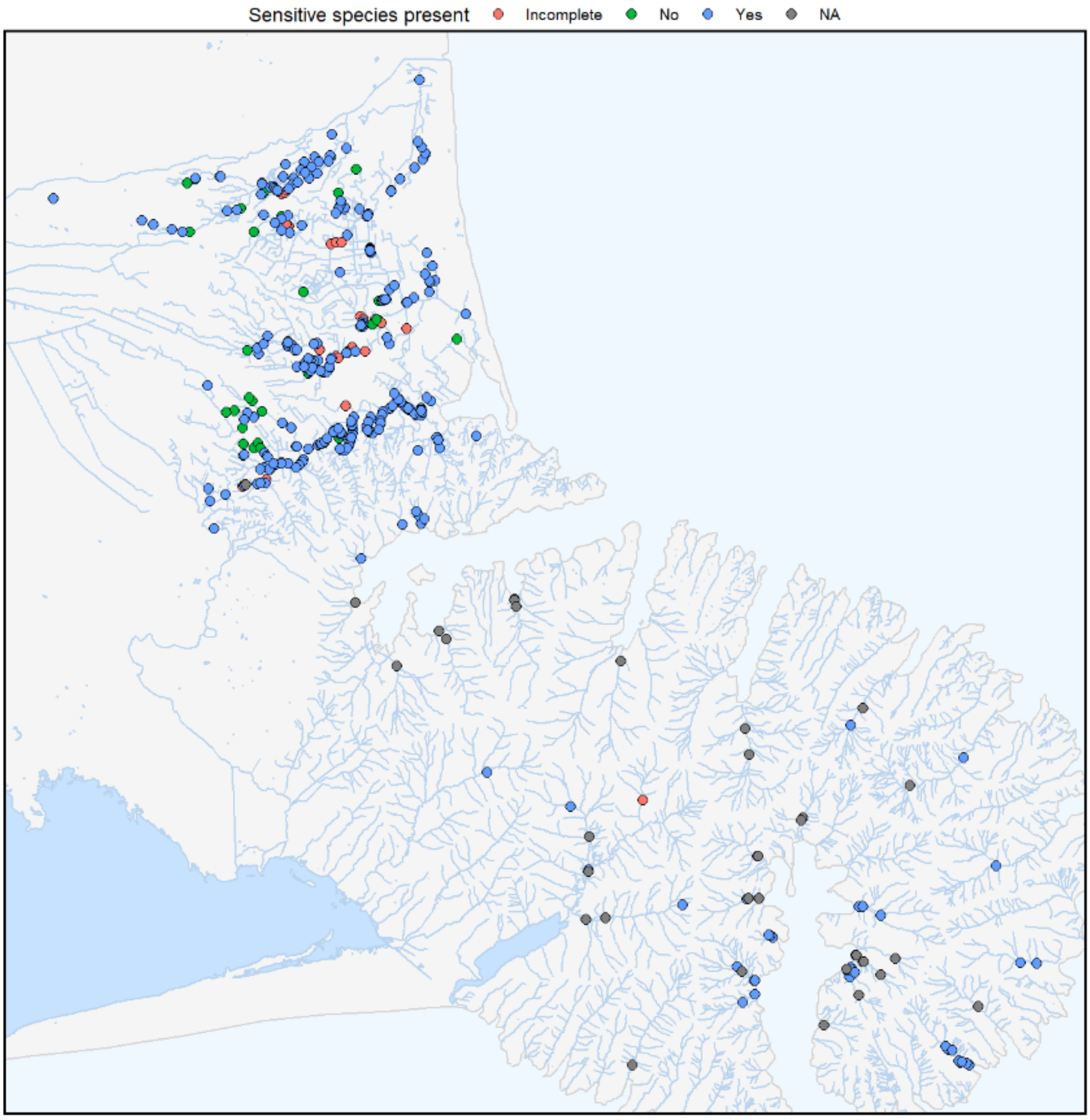

Figure B-1: Locations of sites from the Waterway Species Database that contained site co-ordinates, had records less than 10 years old and contained sensitive species. Data are compiled from various reports and the New Zealand Freshwater Fish Database. Sensitive species were assessed as the presence of threatened or at-risk fishes, kōura, kākahi or an MCI/QMCI score of 'excellent'. "Incomplete" refers to sites that were assessed for either macroinvertebrates or fishes, not both. "NA" indicates sites at which these data were not available but were included in the database.