Pūharakekenui Styx River Weed Management

Cost Benefit Analysis for Schedule 4S-4T of CRC252424
Prepared for Christchurch City Council

27 June 2025

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Executive Summary

Pūharakekenui / Styx River, located in Ōtautahi / Christchurch, is spring-fed, low-lying and prone to flooding. Christchurch City Council (CCC) is mandated to manage flooding effectively as part of the comprehensive stormwater network discharge consent (CSNDC; CRC252424). This report summarises findings and recommendations from assessments conducted by Boffa Miskell to address Schedule 4 Items S, T, and U of the consent conditions.

Four control methods were evaluated: hessian matting, aquatic herbicide application, mechanical cutting, and riparian shading. Each method was assessed for how effective it was in reducing macrophyte biomass in mitigating flood risks. The ecological and regulatory considerations for each control method were also discussed. Macrophyte control can provide ecological benefits, but certain control methods can cause environmental impacts on fauna. Planning requirements and resource consents also need to be assessed to ensure compliance with current environmental regulations.

Hydrological modelling assessed flood scenarios for the four control methods. All control methods showed flood risk reduction compared to not undertaking any control, with hessian matting demonstrating the highest efficacy, followed by aquatic herbicide and riparian shading. Mechanical cutting showed the least reduction in flooding.

To compare costs and benefits, a Cost Benefit Analysis approach was used to compare the costs associated with each method over 50 years. Hessian matting was found to be the most expensive option at $6,906,707, while aquatic herbicide application was the least costly at $406,440 (both Net Present Value). However, despite its higher cost, hessian matting was the most effective in flood reduction due to the certainty of control and its ability to be deployed in all conditions.

A cost-effectiveness analysis was undertaken to compare the relative performance of each control method against the area of land removed from the floodplain as a result of the modelling results. This analysis showed that the application of herbicide is the most cost-effective method, and hessian matting is the most expensive.

Using a multi-criteria analysis (MCA) further enabled the evaluation of the four control methods, taking into consideration non-monetised costs and benefits such as deployment effectiveness, ecological impacts, and floodplain effects. The MCA evaluation tested a range of weighting scenarios, with riparian shading and hessian matting consistently ranking highest overall.

We provide recommendations for future trials, including trialling the use of hessian matting as a short- to long-term control method, used in conjunction with riparian shading as a preventative solution to managing excessive growth of macrophytes to mitigate flooding in Pūharakekenui / Styx River.

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1.0 Introduction

1.1 Background

In December 2019, the Canterbury Regional Council (ECan) granted CCC a comprehensive stormwater network discharge consent (CSNDC; CRC252424) to discharge water and contaminants to land and water from the stormwater network. As part of this global consent, CCC is required to carry out several actions relevant to Pūharakekenui / Styx River weed management (as listed in Schedule 4, Items R-X of CRC252424).

Boffa Miskell was engaged by CCC to assist with Schedule 4 Items S, T and U of the CSNDC, building on work previously completed by NIWA (Item R) (Matheson et al., 2022; Matheson & Clements, 2020).

1.2 Consent decision and conditions

The requirements of Schedule 4 Items R-X of the CSNDC (CRC252424) are set out in Table 1 below.

Table 1. Schedule 4, Items R-X of CSNDC (CRC252424) and the section of the report that addresses each of these items.

Pūharakekenui /Styx River Weed Management	**Section of this report**
r. Investigate the degree to which various options in river channel weed (macrophyte) management practices mitigate flood effects on the Pūharakekenui /Styx River under a range of river flow scenarios. Factors to be considered shall include: (i) International weed management practices in similar settings; and (ii) The factors which promote or suppress growth of the specific prolific weed species in the Pūharakekenui /Styx River, including sediments, dry weather flows, stormwater discharges covered by the resource consent, other discharges, shading and climatic factors.	Previously completed by NIWA Section 2.0
s. Based on the results of the investigation under Item (r) above, and through engagement with Canterbury Regional Council, the Consent Holder shall identify the best practicable options for mitigating flooding through river channel weed management. Factors to be considered shall include: (i) A range of river flow scenarios including dry weather (spring-fed) flows and storm flows where operational/maintenance management will be beneficial; (ii) A range of river channel operational/maintenance management scenarios (iii) Flooding effects including level, extent and duration; (iv) Available technical knowledge; (v) Potential for practical implementation of options;	Section 3.0

Pūharakekenui /Styx River Weed Management	Section of this report
(vi) Costs for implementing options; (vii) Available regulatory mechanisms; (viii) Consideration of ecological effects; and (ix) Consideration of overlapping powers and responsibilities between Canterbury Regional Council and Christchurch City Council under other legislation.	
t. Conduct a cost/benefit analysis of the identified best practicable options for carrying out a targeted trial for achieving reduced flooding from changes in the weed management of the Pūharakekenui/Styx River.	Section 4.0
u. Determine the best approach to incorporating the variable weed condition within the Pūharakekenui/Styx River hydraulic model and resulting design flood scenarios.	Section 3.0
v. Test the Pūharakekenui/Styx River model calibration against other storm events, as they arise, to calibrate/validate model sensitivity to varying weed conditions.	Not addressed in this report
w. Apply, through engagement with the Canterbury Regional Council, the results of the cost/benefit analysis in a targeted trial for the selected best practicable options for weed management of the Pūharakekenui/Styx River river channel.	Not addressed in this report
x. If the Consent Holder determines it warranted as a result of the trials in Item (w) above, implement the selected best practicable option within the Pūharakekenui/Styx River Area SMP.	Not addressed in this report

1.2.1 Agencies: interests and responsibilities

Environment Canterbury (ECan) is the regional council for the Canterbury region in the South Island of New Zealand. ECan is responsible for a wide variety of functions, including regional biosecurity, river engineering, environmental monitoring and investigations, regional policy and planning, and considering applications for certain resource consents – land use consents (including beds of waterbodies), coastal permits, water permits, and discharge permits. ECan is responsible for ensuring that CCC fulfils its consent requirements.

CCC is the territorial authority for Christchurch in New Zealand. Initially focused on sanitation, the Christchurch Drainage Board shifted its priority to mitigating flood risks under the Christchurch District Drainage Act 1951. CCC is the Consent Holder for the CSNDC (CRC252424) and is responsible for fulfilling the consent requirements.

1.3 Geographic scope

The focus area for the scope of work is the c.14.6 km reach of Pūharakekenui / Styx River from Redwood Springs downstream to the tide gates (Figure 1). This is the area within which the estimated costs and benefits arising from the proposed control methods have been calculated.

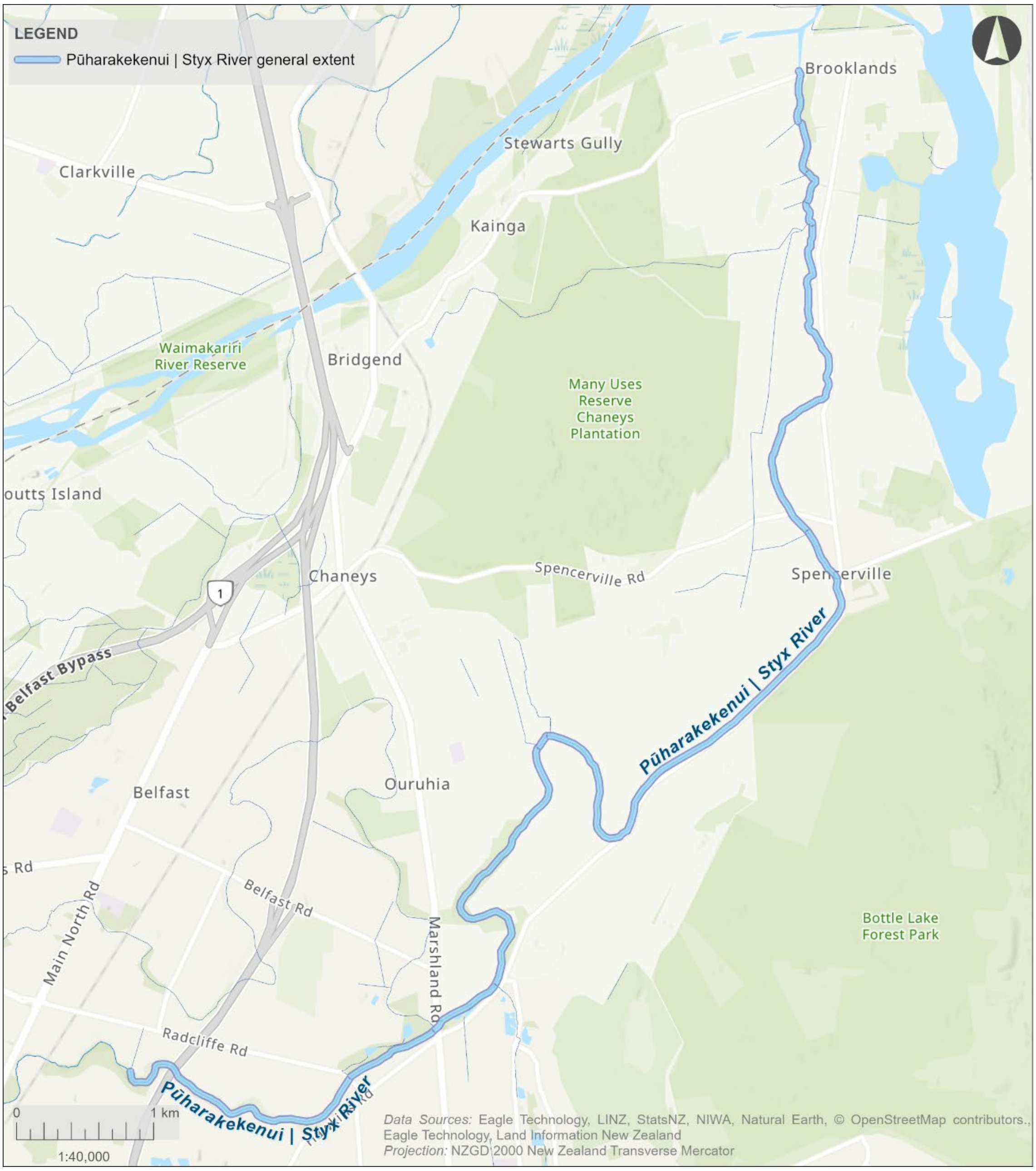

Figure 1. Map showing the c.14.6 km reach of the Pūharakekenui / Styx River mainstem from Redwood Springs downstream to the tide gates. The study reach is shown by the dark blue river line.

2.0 How weed management practices mitigate flood effects on Pūharakekenui / Styx River

NIWA was contracted by CCC in September 2020 to investigate the impediment of drainage by excessive aquatic weed (macrophyte) growth. This previous work was undertaken to fulfil **Schedule 4 Item R**, which states: *Investigate the degree to which various options in river channel weed (macrophyte) management practices mitigate flood effects on the Pūharakekenui/Styx River under a range of river flow scenarios*. NIWA undertook an assessment of various options for managing river channel weed to mitigate these effects (Matheson & Clements, 2020).

Mattheson & Clements (2020) identified the following key findings:

- *Potamogeton crispus* (curly leaf pondweed) and *Elodea canadensis* (Canadian pondweed) are the prevalent weed species in the river.
- The potential weed management options considered were mechanical harvesting, riparian shading, aquatic herbicides, nutrient limitation, grass carp and periodic saline intrusion.
  - Mechanical harvesting has been the primary method of nuisance weed control in Pūharakekenui / Styx River since the 1990s, but in recent years has been found to be less effective.
  - Diquat and riparian shading are considered to have the greatest potential to contribute to more effective weed management in the Pūharakekenui / Styx River system.
  - Nutrient limitation, grass carp and periodic saline intrusion were unlikely to be suitable weed management methods.
- An investigation scope comprising the following was proposed:
  - Delimitation of the weed nuisance.
  - Review of the weed harvest operation.
  - Diquat efficacy trial.
  - Riparian shade evaluation.
  - Water, sediment and climate effects.

NIWA proposed and designed efficacy monitoring protocols for this project from November 2020 to May 2021.

Boffa Miskell was separately engaged by CCC to test the effectiveness of diquat in March 2022. This work aimed to test the efficacy of diquat in controlling curly leaf pondweed and Canadian pondweed within a designated site in the lower Pūharakekenui / Styx River. NIWA undertook monitoring following the work to understand the efficacy of diquat treatment on these two macrophyte species, and the subsequent effects on water quality and flow to fulfil the requirements of Schedule 4 Item R.

NIWA published the findings of the investigation and monitoring in an interim report in July 2021 and a final report in July 2022 (Matheson et al., 2022).

Key findings of the Matheson et al. (2022) report included:

- Increasing water levels and, therefore, risk of flooding in the lower Pūharakekenui / Styx River is most likely due to a trend of increasing baseflow discharge, potentially exacerbated by increased flow impedance caused by aquatic weed and sediment accrual.
- The aquatic weed, *Egeria densa* (or egeria), is present in the nearby Avon River where the weed harvester also operates. There is a substantial risk that this plant may be transferred to Pūharakekenui / Styx River as fragments on the harvester, and this requires immediate action to reduce the potential for the establishment of the species.
- Riparian planting to increase shade of the river is expected to reduce aquatic weed growth generally and increase conveyance of the channel, mitigating flood risk even when higher discharges occur. Adding 10 meters of dense riparian vegetation[1] in width and height would significantly decrease weed accumulation over much of the river's length. Additional riparian vegetation should be achieved as dense plantings of evergreen natives, to achieve high and consistent shading levels as well as contribute to indigenous biodiversity.
- Diquat application resulted in a small reduction in weed nuisance, but trial conditions were not ideal, and further evaluation may reveal greater efficacy. It is unlikely that the diquat application achieved a sufficient concentration and exposure time to achieve effective weed control. Matheson et al. (2022) recommended repeating the trial under stable flow conditions, and further trials should include higher resolution measurements of diquat, enabling rates of diquat concentration achieved after application to be determined over time.

Several recommendations were also provided by NIWA following the investigation. Of these recommendations by NIWA, the following is relevant to the scope of work to fulfil Schedule 4 items S, T and U of the CSNDC:

- Increase riparian plantings to a height equal to the wetted width in more open sections of the river, ideally on both banks, ensuring plantings create a dense screen.

Note that this work was not intended to cover Schedule 4 Item W: Identifying the best practicable options for weed management. This item is discussed in Section 8.0.

Schedule 4 Item S requires the CCC to identify the best practicable options for mitigating flooding through river channel weed management, with factors to be considered including:

(i) A range of river flow scenarios including dry weather (spring-fed) flows and storm flows where operational/maintenance management will be beneficial;
(ii) A range of river channel operational/maintenance management scenarios
(iii) Flooding effects including level, extent and duration;
(iv) Available technical knowledge;
(v) Potential for practical implementation of options;

[1] All references to riparian vegetation throughout this report should assume a minimum height of 10 m and minimum width of 10 m. For the Pūharakekenui / Styx River specifically Matheson et al. (2022) recommended dense plantings that are at least as high as the river's wetted width to achieve sufficient shading (average 70% shaded) for the control of nuisance weeds. For the purposes of consistency in this desktop modelling exercise, we have opted to use the value of 10 m for riparian vegetation, which would be sufficient to achieve the 1:1 ratio at open-canopy locations (Matheson et al., 2022).

(vi) Costs for implementing options;
(vii) Available regulatory mechanisms;
(viii) Consideration of ecological effects; and
(ix) Consideration of overlapping powers and responsibilities between Canterbury Regional Council and Christchurch City Council under other legislation.

2.1 Macrophyte control methods

The following sections provide a summary of four macrophyte control methods, the differing efficacy of these, and ecological and regulatory considerations.

2.1.1 Efficacy of control method

This section explores the following items of Schedule 4 Item S:

(ii) A range of river channel operational / maintenance management scenarios.

(iv) Available technical knowledge.

(v) Potential for practical implementation of options.

The control methods described below are primarily based on the findings from NIWA under Schedule 4 Item R, with some additional recommendations made by Boffa Miskell. The information provided in Sections 2.1.1.1 to 2.1.1.4. It is focused on control efficacy relevant to the Pūharakekenui / Styx River. Ecological and regulatory considerations are provided in Sections 2.2 to 2.3.3. All control methods are assumed to be carried out following standard operating procedures. No aquatic weed control method is 100% effective. Environmental factors, regrowth, and reinfestation can all affect control success. Monitoring and follow-up maintenance are essential to prevent macrophyte reestablishment. A strategic approach, incorporating periodic monitoring and adaptive management, is necessary to maintain effectiveness over time.

The control methods considered were:

1. Hessian matting (additional recommendation by Boffa Miskell)
2. Aquatic herbicide application (included in NIWA's recommendations)
3. Mechanical cutting (included in NIWA's recommendations)
4. Riparian shading (included in NIWA's recommendations)

Diver-based hand weeding (an additional recommendation by Boffa Miskell) was considered as an additional control method. However, it was agreed with CCC that diver-based hand weeding was more suited as a maintenance method to assist other control methods, as opposed to a stand-alone control method. Diver-based hand weeding is generally best suited to managing small-scale incursions of a new aquatic weed, not for routine large-scale management of well-established weed infestations. Diver-based hand weeding is labour-intensive and costly over large areas. Therefore, this method was not investigated further in this report.

Dredging as a macrophyte control method was not considered by NIWA (Matheson & Clements, 2020) and was not recommended by Boffa Miskell (Boffa Miskell Ltd, 2023b). However, Matheson et al. (2022) identified an extensive area of raised, shallow river-bed in the lower part of the Pūharakekenui / Styx River, which conceivably contributes to flooding risk. They noted that CCC might consider dredging of sediment in this area to improve flow conveyance and lower flood risk. CCC does not support this control method for macrophytes due to the numerous negative ecological effects associated with dredging.

2.1.1.1 Hessian matting

Hessian matting offers a sustainable, fast, and effective approach to controlling macrophytes. It is a total species method, as it works by blocking light access, preventing photosynthesis of any macrophytes under the matting. Hessian matting has been widely applied in the southern lakes and Kawarau River for the control of *Lagarosiphon major*. Within these lagarosiphon weed beds, *Elodea canadensis* and *Potamogeton crispus* are also commonly present, and as a result have been repeatedly exposed to incidental suppression as by-kill through the application of hessian matting control. While smaller native species can penetrate its weave and regrow, larger invasive species are effectively prevented from regrowing. The tightly woven structure also inhibits exotic macrophytes from reestablishing by limiting root establishment. Once installed, the matting smothers macrophytes on the substrate and prevents regrowth by blocking available sunlight. Due to its relatively smooth surface, hessian matting is expected to increase water flow rates by reducing river-bed surface roughness. When correctly applied, hessian matting typically results in significant macrophyte mortality within a few months before the 100% biodegradable matting naturally breaks down over its lifespan[2].

Hessian matting is laid by divers using a drum to roll the hessian out underwater. This helps to crush the weed bed underneath to prevent billows or air pockets. This installation technique is an innovation that has become standard operating procedure within the last three years. When hessian is laid in flowing water, the most upstream extent of the matting is thoroughly pinned in place to prevent lifting. All subsequent sheets are laid overlapping so the upstream edge is tucked beneath the downstream end and cannot flap free. These techniques have been used in river systems such as the Kawarau River and have been found to prevent billows and air pockets from forming.

In terms of durability, hessian matting is generally resilient. This means it can withstand environmental factors that could lead to early degradation, including water flow, sedimentation, and exposure. When deployed in suitable locations, it typically performs well in lake and river environments over its anticipated lifetime. This versatility allows deployment in various conditions, favouring public acceptance where herbicide use is contentious. Hessian matting brings an immediate reduction of substrate roughness compared to the use of herbicides, which can take six weeks before changes in macrophyte biomass and bed roughness are observable (herbicides can also be ineffective, depending on several environmental conditions, see Section 2.1.1.2). The fine weave of hessian matting limits the ability of macrophytes to reestablish as plants cannot penetrate through for roots to reach the underlying sediment. However, plants can reestablish on top of the matting once sediment builds up, but as roots cannot easily penetrate through the weave, it is relatively easy to remove them during routine maintenance.

However, using hessian matting does present challenges. It is labour-intensive to install and requires maintenance to ensure any rips or tears are repaired. There is also the cost associated with the involvement of divers for deployment and repair. Some physical environmental factors can also influence the efficacy of hessian matting. A flat riverbed or suitable substrate is required for pinning with stakes, rocks, or sandbags. Excessive debris or large rocks can cause billowing or unevenness in the matting, which prevents natural sediment accumulation and reduces its effectiveness by allowing light penetration and potential damage. Excessive depth of soft sediments can also inhibit securing hessian to the bed, and when using over deep

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[2] The lifespan of hessian matting is expected to be between 6 months – 36 months, depending on the depth of application, water movement, sediment accumulation, UV exposure, biodegradation, and material density.

macrophyte beds, the matting can be lumpy, but this flattens out as the macrophytes die and degrade. Using the drum roller when placing and pinning matting can help minimise this.

It may not be appropriate to cover the substrate in some situations, specifically where beds of native freshwater mussels (kākahi) are present. In areas of high biodiversity, other control methods may be more appropriate.

Summary – Hessian Matting

Hessian matting offers a viable strategy for managing macrophytes. Unlike herbicide, which requires very specific environmental conditions for deployment, hessian requires few environmental factors and can be laid year-round, including in very shallow or narrow water bodies. This makes it well-suited for deployment on a set schedule to align with council logistics and budgets. Key considerations include ensuring suitable water velocity and substrate to secure the matting effectively.

Hessian is highly successful at controlling macrophytes through shading and provides an immediate reduction in bed roughness once laid, unlike other control methods that may take weeks or months to achieve similar results. It does not rely on external factors to be effective.

Like all control techniques, hessian matting requires periodic maintenance to ensure its continued effectiveness over the product's life. Divers should revisit sites approximately every six to twelve months, depending on site conditions, to:

- patch any tears or holes in the hessian
- add pegs where additional securing is needed
- remove macrophytes establishing in the accumulated sediment
- clear debris or foreign materials displaced onto the matting

2.1.1.2 Aquatic herbicide application

Within New Zealand, there are currently only two registered herbicides for controlling aquatic macrophytes. These herbicides are diquat and endothall. Both are effective tools for managing macrophytes under the right environmental conditions.

Diquat, a contact herbicide, dehydrates plant tissue upon application and is particularly suited for large-scale treatments in lakes or ponds with still water, where maintaining optimal concentration levels over longer periods enhances efficacy due to low rates of water movement and dilution. Label requirements dictate that diquat is applied at a rate of 30 litres per hectare. Herbicide treatment is more effective in operations where high proportions of a water body are treated at once. It is difficult to achieve suitable concentrations when treating small areas in large or deep waterbodies (due to the dilution from the surrounding untreated water), which affects efficacy.

The label requirement for diquat specifies that it must not be used in water with a flow rate of over 30 cm/s. The Pūharakekenui / Styx River has an average flow of 58 cm/s (Boffa Miskell Ltd, 2015); however, this will vary significantly depending on location along the river, position within the channel, and the tidal influence at the time, as the incoming tide will slow the flow. Prior to applying herbicide in the Pūharakekenui / Styx River, it is recommended to assess weed condition and measure flow rates to determine whether a site is suitable for treatment at that time. Spraying would be carried out in an upstream direction and targeted at low-flow areas to comply with the label conditions and optimise efficacy.

Diquat damages the shoots of targeted macrophytes, causing them to degrade, provided they are exposed to the optimal dose (1 mg/L for a sufficient length of time (≥10 minutes) (Matheson et al., 2022). If contact time or dose are sub-optimal, damage may be negligible or limited to the shoot tips only; the latter can slow growth for the time required for a new bud to form beneath the damaged tip. It is very hard to achieve consistent results with diquat in a flowing water environment due to water movement.

Furthermore, herbicides such as diquat can be adsorbed with sediment and organic particles in the water, so the effectiveness in macrophyte control is reduced. Diquat should not be applied when water is turbid or enriched with organic matter, or where macrophytes have a high cover of algae and silt on leaf surfaces.

Endothall, a systemic herbicide, is also more suitable for enclosed environments like small ponds than flowing water environments, due to its need for prolonged contact with macrophytes, typically hours to days. However, endothall is not affected by sediment like diquat, but the contact times required for effective results are hours to days (compared to minutes to hours for diquat). Endothall requires specific EPA permission and post-treatment monitoring (while diquat does not) to undertake any controls within New Zealand. These added requirements make it an extremely costly herbicide to use, compared to diquat. Endothall is species selective and is not regarded as an effective control of *Elodea canadensis* (or *Egeria densa*) (Wells & Champion, 2010). Elodea is a key target species for biomass reduction in the Pūharakekenui / Styx River. Selecting the appropriate herbicide for a given situation and the species being targeted is critical to achieving effective submerged weed control.

Advantages of herbicide use include cost-effectiveness for large-scale treatments compared to physical removal methods, such as mechanical cutting. However, resource consent and adherence to stringent health and safety protocols are required for using herbicides. Environmental factors like weather, sedimentation levels, water flow rates, and water temperature significantly influence herbicide efficacy and contact time, requiring pre-application assessments to optimise outcomes and a good understanding of the environmental factors that can influence efficacy.

Even when these environmental factors above have been considered and deemed acceptable for herbicide use, treatment outcomes can fail, particularly in riverine environments where it can be hard to achieve the required contact times for effective control. Furthermore, less predictable, or more difficult to determine, variables such as plant photosynthesis, temperature stratification, and underwater currents can all affect how the herbicide interacts with macrophytes. When treatments are effective, it will take up to 3 months for effects to become fully apparent, and plants are very rarely fully controlled; often, they will lie flat and become dormant for several months before slowly coming back to life. Both diquat and endothall can be applied using various methods, such as helicopter booms, boat-based booms, knapsacks, or diver-based injections, often with added gelling agents. However, the water body needs to be navigable by boats to apply the herbicide; this may be an important determinant in narrow shallow rivers like Pūharakekenui / Styx River.

Summary – Aquatic Herbicide Application

Aquatic herbicides offer a practical solution for controlling large areas of macrophytes. Successful implementation hinges on several factors, such as regulatory compliance, contractor availability, and environmental factors. When herbicide application is successful, it can provide widescale macrophyte degradation. However, it is difficult to predict all potential factors that influence whether an application will be successful in controlling macrophytes.

These factors are only amplified in a riverine environment such as Pūharakekenui / Styx River.

2.1.1.3 Mechanical cutting

Mechanical cutting is currently the primary method used by the CCC to manage macrophytes in the Pūharakekenui / Styx River. This control method involves specialised vessels equipped with cutter bars and conveyor belts. These vessels cut the weed to a depth of around 1.5 m below the surface. The conveyor belt moves the macrophytes out of the water onto the rear of the vessel; cut macrophyte material is then transported to designated temporary storage areas on the banks of the river, and, where accessible, loaded onto trucks and disposed of.

The advantages of mechanical cutting include its ability to provide immediate results by increasing water flow and reducing biomass quickly down to a certain depth. It requires minimal lead-in time and can be executed with fewer restrictions regarding timing and environmental conditions, making it suitable even for low visibility or higher flow environments. However, it can be time-consuming for large water bodies or areas with dense plant biomass.

Despite its advantages, mechanical cutting has several limitations. Environmental factors significantly influence the effectiveness of mechanical cutting. These include not effectively reducing biomass in areas with substantial debris on the riverbed, such as submerged tree material or rocks; it also requires the waterway to be navigable and requires a suitable area to offload any cut plant material onto the banks for disposal. There is emerging evidence that fish and other freshwater fauna are injured and killed during mechanical cutting (Boffa Miskell, 2024). It is also very labour-intensive and is only a temporary solution. It doesn't kill the plants, as their regrowth can occur within weeks to months under favourable conditions. Fragmentation of cut plants also poses a risk of downstream establishment if suitable habitats are available. Boat-based cutters are limited to approximately 1.5 meters in depth; if water levels are too high, they potentially will not be able to remove enough biomass.

Summary – Mechanical Cutting

Mechanical cutting offers a straightforward but labour-intensive option to remove macrophyte biomass to a certain depth. The removal of biomass at the location of cutting is immediate. It is only effective for a short period of time as cut shoots regrow, and it requires navigable water. Mechanical cutting can produce plant fragments that are capable of recolonising downstream areas or being moved by anthropogenic means to other areas. This method maintains, rather than controls, macrophytes.

2.1.1.4 Riparian shading

Riparian shading is an effective strategy to manage submerged macrophyte growth, including *Elodea canadensis* (Ellawala Kankanamge et al., 2019) and *Potamogeton crispus* (Matheson, Costley, et al., 2018). Use of shading to manage excessive macrophyte cover has been trialled, using black polythene covers as a surrogate of riparian vegetation (Collins et al., 2020). Shading by riparian vegetation, like hessian matting, reduces light penetration into the water, thereby limiting photosynthetic capacity and macrophyte growth.

A minimum riparian planting height equal to the wetted width of the river channel is recommended for providing sufficient shading for management of submerged macrophyte growth in the Pūharakekenui / Styx River (Matheson et al., 2022). Riparian vegetation widths of 20 m have been found to be more likely to support self-sustaining indigenous vegetation with fewer maintenance requirements (e.g., less weed control requirements) than narrower buffers; buffer widths of 15-20+ m are highly likely to be self-sustaining, with virtually no maintenance required (Parkyn et al., 2000). Using riparian planting to create shading is a sustainable long-term approach for management of nuisance macrophyte growth, as supported by recent assessments indicating its potential to suppress macrophyte growth in the Pūharakekenui / Styx river, which should mitigate flooding risk (Matheson et al., 2022). The advantages of riparian shading are that once vegetation is well established, there is likely to be minimal input required to maintain the plantings, except where any trees or shrubs are lost via natural circumstances.

The potential need for land acquisition to implement sufficient riparian planting width may be a disadvantage of riparian shading for macrophyte control. There are also high initial costs for large-scale plantings and the need for intensive maintenance for several years to ensure plant survival and suppress weed growth and any browsing of pest animals. Key factors, such as vegetation type and species to be planted, planting density, foliage density for shading and ongoing maintenance to prevent weed encroachment and animal browsing. This will need to be considered and addressed to ensure the success of the riparian plantings. The presence of existing infrastructure (e.g. roads and buildings) close to the river may limit the extent to which riparian plantings can be added and stream shading created. Riparian planting will generally not be fully effective for shading until the plantings are mature. For larger trees and shrubs, this may take 5 to 10 years or longer, depending on the species selected and the target height to be attained.

Other Environmental considerations, such as water body width and existing infrastructure (roads and buildings), influence the effectiveness of riparian shading. There are several areas along the Pūharakekenui / Styx River corridor that cannot be effectively shaded by riparian plantings due to limited (<10 meters) buffer width available for planting. Existing pest plant species will also need to be identified and removed before effective riparian management can be implemented. Riparian planting will not be fully effective until the trees are at maturity to prevent light penetration; this can take up to 25 years to reach maturity.

Summary – Riparian Shading

Once established, riparian plantings are a low-maintenance, effective control solution for reducing light availability and limiting submerged macrophyte biomass in waterbodies (Ellawala Kankanamge et al., 2019; Matheson, Mouton, et al., 2018). Riparian plantings can also provide other benefits (see Section 2.2). However, there is often a long lead-in time for plantings to reach maturity.

2.2 Ecological considerations

The following information considers the ecological effects of the four control methods discussed in Section 2.1.1, in accordance with **Schedule 4 Item S (viii)**.

Pūharakekenui / Styx River is recognised as a Site of Ecological Significance in the Christchurch District Plan, supports several uncommon, rare, or threatened indigenous plants, birds, and freshwater species, and is an important ecological connection route for a variety of indigenous fish species. It is listed as critical habitat for kākahi / freshwater mussels in the Canterbury Land and Water Regional Plan.

Each control method considered has some potential ecological benefits and adverse effects, which are summarised in Table 2. Guided by these effects and the ecological value of Pūharakekenui / Styx River, the order of these methods (from an ecological perspective) from lowest to highest risk are:

In addition to limiting excessive growth of macrophytes via shading, riparian plantings provide multiple other ecosystem services, such as inputs of leaf litter and woody debris to provide food and habitat resources to freshwater fauna, stabilising banks and reducing erosion and sediment inputs, reducing fluctuations in water temperatures and dissolved oxygen levels (through shading), as well as provision of habitat, food, and shelter for terrestrial species (birds, insects, lizards). These aspects variously contribute to positive effects on instream habitat and water quality, which in turn benefit instream fauna.

The riparian margins along the lower reaches of Pūharakekenui / Styx River are primarily dominated by exotic deciduous trees. Exotic trees have been historically favoured when re-vegetating riparian margins, as they can reduce bank erosion, shelter adjacent farmland, and generally grow quickly. However, many of the commonly used exotic trees (e.g., willow and poplar) are deciduous and do not provide effective shading in autumn, winter, and early spring. In addition, the seasonal inputs of leaf litter during autumn leaf fall can also smother instream habitat and adversely affect water and habitat quality.

The use of riparian vegetation, especially large-stature and dense indigenous vegetation, is likely to be the most suitable long-term option (as a preventative rather than control method) to provide sufficient shading to limit submerged macrophyte growth in the Pūharakekenui / Styx River.

Diquat is an **aquatic herbicide** approved for use in New Zealand to control submerged freshwater macrophytes. Based on the literature, when applied in the prescribed dose (1 ppm), diquat has no identified toxic effects on non-target indigenous aquatic flora or fauna (Clayton, 2004; NIWA, n.d.) Invertebrate communities in post-herbicide control environments have been found to be impacted, where taxa residing in stream margins and on the streambed were unaffected, but taxa associated with macrophyte habitat (e.g., snails, some caddisfly taxa) declined or were lost entirely from the system (Brooker & Edwards, 1974). It is likely that this is due to loss of habitat (i.e. macrophytes removed by diquat), rather than direct toxic effects of diquat on these biotas. However, the use of herbicides to control macrophytes can result in changes in water quality & chemistry. For example, dying and decaying plant matter may cause changes to water quality and pose a risk to freshwater life, particularly when managing large macrophyte beds and with a good treatment success rate. Plant decomposition can rapidly release nutrients, such as nitrogen and phosphorus (Strange, 1976), which may create a high-nutrient environment that favours the regrowth of macrophytes (Collins, 2018). Decomposing plant material post-herbicide application can also decrease dissolved oxygen (DO) concentrations to levels that may harm aquatic fauna (James, 2013; Jewell, 1971). However, there may be no or little change in DO concentrations in flowing water where significant reaeration due to air-water mixing occurs (Young et al., 2004) and / or where the degree of weed control and vegetation decomposition is modest (de Winton et al., 2017).

Hessian matting, by design, smothers areas of the waterway bed, which could reduce habitat quality, cause the mortality of non-target macrophyte species, and may restrict the movement of mobile fauna. For synthetic benthic barriers, densities of macroinvertebrates beneath the barrier have been found to decline by c.70-90% (Ussery et al., 1997), likely due to a decline in DO concentrations. As previously mentioned, the decomposition of plant material can cause a reduction in DO concentrations (James, 2013), and the use of a barrier could drive hypoxic conditions as the smothered macrophytes decompose. It is important to note that as hessian matting is more permeable than synthetic fibres, it can allow for the transfer of gases and water (Caffrey et al., 2010), and as it breaks down within months, gas and water transfer would likely increase over time. Hessian matting may restrict movement and smother some instream fauna. This risk of smothering and loss of connection to the open water column is of particular concern for less mobile taxa (e.g., kākahi) or taxa that live burrowed into sediment during certain life stages (e.g., kanakana / lamprey). Potential for smothering of habitat and fauna will be an important consideration if deploying hessian matting to control excessive growth of macrophytes in Pūharakekenui / Styx River.

Mechanical cutting can cause the mortality of non-target macrophyte species, increase suspended sediments, and disturbance, injury, or mortality of fauna. The weed cutter boat, by design, is loud and creates a large area of turbulent water near the boat's propeller. Stream bed disturbance during mechanical excavation has resulted in localised, short-term increases in suspended sediment immediately after macrophyte removal (Greer et al., 2017). This may reduce water column visibility and have local, but temporary, effects on visually feeding fish species. Macroinvertebrate and fish species may also inhabit or seek temporary refuge in macrophyte beds and are likely to be disturbed, injured, or killed by the cutter. Recent observations of the weed-cutter boat in operation in non-wadable reaches of Ōpāwaho / Heathcote River found many injured and dead fish caught in the cut macrophytes that were piled on the river banks (Boffa Miskell, 2024). This risk of injury and mortality was previously unknown and is an important consideration when using the weed harvester to mechanically cut and remove excessive growth of macrophytes from Pūharakekenui / Styx River.

Table 2. Summary of potential adverse ecological effects and benefits for macrophyte control methods (Boffa Miskell Ltd, 2023a).

Ecological Rank[3]	Option	Potential adverse ecological effects	Potential ecological benefits
1	Riparian Shading	• Seasonal inputs of leaf litter and poor water quality and instream habitat conditions if exotic deciduous vegetation dominants the riparian margin.	• Opportunity to increase shade, aquatic and terrestrial biodiversity, and consistent food resource input through planting indigenous vegetation. • Increased open space for in-stream fauna that don't rely on exotic macrophytes for habitat to establish, inhabit, and migrate through. • Reduced diurnal fluctuations in dissolved oxygen concentrations that are associated with in-stream plant photosynthesis and respiration, when excessive macrophyte growth is controlled. • Riparian shading can increase the presence and abundance of native macrophytes relative to exotic macrophytes, especially for submerged species (Matheson et al., 2017; Matheson, Mouton, et al., 2018; Mouton et al., 2019).
2	Herbicide Application	• Risk of toxicity to instream fauna if the prescribed application dose is exceeded. • Changes to water quality from decaying plant matter. • Mortality or displacement of taxa associated with macrophyte habitat. • Repeated and potentially cumulative effects if herbicide application needs to be frequently used to control the excessive growth of macrophytes.	• Increased open space for in-stream fauna that don't rely on exotic macrophytes for habitat to establish, inhabit, and migrate through. Reduced diurnal fluctuations in dissolved oxygen concentrations, that is associated with instream plant photosynthesis and respiration, when excessive macrophyte growth is controlled. • Diquat use may allow those native macrophytes that are present and not susceptible to the herbicide (i.e. charophytes) to temporarily increase in abundance until the exotic macrophytes regrow.
3	Mechanical Cutting	• Increased turbidity. • Mortality or displacement of taxa associated with macrophyte habitat.	• Increased open space for in-stream fauna that don't rely on exotic macrophytes for habitat to establish, inhabit, and migrate through. • Reduced diurnal fluctuations in dissolved oxygen concentrations, that is associated

[3] Methods are ranked on their ecological impacts. One being the best, five being the worst.

Ecological Rank[3]	Option	Potential adverse ecological effects	Potential ecological benefits
		• Risk of spreading invasive macrophyte species within or between waterways due to fragments on the harvester. • Repeated and potentially cumulative effects if this method needs to be frequently used to control the excessive growth of macrophytes.	with instream plant photosynthesis and respiration, when excessive macrophyte growth is controlled.
3	Hessian Matting	• Smothering, mortality, or displacement of non-target taxa, especially sedentary benthic and macrophyte-dwelling taxa, but also entrapped mobile species. Sudden and complete loss of macrophyte habitat. • Changes to water quality from decaying plant matter under the barrier.	• Small indigenous macrophyte species may be able to grow through larger gaps in the weave. • Reduced diurnal fluctuations in dissolved oxygen concentrations, that is associated with instream plant photosynthesis and respiration, when excessive macrophyte growth is controlled.

2.3 Regulatory considerations

2.3.1 Overview of Regulatory Considerations

A high-level assessment of the Christchurch District Plan (CDP) and Canterbury Land and Water Regional Plan (CLWRP) requirements[4] was undertaken for the proposed macrophyte management options. Consideration was given to the global consent for works within waterways held by CCC (CRC146620) and a certificate of compliance held by CCC from ECan for a trial of diquat application for aquatic weed management purposes within Pūharakekenui / Styx River (CRC223323). Consideration was also given to the overlapping legislative powers and responsibilities between ECan and CCC below. The map below provides an overview of key ecological and planning features along the Pūharakekenui / Styx River, including water takes, protected groundwater zones, spawning habitats for īnanga and trout, critical and significant ecological areas, and relevant cadastral and infrastructure boundaries (Figure 2).

[4]As at 5 December 2023.

Figure 2. Map of Pūharakekenui / Styx River showing key ecological and planning considerations.

File Ref: LowerStyx.aprx / BM210924_02_SiteAssessment_2023_A3L

Boffa Miskell

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Data Sources:
District plan data sourced fro CCC data service
CLWRP data sourced from ECan data service

Projection: NZGD 2000 New Zealand Transverse Mercator

LEGEND

- Surface Water Take
- Christchurch Groundwater Protection Zone
- Listed īnanga spawning habitats (CLWRP)
- Listed Spawning Habitat (CCC)
  - Inanga
  - Trout
- Listed Critical Habitats (CLWRP)
- Sites of Ecological Significance
- LExtent
- Cadastre
- Primary Road Parcels
- OS Water & Margins

Site Assessment 2023

Date: 12 March 2024 | Revision: 0

Plan prepared for CCC by Boffa Miskell Limited

Project Manager: marcus.girvan@boffamiskell.co.nz | Drawn: BMc | Checked: CHe

Figure 2

The following information includes the regulatory considerations of the four control methods discussed in Section 2.1.1, in accordance with **Schedule 4 Item S (vii) and (ix)**:

(vii) Available regulatory mechanisms;

(ix) Consideration of overlapping powers and responsibilities between Canterbury Regional Council and CCC under other legislation.

Christchurch District Plan

The Open Space Water and Margins zone covers the majority of waterways and riparian margins within the district. The spatial extent of this zone varies between waterways in the Pūharakekenui / Styx River catchment.

There are also several ecological and other constraint overlays that should be considered when undertaking any control work in or around water bodies, including in Pūharakekenui / Styx River. For example, Pūharakekenui / Styx River is identified as a Site of Ecological Significance (SES), supporting at-risk fish species and their migration routes and indigenous vegetation and avifauna representative of the Low Plains Ecological District. The catchment is also identified as a Site of Significance to Māori, a Significant Feature, and an Outstanding Natural Feature. The Pūharakekenui / Styx River is also identified as a downstream waterway.

The Christchurch District Plan (CDP) contains controls on waterbody maintenance and enhancement and earthworks in these setbacks, but exempts permitted activities in the Open Space – Water and Margins zone.

Canterbury Land and Water Regional Plan

The Pūharakekenui / Styx River catchment is located within the Christchurch – West Melton subregion. The Plan includes several overlays, or ‘constraints’, that influence planning requirements associated with the macrophyte management options under consideration. These are outlined below and identified in Table 3.

The study area contains identified ‘critical habitat’ areas. These are located at the intersection of the river and Marshland Road, and two areas in the section of Pūharakekenui / Styx River adjacent to Lower Styx Road extending towards Spencerville. Applicable notations on planning maps include the identification of groundwater protection zones and surface water takes. Refer to Appendix 1Appendix 4: Maps of land zones affected by flooding for maps showing the flooding extent for each different control method, and Figure 1 of Appendix 5Appendix 5: Analysis of the ecological effects and planning implications for macrophyte management options within the Pūharakekenui / Styx River for a map showing key ecological and planning considerations.

The Canterbury Land and Water Regional Plan (CLWRP) contains rules relevant to the consideration of macrophyte management options within the bed of a river and within riparian margins. These include the planting and removal of vegetation, the placement of structures and the discharge of agrichemicals.

Table 3. Summary of planning considerations for macrophyte control methods (Boffa Miskell Ltd, 2023a).

Option	CCC Requirements	ECan CLWRP Requirements Other	
Riparian Shading	Permitted activity (conservation activity)	Potentially covered by global waterways consent (CRC146620) Alternatively: • In the bed of a river – permitted activity (Rule 5.163) /restricted discretionary activity (Rule 5.164) • In riparian margins – permitted activity (Rule 5.167/ restricted discretionary activity (Rule 5.169).	CRC146620 functions as a comprehensive global consent for stormwater discharges in Christchurch. However, the consent is primarily for stormwater discharges, not vegetation management. Riparian planting may not be explicitly included unless it is tied to stormwater outcomes or included in a site-specific stormwater management plan. Rule 5.163 permits small-scale vegetation clearance, earthworks, or land use within 10 m of a water body, provided it doesn't cause erosion, sediment discharge, or damage to the bed or banks, and meets size and location limits. Rule 5.164 requires consent for introducing, removing, or disturbing vegetation in a lake or riverbed if certain permitted activity conditions are not met, with discretion limited to environmental and cultural effects. Rule 5.167 permits limited vegetation clearance and earthworks near waterbodies if erosion risks are low and key conditions around vegetation type, ground cover, and habitat protection are met. Rule 5.169 requires consent as a restricted discretionary activity for vegetation clearance or earthworks in riparian margins if the conditions of permitted activity rules (5.167 or 5.168) are not met.
Herbicide Application	-	Permitted activity (Rule 5.22)/ discretionary activity (Rule 5.23).	Rule 5.22 permits the discharge of HSNO-approved agrichemicals onto land or into water, including lake or riverbeds, if mixing and cleaning occur safely away from water sources, backflow prevention is in place, and discharges avoid drinking-water protection zones. Rule 5.23 requires consent as a discretionary activity if any conditions of Rule 5.22 for agrichemical discharge into land or water are not met.
Hessian Matting	-	Discretionary activity (Rule 5.141A)	
Mechanical Cutting	Permitted activity (conservation activity)	Permitted activity (Rule 5.163) / restricted discretionary activity (Rule 5.164)	Rule 5.163 permits the planting, removal, or disturbance of vegetation in a lake or riverbed, including associated sediment discharge, if conditions around flood control, species type, spawning habitats, and sediment limits are met.

Option	CCC Requirements	ECan CLWRP Requirements Other	
			Rule 5.164 classifies vegetation disturbance or planting in a lake or riverbed as a restricted discretionary activity if conditions of Rule 5.163 (excluding 2, 4, and 9) are not met, with discretion limited to environmental and cultural effects.

Section 2.3.2 provides further explanation regarding the implications of regulatory control mechanisms.

Other authorisations

The study area is not identified as a Statutory Acknowledgement Area under the Ngai Tahu Claims Act 1998. A silent file area identified in the Mahaanui Kurataiao Ltd Iwi Management Plan (Ōtūkaikino (Belfast)) is located at the eastern end of the study area. Pūharakekenui / Styx River is also identified as Ngā Wai 95 in the CDP. Ngā Wai 95 is a recognised cultural framework that integrates mana whenua values into planning work for culturally significant waterbodies to Ngāi Tahu.

2.3.2 Implications of Regulatory Control Mechanisms

Riparian shading

The provisions of the CDP provide for conservation activities (which include weed and pest control, and restoration planting) as a permitted activity within the Open Space Water Margins Zone. The term 'restoration planting' is not defined in the Plan but is considered to include riparian planting proposed for this weed management option.

Planting controls are influenced by the planning overlays that apply to the site. Requirements will need to be determined according to the specific part of the study area. For example, where planting is proposed within an SES, utilising indigenous species that are naturally occurring and sourced from within the relevant ecological district is required.

CCC holds a global consent (CRC146620) from ECan for waterway enhancement purposes. This consent provides for margin and berm planting for waterway enhancement purposes. The consent requires the use of indigenous species, with new plants sourced from local stock (provenance). It is considered that the planting proposed would be covered within the ambit of this consent; however, this should be verified with CCC and ECan. If this is not considered to be the case, any planting and the removal of existing vegetation[5], and associated discharge of sediment would need to be considered in terms of Rule 5.163 (applies to within river beds) and Rule 5.167 (applies to land within 5 m of a river bed) of the CLWRP. Both rules include a condition that the vegetation clearance does not occur in any critical habitat areas.

A resource consent may be required for riparian planting if permitted activity conditions cannot be met. If the required conditions can be met, this is provided as a permitted activity, or alternatively, a resource consent for a restricted discretionary activity would be required.

For the purposes of the CBA in Section 4.0 of this report, a worst-case scenario has been assumed, whereby a resource consent from ECan would be required to deliver this control method, and that it would have a 30-year expiry date.

Herbicide spraying

ECan is the regulatory agency responsible for the discharge of contaminants into and onto water. Rule 5.22 of the CLWRP controls the discharge of agrichemicals (Environment Canterbury, 2025). This is a permitted activity, provided that certain conditions are met. These conditions control the location and manner in which agrichemicals are mixed. These include: herbicides must be HSNO-approved and used according to approval conditions, no mixing or rinsing within 5 m of water bodies or in river/lake beds unless using a bunded system or hand-held method, a backflow prevention system is required when drawing water for mixing They

[5] It has been assumed that the removal of vegetation is limited to exotic species; and any replacement / riparian planting is limited to indigenous species.

also require that the discharge not occur within a community drinking water protection zone or within 250 m upstream or 100 m downstream of any other surface water intake.

A resource consent may be required for the use of diquat in some areas of Pūharakekenui / Styx River, depending on specific compliance with the various conditions of Rule 5.22 (Environment Canterbury, 2025), (in particular, those areas identified as critical habitat areas, community water protection zones, or within the specified buffer distances from surface water intakes). If the conditions in Rule 5.22 are met, this would be assessed as a permitted activity. Alternatively, resource consent would be required as a discretionary activity.

For the purposes of the CBA in Section 4.0 of this report, a worst-case scenario has been assumed, whereby a resource consent from ECan would be required to deliver this control method, and that it would have a 30-year expiry date.

Hessian matting

ECan is the regulatory agency responsible for the erection of structures within the bed of a river. Previous advice received from ECan is that hessian matting is considered to be a structure in terms of the definition contained in the CLWRP[6]. This type of structure is not specifically provided for in the Plan and, therefore, consent would be required as a discretionary activity under the provisions of Rule 5.141A. This rule also provides for the associated disturbance of the bed and discharge associated with the placement of a structure.

For the purposes of the CBA in Section 4.0 of this report, it has been assumed that a resource consent from ECan would be required to deliver this control method, and that it would have a 30-year expiry date.

Mechanical cutting

It is considered that ECan is the principal consent authority for activities on the bed of rivers. If the provisions of the City Plan are also considered in this context (depending on the specific nature and extent of the activity undertaken), the Open Space Water and Margins zone provides for conservation activities (which include weed control) as a permitted activity.

It was unclear which consent CCC holds to authorise the mechanical removal of weed. However, correspondence with CCC has indicated that current mechanical weed cutting within the bed of a river is permitted under the provisions of the CLWRP. The provisions of Rule 5.163 of the CLWRP provide for vegetation clearance in the beds of rivers subject to specified conditions[7] (i.e. If these conditions cannot be met, a resource consent is required for a restricted discretionary activity.

For the purposes of the CBA in Section 4.0 of this report, it has been assumed that a resource consent from ECan would be required to deliver this control method, and that it would have a 30-year expiry date.

[6] This has been discussed with a Principal Consents Planner at ECan.

[7] These conditions include a requirement that this activity does not occur within a critical habitat area, within identified inanga spawning areas during spawning periods and that required suspended sediments and visual clarity levels are met.

2.3.3 Conclusion

There are several regulatory requirements that may limit the undertaking of macrophyte management options within Pūharakekenui / Styx River as permitted activities. It may be possible to work around some of the consenting requirements if there is flexibility in the options adopted in specific areas (i.e., avoiding works in īnanga spawning areas within spawning periods; limitation of use of some methods over others in particular stretches). It is recommended that further discussions be held within CCC and between CCC and ECan once the preferred control methods and locations are identified. Alternatively, a specific resource consent could be obtained for this purpose to enable flexibility in approach.

In light of the above circumstances, it has been assumed that a resource consent will be required for each of the delivery methods, and this has been factored into the CBA under Section 4.0 of this report.

2.4 Remaining factors to consider

The remaining factors to be considered under Schedule 4 Item S are as follows:

(i) A range of river flow scenarios, including dry weather (spring-fed) flows and storm flows, where operational/maintenance management will be beneficial;

(iii) Flooding effects including level, extent and duration;

(vi) Costs for implementing options;

Requirements (i) and (iii) are addressed through the hydrological modelling required by Schedule 4 Item U (Section 3.0). Requirement (vi) is addressed in the Cost Benefit Analysis (CBA) required by Schedule 4 Item T.

3.0 Determining the best approach to incorporating weed condition in the hydraulic model

Schedule 4 Item U requires the Consent Holder to determine the best approach to incorporating the variable weed condition within the Pūharakekenui/Styx River hydraulic model and resulting design flood scenarios. Hydrological flood modelling was undertaken to address this requirement, as well as to fulfil the requirements of **Schedule 4 Item S (i) and (iii)**.

This information was used to inform the CBA required in Schedule 4 Item T; thus, Item U was addressed prior to Item T.

The CCC and Boffa Miskell, in collaboration with DHI Water & Environment (DHI), undertook hydrological flood modelling to understand the potential flood risk benefits from various weed control methods in the Pūharakekenui / Styx River. The following provides a summary of the technical work completed by DHI, with the full report provided in Appendix 1.

CCC provided the Pūharakekenui / Styx River model in MIKE FLOOD version 2016. The model was run in MIKE FLOOD version 2017. Five scenarios were run through the hydrological model: four control methods (hessian matting, aquatic herbicide application, mechanical cutting, and riparian shading) and a 'no control' river flow scenario.

Each control method was assigned a Manning's Roughness Coefficient 'n' value based on three months post-control (Table 4). The three-month post-control timeframe was chosen to provide a practical assessment of how each method influences flood reduction in the short term. It was determined to be out of the scope of this work to do fieldwork to determine the channel roughness of various weed control methods. Therefore, Manning's Roughness Coefficient 'n' values were calculated using desktop analysis methods, and in a series of meetings between DHI and CCC. This value was applied only to the main river channel roughness as per the control scenario shapefiles. The roughness was only modified in the main river channel bed. The Manning's Roughness Coefficient 'n' for the riverbank roughness for all control method scenarios was 2.4. This was consistent for the entire river length as per the calibration of the MIKE FLOOD version 2017 model. A 10-year 48-hour design rainfall event under Existing Development (ED) conditions was used in the MIKE FLOOD model to simulate flows in the Pūharakekenui / Styx River. This event represents a theoretical storm with a 10% Annual Exceedance Probability (AEP), delivering rainfall continuously over a 48-hour period, and reflects existing land use and impervious surface coverage such as roads, buildings, and drainage infrastructure. This scenario was selected as it aligns with the type of storm event CCC is aiming to mitigate through decreasing bed roughness. It was agreed that modelling more extreme events (e.g. 20- or 50-year storms) would show minimal benefit from reduced bed roughness due to the magnitude of those flood flows. Therefore, the 10-year 48-hour event provides a standardised and relevant baseline for assessing the flood reduction potential of control methods under typical but significant storm conditions.

Table 4. Manning's Roughness Coefficient 'n' for each control method.

Control method	3 months post-control
Hessian matting	0.032
Aquatic herbicide spraying	0.048
Mechanical cutting	0.062
Riparian shading	0.045
No control	0.150

Reasonable flood risk reduction can be seen for all methods compared to 'no control'. The reduction in water level varies in the floodplain depending on location and where the management method has been applied. Results showed that hessian matting produces the largest reduction in flooding three months after control, followed by herbicide application and riparian shading, three months post-achievement of target shade level (second equal). Mechanical cutting produces the smallest reduction in flooding.

The hydrological modelling results shown in Figure 6 of Appendix 1 indicate no significant differences among macrophyte management methods for water levels downstream of location 17185, just above Spencerville Road. The graph suggests the flood reduction benefits seen upstream do not carry through to the lower reaches of the Pūharakekenui / Styx River. These findings are likely due to the environmental conditions of the lower river system, making it more prone to flooding. These include minimal elevation change, proximity to the ocean, increasing tidal interactions and backwater effects. These influence the river's ability to discharge water effectively. Additionally, the model has inherent limitations in fully capturing the complexity of hydrodynamic interactions. Undertaking specific field trials, especially in the lower reaches of the river, would help determine how macrophyte control methods might influence the flood response.

The extents for each weed control method were determined through a desktop analysis using high-resolution aerial imagery. This approach allowed for an assessment of where specific control techniques could feasibly be applied, based on observable site characteristics. Key factors considered during this process included.

- Existing vegetation canopy cover
- Access to the river channel and banks
- Presence of hard infrastructure
- Other site-specific conditions visible within the imagery

Although this method is not without limitations due to its desktop nature, it represented the most practical and efficient approach available. The analysis enabled the identification of areas where each control method was likely to be suitable.

Once the preliminary extents were defined, they were reviewed and agreed upon by both DHI and CCC prior to their use in the hydraulic modelling. High-definition imagery was used to refine the shapefiles, ensuring confidence in the spatial accuracy of the control areas. These shapefiles were then used to assign specific Manning's n values to each control method in the model.

4.0 Cost benefit analysis of the best practicable options

4.1 Objective

The objective of this CBA was to systematically evaluate the costs and benefits of a series of methods to control macrophytes within the Pūharakekenui / Styx River to improve the flood carrying capacity of the catchment. This assessment has been carried out to fulfil the requirement of **Schedule 4 Item T**.

4.2 Methodology

This CBA has been undertaken in general accordance with The Treasury's *"Guide to Social Cost Benefit Analysis".* The guidance outlines seven steps that should be undertaken when preparing a CBA:

Step 1: Define the problem, options to address the problem, and the counterfactual (the do-nothing scenario).

Step 2: Identify who gains and who loses.

Step 3: Identify the costs and benefits associated with the counterfactual and the options to address the problem.

Step 4: Value the costs and benefits.

Step 5: Discount and compare costs and benefits.

Step 6: Assess the CBA to determine whether more research is required.

Step 7: Prepare final report.

These steps have been followed as outlined in the remainder of this section; however, it is noted that CCC has requested that the CBA only assess the monetised costs associated with the delivery of the various control methods[8]. While monetised benefits have not been factored into the CBA, we have discussed the relative benefits associated with each control method in qualitative terms in Section 2.0. A 'cost effectiveness' assessment has been undertaken to compare the cost per ha of land within the reduced floodplain arising from the delivery of each control method (see Section 0). Section 5.0 provides a multi-criteria analysis of the non-monetised costs and benefits associated with each control method.

4.3 Define the problem, and options to address the problem

4.3.1 Problem definition

The Pūharakekenui / Styx River catchment currently experiences flooding, and one of the factors that contributes to this flooding is the excessive growth of macrophytes in the river channel, which reduces the capacity of the river system to provide for flood flows.

4.3.2 Options to address the problem

The options that are being considered in this CBA to address the problem have been previously outlined in this report and are as follows:

- Hessian matting
- Aquatic herbicide application
- Mechanical cutting
- Riparian planting

An overview of each of these methods is provided in Section 2.1, and the full desktop analysis of the control methods is provided in Appendix 112.

4.3.2.1 Hessian matting

Hessian is a medium-term solution for controlling macrophytes. Hessian matting may be damaged by debris and recreational activities (such as angling) over time, reducing its effectiveness by allowing the macrophytes to receive light. Regular (i.e., six-monthly to annual) maintenance is required to ensure the matting is functioning properly. Divers will check for and repair rips and remove any macrophyte propagules colonising the top of the hessian. Refer to

[8] Email from Tom Parsons to Deborah Rowe dated 16 May 2024

Section 2.1.1.1 for further information on hessian installation and maintenance. It has been assumed in the CBA that the hessian will need to be fully replaced every three years, provided it is properly maintained over its lifetime. It has also been assumed that maintenance activities will occur on an annual basis.

Hessian matting is deployed once to achieve the reduction in bed roughness as used in the MIKE FLOOD version 2017 hydrological model. However, the reduction in bed roughness used in the hydrological modelling is achieved 3 months after the deployment of hessian matting.

Once hessian matting is in place, it is predicted to reduce Manning's roughness coefficient to 0.032. This was the lowest roughness coefficient of the treatment options explored.

4.3.2.2 Aquatic herbicide application

The full result of the herbicide application may not be observed for several weeks to several months, depending on how much herbicide is absorbed by the plant, and plants begin to die. For this reason, we have determined that an annual application of diquat is necessary to achieve effective macrophyte control. While we acknowledge that more frequent herbicide applications may be beneficial, practical constraints limit this to once a year. Over the lifetime of control, achieving two consistent treatment events annually is unlikely due to factors such as sedimentation, weed condition, suitable weather, and flow conditions. It is assumed that diquat would be the herbicide used, however, new herbicides may become available.

This method is deployed once to achieve the reduction in bed roughness as used in the MIKE FLOOD version 2017 hydrological model, noting that this reduction in bed roughness is achieved 3 months after the deployment of the control method. Aquatic herbicide application had the second-highest Manning's roughness coefficient of 0.048.

4.3.2.3 Mechanical cutting

The current approach for managing aquatic macrophytes in Pūharakekenui / Styx River is mechanical harvesting using a specialised watercraft equipped with cutter bars and conveyor belts that efficiently gather and cut the weeds.

Mechanical harvesting may need to be repeated within a growing season to remove all weed biomass. Weed beds can re-establish relatively quickly from remnant stems that are not removed. The required frequency of cutting can vary from a few weeks to several months; this depends on the rate of growth, the location, and the size of the water body. For the purposes of the CBA, we have assumed that the harvester will be deployed twice a year based on earlier advice provided by the CCC. This was that the harvester is deployed in the Pūharakekenui / Styx River from Radcliffe Road to the tide gates two to three times per year (Matheson & Clements, 2020). Matheson and Clements (2020) used the citation (CCC, pers. comm.) in reference to this information.

Mechanical cutting will allow for immediate increased water flow until the macrophytes grow back; therefore, it is efficient in immediately achieving improved flood conveyance but is a much more temporary solution than hessian matting or herbicide application.

This method is deployed once to achieve the reduction in bed roughness as used in the MIKE FLOOD version 2017 hydrological model, noting that this reduction in bed roughness is achieved 3 months after the deployment of the control method. Mechanical cutting had the highest Manning's roughness coefficient of 0.062.

4.3.2.4 Riparian planting

Earlier work by NIWA recommends that riparian buffers are dense and roughly as tall (including bank height) as the river is wide (including any planting setback) to provide sufficient shading for temperature and nuisance instream plant control, and inputs of leaves and wood (Matheson & Clements, 2020). For the purposes of this assessment, we have assumed that both banks of the river would be planted with a mix of trees and shrubs within a riparian margin of 10 m, and that this area is unimpeded by existing buildings, infrastructure, or recreational facilities. Land access or land acquisition costs have not been captured in the assessment. As discussed in Section 2.1.1.4, Parkyn et al. (2000) found riparian vegetation widths of 20 m were more likely to support self-sustaining indigenous vegetation with fewer maintenance requirements (e.g., less weed control requirements) than narrower buffers, so this may be an aspirational minimum buffer distance in some areas along Pūharakekenui / Styx River.

This method is deployed once to achieve the reduction in bed roughness as used in the MIKE FLOOD version 2017 hydrological model, noting this reduction in bed roughness is achieved 3 months after the plants reach full maturity and have achieved their maximum growth height. Riparian shading had the second-smoothest Manning's roughness coefficient of 0.045. Riparian planting is expected to result in the second equal largest reduction in flooding (of the options assessed). Riparian shading is also considered a preventative measure rather than a method to control excessive macrophyte growth.

4.3.3 Counterfactual

A CBA would usually describe a 'do nothing' or 'existing' option, against which the options for addressing the problem would be compared. For the purposes of this assessment, the mechanical harvesting option represents the current approach that CCC takes to managing macrophyte growth in Pūharakekenui / Styx River and has been used as the counterfactual in the CBA. The unit operates in the lower section of the river, from just upstream of Radcliffe Road Bridge downstream to the tide gates and is usually cut two or three times per year (Matheson & Clements, 2020).

4.4 Costs and benefits

4.4.1 Cost identification and calculation

This section aims to describe the costs associated with the proposed control methods. The costs are categorised as follows:

- Capital costs – costs incurred during the initial set-up and implementation phase or to purchase replacement equipment (e.g., construction and infrastructure, equipment purchase, planning and design).
- Operational costs – recurring internal costs required to deliver the control methods (e.g., CCC staff time to oversee the project).
- Maintenance costs – costs for ongoing delivery of the control methods (e.g., labour, materials).
- Indirect costs – additional costs that may arise indirectly due to the project (e.g., communications and engagement with stakeholders).

All costs are based on the cost of delivering / maintaining the control method across the entire control area of land / water, as applicable.

The calculation of the relative costs of each control method is set out in the CBA included in Appendix 3.

4.4.2 Cost estimation

Estimates have been made of the total area within which each control method would need to be deployed (Table 5). This was calculated based on an estimation of the total river length within which each control method is deployed, multiplied by an estimated average width of the river. It is noted that the estimated river lengths differ for each of the control methods and reflect those used in the DHI modelling. These estimates were derived using the most relevant and up-to-date aerial imagery available to analyse the river and identify areas where each method could feasibly be implemented. This desktop analysis allowed for a targeted evaluation of the lower Pūharakekenui / Styx River, meaning that the area associated with each method reflects the practical application of the control tools, rather than a uniform measurement across all methods.

The estimated costs for each of the control methods against each of the above categories are set out in Table 6 to Table 9 below, presented over a 50-year period to align with the timeframe of this CBA. The costs were first calculated on a per-hectare basis.

In the case of the deployment area for the riparian planting, it has been assumed that the width of the riparian planting area would be 10 m and apply to both banks (i.e., 20 m width in total) of the river for the lengths of the river where the control would be deployed.

Table 5. Total area over which each control method would need to be deployed.

Control method	Total length of river where deployment required (m)	Total area where control method required (ha)
Hessian matting	6,967.5 m	10.45 ha
Aquatic herbicide application	10,102.9 m	15.15 ha
Mechanical cutting	7,395.7 m	11.1 ha
Riparian planting	9,602 m	28.81 ha

Table 6. Costs associated with hessian matting and related assumptions ($ / total deployment area).

Control method: Hessian matting			
Cost category	**Year 1**	**Year 2-50**	**Total (50 years)**
Capital costs	$758,572	$12,137,162	**$12,895,735**
Operational costs	-	-	**-**
Maintenance costs	-	$4,819,416	**$4,819,416**
Indirect costs	-	-	**-**
Total costs[9]	**$758,572**	**$16,956,578**	**$17,715,151**
Explanations and assumptions: • The capital costs are those associated with delivering the control method for the first time. It includes labour, equipment, and materials.			

[9] Costs have not been adjusted to reflect current value

Control method: Hessian matting			
Cost category	**Year 1**	**Year 2-50**	**Total (50 years)**
• It is assumed that matting would need to be fully replaced every 3 years, whereupon another capital cost outlay would be required. This is reflected in the figures above. • Annual maintenance of hessian is required in the two years following the capital cost outlay. Refer to Section 2.1.1.1 for further information about hessian maintenance. • The total annual maintenance costs in Year 2 are assumed to be half of the labour costs required in Year 1 (initial deployment). Maintenance in Year 3 is assumed to be half of the labour costs of Year 2, as there is an assumed reduction in macrophyte densities. If control is carried out from the upstream sections downstream, and the recommended hessian coverage is implemented in a consolidated timeframe, the resulting biomass that could generate propagules is significantly reduced. This approach directly lowers the level of ongoing maintenance required. Maintenance includes labour costs only, as the materials cost is considered to be minimal. • The initial deployment of hessian will always be the most expensive phase due to high labour and material costs. Following the initial three-year period of maintenance on the previously laid hessian, a new cycle would begin. At that stage, a new area may require treatment, although it is unlikely to be identical to the previously treated area. These factors have informed the proposed timeframes and cost expectations. It has been assumed that each of the methods will require a resource consent from ECan, that the costs associated with obtaining this consent will be $20,000, and that the consent will expire 30 years after its issue (requiring a consent renewal application in Year 28). • It has been assumed that the ongoing operation of the delivery of all control methods would be managed by CCC, and these costs have not been included. • These cost estimates, assumptions, and requirements are based on Boffa Miskell's experience in managing and delivering over 67 hectares of hessian matting deployed across multiple lakes and rivers in the South Island of New Zealand over the past 10 years. • It has been assumed that this control method is required to be delivered every year (either as a capital cost outlay or maintenance) throughout the duration of the assessment period. • It has been assumed that no indirect costs are incurred for the delivery of this control method.			

Table 7. Costs associated with aquatic herbicide application and related assumptions ($ / total deployment area).

Control method: Aquatic herbicide application			
Cost category	**Year 1**	**Year 2-50**	**Total (50 years)**
Capital costs	-	-	-
Operational costs	-	-	-
Maintenance costs	$20,372	$998,200	$1,018,572
Indirect costs	-	-	-
Total costs[10]	**$20,372**	**$998,200**	**$1,018,572**
Assumptions: • This method will need to be deployed annually. This is based on experience from similar control operations that require contractors to control the same site each year to achieve			

[10] Costs have not been adjusted to reflect current value.

Control method: Aquatic herbicide application			
Cost category	**Year 1**	**Year 2-50**	**Total (50 years)**

sufficient macrophyte control. Diquat efficacy can be variable, so annual application allows for this variability.

- It is assumed that no capital costs are incurred for this control method as it has been assumed that it will not require any equipment purchase, construction, land acquisition or other similar capital costs.
- It has been assumed that each of the methods will require a resource consent from ECan, that the costs associated with obtaining this consent will be $20,000, and that the consent will expire 30 years after its issue (requiring a consent renewal application in Year 28). It has been assumed that the ongoing operation of the delivery of all control methods would be managed by CCC, and these costs have not been included.
- Maintenance costs include all planning, labour, equipment and materials required to deliver the control method each time it is deployed. It has been assumed that qualified subcontractors would be engaged to provide this service, and that they would supply their own equipment.
- These cost estimates are based on Boffa Miskell's experience in delivering thousands of hectares of aquatic herbicide control in lakes and rivers throughout New Zealand.
- It has been assumed that this control method is required to be delivered every year throughout the duration of the assessment period.
- No land access or acquisition costs have been captured in the assessment as requested by CCC. Any costs that would arise in relation to this method would be expected to be limited to arranging access to the river to support the deployment of the method. This can usually be obtained over publicly owned land adjacent to the river, so it is not expected that any costs associated with this aspect would be significant for this method.

Table 8. Costs associated with mechanical cutting and related assumptions ($ / total deployment area).

Control method: Mechanical cutting			
Cost category	**Year 1**	**Year 2-50**	**Total (50 years)**
Capital costs	-	$3,125,000	$3,125,00
Operational costs	-	-	-
Maintenance costs	$105,200	$5,154,800	$5,260,000
Indirect costs	-	-	-
Total costs[11]	**$105,200**	**$8,279,800**	**$8,385,000**

Assumptions:

- The equipment used for the mechanical cutting operation will be required to be replaced once every 10 years, with the first replacement in Year 10. CCC owns the existing harvester, so an initial capital outlay is not required to purchase one.
- The cost of the replacement equipment will be $625,000.
- Annual equipment maintenance costs of $30,000 per annum have been provided for.
- That the delivery control method is undertaken twice per year, at a cost of $37,600 per delivery.

[11] Costs have not been adjusted to reflect current value.

Control method: Mechanical cutting			
Cost category	**Year 1**	**Year 2-50**	**Total (50 years)**
• The costs exclude any costs associated with the disposal of harvested weed material. • It has been assumed that the ongoing operation of the delivery of all control methods would be managed by CCC, and these costs have not been included. • It has been assumed that each of the methods will require a resource consent from ECan, that the costs associated with obtaining this consent will be $20,000, and that the consent will expire 30 years after its issue (requiring a consent renewal application in Year 28). No land access or acquisition costs have been captured in the assessment as requested by CCC. Any costs that would arise in relation to this method would be expected to be limited to arranging access to the river to support the deployment of the method. This can usually be obtained over publicly owned land adjacent to the river, so it is not expected that any costs associated with this aspect would be significant for this method.			

Table 9. Costs associated with riparian planting and related assumptions ($ / total deployment area).

Control method: Riparian planting			
Cost category	**Year 1**	**Year 2-50**	**Total (50 years)**
Initial capital costs	$1,958,808	$5,100	$1,963,908
Operational costs	-	-	-
Maintenance costs	-	$480,100	$480,100
Indirect costs	-	-	-
Total costs[12]	**$1,958,808**	**$485,200**	**$2,444,008**
Assumptions: • That riparian planting will be undertaken along both banks of the river, each with an assumed margin width of 10 m. The total area within which the control will be delivered has not made any deduction for existing buildings, roads or other infrastructure that would impede riparian planting. • Plants will consist of a mix of indigenous trees and shrubs, with trees capable of growing to a height that will shade the river. • Plants will be planted at an average density of 10,000 plants per hectare (1 plant per m^2). • The capital costs exclude fencing, as there are too many variables that might inform whether fencing of riparian areas will be required. CCC may wish to consider fencing riparian margins (e.g., from stock where needed); these areas will need to be identified through a ground-truthing survey. These costs could be significant, depending on the extent to which fencing is required. • It is assumed that replacement infill planting for any plants that have not survived would be undertaken in Year 3, based on a replacement rate of 5% of the plants initially planted. • It has been assumed that the ongoing operation of the delivery of all control methods would be managed by CCC, and these costs have not been included.			

[12] Costs have not been adjusted to reflect current value.

Control method: Riparian planting			
Cost category	**Year 1**	**Year 2-50**	**Total (50 years)**
• Maintenance costs provide for nominal sums for weed control, pest plant control and animal pest control. It has been assumed that maintenance would be delivered twice annually in Years 2 and 3, and once in Year 4. Further maintenance is not expected to be required. • It has been assumed that each of the methods will require a resource consent from ECan, that the costs associated with obtaining this consent will be $20,000, and that the consent will expire 30 years after its issue (requiring a consent renewal application in Year 28). • No land access or acquisition costs have been captured in the assessment as requested by CCC. Land acquisition or access costs associated with this method could be significant, particularly when compared with the other control methods. The costs would likely be determined by a range of factors, including the ownership of land along the river margins (and how much is already owned by CCC), and the extent to which land along the river margins is already planted in a manner that achieves the characteristics required to achieve macrophyte control. There may also be other mechanisms that CCC could use to achieve riparian planting, including incentivising landowners to undertake planting on their own land (meaning CCC does not necessarily have to acquire all land to deliver this control method).			

A summary of the costs associated with each control method is set out in Table 10, below. This summary of costs indicates that the aquatic herbicide method has the lowest overall costs across the 50-year timeframe, and that the deployment of hessian matting is the costliest option. However, it is important to note that once riparian planting is established, it will be an effective control solution for limiting macrophyte biomass in waterbodies, so future investment/cost would be near zero once plantings are well established.

As noted in the assumptions for each of the control methods outlined above, land access and acquisition costs have been excluded from the analysis, as have any fencing costs. These types of costs could make a significant difference to the overall costs for the delivery of the riparian planting method, in particular, depending on the specific locations where this method would be deployed, the use and ownership of that land, and the underlying value of that land. There is also a range of options available to achieve riparian planting on riparian margins that don’t necessarily require CCC to acquire the land, e.g. incentivising private landowners to undertake the planting or delivering the planting only on CCC-owned or other publicly owned land. If these costs were factored into the analysis, it is possible that the riparian planting method could be the most expensive method. These costs, and their potential implications on the overall rankings of the methods, are shown in Table 10.

Table 10. Comparison of costs associated with each control method. $ symbols have been shown to indicate likely variability in cost, from low ($) to very high ($$$$) cost.

Control method	Capital costs	Whole of life costs	Present value of all costs[13]	Relative value ranking	Costs excluded from CBA	Potential implications on ranking if included
Hessian matting	$12,935,735	$17,755,151	**$6,906,707**	**$$$$**	Land access	**$$$**
Aquatic herbicide application	$40,000	$1,058,572	**$406,440**	**$**	Land access	**$**
Mechanical cutting	$3,165,000	$8,425,000	**$2,945,808**	**$$$**	Land access	**$$**
Riparian planting	$1,983,908	$2,464,008	**$2,398,213**	**$$**	Land access / acquisition Fencing	**$$$$**

[13] 'Present value of all costs' is the sum of all costs over the life of the project (50 years) discounted to their equivalent value in today's terms.

4.5 Comparison of costs and benefits

4.5.1 Net Present Value and Benefit Cost Ratio

A CBA would usually involve an assessment of the Net Present Value (NPV), which compares all expected benefits arising from a project to the present value of all expected costs. The NPV has been calculated for the expected costs associated with each control method (see Table 10), but as the benefits have not been monetised, a Benefit-Cost Ratio (BCR) cannot be calculated.

4.5.2 Comparison of land affected by the different flood scenarios

As outlined in Section 3.0, Boffa Miskell engaged DHI to undertake flood modelling to understand the potential flood risk benefits from various weed control methods in Pūharakekenui / Styx River. The results of DHI's study provided data about the impact that each of the control methods would have on the overall extent and water level depths of flooding in a 10-year, 48-hour rainfall event as compared to a baseline event with no control method.

To get some sense of the relative benefit of each control method as indicated by the type of land where flooding was reduced, we have undertaken a cost-effectiveness analysis to determine the cost (present value of all costs) per hectare of land that is removed from the baseline floodplain by each of the control methods. The results of this analysis are set out in Table 11 below.

Table 11: Cost per hectare of land removed from the baseline floodplain by each control method

Method	Present value of costs ($)	Area of floodplain reduced (ha)	$ per ha reduced floodplain ($/ha)
Hessian matting	$ 6,906,707.23	148.0042	$46,494.29
Mechanical cutting	$2,920,451.50	115.7957	$25,220.72
Riparian planting	$2,398,213.07	131.3991	$18,210.59
Aquatic herbicide	$406,440.48	127.5658	$2,987.35

In addition, as a way to compare the potential underlying relative value of the land that is protected by the reduction in flooding, we identified the zoning of land within the floodplain under the baseline scenario and each of the control method scenarios. Maps have been provided in Appendix 4.

Under the baseline scenario, 81% of the land affected by flooding is within rural and open space zones; 16% of the land is within specific purpose zones; the remaining 3% of land that is affected by flooding under the baseline scenario is within a combination of the residential, transport, industrial and commercial zones (Figure 3).

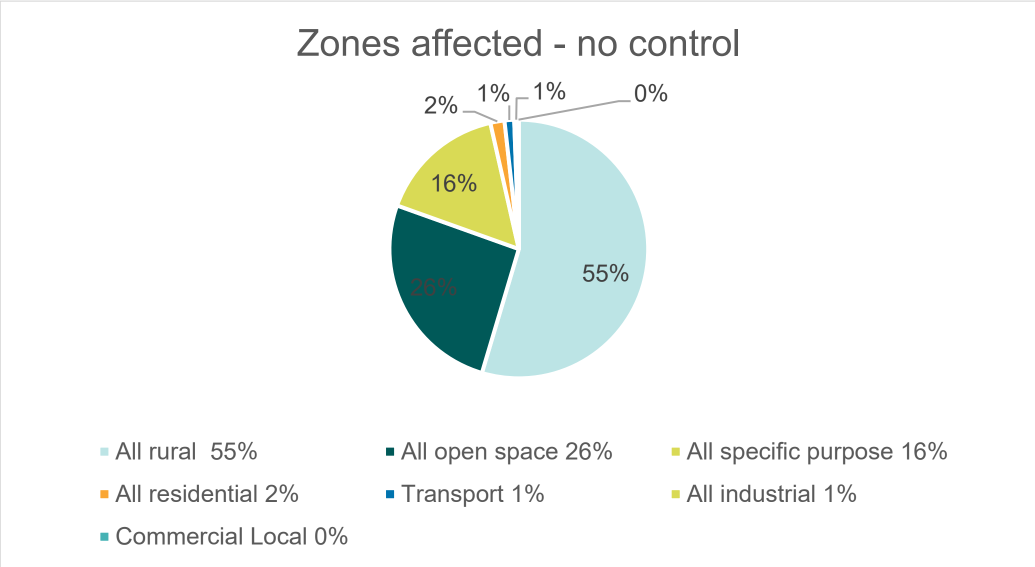

Figure 3. Relative proportion of land in various District Plan zones affected by flooding under the baseline scenario (no control).

The hessian matting control method results in the greatest reduction in area of flooding (from an overall area of 437 ha, reduced to 289 ha). There is generally an equivalent reduction in the overall proportions of land in the various zones, i.e., rural, open space, and specific purpose zoned land, which remains the land that is most affected by the resultant flooding extents.

Rural land is the type of land that experiences the greatest reduction in the extent of flooding when compared to the baseline flood levels, as illustrated in Figure 4 below. Figure 5 to Figure 10 show the reduction in the extent of the other zone types affected.

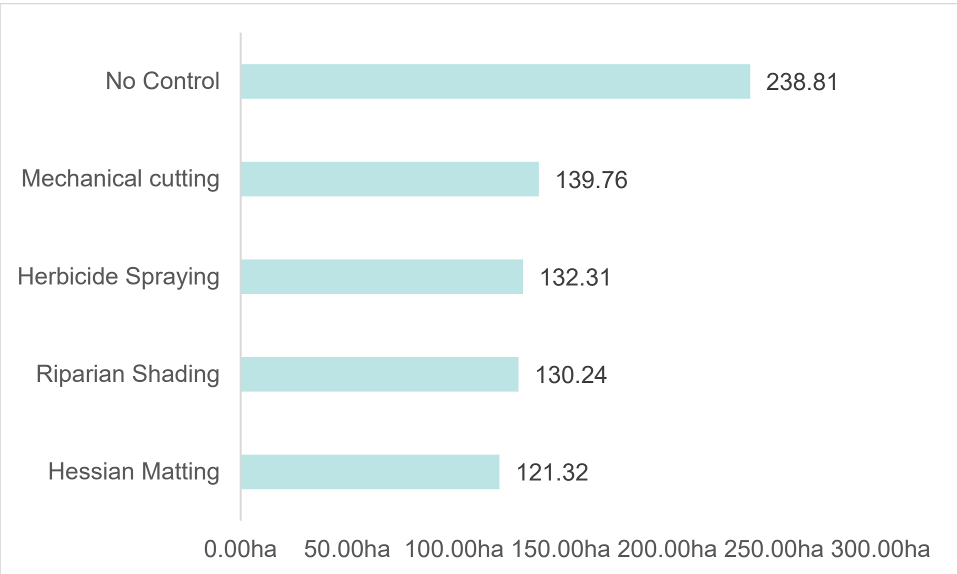

Figure 4. Relative proportion of rural land affected by flooding under the baseline scenario compared to the various control method scenarios.

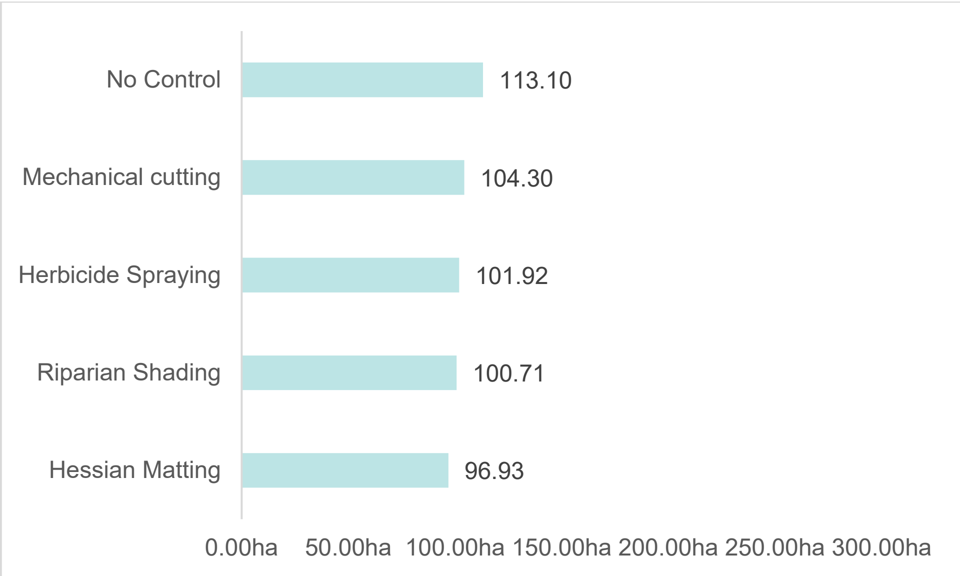

Figure 5. Relative proportion of open space land affected by flooding under the baseline scenario compared to the various control method scenarios.

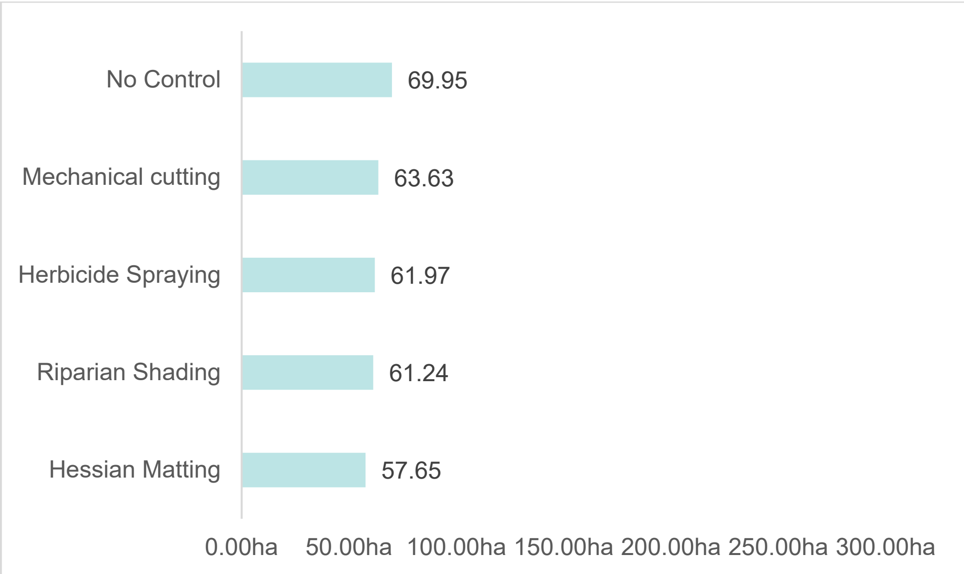

Figure 6. Relative proportion of specific purpose land affected by flooding under the baseline scenario compared to the various control method scenarios.

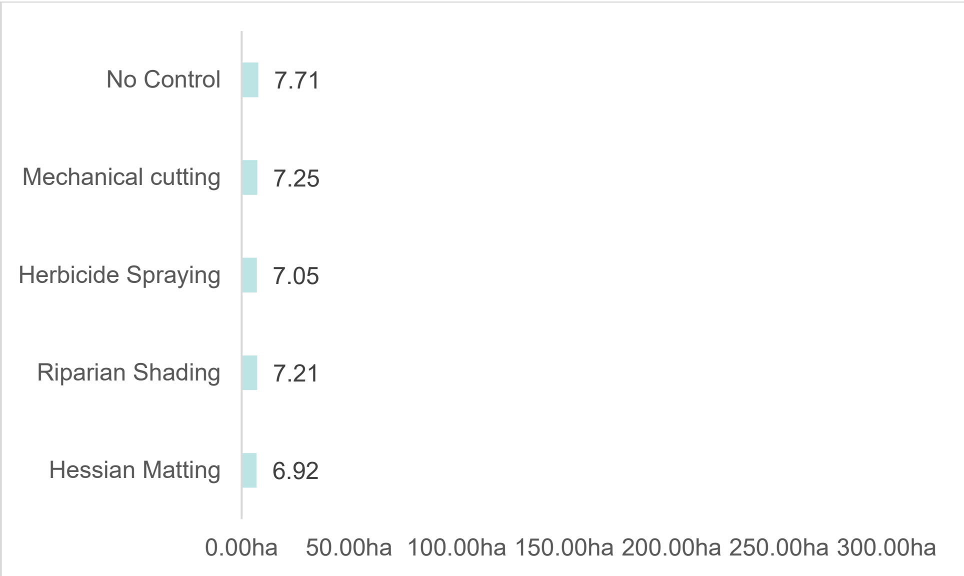

Figure 7. Relative proportion of residential land affected by flooding under the baseline scenario compared to the various control method scenarios.

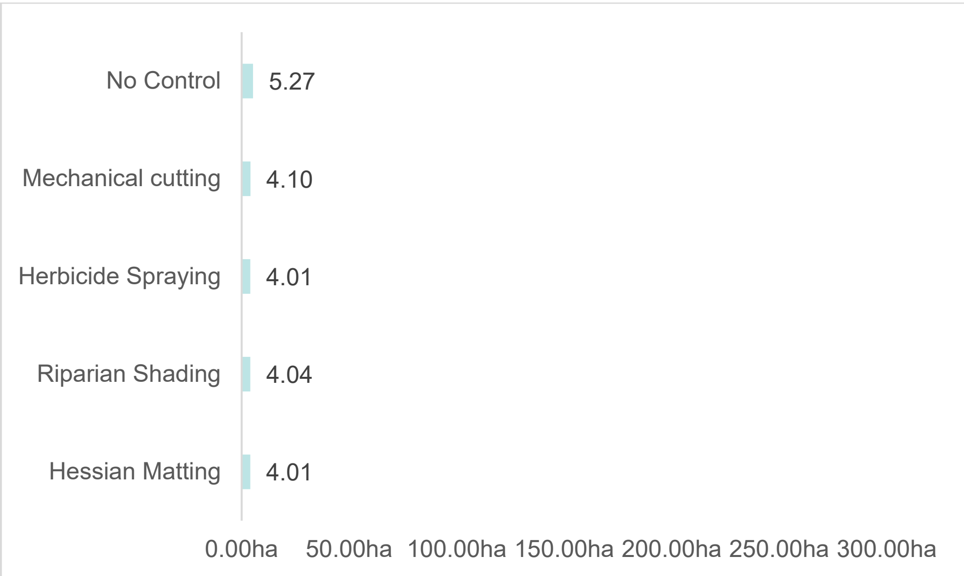

Figure 8. Relative proportion of transport land affected by flooding under the baseline scenario compared to the various control method scenarios.

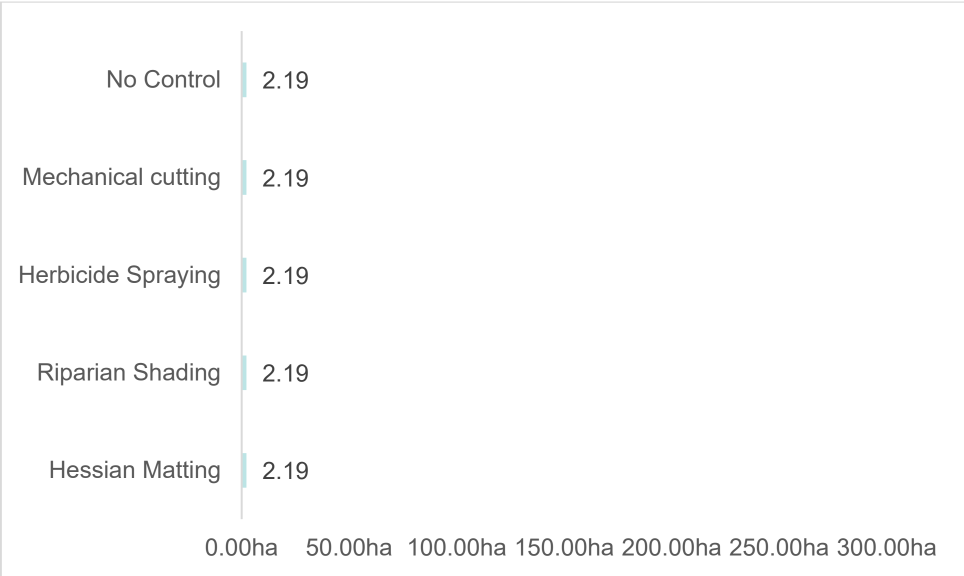

Figure 9. Relative proportion of industrial land affected by flooding under the baseline scenario compared to the various control method scenarios.

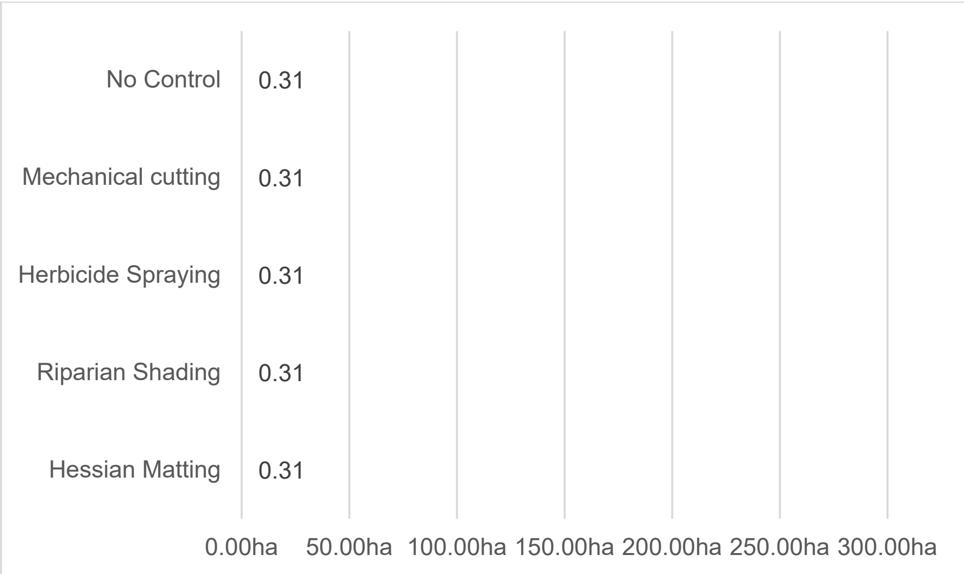

Figure 10. Relative proportion of commercial land affected by flooding under the baseline scenario compared to the various control method scenarios.

4.6 Sensitivity analysis

A sensitivity analysis has been undertaken to test the impact of the following on the overall costs for each method:

- Different discount rates (7.5% and 10% compared to the baseline of 5%).
- Reductions to the total area of total riparian margin control area by 10% and 20% to allow for the presence of existing features that may preclude planting.
- Amendments to the width of the riparian margin (5 m and 15 m as compared to the baseline of 10 m).

Applying the different discount rates does not change the relative ranking of the most expensive and least expensive control methods (hessian matting and aquatic herbicide, respectively). However, the amended discount rates mean that mechanical cutting becomes less expensive than riparian planting, which stays relatively constant across the different discount rates. This is likely explained by the fact that costs associated with riparian planting are relatively early in the overall 50-year assessment period, and these are less 'sensitive' to an increase in the discount rate (as compared to methods that require costs on a regular basis over the entire 50-year period) (Table 12).

Table 12: Sensitivity analysis findings – various discount rates

Control method	Total cost NPV (5% discount rate) (baseline)		Total cost NPV (7.5% discount rate)		Total cost NPV (10%)	
Hessian matting	$6,906,707	$$$$	$5,079,131	$$$$	$4,017,218	$$$$
Aquatic herbicide application	$40,644	$	$296,886	$	$233,363	$
Mechanical cutting	$2,945,808	$$$	$2,054,250	$$	$1,543,173	$$
Riparian planting	$2,398,213	$$	$2,373,181	$$$	$2,351,114	$$$

Note: $$$$ indicates the most expensive option; $$$ the second most expensive option; $$ the third most expensive option; and $ the cheapest option.

Reducing the total area of the riparian planting area by 10% and 20% reduces the overall costs of the riparian planting control, but it only becomes less expensive than mechanical cutting when the area is reduced by 20% (and becomes approximately $50,000 cheaper in present value terms). Amending the width of the riparian margin from 10 m to 5 m results in savings to the overall costs of this method, to the extent that it becomes cheaper than the mechanical cutting method (by approximately $1.7m in present value terms). While increasing the width of the riparian margin from 10 m to 15 m increases the overall costs of this method, the costs do not increase to such a degree that the method becomes more expensive than hessian matting.

At this stage, it is not possible to assess any associated change in benefit associated with a reduction in the overall area of riparian planting proposed. This would require a more detailed understanding of the spatial extent of the reduced planting area, which is not available at present.

Whilst riparian planting is neither the least nor most expensive (cf. herbicide – least; and hessian – most), riparian planting is considered a long-term and preventative measure and also provides multiple additional benefits when considering the Council's six-values approach.

5.0 Multi-criteria analysis

A comparison of the monetised costs of the control methods is set out in Section 4.4; noting that monetised benefits have not been addressed in the CBA. The relative non-monetised costs and benefits associated with the various control methods have been described in a general sense in Section 2.0, and have been used to inform this multi-criteria analysis (MCA) to supplement the findings of the CBA. The purpose of including this MCA within this report is to provide a broader context analysis of matters that have not been able to be addressed in the CBA.

The evaluation criteria that have been considered fall into four broad categories: matters that relate to the deployment and effectiveness of the various control methods; ecological impacts; effects on flooding levels; and potential regulatory implications. These are described further in Table 13 below. These criteria were selected by the authors and seek to focus on matters that can assist with a greater understanding of differentiating between the control methods beyond the matters addressed in the CBA. It is acknowledged that if the MCA were to be undertaken with a wider group of people, including the council and/or stakeholders, the criteria selected, evaluation of options against the criteria, and weighting applied could all differ.

There are likely other factors that could be considered in this MCA, e.g., considerations from a Te Ao Māori worldview, heritage, landscape and recreation. The MCA could be updated at a future stage to include these additional factors or considerations. See Section 6.0 for further information on the CCC's Six-Values approach to waterway asset management.

Table 13: Categories and criteria used for Multi-Criteria Analysis (MCA)

Effectiveness and deployment	**Ecological effects**	**Floodplain reduction**
• Time to take effect. • Duration of solution. • Effectiveness at preventing re-establishment of macrophytes. • Conditions that inform deployment of method.	• Water & habitat quality effects. • Physical harm to fauna.	• Extent of reduction in floodplain levels.

The MCA that follows firstly sets out how each method compares in relation to the various evaluation criteria (refer to Section 0). The methods are compared across a scale ranging from 'Poor' to 'Excellent', with a description of how the scale applies to each criterion in the summary table. Colour coding is used throughout the MCA to reflect this scale as follows:

Excellent	**Good**	**Moderate**	**Poor**

Following the comparison of each method against each of the evaluation criteria, 'raw scores' are given to each control method based on the scale each method achieved across the various criteria using the following scoring system:

- Excellent – 4

- Good – 3
- Moderate – 2
- Poor – 1

Due to the different number of criteria under each of the broad categories outlined in Table 13, the raw scores were then adjusted as set out in Table 14 below to balance the differences between the number of criteria in each category, resulting in aggregate scores for each method against the four categories.

Table 14: Multipliers used to apply to raw scores to balance differences between the number of criteria in each category

Category	Number of criteria	Multiplier applied to raw score for criteria
Effectiveness and deployment	4	Raw score x 1
Ecological	2	Raw score x 2
Floodplain reduction	1	Raw score x 4

Two weighting scenarios were then applied to the aggregated scores. For the purpose of this analysis, it has been assumed that the extent of floodplain reduction should always receive the highest weighting, given that it is the principal objective of this assessment (x4). The two scenarios, therefore, arise from giving the ecological score and the effectiveness and deployment score weightings of second or third priority, respectively, as illustrated in Table 15:

Table 15: Weighting scenarios

Weighting	Scenario 1	Scenario 2
Multiplier applied to aggregate score	**Criteria category**	**Criteria category**
Raw score x 4	Floodplain reduction	Floodplain reduction
Raw score x 3	Effectiveness and deployment	Ecological
Raw score x 2	Ecological	Effectiveness and deployment

It is acknowledged that the weighting that is applied to the various categories of criteria will affect the overall weighted scores.

We have undertaken sensitivity testing to illustrate how the results could change with different weighting scores under some different scenarios, as illustrated in Table 16. The first two of the scenarios retain floodplain reduction as the most weighted outcome, but with an increased weighting (x10). The first two scenarios also amend the weighting attributed to the second and third weighted categories, with multipliers of 2 and 5, respectively. Under the third scenario, the highest weighting (x10) is attributed to the ecological category, and under the fourth scenario, the greatest weight is given to effectiveness and deployment (x10).

Table 16: Weighting scenarios

	Weighting values			
Criteria category	**Sensitivity testing 1**	**Sensitivity testing 2**	**Sensitivity testing 3**	**Sensitivity testing 4**
Floodplain reduction	10	10	5	2
Effectiveness and deployment	2	5	2	10
Ecological	5	2	10	5

The results of applying this methodology are set out below.

5.1 Evaluation criteria

5.1.1 Time to take effect

The time that each control method takes to take effect (achieve the reduction in bed roughness) varies. Hessian matting and mechanical cutting both take effect immediately (noting that they achieve different levels of reduced bed roughness), whereas aquatic herbicide may take up to 3 months to take effect. Riparian shading takes the longest period of time to take effect and could be many years, depending on the species planted, the type and condition of existing riparian vegetation, and the time taken for plantings to achieve a height sufficient to achieve the required level of shading.

Table 17: Time for control to take effect

Method	**Excellent**	**Good**	**Moderate**	**Poor**
	(Immediate)	**(0-3 months)**	**(3-6 months)**	**(>6 months)**
Hessian matting	Immediate			
Aquatic herbicide		Good		
Mechanical cutting	Immediate			
Riparian shading				Poor

5.1.2 Duration of solution

The duration of the solution is the estimated period that the reduced bed roughness is maintained before the method needs to be fully deployed again. While this aspect has also been factored into the CBA to a certain extent by the frequency that each method is required to be deployed, there may be a ‘lag period’ between the point that the control method ceases to be 100% effective and its redeployment due to practical and seasonal limitations on redeploying a particular control method, so understanding the relativity of each methods’ duration of solution may be useful.

For example, while aquatic herbicide effectiveness may cease after 3-6 months, redeployment of the solution is subject to a range of conditions being found to be optimal and is best deployed in the growing season (i.e. not in winter).

Table 18: Duration of solution

Method	Excellent	Good	Moderate	Poor
	>1 year	6-12 months	3-6 months	<3 months
Hessian matting		Good		
Aquatic herbicide			Moderate	
Mechanical cutting				Poor
Riparian shading	Excellent			

5.1.3 Effectiveness at preventing re-establishment

Each of the control methods has different levels of success at preventing (or minimising) the reestablishment of nuisance levels of macrophytes. This is a factor that partially informs the frequency of the deployment of the methods as captured in the CBA, but is also a useful comparator when considering the long-term investment in one method over another.

Hessian matting has been given an 'excellent' rating as it smothers macrophyte growth immediately. Provided that appropriate maintenance activities are taken out in accordance with best practice to repair any damaged areas, and remove macrophyte growth that might establish on the surface of the matting (which could occur from upstream untreated infestations for example), the control method is considered to be extremely effective at preventing re-establishment of nuisance levels of macrophytes as it not only controls all of the macrophytes it smothers, it also creates a barrier for fragments to deploy their roots into the sediment.

Riparian shading, once established to the specified requirements to achieve the necessary levels of shading, is also extremely effective at reducing excessive or nuisance levels of macrophytes and has been given an excellent rating.

Aquatic herbicide is moderately effective at preventing re-establishment of nuisance levels of macrophytes, as the method with the current available herbicide, diquat, does not typically kill all of the plant matter, thereby enabling the plants to regrow and re-establishment, albeit to a lesser degree. Although herbicide control can achieve amazing results, there are too many external factors, such as sediment levels and herbicide contact time, that can affect efficacy.

Mechanical cutting does not kill the plants at all; regrowth can occur within weeks to months under favourable conditions. Boat cutters are limited to approximately 1.5m in depth; therefore, if water levels are too high, they potentially will not be able to remove enough biomass. Therefore, significant re-establishment is always guaranteed with this method.

Table 19: Effectiveness at preventing re-establishment

Method	Excellent	Good	Moderate	Poor
	Extremely effective	Highly effective	Moderately effective	Limited effectiveness
Hessian matting	Excellent			

Method	Excellent	Good	Moderate	Poor
	Extremely effective	**Highly effective**	**Moderately effective**	**Limited effectiveness**
Aquatic herbicide			Moderate[14]	
Mechanical cutting				Poor
Riparian shading	Excellent			

5.1.4 Number of conditions that limit deployment

As set out in Section 2.1, there is a range of conditions that can limit the deployment of the various methods, such as weather, access, water supply, etc. Greater numbers of conditions can result in increased complexity associated with the planning and deployment of the method and may also affect the effectiveness of the method (e.g., if a method is deployed when certain conditions are present). For the purposes of this MCA, we have compared the various control methods based on the number of conditions that inform the deployment of each method.

[14] This assumes that the spraying is undertaken in ideal conditions and achieves the highest level of effectiveness.

Table 20: Number of conditions that limit deployment

Method	Excellent	Good	Moderate	Poor
	0-3 conditions	4-6 conditions	7-9 conditions	10-12 conditions
Hessian matting	Excellent			
Aquatic herbicide				Poor
Mechanical cutting		Good		
Riparian shading	Excellent [15]			

5.1.5 Water and habitat quality effects

As outlined in Section 2.2, the removal of macrophytes can have many ecological effects, such as altering water chemistry and increasing suspended sediments. Each of the control methods have different levels of effect on water and habitat quality. Riparian shading is anticipated to deliver positive benefits to habitat and water quality, provided that native and non-deciduous plants are used (to minimise / avoid leaf litter fall into the river).

By contrast, hessian matting and aquatic herbicide have the potential to result in adverse impacts on water quality arising from the decay of plant matter left in the waterway after the deployment of these control methods. Mechanical clearing can resuspend sediments and temporarily increase the turbidity of the water.

Table 21: Water and habitat quality effects

Method	Excellent	Good	Moderate	Poor
	Delivers positive benefits	No impact	Potential adverse impact	Adverse impact
Hessian matting			Moderate	
Aquatic herbicide			Moderate	
Mechanical cutting			Moderate	
Riparian shading	Excellent [16]			

5.1.6 Physical harm to fauna

As outlined in Section 2.2, the removal of macrophytes can have many ecological effects, such as disturbance, injury, or mortality of fauna. Each of the control methods have different levels of effect on fauna in the river. Riparian shading is expected to deliver positive benefits to fauna within the river due to its non-invasive nature, but it will take time to achieve these outcomes.

[15] Note that land tenure is one of these factors, which is likely to involve a far greater level of complexity than the other factors described in Section 2.1.

[16] This assumes the prioritisation of large-stature indigenous vegetation.

By contrast, hessian matting and mechanical cutting bring associated adverse impacts on in-stream fauna due to smothering (hessian matting) or direct harm during mechanical cutting operations. Aquatic herbicide, hessian matting and mechanical cutting could all result in the displacement of fauna that use the weed macrophytes as habitat.

Table 22: Physical harm to fauna

Method	Excellent	Good	Moderate	Poor
	Delivers positive benefits	**No impact**	**Potential adverse impact**	**Adverse impact**
Hessian matting				Poor
Aquatic herbicide			Moderate	
Mechanical cutting				Poor
Riparian shading	Excellent			

5.1.7 Extent of reduction in floodplain levels (mm)

As outlined in the DHI memorandum in Appendix 21. Each of the control methods results in varying reductions in the levels of flooding in the modelled flood event. Noting the various assumptions that have been relied upon to inform this modelling, a comparison of these outcomes arising from each method is set out below.

Table 23: Extent of reduction in floodplain levels

Method	Excellent	Good	Moderate	Poor
	451-600mm	**301-450mm**	**151-300mm**	**0-150mm**
Hessian matting	Excellent (575mm)			
Aquatic herbicide		Good (440mm)		
Mechanical cutting		Good (400mm)		
Riparian shading		Good (450mm)		

5.2 Summary by method

This section summarises how each method scores against the combined criteria.

Hessian matting

Table 24: Summary of hessian matting scores

Criteria	Excellent	Good	Moderate	Poor
Time to take effect	Immediate			
Duration of solution		6-12 months		
Effectiveness	Extremely effective			
Number of conditions that limit deployment	0-3 conditions			
Water quality effects			Potential adverse impact	
Physical harm to fauna				Adverse impact
Extent of reduction in flooding levels (mm)	575 mm			

Aquatic herbicide application

Table 25: Summary of aquatic herbicide application scores

Criteria	Excellent	Good	Moderate	Poor
Time to take effect		0-3 months		
Duration of solution			3-6 months	
Effectiveness			Moderate	
Number of conditions that limit deployment				10-12 conditions
Water quality effects				Adverse impact
Physical harm to fauna			Potential adverse impact	
Extent of reduction in flooding levels (mm)		440 mm		

Mechanical cutting

Table 26: Summary of mechanical cutting scores

Criteria	Excellent	Good	Moderate	Poor
Time to take effect	Immediate			
Duration of solution				<3 months
Effectiveness				Limited effectiveness
Number of conditions that limit deployment		4-6 conditions		
Water quality effects				Adverse impact
Physical harm to fauna				Adverse impact
Extent of reduction in flooding levels (mm)		400 mm		

Riparian shading

Table 27: Summary of riparian shading scores

Criteria	Excellent	Good	Moderate	Poor
Time to take effect				Poor
Duration of solution	>1 year			
Effectiveness	Extremely effective			
Number of conditions that limit deployment	0-3[17]			
Water quality effects	Delivers positive benefits			
Physical harm to fauna	Delivers positive benefits			
Extent of reduction in flooding levels (mm)		450 mm		

5.3 Summary and findings

Applying the methodology outlined above results in the following scores for each of the methods under the two scenarios (refer to Table 28). The shading indicates the lowest scoring method (red) up to the best scoring method (green).

[17] Note that land tenure is one of these factors, which is likely to involve a far greater level of complexity than the other factors listed in Table 27.

Table 28: Overall weighted scores

Overall weighted scores		
Control method	**Scenario 1**	**Scenario 2**
Hessian matting	121	112
Aquatic herbicide	84	82
Mechanical cutting	83	78
Riparian shading	119	122

In both scenarios, floodplain reduction is afforded the highest weighting (multiplier of 4).

Scenario 1 weights Effectiveness and Deployment over Ecological Values (multipliers of 3 and 2, respectively). Under this weighting scenario, hessian matting achieves a higher score than riparian shading by 2, which is the second preferred option. There is very little material difference between these two leading options under this scenario.

Scenario 2 weights Ecological Values over Effectiveness and Deployment (multipliers of 3 and 2, respectively). Under this weighting scenario, riparian shading achieves a higher score than hessian matting, by a greater margin than the difference in scores between the two highest scoring options in Scenario 1.

This scenario testing demonstrates that the weighting afforded to each of the criteria groupings can affect the overall preferred option as illustrated by the MCA.

We have undertaken sensitivity testing to illustrate how the results could change with different weighting scores under some different scenarios, as illustrated in Table 16. The outcomes of this sensitivity testing illustrate that riparian shading and hessian matting are consistently the favoured options under all scenarios, as illustrated in Figure 11.

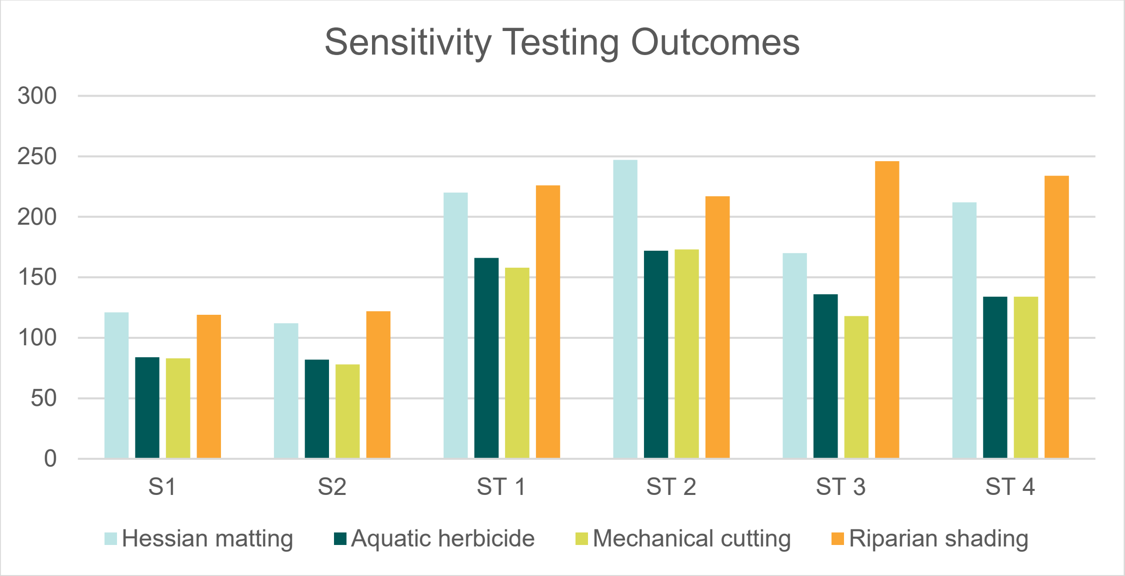

Figure 11: Sensitivity testing - MCA outcomes (S = Scenario, ST = sensitivity testing)

The summarised results of the MCA for each control method are included as Appendix 6.

6.0 Six values approach to waterway asset management

CCC takes a six-values approach to sustainable waterway and wetland management, incorporating ecology, drainage, culture, heritage, landscape, and recreation. This approach seeks to ensure that surface waters contribute to the environmental, social, cultural, and economic well-being of current and future generations. CCC has taken a combined approach to merging legislative requirements and sustainability principles into one strategy for natural asset management. This approach was initially outlined in the 2000 version of The Styx River Vision 2000-2040 by the Styx Living Laboratory Trust and has since guided diverse methods to achieve outcomes aligned with the six core values.

The control methods have been considered in the context of CCC's Six Values approach to waterway asset management, but only at a very high level, as input from additional technical experts is required. While this assessment is not strictly necessary to support the main objective of this report (the CBA), it is of importance to CCC in a wider sense, given the importance of the inclusion of the six values in its decision-making processes.

The six core values identified are: ecology, drainage, culture, heritage, landscape, and recreation. In the *Pūharakekenui/ Styx River Catchment: Tauākī Wai Pātaua: Vision and Values* (Christchurch City Council & Opus International Consultants Ltd, 2017), 'desired outcomes' have been identified for each of the six values, as well as a description of existing conditions and issues that relate to each value.

The following sections provide a high-level assessment of which 'desired outcomes' may be achieved through the various control methods. Further consideration of these values may be included as a next step to determining the best practicable options for controlling macrophyte growth as mitigation to reduce flooding in Pūharakekenui / Styx River.

6.1 Ecology

This value refers to the *'inter-relationships between organisms and their environment'*. The ecological impacts of each control method have been addressed in the Stage 3A memo provided in Appendix 35 and are summarised in Section 2.2. High-level or general ecological considerations have been included in the MCA set out in Section 5.0.

Outcomes identified in *Pūharakekenui/ Styx River Catchment: Tauākī Wai Pātaua: Vision and Values* (Christchurch City Council & Opus International Consultants Ltd, 2017) that may be achieved through riparian planting, including:

- Increased use of evergreen tree species along river margins to increase shading and reduce concentrated leaf fall in autumn.
- Conservation of the remaining areas of native vegetation and riparian plantings.
- Maintenance and enhancement of habitats and ecological linkages along bird migration routes using riparian planting.
- Restoration of areas with currently low ecological values or poor water quality through intensive management of water quality, and riparian and in-stream habitat enhancement, including pest plant control.

- Developing riparian and neighbouring land into suitable habitat to re-establish the locally extinct mātātā / South Island fernbird.
- Erosion protection measures, implemented in areas where bank stability is an issue, primarily in the form of riparian planting and soft-engineering options to reduce in-stream sedimentation issues.
- Ensure native plant communities are resilient to the impacts of historic fragmentation/isolation and future climate change.

6.2 Drainage

This value refers to the '*inter-relationships between groundwater and surface water, natural flow regimes and management of storm events*'. This value has been addressed in the hydrological modelling for the various control methods (provided in Appendix 2).

Riparian planting may help to achieve the following outcome:

- Maximise rain interception by tree canopies through encouraging extensive tree cover in storm water facilities, public reserves, riparian areas, road reserves and private property throughout the catchment.

All control methods may contribute positively (to varying degrees, whether directly or indirectly) to the following outcomes:

- Protection of floodplains and ecological values within the catchment, while managing drainage needs.
- Restoration of the natural flow regime through detention, water quality management and ecological restoration work.
- Flood risk reduced or at least returned to pre-earthquake levels.
- Minimise the impact of waterway management practices on water levels and the health and viability of riparian habitat.
- Protection and enhancement of mahinga kai.

6.3 Culture

This value refers to the *'communities' perception of a resource and its values, indicated by community involvement in the management, celebration of past events and planning for the future.* The Pūharakekenui / Styx River is of very high importance to mana whenua, and key objectives for mana whenua associated with stormwater management relevant to aquatic weed management include: improving water quality in rivers and streams; restoring riparian margins; and protecting and restoring mahinga kai (Christchurch City Council & Opus International Consultants Ltd, 2017).

CCC has a responsibility to engage with mana whenua partners, including Ngā Papatipu Rūnanga, Te Rūnanga o Ngāi Tahu and Mahaanui Kurataiao Ltd, to understand their perspectives on the use of various control methods in Pūharakekenui / Styx River. Several outcomes have been identified in *Pūharakekenui/ Styx River Catchment: Tauākī Wai Pātaua: Vision and Values* (Christchurch City Council & Opus International Consultants Ltd, 2017) to recognise and improve the cultural values of the catchment. The use of various control methods to reduce the risk of flooding in the Pūharakekenui / Styx River may contribute generally to the following cultural outcomes (through a reduction in floodplain water levels during flood events):

- Recognise and protect sites of cultural significance, including, where appropriate, the marking of these through restoration, interpretation and / or events.
- Identification, protection, and enhancement of mahinga kai and natural spring and wetland sites and the improved ability to harvest mahinga kai for cultural purposes.
- Protect and accentuate the stories of the land, its natural drainage and vegetation patterns, cultural features and landmarks. Work with private landowners while recognising private property rights and the need to use a range of protection methods to achieve desired outcomes as a win-win situation.

However, consideration of mana whenua values, aspirations, and concerns need to be included as a next step to determining the best practicable options for controlling macrophyte growth as mitigation to reduce flooding in Pūharakekenui / Styx River.

6.4 Heritage

This value '*includes built and natural sites, features and activities of historical, social, cultural, spiritual, architectural, aesthetic, technological, craftsmanship, archaeological, scientific and contextual value'.* While the control methods may not directly address heritage values, their contribution to a reduction in floodplain levels can help protect natural sites and features of historical, social, and cultural significance along the Pūharakekenui / Styx River. Therefore, these methods may help to achieve the following outcomes:

- Improved understanding, protection and / or enhancement of heritage values, built and natural heritage sites and settings, in line with best practice heritage conservation.
- Recognition, protection and/or enhancement of the traditional network of Ngāi Tūāhuriri / Ngāi Tahu settlement and mahinga kai sites.

6.5 Landscape

This value refers to the '*special character of sites and places, their aesthetic qualities and their meaning to the community'*. Riparian planting may enhance the aesthetic qualities of the catchment by restoring natural vegetation and creating visually attractive landscapes. Riparian zones may also contribute to the special character of the site and enhance their significance to the community. Riparian planting may help to achieve the following outcome:

- A high level of natural character and rural amenity shall be preserved throughout the catchment through adequate separation and/or screening of land uses and activities that adversely impact these values.

6.6 Recreation

This value includes sport (formal, organised, competitive activities) and recreation (informal, unstructured leisure activities) on and beside the river and the facilities that support these activities. Recreation opportunities are a combination of a setting and an activity that result in an experience. The setting in particular is dependent on the other five values, and correspondingly can generate an appreciation of those values. All the control methods for nuisance weeds in the

Pūharakekenui / Styx River will enhance the recreation value. For example, the aesthetic enjoyment of the river environment will be enhanced by the reduction in macrophytes. Riparian planting can enhance recreational opportunities by creating natural 'green spaces' for people to enjoy. Healthy riparian habitats support a diverse range of fauna and flora, making them popular destinations for recreational activities.

Riparian planting also may offer an opportunity to involve the community in planting projects. This may help to foster a sense of connection, awareness, and appreciation for the Pūharakekenui / Styx River. Therefore, riparian planting may support the following outcomes:

- Provide opportunities to enjoy, learn about, and appreciate nature and cultural values.
- Encourage community involvement in planting and other restoration activities and on-going management of sites as a recreation activity.

7.0 Partnership with the Styx Living Laboratory Trust

The Styx Living Laboratory Trust is a local river care group established in 2002 that focuses on the protection, restoration, and promotion of the Pūharakekenui / Styx River and its surrounding environment[18]. The Trust works to conserve its biodiversity, improve water quality, and enhance recreational opportunities for the community. It engages in activities such as habitat restoration, native vegetation planting, water quality monitoring, and advocating for sustainable land management practices. The Trust also conducts educational programmes and community events to raise awareness about the importance of preserving the Styx River and its ecosystem.

The Trust is already undertaking several planting projects, including the planting of native eco-sourced plants along the riparian margins of the lower Styx River. CCC should consider the involvement of Styx Living Laboratory Trust in supporting the implementation of riparian planting, particularly on private land.

8.0 Conclusion

The results of the CBA determined the following:

- Hessian matting was the most effective method in reducing flooding in the hydrological model; however, it has the highest present value cost of $6,906,707 over a 50-year period.
- Aquatic herbicide application was second in effectiveness for reducing flooding in the hydrological model and has the lowest present value cost of $406,440 over a 50-year period.

[18] https://www.thestyx.org.nz/styx-visions

- Riparian shading was also second equal in effectiveness for reducing flooding in the hydrological model and has the third most expensive present value cost of $2,398,213 over a 50-year period, noting that land acquisition and fencing costs could significantly increase the overall costs of this control method..[19]
- Mechanical cutting produced the smallest reduction in flooding in the hydrological model and has the second-most-expensive present value cost of $2,945,808 over a 50-year period.

In addition to the above, riparian shading achieved the highest ranking in the MCA, followed by hessian matting. Mechanical cutting results are the lowest-ranked method due to the number of criteria that achieve only a 'poor' ranking. The application of aquatic herbicide is the third most preferred method.

The results of the MCA of the three categories, comparing the non-monetised costs and benefits associated with the control methods, found that riparian shading achieves the highest ranking and should, therefore, be considered as the best control method, followed by hessian matting. Mechanical cutting results are the lowest-ranked method due to the number of criteria that achieve only a 'poor' ranking. The application of aquatic herbicide is the third most preferred method.

A summary of the various comparative data for each of the control methods is shown in Table 29.

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[19] Note that the costs for this control method exclude any land acquisition costs (at the request of CCC), but that these have the potential to be significant. There are many variables that would inform the extent to which land acquisition would be required to deliver this control method, however once these costs are factored in, there is the possibility that this method would become the most expensive control method.

Table 29: Overview of the control methods against the various comparators in this report.

Method	Present value of costs		Area of floodplain reduced		$ per ha reduced floodplain		MCA rankings	
	$	Ranking	Ha	Ranking	$/ha	Ranking	Scenario 1	Scenario 2
Hessian matting	$6,906,707	4	148.0042	1	$46,665.62	4	112	121
Mechanical cutting	$2,945,808	3	115.7957	4	$25,439.70	3	78	83
Riparian planting	$2,398,213	2	131.3991	2	$18,251.36	2	122	119
Aquatic herbicide	$406,440	1	127.5658	3	$3,186.13	1	82	84

We conclude that hessian matting is the best practicable short-to-medium option for controlling excessive macrophyte growth in Pūharakekenui / Styx River and that riparian planting is the preferred long-term preventative measure.

Riparian planting initially is a larger investment cost to establish; however, being a preventative measure means that it will continually provide effective management of macrophytes. Riparian planting also aligns strongly with the Council's overarching six values approach to managing the Pūharakekenui / Styx River catchment. There are, however, some areas along Pūharakekenui / Styx River where riparian planting is not suited due to various environmental factors. Within these areas, hessian matting should be adopted as a complementary and short-to-medium control method used in conjunction with and while riparian planting is being established and plantings/trees mature. Hessian matting provides an immediate effect on bed roughness and is reliant on very minimal external factors to be effective. It is highly suited to be brought into the Council's routine maintenance 'toolkit'.

A targeted trial of hessian matting for achieving reduced flooding from changes in the weed management of the Pūharakekenui / Styx River should be the next step. Hessian matting is preferred because bed roughness is immediately reduced once the matting is deployed, the matting does not require any additional machines or watercraft to assist with deployment, meaning it can be deployed in all areas even those with limited access, it does not rely on any specific environmental conditions except access to the river, and it can be deployed year-round, which makes it ideal for fitting into council maintenance cycles. A hessian matting trial would serve to validate the calculated Manning's Roughness Coefficient ('n' value) while also assessing the durability and effectiveness of this control method in the Pūharakekenui / Styx River. Previous work (Matheson et al., 2022) has trialled other methods in this river's environment, but hessian matting has not yet been practically tested. Other methods, such as aquatic herbicide application, require very specific conditions to be effective.

8.1 Final recommendations

We recommend that the following be considered by CCC:

- Riparian planting is the preferred long-term preventative solution or measure for reducing excessive macrophyte growth to mitigate flooding effects in Pūharakekenui / Styx River. Riparian margins, once established, act as a preventative measure to reduce bed roughness. Riparian plantings also provide additional benefits that align strongly with CCC's six values management approach within the Pūharakekenui / Styx River.

- CCC should undertake comprehensive planning assessments to determine the following:

    - For riparian planting, investigate land and tenure and ownership throughout the margins of the Pūharakekenui / Styx River,

    - Explore alternatives to purchasing land (e.g., lease agreements, QEII covenants), and

    - Consider planting programs to help landowners convert parts of their property into riparian planting zones along the river.

  - Concurrently, identify what specific resource consents are needed to implement all control methods. It is essential to keep the control toolbox with as many control methods as possible, as future legislation changes could limit the current control methods available, and a variety of options are required until the long-term preventative measure of riparian planting has successfully reduced excessive growth of macrophytes in the river.

- Start investigations and trials to identify plant species that offer maximum shade - consider growth rates and heights of mature plants. This could be undertaken in partnership with local community groups such as The Styx Living Laboratory Trust and mana whenua.

- Ground-truthing of potential constraints such as localised terrain, river dynamics, and environmental constraints that influence control method effectiveness. This would require detailed mapping, including:

  - Where riparian planting and hessian matting can be implemented (and should be avoided – particularly relevant to hessian matting when considering CCC's six values)

  - River depths, width, and debris on the bed

  - Locations of buildings and infrastructure

  - Areas where the river margins are less than 10 meters wide

  - Sites requiring fencing or other protective measures

  - Identification of any hazards or other obstacles that could directly affect control methods.

- To validate the assumptions made in the hydrological modelling and better understand the long-term efficacy and limitations of the different macrophyte control options, it is recommended that CCC undertake independent, large-scale field trials of the three short-term control methods: hessian matting, aquatic herbicide application, and mechanical cutting.

  - Each method should be trialled independently at separate sites to avoid overlap in effectiveness, particularly from upstream influences such as fragment reduction or shading impacts.

  - The trials should be conducted at a sufficient scale to allow CCC to understand the true logistical and cost implications of deploying each method across broader sections of the Pūharakekenui / Styx River.

  - The trials would also allow for the CBA and MCA inputs to be updated with real-world data.

  - Trials should include bed roughness monitoring before, during, and after control to evaluate changes to hydraulic resistance over time.

- Assess re-invasion rates and the duration of control effectiveness for each method.

- Monitoring should also include assessments of macrophyte regrowth rates, which species are coming back first, decomposition impacts, and ecological response to provide a full picture of feasibility and resilience.

The findings from these trials will validate the report's assumptions, identify feasible short- to medium-term control methods, and inform evidence-based decisions for long-term weed management to reduce flooding risk in the Pūharakekenui / Styx River.

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Appendix 1: Pūharakekenui / Styx River weed management flood modelling

MEMO

To: Jourdan Lethbridge – Boffa Miskell

Cc:

From: Greg Whyte

Date: 7th December 2023

Subject: Pūharakekenui/Styx River Weed Management Flood Modelling

Introduction

DHI was engaged by Boffa Miskell (BM) to undertake some Flood Modelling to understand the potential flood risk benefits from various weed control methods in the Pūharakekenui/Styx River. CCC provided the Pūharakekenui/Styx River model in MIKE FLOOD version 2016. This calibrated model has Mannings main river channel roughness of n=0.032 and 0.045 or M=31.3 to 22.2.

Methodology

The model was run in MIKE FLOOD version 2017, which is very similar to its original version, and thought to not have any significant changes to the software over this period. The model would be used in a comparative context anyway.

An initial workshop was held with Christchurch City Council (CCC) and Environment Canterbury (ECan) to kick off the project and discuss the details. Several other meetings were held to discuss roughness values and the potential data gathering/monitoring to determine channel roughness for various weed control methods. Table 1 provides the Mannings roughness values used for the four control methods: Hessian Matting, Herbicide Spraying, Cutting and Riparian Shading. It was also decided to use the Existing Development (ED) 10-year 48-hour design rainfall event with no sea level rise or climate change allowance.

Table 1 – Roughness values used

	Manning's Roughness Coefficient 'n'
Control Methods	**3 months post control**
Hessian matting	0.032
Aquatic herbicide spraying	0.048
Mechanical cutting	0.062
Riparian shading	0.045
No control	0.15

BM supplied a shape file that defined the extent of the different weed control methods. These can be seen in Figure 1, noting that the “No Control” scenario assumes the roughness of 0.15 is applied from upstream of Radcliffe Road to the tide gates. The roughness has only been modified from the supplied model in the main river channel bed.

Five model simulations were run, as listed in Figure 1, as well as the “No Control” scenario.

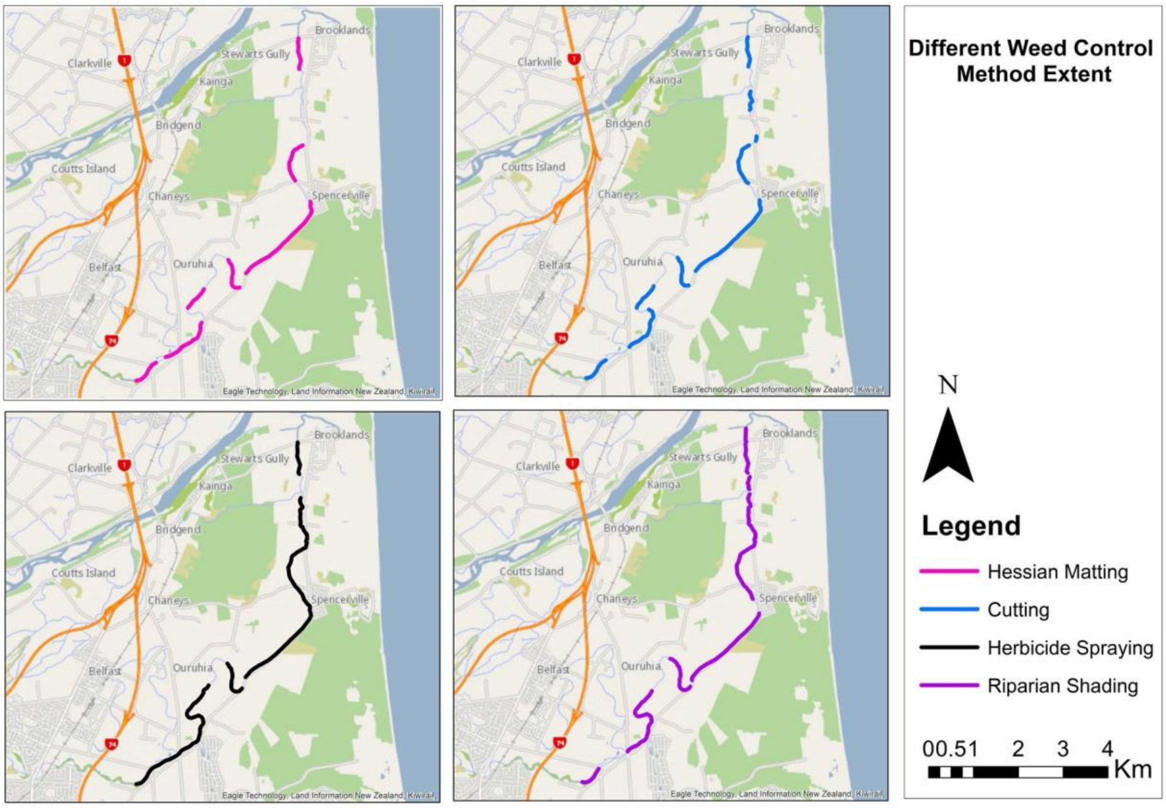

Figure 1 – Extents of Different Weed Management Strategies

Results

The model results have been processed for maximum water levels for each scenario. Four difference maps were then produced where the base or “No Control” scenario was subtracted from the Weed Control scenario to get a reduction in maximum water level. These difference maps are below as Figure 2 - Figure 5. It can be seen from these figures that the reduction in water level varies in the floodplain depending on location and where the management method has been applied. Reasonable flood risk reduction can be seen for all methods compared to “No Control”.

Figure 6 is a long section of maximum water levels for each modelled scenario, showing a maximum reduction of 650 millimetres in the Styx River main channel for the Hessian Matting scenario. It should be noted that there is a bridge structure that is used in the model at Radcliffe Road that has a small instability which shows a water level spike in Figure 6 for the “No Control” scenario. This occurs 14 hours before the peak water levels, and due to this we don’t believe it affects peaks water levels and peak water level comparisons.

The “Cutting”, control method difference results in Figure 2, show that there is a reduction in floodplain flooding from just downstream of State Highway 74 to the Styx River tide gates. The “Cutting” control method produces the smallest reduction in floodplain levels, where the floodplain mimics reductions in the main river channel, which are shown in Figure 6. The largest reductions in flood levels occur over the reach from approximately 500 metres upstream of Radcliffe Road to Teapes Road, ranging in 350 to 450 millimetres. There are also some very localised small areas that due to the reduction in flooding are now dry, which are shown as green in Figure 2.

Figure 2 – Water Level Difference Map-Cutting Minus No Control

The “Herbicide Spraying”, control method difference results in Figure 3, show that there is a reduction in floodplain flooding from just downstream of State Highway 74 to the Styx River tide gates. The “Herbicide Spraying” control method produces the second equal largest reduction in floodplain levels, where the floodplain mimiks reductions in the main river channel which are shown in Figure 6. The largest reductions in flood levels occur over the reach from approximately 500 metres upstream of Radcliffe Road to Teapes Road, ranging in 380 to 500 millimetres. There are also some very localised small areas that due to the reduction in flooding are now dry, which are shown as green in Figure 3.

Figure 3 – Water Level Difference Map-Herbicide Spraying Minus No Control

The “Hessian Matting”, control method difference results in Figure 4, show that there is a reduction in floodplain flooding from just downstream of State Highway 74 to the Styx River tide gates. The “Hessian Matting” control method produces the largest reduction in floodplain levels, where the floodplain mimiks reductions in the main river channel which are shown in Figure 6. The largest reductions in flood levels occur over the reach from approximately 500 metres upstream of Radcliffe Road to Teapes Road, ranging in 500 to 650 millimetres. There are also some very localised small areas that due to the reduction in flooding are now dry, which are shown as green in Figure 4.

Figure 4 – Water Level Difference Map-Hessian Matting Minus No Control

The “Riparian Shading”, control method difference results in Figure 5, show that there is a reduction in floodplain flooding from just downstream of State Highway 74 to the Styx River tide gates. The “Riparian Shading” control method produces the second equal largest reduction in floodplain levels, where the floodplain mimiks reductions in the main river channel which are shown in Figure 6. The largest reductions in flood levels occur over the reach from approximately 500 metres upstream of Radcliffe Road to Teapes Road, ranging in 400 to 500 millimetres. There are also some very localised small areas that due to the reduction in flooding are now dry, which are shown as green in Figure 5.

Figure 5 - Water Level Difference Map-Riparian Shading Minus No Control

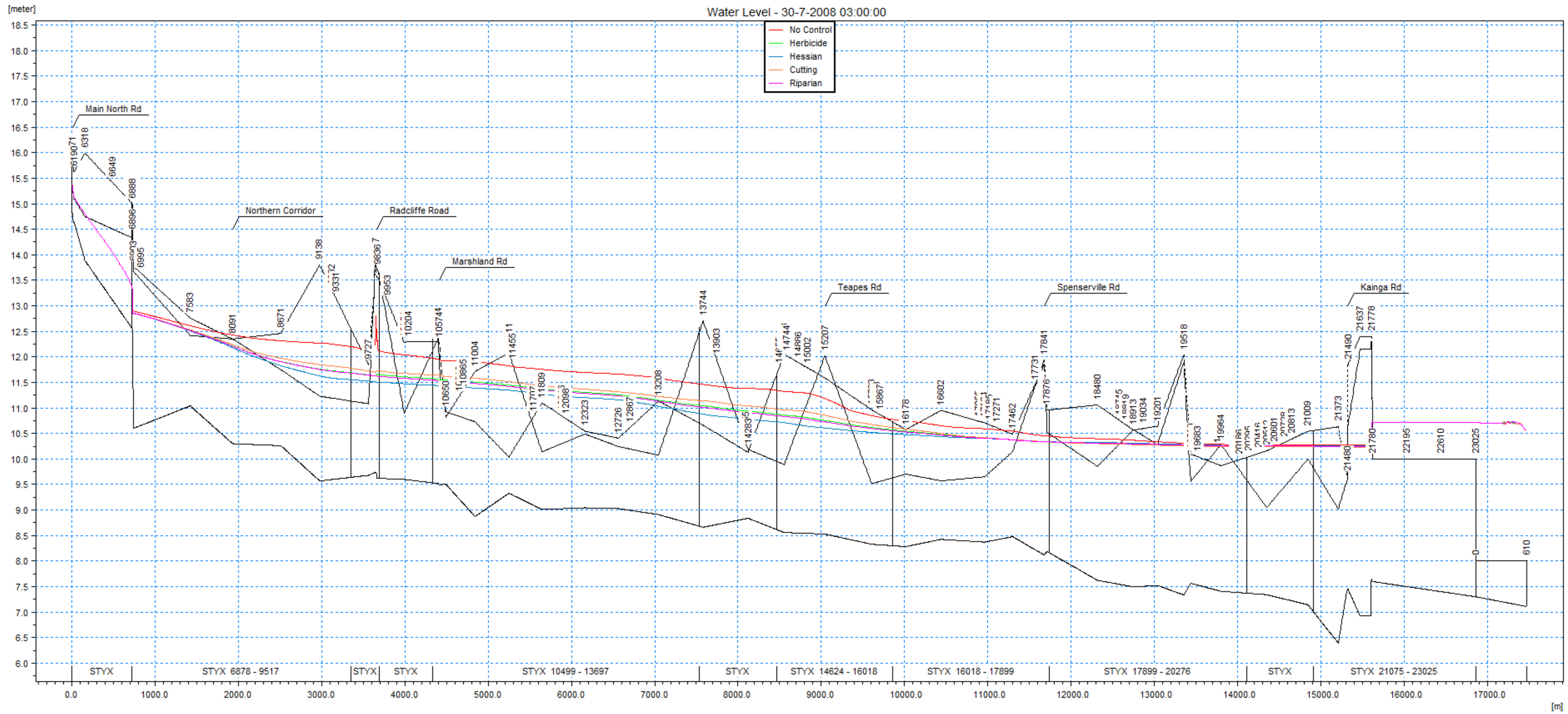

Figure 6 - Long Section of Maximum Water Levels in Styx River

Appendix 2: Desktop analysis of five macrophyte control methods

Boffa Miskell

Memorandum

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Attention:	Florian Risse
Company:	Christchurch City Council
Date:	18 April 2023
From:	Jourdan Lethbridge
Message Ref:	Desktop analysis of five macrophyte control methods
Project No:	BM200717G

Introduction

In December 2019, the Canterbury Regional Council issued Christchurch City Council (CCC) with a comprehensive stormwater network discharge consent (CSNDC; CRC231955) to discharge water and contaminants to land and water from the stormwater network. As part of this global consent, the CCC must carry out a number of actions relevant to Pūharakekenui | Styx River weed management (as listed in Schedule 4, Items R-X of CRC231955).

Boffa Miskell has been engaged by the CCC to assist with Items S, T and U, building on work previously completed by NIWA (Item R) (F. Matheson et al., 2021).

Scope | He kupu arataki

This memorandum addresses the first stage of Boffa Miskell's technical work, to carry out a desktop analysis of five macrophyte control methods, which will be used to inform river flow and flood modelling scenarios and Item S of Schedule 4.

This memo provides an overview of the five key aquatic macrophyte control methods that could influence the water levels in Pūharakekenui | Styx River. This memo also describes why these control methods have been selected for analysis, their operational advantages, disadvantages, what physical environmental factors might limit the success of each of the methods, and the lifespan and efficacy of each control method.

We have not included discussion on any ecological or planning aspects of the control methods; these will be covered under Stage 4 of the project and included in the final deliverable.

The control methods described in this memo are largely based on the findings from NIWA (F. Matheson et al., 2021) with some additional recommendations made by Boffa Miskell.

The five macrophyte control methods are:

1. Hessian matting (additional recommendation by Boffa Miskell)
2. Diver-based hand weeding (additional recommendation by Boffa Miskell)
3. Aquatic herbicide application (included in NIWA's recommendations)
4. Mechanical cutting (included in NIWA's recommendations)
5. Riparian shading (included in NIWA's recommendations)

This memo provides information that will support the MIKE FLOOD 2020 hydrological modelling scenarios for Pūharakekenui | Styx River. It will also help to inform the Manning's Roughness Coefficients channel roughness scenarios for the five macrophyte control methods.

This work focusses on the 14.6 km length of the Lower Styx River from Redwood Springs downstream to the tide gates.

Background | Tāhuhu kōrero

Pūharakekenui | Styx River is a spring-fed, low-lying river in Ōtautahi | Christchurch; the river is approximately 23 km long, with the catchment comprising 7000 ha. The river begins in the suburb of Harewood and travels north-east, discharging into the sea via Brooklands Lagoon and the Waimakariri River. The main tributaries of the river are Smacks Creek and Kā Pūtahi Creek, which are also spring-fed.

Water levels in Pūharakekenui | Styx River are strongly affected by macrophyte growth and accumulation in the river channel, particularly over the summer months (Christchurch City Council, 2017). In the lower river, aquatic macrophytes are controlled using a mechanical harvester to manage water levels and prevent flooding of surrounding low-lying land. In their recent report (Matheson et al., 2021), NIWA determined that water levels in Pūharakekenui | Styx River were reduced appreciably by macrophyte harvesting activities. Their analysis indicated an increase in efficacy of harvesting to reduce water levels and, therefore flooding risk, in the mid-lower river; however, NIWA suggested that harvesting has become less effective in the upper part of the river.

1.0 Hessian matting

Hessian matting is made from a biodegradable vegetable fibre called jute; this is spun into threads and then woven into a matting. The hessian matting is laid over the target macrophytes by divers and is securely pinned to the substrate using stakes, rocks, or sandbags. Over time, depending on sedimentation levels and flow rates, sediment will accumulate on the hessian acting as a further barrier limiting the availability of light to the macrophytes underneath, thus preventing growth, and reducing biomass as the macrophytes underneath the matting decay. This method is often referred to as bottom-lining.

Hessian matting has been chosen as one of the five control methods for the following reasons:

- it provides a fast-acting, medium-term solution for controlling macrophytes through starving them of light
- however, some native macrophytes are able to grow through the weave in the hessian due to their smaller size, compared to common exotic species. But invasive macrophytes cannot growth through the weave as they are too large.
- hessian matting also reduces the of exotic macrophytes recolonising the control area of the waterbody, due to the tight weave of the matting limiting macrophyte roots establishing sufficient hold for growth.
- once installed it immediately reduces substrate roughness, which can provide increased flow rates within the waterbody.
- it has a high efficacy; as long as it is installed correctly macrophyte mortality can be expected within a couple of months.

The hessian matting will stay in place for several months, after which it starts to naturally biodegrade.

Advantages

Fragment containment. The hessian matting acts to contain and smother the macrophytes, preventing their growth and spread. The hessian will prevent growth of exotic species (but smaller native species can grow through the fine weave of the matting) for as long as the matting stays in place and is able to block sunlight and prevent photosynthesis. Once macrophytes have been covered with hessian matting this prevention of photosynthesis will begin.

Durability. Hessian matting is reasonably durable in the right environment, which means that it can withstand the effects of water, sunlight, and wind.

Able to be deployed in most conditions. Unlike diquat herbicide application, which requires macrophytes and the water to be free of sediment, hessian does not require these conditions.

No aquatic herbicide application is required with this control method. Any method that does not use herbicide, particularly in waterbodies, tends to be more publicly favoured, particularly in catchments where herbicide use is opposed by iwi, stakeholders and the general public.

Reduces bed roughness as soon as the hessian has been deployed. The MIKE FLOOD 2020 hydrological model uses Manning's roughness coefficient, a hydraulic parameter which specifies different roughness values of waterways in the model or parts of waterways (Greg Whyte DHI, personal communication, 2022). It is expected that the deployment of hessian matting will result in a Manning's roughness coefficient, as the macrophytes are immediately suppressed, immediately reducing roughness of the waterway. This is an advantage to other control methods (such as aquatic herbicide application) where it can take weeks to months to see a reduction in macrophyte biomass and bed roughness.

Disadvantages

Labour intensive and therefore an expensive control method. This is due to the cost of the hessian matting itself, delivery of the product, and high labour costs due to the use of multiple divers to prepare and undertake installation of the matting.

Maintenance required. Over time, the hessian matting may be damaged by debris and recreational activities (such as angling), reducing its effectiveness by allowing the macrophytes to receive light. Regular maintenance is required to ensure the matting is functioning properly; if rips are found, these need to be repaired with new hessian.

A long lead-in time is required as the hessian matting needs to be ordered from overseas and then shipped to New Zealand. The order typically needs to be made by May each year, with delivery expected by December of the same year. Due to the fixed shipping price, it is more cost-effective to purchase the product in bulk, however, storage of these bulk supplies will also need to be considered.

Physical environmental factors

Key physical environmental factors to be considered for the viability of hessian matting as a macrophyte control tool include:

- A relatively flat riverbed where hessian is being laid or a substrate that allows the hessian to be pinned securely using stakes.
- Too much debris (e.g., branches) or large rocks on the bed of the waterbody may impact on the ability of sediment to accumulate on top of the hessian, and thus decrease the efficacy of the hessian. Debris increases the likelihood that light can penetrate through the hessian weave as sediment is unable to build up on matting that is not laid flat. There is also an increased likelihood of the hessian being damaged or ripped by the debris.
- Divers need to have good access to the control site either from the adjacent riverbank, or the ability to transport the hessian to site using a boat.

Lifespan

Hessian is designed to last for 6-18 months, making it a medium-term solution for controlling macrophytes.

Efficacy

Hessian needs to be able to lie flat so that sediment can build up on top of the weave and prevent photosynthesis. Therefore, the efficacy of hessian can be affected by the following:

- Low amount of naturally occurring sediment within the water body.
- Debris on the bed of the waterbody, this creates billowing in the hessian and prevents sediment build up.

- Low water levels leaving allowing the hessian to dry out will affect its integrity.
- Large patches of macrophytes, if the beds of macrophytes are too large the hessian will not be able to be pinned down flat on the bed and sediment will not be able to build up.

Summary of control method

Using hessian matting to control macrophytes is an effective solution when undertaken with the optimal physical environmental factors. However, it is important to consider the potential limitations of the method, including the need for regular maintenance and the high labour and material costs. Overall, hessian matting is a useful tool in the management of macrophytes, but it should be used in conjunction with other methods to ensure the best possible outcome.

2.0 Diver-based hand weeding

Diver-based hand weeding is an effective control method for smaller macrophyte infestations. This method does not require additional tools or equipment as divers remove the macrophytes manually. All plant material, including the root system, is pulled from the substrate, and placed into catch-bags. This results in a low likelihood of re-growth and limited fragmentation. Divers carrying out hand weeding can simultaneously undertake surveillance, identifying any new infestations or areas where maintenance work might be required.

Advantages

High degree of precision, targeting only specific macrophyte, leaving non-target species undisturbed.

Minimal lead-in time is required as hand weeding does not require any additional consents or notifications.

Site access is usually suitable, as divers can access areas where it might be difficult or very costly to access with a boat or machinery, e.g., areas blocked by fallen trees or areas with poor site access.

Surveillance. While undertaking hand weeding activities, divers can conduct surveillance, observe trends, and identify where there might be a need for alternative control methods. This can assist with future planning for the site.

Disadvantages

Labour intensive and therefore expensive. This is due to the time cost for using multiple divers to undertake this work.

Only suitable for small-scale plant removal. Once infestations exceed 2 m^2, it may be more cost-effective to use other methods of control such as hessian or aquatic herbicide application.

Physical environmental factors

Physical environmental conditions to consider in the use of diver-based hand weeding include:

- High water flow may impact hand weeding if it is a risk to diver health and safety. An option for mitigating this risk is for divers to be tethered to a vessel or the shoreline, however this can make the operation more complex and time consuming.
- Moderate to high water clarity is essential for a diver to be able to identify their target species and successfully navigate within the waterway. Poor visibility can be caused by high sedimentation, usually after rainfall, or by divers stirring up sediment when working close to the riverbed.

Lifespan

Results from hand weeding will last weeks to months dependent on the rate of reinvasion by the same or another species.

Efficacy

The efficacy of hand weeding is dependent on the rate of reinvasion by the same or another species.

Summary of control method

Diver-based hand weeding is a proven control method for targeted reduction of macrophyte biomass within a waterbody. Divers can operate with minimal equipment and access areas where boats cannot. An added benefit is the intelligence gathered by divers during control, which can inform future operations. Diver-based hand weeding is best suited for smaller infestations where macrophyte biomass is low.

3.0 Aquatic herbicide application

There are two aquatic herbicides registered in New Zealand for application directly into water for the purpose of controlling submerged aquatic macrophytes: diquat and endothall.

Diquat, a contact herbicide, is most commonly used and is effective on most invasive macrophytes, while leaving native species relatively unaffected (when applied at label rates). Diquat is absorbed rapidly and works on the plant tissue by inducing dehydration, thereby damaging the cells that aid in photosynthesis (National Institute of Water & Atmospheric Research Ltd., 2023). It is most effective when controlling large areas as the optimal herbicide concentration can be maintained for longer (minutes to hours), compared to shorter duration applications, which are more susceptible to dilution. When this method has been used to target small infestations, the greatest success has been achieved when the herbicide can be contained, e.g., using drop nets or large drums to hold the herbicide in place.

Endothall, a systemic herbicide, has been used to eradicate exotic and invasive macrophyte species in New Zealand where the herbicide can be contained, e.g., small, enclosed ponds. Endothall is far less effective in flowing river systems due to the required length of time the herbicide needs to be in contact with the macrophytes (hours to days) and, as such, is not recommended for use in Pūharakekenui | Styx River.

These herbicides can be mixed with a gelling agent to aid in effective targeting then applied by a helicopter boom, boat via a boom, gun and hose, knapsack, or diver-based injection.

Advantages

Control of large areas. At present, diquat is the only herbicide capable of controlling macrophytes in flowing river systems over large areas within a relatively short timeframe. Alternative techniques, such as hessian bottom lining, are comparatively slower to implement, and their application may not align with the rate of macrophyte growth.

Macrophytes damaged by diquat can be slow to regrow, potentially reducing plant biomass for a period of months.

Cost effective. Aquatic herbicide application is generally the most cost-effective method for large-scale aquatic macrophyte control and is recognised as less expensive than physical removal methods. Can be a good short-term control option or one to be used in conjunction with others.

Disadvantages

Resource consents may be required to undertake herbicide application (note, consents may also be required for other control methods) and could specify conditions for public notification, stand-down times, and where and when warning signs should be erected. The conditions of consent can limit what control can be delivered and when. Obtaining a resource consent can require a long lead-in time due to processing timeframes.

Advanced planning. Aquatic herbicide operations often require a significant amount of planning to ensure consent requirements and health and safety conditions are met. This means that herbicide application may not be able to be delivered at short notice.

Chemical pricing. The cost of purchasing diquat can fluctuate due to international markets, and the price has steadily increased over the past few years. This can make it difficult to budget for an operation 6-12 months in advance.

Control timing can be unpredictable due to diquat being easily deactivated (made ineffective) when the target macrophytes are covered with sediment or high concentration of suspended sediments in the water. Pre-application assessments are required before any control can take place to identify macrophyte extent and abundance and determine sedimentation levels and suspended sediment conditions. As a result, scheduling of herbicide application may be subject to change.

Varying results. The results of the herbicide application can vary. Diquat may not completely kill the target macrophyte outright, most often only suppressing growth for a period of time. The full result of the herbicide application may not be observed for a period of several weeks to several months depending on how much herbicide is absorbed by the plant, growth rates.

Physical environmental factors

There are certain environmental requirements for the successful use of aquatic herbicide application as a control technique, which include:

- Herbicide application requires minimal sedimentation on the macrophytes that are being controlled and low suspended sediment concentrations within the water column.
- Diquat is generally more effective in waterways with minimal water flow. If the flow is too high, the herbicide may not be maintained at a high enough concentration for long enough and therefore may not have the desired effect.
- Helicopter and boat application methods require adequate site access. Boats require a launch site and navigable waterbody, and helicopters require an appropriate loading area with access to water. Helicopter use is not appropriate where there are hazards such as power lines and overhanging trees.

Lifespan

Aquatic herbicide application has a lifespan of months to serval months depending on the success of the application.

Efficacy

The two main factors affecting efficacy for aquatic herbicide application are:

- Contact time between the herbicide and the macrophyte, this needs to be minutes to hours and will be affected by flow rates and water depth.
- The amount of suspended sediments in the water or sediment present on the plant will deactivate the herbicide and make it ineffective.

Summary of control method

Aquatic herbicide application is a practical and cost-effective method for controlling larger areas of aquatic macrophytes. With suitable environmental conditions, several hectares can be treated in a day. Preparation is required for herbicide application, including a delivering a delimitation survey, macrophytes and water condition assessments, public notifications and may require a resource consent.

4.0 Mechanical cutting

Currently, the primary approach for managing aquatic macrophytes in Pūharakekenui | Styx River involves the use of mechanical harvesting. This method employs specialised watercraft equipped with cutter bars and conveyor belts that efficiently gather and cut the weeds. The harvested weed is then transported to a designated temporary storage area for further processing (Matheson & Clements, 2020).

Mechanical cutting is a control method using a cutter attached to a boat or a handheld cutting chain using divers, to remove unwanted vegetation from freshwater environments. Vegetation that has been cut is often left to float downstream; it can be removed from the waterbody, but this adds additional cost and complexity. This method should only be used in environments that are already saturated with macrophytes, as to not risk spread into macrophyte-free areas.

Mechanical cutting can be used in conjunction with other control methods, such as aquatic herbicide application and hessian matting. Mechanical cutting reduces the biomass making laying hessian faster and easier. Mechanical cutting can also promote clean, fresh growth, which absorbs herbicide more effectively, therefore cutting macrophyte several months prior to a planned diquat application can be beneficial. The required frequency of cutting can vary from a few weeks to a several months; this depends on the rate of growth, the location, and the size of the waterbody.

Advantages

Immediate results. Water flow can be increased very quickly by cutting the vegetation and consistent results are guaranteed down to a certain depth.

Short lead-in time. There are minimal restrictions around when and where cutting can be carried out, which means it can be undertaken at relatively short notice. There are also minimal environmental factors that limit its use, and it can be done in low visibility or higher flow environments. Specific health and safety requirements will need to be considered when using divers.

Disadvantages

Duration of operation. Mechanical cutting can be a time-consuming process, especially if the waterbody is large or if plant biomass is high.

Varying efficacy. Mechanical cutting may not be effective in reducing the biomass of macrophytes in areas with a high amount of debris on the riverbed, e.g., submerged tree material. It is only a temporary solution, and plants can regrow within weeks to months under the right conditions.

Fragmentation. Mechanical cutting can produce high levels of plant fragmentation, so it should only be used where a waterbody is already saturated by those particular species of macrophyte. Fragments may be able to establish downstream if there is a suitable habitat.

Physical environmental factors

The following key environmental factors will affect the implementation of mechanical cutting as a control method:

- If the water is too deep, the cutting equipment may not reach the target macrophytes. If the water is too shallow to navigate by boat, then this approach may be unsuitable. When using the boat-based cutter the depth and morphology of the riverbed needs to be considered as the cutter can be damaged if it contacts the riverbed. The boat-based cutter can cut to a maximum depth of approximately 1.5 m. The diver-based cutting chain is limited only by diver depth limits.
- Debris such as large logs, sticks, and navigational hazards in the waterbody will limit where cutting can occur. This applies to both boat-based cutting and handheld cutting, as the cutting chain can also get caught on environmental debris.

Lifespan

The lifespan of the results from mechanical cutting is weeks to months depending on the rate of growth of the cut macrophytes, and how much biomass is removed.

Efficacy

The efficacy of mechanical cutting is dependent on the following:

- Depth of the macrophytes being cut.
- How much debris is present throughout the site of where cutting is taking place.
- The growth rates of the macrophytes being cut.

Summary of control method

Mechanical cutting is a simple method to deploy and can quickly reduce biomass within a waterbody. However, it should only be undertaken where the environment is already saturated with macrophytes due to the fragmentation and resulting spread potential. Mechanical cutting will allow for immediate increased water flow until the macrophytes grow back.

5.0 Riparian shading

Shading of the waterbody by vegetation and trees along the banks of rivers and lakes (riparian vegetation) can reduce the growth of macrophytes. Reduced light availability (by shading) impacts the ability for macrophytes to photosynthesis, such that riparian shading can reduce or limit macrophyte presence and abundance (Collins et al., 2020).

Riparian shading is considered a long-term solution for controlling macrophytes (Collins et al., 2020) and a recent assessment by NIWA determined that riparian planting to increase shade of the river is likely to reduce aquatic macrophyte growth generally and increase conveyance of the channel, mitigating flood risk (Matheson et al., 2021).

The success of riparian shading depends on several factors, including the type of vegetation used, the intensity of shading, and maintenance to stop weedy plant species from outcompeting or pest animals browsing the chosen vegetation (McKergow et al., 2016). Therefore, it is important to carefully consider environmental conditions and long-term goals when planning and implementing riparian shading.

Advantages

Long-term solution. Riparian planting as a control method has a long lifespan, as once established, the plantings will remain in place for many years.

Minimal long-term maintenance. Once the riparian plantings have become established, the ongoing maintenance is very low. Those that are >20 m wide are essentially self-sustaining (Lee et al., 2004).

Disadvantages

High initial cost. Establishing riparian shading can be a costly process, particularly if large areas of trees and shrubs need to be planted.

Initial maintenance. Any riparian planting along the banks of a waterbody will need to be maintained initially, while they establish. This includes control of terrestrial weed species that can encroach on new plantings, as well as control of browsing animals. Continued pruning will also be required as trees grow.

Timing. It can take several decades before the desired level of shading is achieved, as the trees and shrubs need time to grow and mature. This can be mitigated by choosing fast growing species, with some species providing sufficient shading of submerged macrophyte beds within three years (Collins et al., 2020).

Impact other control methods. Riparian planting may impact control methods by reducing site access or affecting the implementation. For example, plantings may limit where vessels can be launched from, or the plantings may drop debris into the waterbody that could impact hessian matting deployment or mechanical cutting.

Space requirements, it is recommended riparian margins are >20m in width to have the best outcomes (Lee et al., 2004).

Physical environmental factors

Environmental requirements that should be considered when using riparian shading as a control method include:

- Wider water bodies may be harder to effectively shade and taller species and wider riparian corridors may be needed to provide sufficient shading for controlling excessive macrophyte growth.
- Areas with highly modified riparian margins such as footpaths, roads and walking tracks may not be suitable for riparian planting and sufficient shading of the waterbody. Careful consideration is needed before trees are planted in areas with power lines overhead.

Lifespan

The lifespan of riparian shading is dependent on how long the trees live for, and if the trees being used are evergreen.

Efficacy

This is dependent on how much light can be prevented from entering the waterbody by the riparian shading.

Summary of control method

Riparian shading can be an appropriate long-term solution for limiting excessive growth of macrophytes within a waterbody. However, significant up-front planning and costs are required to select and establish the appropriate vegetation, ensuring an adequate level of shading, and developing and implementing a long-term maintenance plan.

6.0 Dredging

Dredging was not one of the macrophyte management options considered by NIWA (Matheson & Clements, 2020), but has been included here at the request of the CCC.

Dredging involves removing fine sediments and debris from waterbodies using specialised, long-reach excavators. As a result of removing the fine sediments on the bed, macrophytes are often also removed. However, dredging is not a macrophyte control method, *per se*. The removed sediment or bed material is disposed of either on the riverbank or off-site.

While dredging can be used to increase the capacity and conveyance of water within a waterbody (through removal of fine sediments and macrophytes), it can have significant adverse effects on ecosystems; dredging creates a large disturbance and causes a lot of fine sediments to be suspended in the water column, which can cause sedimentation of downstream ecosystems (Greer, 2014).

Other considerations with respect to dredging include:

- **High costs**. Dredging can be expensive, particularly for large waterbodies. This is due to the cost of the dredging equipment, labour, and disposal of the removed material.
- **Riverbank instability.** Riverbank stability can be undermined if dredging occurs too close to existing riverbanks, or if the proposed cut from dredging is too deep. Riverbanks can collapse as a result, which can cause further build-up of sediment, exacerbating problems with waterflow (Harvey & Lisle, 1998).
- **Site access**. Long-reach excavators need access from the riverbanks to the waterbody. Access can be limited by several factors such as riparian vegetation, buildings, roads and wetlands. Therefore, it is often not suitable to be an effective method for reducing macrophytes throughout an entire waterbody.

The use of dredging for macrophyte control in Pūharakekenui | Styx River is not recommended.

Conclusion | He whakamutunga

There are a range of methods available for controlling macrophytes within Pūharakekenui | Styx River to increase the water flow and potentially mitigate the risk of flooding. Each of the above methods can be effective depending on the physical characteristics of the waterbody (e.g., its width, depth and flow rate), the level of macrophyte infestation and the broader objectives for control work. It is, therefore, important to identify these factors at the outset as part of the development of an overall management strategy. Some of the methods can work well together, e.g., mechanical cutting and herbicide application; hessian matting and riparian shading.

Implementing a 'toolbox' of techniques will ensure the most effective results, and ultimately, reduced flooding risk.

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Appendix 3: Cost Benefit Analysis

Pūharakekenui Styx River Weed Management
Cost Benefit Analysis for Schedule 4S-4T of CRC231955

Prepared for Christchurch City Council

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Project Manager
Stormwater & Waterways Delivery

Issue Date 25-Jul-24

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CBA Methodology (Overview)

This CBA has been undertaken in general accordance with The Treasury's "Guide to Social Cost Benefit Analysis". The guidance outlines seven steps that should be undertaken when preparing a CBA:

Step 1:	Define the problem, options to address the problem, and the counterfactual (the do-nothing scenario).
Step 2:	Identify who gains and who loses.
Step 3:	Identify the costs and benefits associated with the counterfactual and the options to address the problem.
Step 4:	Value the costs and benefits.
Step 5:	Discount and compare costs and benefits.
Step 6:	Assess the CBA to determine whether more research is required.
Step 7:	Prepare final report.

Economic Analysis

Macrophyte Control for the purpose of improving flood flows in the Styx River

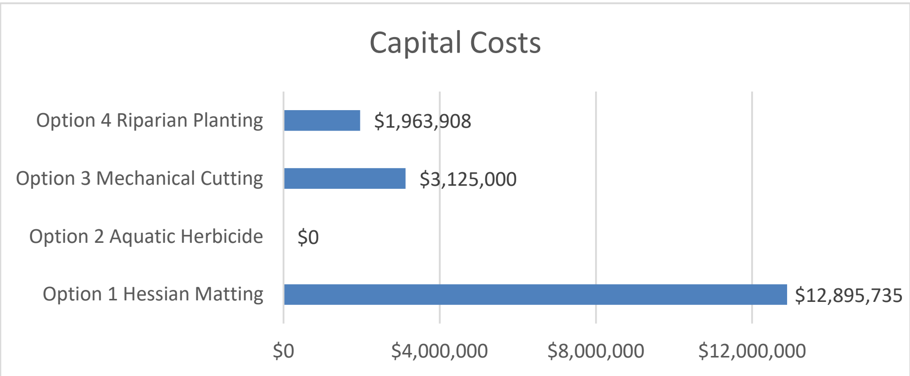
Summary Table

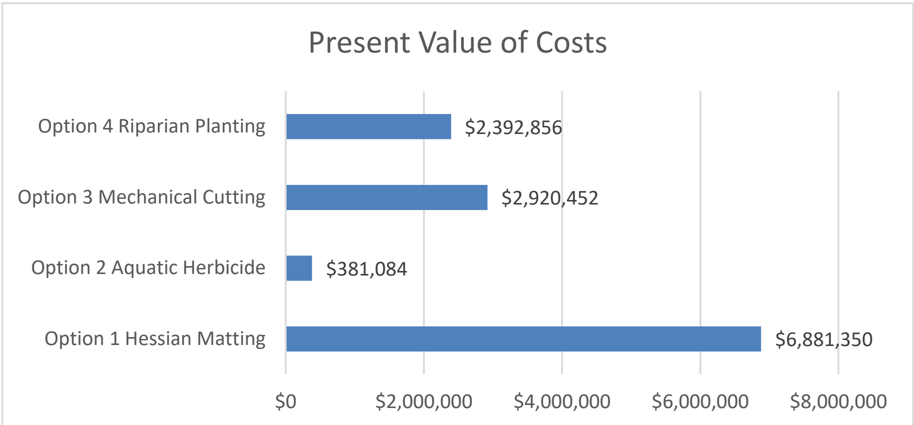
Thursday, 25 July 2024

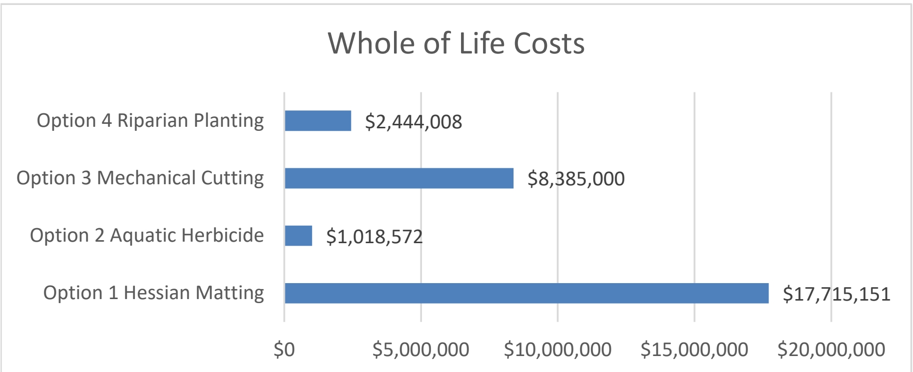
	Option 1 Hessian Matting	Option 2 Aquatic Herbicide	Option 3 Mechanical Cutting	Option 4 Riparian Planting
Appraisal period (years)	50	50	50	50
Capital Costs	$12,895,735	$0	$3,125,000	$1,963,908
Whole of Life Costs	$17,715,151	$1,018,572	$8,385,000	$2,444,008
Cost-benefit analysis of monetary costs and benefits at the Public Sector Discount Rate				
Present Value of Benefits	$0	$0	$0	$0
Present Value of Costs	$6,881,350	$381,084	$2,920,452	$2,392,856
Benefit Cost Ratio	0.00	0.00	0.00	0.00
Net Present Value	-$6,881,350	-$381,084	-$2,920,452	-$2,392,856

Control area (ha)	10.45125	15.1545	11.09355	19.204

Discount rate 5% *This rate can be amended in this cell to compare the results of the CBA.*







Cost Benefit Analysis **Macrophyte Control for the purpose of improving flood flows in the Styx River**

Option 1: **Hessian matting**

Thursday, 25 July 2024

Key Assumptions:

Public Sector Discount Rate 2011	5.00%
Appraisal period (years)	50 years

Summary of the Results of the Analysis:

Capital Costs	$12,895,735
Whole of Life Costs	$17,715,151
Present Value of Benefits	$0
Present Value of Costs	$6,881,350
Benefit Cost Ratio	0.00
Net Present Value	-$6,881,350

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Year	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**
Discount factor (mid-year)	0.97590	0.92943	0.88517	0.84302	0.80288	0.76464	0.72823	0.69355	0.66053	0.62907	0.59912	0.57059	0.54342	0.51754	0.49290	0.46942	0.44707	0.42578	0.40551	0.38620	0.36781	0.35029	0.33361
Discount factor (start of year)	1.00000	0.95238	0.90703	0.86384	0.82270	0.78353	0.74622	0.71068	0.67684	0.64461	0.61391	0.58468	0.55684	0.53032	0.50507	0.48102	0.45811	0.43630	0.41552	0.39573	0.37689	0.35894	0.34185
Benefits (monetised benefits not assessed - refer MCA)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Benefits (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits (mid-yr)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits	$0																						
Operational costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance costs	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31
Indirect costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs (mid-year)	$0	-$ 192,773.31	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773
Capital Costs	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -
Total Costs	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773
Total Capital Costs	-$ 12,895,734.67																						
Total Whole of Life Costs	-$17,715,151																						
Present Value of Costs (mid-year)	$0	-$179,169	-$85,323	$0	-$154,773	-$73,705	$0	-$133,699	-$63,669	$0	-$115,494	-$55,000	$0	-$99,768	-$47,511	$0	-$86,183	-$41,042	$0	-$74,448	-$35,454	$0	-$64,311
Present Value of Costs (start year)	-$758,573	$0	$0	-$655,284	$0	$0	-$566,059	$0	$0	-$488,983	$0	$0	-$422,402	$0	$0	-$364,886	$0	$0	-$315,203	$0	$0	-$272,284	$0
Present Value of Costs (by year)	-$758,573	-$179,169	-$85,323	-$655,284	-$154,773	-$73,705	-$566,059	-$133,699	-$63,669	-$488,983	-$115,494	-$55,000	-$422,402	-$99,768	-$47,511	-$364,886	-$86,183	-$41,042	-$315,203	-$74,448	-$35,454	-$272,284	-$64,311
Present Value of Costs	-$6,881,350																						
Net Cash Flows	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773
Net Present Value (by year)	-$758,573	-$179,169	-$85,323	-$655,284	-$154,773	-$73,705	-$566,059	-$133,699	-$63,669	-$488,983	-$115,494	-$55,000	-$422,402	-$99,768	-$47,511	-$364,886	-$86,183	-$41,042	-$315,203	-$74,448	-$35,454	-$272,284	-$64,311
Cumulative NPV	-$758,573	-$937,742	-$1,023,065	-$1,678,348	-$1,833,121	-$1,906,827	-$2,472,885	-$2,606,584	-$2,670,254	-$3,159,236	-$3,274,730	-$3,329,730	-$3,752,132	-$3,851,900	-$3,899,411	-$4,264,297	-$4,350,481	-$4,391,523	-$4,706,725	-$4,781,174	-$4,816,627	-$5,088,911	-$5,153,223

23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
2048	**2049**	**2050**	**2051**	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**	**2067**	**2068**	**2069**	**2070**	**2071**	**2072**	**2073**	**2074**
0.31773	0.30260	0.28819	0.27446	0.26139	0.24895	0.23709	0.22580	0.21505	0.20481	0.19506	0.18577	0.17692	0.16850	0.16047	0.15283	0.14555	0.13862	0.13202	0.12573	0.11975	0.11404	0.10861	0.10344	0.09852	0.09383	0.08936
0.32557	0.31007	0.29530	0.28124	0.26785	0.25509	0.24295	0.23138	0.22036	0.20987	0.19987	0.19035	0.18129	0.17266	0.16444	0.15661	0.14915	0.14205	0.13528	0.12884	0.12270	0.11686	0.11130	0.10600	0.10095	0.09614	0.09156
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31	-$ 96,391.88	$ -	-$ 192,773.31
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$96,392	$0	-$192,773	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773	-$96,392	$0	-$192,773
$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -	$ -	-$ 758,572.63	$ -
-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773
-$30,626	$0	-$55,555	-$26,456	$0	-$47,990	-$22,854	$0	-$41,456	-$19,742	$0	-$35,811	-$17,054	$0	-$30,935	-$14,732	$0	-$26,723	-$12,726	$0	-$23,084	-$10,993	$0	-$19,941	-$9,496	$0	-$17,226
$0	-$235,209	$0	$0	-$203,182	$0	$0	-$175,517	$0	$0	-$151,618	$0	$0	-$130,973	$0	$0	-$113,140	$0	$0	-$97,734	$0	$0	-$84,426	$0	$0	-$72,931	$0
-$30,626	-$235,209	-$55,555	-$26,456	-$203,182	-$47,990	-$22,854	-$175,517	-$41,456	-$19,742	-$151,618	-$35,811	-$17,054	-$130,973	-$30,935	-$14,732	-$113,140	-$26,723	-$12,726	-$97,734	-$23,084	-$10,993	-$84,426	-$19,941	-$9,496	-$72,931	-$17,226
-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773	-$96,392	-$758,573	-$192,773
-$30,626	-$235,209	-$55,555	-$26,456	-$203,182	-$47,990	-$22,854	-$175,517	-$41,456	-$19,742	-$151,618	-$35,811	-$17,054	-$130,973	-$30,935	-$14,732	-$113,140	-$26,723	-$12,726	-$97,734	-$23,084	-$10,993	-$84,426	-$19,941	-$9,496	-$72,931	-$17,226
-$5,183,849	-$5,419,058	-$5,474,612	-$5,501,068	-$5,704,251	-$5,752,241	-$5,775,094	-$5,950,611	-$5,992,067	-$6,011,809	-$6,163,426	-$6,199,237	-$6,216,291	-$6,347,264	-$6,378,199	-$6,392,931	-$6,506,070	-$6,532,793	-$6,545,519	-$6,643,253	-$6,666,337	-$6,677,330	-$6,761,757	-$6,781,698	-$6,791,194	-$6,864,125	-$6,881,350

Cost Benefit Analysis **Macrophyte Control for the purpose of improving flood flows in the Styx River**
Option 1: **Hessian matting**

Cost identification and estimation details	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Capital costs								
Deployment of hessian matting (per ha)	-$ 758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00
Subtotal capital costs	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00
Operational costs								
Nil - assume absorbed by CCC and the same for all control methods	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Subtotal operational costs	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Maintenance costs								
Annual diver survey of condition of matting and minor repairs as required	$0.00	-$ 192,773.31	-$ 96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31
Subtotal maintenance costs	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31
Indirect costs								
Nil								
Subtotal indirect costs	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total costs per annum	-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31

Cost identification and estimation details	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16
Capital costs								
Deployment of hessian matting (per ha)	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63
Subtotal capital costs	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63
Operational costs								
Nil - assume absorbed by CCC and the same for all control methods	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Subtotal operational costs	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Maintenance costs								
Annual diver survey of condition of matting and minor repairs as required	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00
Subtotal maintenance costs	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00
Indirect costs								
Nil								
Subtotal indirect costs	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total costs per annum	-$96,391.88	-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63

Cost identification and estimation details	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24
Capital costs								
Deployment of hessian matting (per ha)	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00
Subtotal capital costs	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00
Operational costs								
Nil - assume absorbed by CCC and the same for all control methods	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Subtotal operational costs	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Maintenance costs								
Annual diver survey of condition of matting and minor repairs as required	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88
Subtotal maintenance costs	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88
Indirect costs								
Nil								
Subtotal indirect costs	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total costs per annum	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31	-$96,391.88

Costs on a total control area basis

Total control area for this method (ha) 10.45125

Option 1 - Hessian Matting

Year 25	Year 26	Year 27	Year 28	Year 29	Year 30	Year 31	Year 32	Year 33	Year 34	Year 35	Year 36	Year 37	Year 38	Year 39	Year 40	Year 41	Year 42	Year 43	Year 44	Year 45	Year 46	Year 47	Year 48	Year 49	Year 50
-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00
-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00	$0.00	-$758,572.63	$0.00
$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31
$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31	-$96,391.88	$0.00	-$192,773.31
$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31	-$96,391.88	-$758,572.63	-$192,773.31

Hessian Matting Working Calculations

Capital costs (initial)	**$ per ha**	**Total control area**
Labour	-$ 36,891.00	-$ 385,557.06
Stakes	-$ 13,628.00	-$ 142,429.64
Hessian	-$ 22,063.00	-$ 230,585.93
Capital costs subtotal	*-$ 72,582.00*	*-$ 758,572.63*
Ongoing capital costs		
N/A	-$ 72,582.00	-$ 758,572.63
Ongoing capital costs subtotal		*-$ 758,572.63*
Operational costs		
Nil - same for all methods		
Operational costs sub-total		
Maintenance costs		
Year 1 maintenance	-$ 18,445.00	-$ 192,773.31
Year 2 maintenance	-$ 9,223.00	-$ 96,391.88
		$ -
		$ -
Maintenance costs sub-total	*-$ 27,668.00*	*-$ 289,165.19*
Indirect costs		

Determining total control area

Length of control area (m)	6967.5	m	*This cell can be adjusted to test different scenarios*
Average river width (m)	15	m	*This cell can be adjusted to test different scenarios*
Control area (length of control area x 15m width) (ha)	10.45125	ha	

Cost Benefit Analysis **Macrophyte Control for the purpose of improving flood flows in the Styx River**

Option 2: **Aquatic herbicide**

Thursday, 25 July 2024

Key Assumptions:

Public Sector Discount Rate 2011	5.00%
Appraisal period (years)	50 years

Summary of the Results of the Analysis:

Capital Costs	$0
Whole of Life Costs	$1,018,572
Present Value of Benefits	$0
Present Value of Costs	$381,084
Benefit Cost Ratio	0.00
Net Present Value	-$381,084

	0	1	2	3	4	5	6	7	8	9	10	11
Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Discount factor (mid-year)	0.97590	0.92943	0.88517	0.84302	0.80288	0.76464	0.72823	0.69355	0.66053	0.62907	0.59912	0.57059
Discount factor (start of year)	1.00000	0.95238	0.90703	0.86384	0.82270	0.78353	0.74622	0.71068	0.67684	0.64461	0.61391	0.58468
Benefits (monetised benefits not assessed - refer MCA)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Benefits (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits (mid-yr)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits	$0											
Operational costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance costs	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44
Indirect costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs (mid-year)	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371
Capital Costs (at start of year)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371
Total Capital Costs	$0											
Total Whole of Life Costs	-$1,018,572											
Present Value of Costs (mid-year)	-$19,880	-$18,934	-$18,032	-$17,174	-$16,356	-$15,577	-$14,835	-$14,129	-$13,456	-$12,815	-$12,205	-$11,624
Present Value of Costs (start year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs (by year)	-$19,880	-$18,934	-$18,032	-$17,174	-$16,356	-$15,577	-$14,835	-$14,129	-$13,456	-$12,815	-$12,205	-$11,624
Present Value of Costs	-$381,084											
Net Cash Flows	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371
Net Present Value (by year)	-$19,880	-$18,934	-$18,032	-$17,174	-$16,356	-$15,577	-$14,835	-$14,129	-$13,456	-$12,815	-$12,205	-$11,624
Cumulative NPV	-$19,880	-$38,814	-$56,846	-$74,020	-$90,376	-$105,953	-$120,788	-$134,916	-$148,372	-$161,187	-$173,392	-$185,016

	12	13	14	15	16	17	18	19	20	21	22
Year	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Discount factor (mid-year)	0.54342	0.51754	0.49290	0.46942	0.44707	0.42578	0.40551	0.38620	0.36781	0.35029	0.33361
Discount factor (start of year)	0.55684	0.53032	0.50507	0.48102	0.45811	0.43630	0.41552	0.39573	0.37689	0.35894	0.34185
Benefits (monetised benefits not assessed - refer MCA)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Benefits (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits (mid-yr)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Operational costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance costs	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44
Indirect costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs (mid-year)	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371
Capital Costs (at start of year)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371
Present Value of Costs (mid-year)	-$11,070	-$10,543	-$10,041	-$9,563	-$9,107	-$8,674	-$8,261	-$7,867	-$7,493	-$7,136	-$6,796
Present Value of Costs (start year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs (by year)	-$11,070	-$10,543	-$10,041	-$9,563	-$9,107	-$8,674	-$8,261	-$7,867	-$7,493	-$7,136	-$6,796
Net Cash Flows	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371
Net Present Value (by year)	-$11,070	-$10,543	-$10,041	-$9,563	-$9,107	-$8,674	-$8,261	-$7,867	-$7,493	-$7,136	-$6,796
Cumulative NPV	-$196,086	-$206,629	-$216,670	-$226,233	-$235,341	-$244,014	-$252,275	-$260,143	-$267,635	-$274,771	-$281,567

23	24	25	26	27	28	29	30	31	32	33	34	35	36
2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**
0.31773	0.30260	0.28819	0.27446	0.26139	0.24895	0.23709	0.22580	0.21505	0.20481	0.19506	0.18577	0.17692	0.16850
0.32557	0.31007	0.29530	0.28124	0.26785	0.25509	0.24295	0.23138	0.22036	0.20987	0.19987	0.19035	0.18129	0.17266
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371
-$6,473	-$6,164	-$5,871	-$5,591	-$5,325	-$5,071	-$4,830	-$4,600	-$4,381	-$4,172	-$3,974	-$3,784	-$3,604	-$3,433
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
-$6,473	-$6,164	-$5,871	-$5,591	-$5,325	-$5,071	-$4,830	-$4,600	-$4,381	-$4,172	-$3,974	-$3,784	-$3,604	-$3,433
-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371
-$6,473	-$6,164	-$5,871	-$5,591	-$5,325	-$5,071	-$4,830	-$4,600	-$4,381	-$4,172	-$3,974	-$3,784	-$3,604	-$3,433
-$288,040	-$294,204	-$300,075	-$305,666	-$310,991	-$316,063	-$320,892	-$325,492	-$329,873	-$334,045	-$338,019	-$341,803	-$345,407	-$348,840

37	38	39	40	41	42	43	44	45	46	47	48	49
2049	**2050**	**2051**	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**
0.16047	0.15283	0.14555	0.13862	0.13202	0.12573	0.11975	0.11404	0.10861	0.10344	0.09852	0.09383	0.08936
0.16444	0.15661	0.14915	0.14205	0.13528	0.12884	0.12270	0.11686	0.11130	0.10600	0.10095	0.09614	0.09156
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371
-$3,269	-$3,113	-$2,965	-$2,824	-$2,689	-$2,561	-$2,439	-$2,323	-$2,213	-$2,107	-$2,007	-$1,911	-$1,820
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
-$3,269	-$3,113	-$2,965	-$2,824	-$2,689	-$2,561	-$2,439	-$2,323	-$2,213	-$2,107	-$2,007	-$1,911	-$1,820
-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371	-$20,371
-$3,269	-$3,113	-$2,965	-$2,824	-$2,689	-$2,561	-$2,439	-$2,323	-$2,213	-$2,107	-$2,007	-$1,911	-$1,820
-$352,109	-$355,222	-$358,188	-$361,011	-$363,701	-$366,262	-$368,702	-$371,025	-$373,238	-$375,345	-$377,352	-$379,263	-$381,084

Cost Benefit Analysis **Macrophyte Control for the purpose of improving flood flows in the Styx River**
Option 2: **Aquatic herbicide**

Cost identification and estimation details	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23
Capital costs																							
Nil																							
Subtotal capital costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Operational costs																							
Nil - assume absorbed by CCC and the same for all control methods	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal operational costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance costs																							
Delivery of aquatic herbicide spraying	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44
Subtotal maintenance costs	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44
Indirect costs																							
Nil																							
Subtotal indirect costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total costs per annum	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**

Costs on a total control area basis

Total control area for this method (ha) 15.15435

Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30	Year 31	Year 32	Year 33	Year 34	Year 35	Year 36	Year 37	Year 38	Year 39	Year 40	Year 41	Year 42	Year 43	Year 44	Year 45	Year 46	Year 47	Year 48	Year 49	Year 50
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44
-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44	-$ 20,371.44
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$20,371.44	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**	**-$20,371.44**

Option 2 - Aquatic Herbicide

Aquatic Herbicide Working Calculations

Capital costs (initial)	**$ per ha**	**Total control area**
N/A as use existing equipment		$ -
		$ -
Capital costs subtotal	*$ -*	*$ -*
Ongoing capital costs		
N/A	$ -	$ -
Ongoing capital costs subtotal		*$ -*
Operational costs		
Nil - same for all methods		
Operational costs sub-total		
Maintenance costs		
Application costs	-$ 747.50	-$ 11,327.99
Herbicide costs	-$ 596.75	-$ 9,043.45
		$ -
		$ -
Maintenance costs sub-total	*-$ 1,344.25*	*-$ 20,371.44*

Indirect costs

Assumptions

Determining total control area

Length of control area (m)	10103	m	*This cell can be adjusted to test different scenarios*
Average river width (m)	15	m	*This cell can be adjusted to test different scenarios*
Control area (length of control area x 15m width) (ha)	15.1545	ha	

Cost Benefit Analysis **Macrophyte Control for the purpose of improving flood flows in the Styx River**

Option 3: **Mechanical cutting**

Thursday, 25 July 2024

Key Assumptions:

Public Sector Discount Rate 2011	5.00%
Appraisal period (years)	50 years

Summary of the Results of the Analysis:

Capital Costs	$3,125,000
Whole of Life Costs	$8,385,000
Present Value of Benefits	$0
Present Value of Costs	$2,920,452
Benefit Cost Ratio	0.00
Net Present Value	-$2,920,452

	0	1	2	3	4	5	6	7	8	9	10	11
Year	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Discount factor (mid-year)	0.97590	0.92943	0.88517	0.84302	0.80288	0.76464	0.72823	0.69355	0.66053	0.62907	0.59912	0.57059
Discount factor (start of year)	1.00000	0.95238	0.90703	0.86384	0.82270	0.78353	0.74622	0.71068	0.67684	0.64461	0.61391	0.58468
Benefits (monetised benefits not assesse	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Benefits (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits (mid-yr)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits	$0											
Operational costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance costs	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00
Indirect costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs (mid-year)	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200
Capital Costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 625,000.00	$ -	$ -
Total Costs	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$730,200	-$105,200	-$105,200
Total Capital Costs	-$ 3,125,000.00											
Total Whole of Life Costs	-$8,385,000											
Present Value of Costs (mid-year)	-$102,665	-$97,776	-$93,120	-$88,686	-$84,462	-$80,440	-$76,610	-$72,962	-$69,488	-$66,179	-$63,027	-$60,026
Present Value of Costs (start year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$402,881	$0	$0
Present Value of Costs (by year)	-$102,665	-$97,776	-$93,120	-$88,686	-$84,462	-$80,440	-$76,610	-$72,962	-$69,488	-$469,059	-$63,027	-$60,026
Present Value of Costs	-$2,920,452											
Net Cash Flows	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$730,200	-$105,200	-$105,200
Net Present Value (by year)	-$102,665	-$97,776	-$93,120	-$88,686	-$84,462	-$80,440	-$76,610	-$72,962	-$69,488	-$469,059	-$63,027	-$60,026
Cumulative NPV	-$102,665	-$200,441	-$293,560	-$382,246	-$466,709	-$547,149	-$623,759	-$696,721	-$766,208	-$1,235,268	-$1,298,295	-$1,358,321

	12	13	14	15	16	17	18	19	20	21	22	23
Year	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**
Discount factor (mid-year)	0.54342	0.51754	0.49290	0.46942	0.44707	0.42578	0.40551	0.38620	0.36781	0.35029	0.33361	0.31773
Discount factor (start of year)	0.55684	0.53032	0.50507	0.48102	0.45811	0.43630	0.41552	0.39573	0.37689	0.35894	0.34185	0.32557
Benefits (monetised benefits not assesse	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Benefits (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits (mid-yr)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits												
Operational costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance costs	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00
Indirect costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs (mid-year)	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200
Capital Costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 625,000.00	$ -	$ -	$ -	$ -
Total Costs	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$730,200	-$105,200	-$105,200	-$105,200	-$105,200
Total Capital Costs												
Total Whole of Life Costs												
Present Value of Costs (mid-year)	-$57,168	-$54,445	-$51,853	-$49,383	-$47,032	-$44,792	-$42,659	-$40,628	-$38,693	-$36,851	-$35,096	-$33,425
Present Value of Costs (start year)	$0	$0	$0	$0	$0	$0	$0	-$247,334	$0	$0	$0	$0
Present Value of Costs (by year)	-$57,168	-$54,445	-$51,853	-$49,383	-$47,032	-$44,792	-$42,659	-$287,962	-$38,693	-$36,851	-$35,096	-$33,425
Present Value of Costs												
Net Cash Flows	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$730,200	-$105,200	-$105,200	-$105,200	-$105,200
Net Present Value (by year)	-$57,168	-$54,445	-$51,853	-$49,383	-$47,032	-$44,792	-$42,659	-$287,962	-$38,693	-$36,851	-$35,096	-$33,425
Cumulative NPV	-$1,415,488	-$1,469,933	-$1,521,786	-$1,571,170	-$1,618,201	-$1,662,994	-$1,705,653	-$1,993,615	-$2,032,308	-$2,069,159	-$2,104,255	-$2,137,679

24	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
2048	**2049**	**2050**	**2051**	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**
0.30260	0.28819	0.27446	0.26139	0.24895	0.23709	0.22580	0.21505	0.20481	0.19506	0.18577	0.17692	0.16850
0.31007	0.29530	0.28124	0.26785	0.25509	0.24295	0.23138	0.22036	0.20987	0.19987	0.19035	0.18129	0.17266
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200
$ -	$ -	$ -	$ -	$ -	-$ 625,000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$730,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200
-$31,833	-$30,317	-$28,873	-$27,499	-$26,189	-$24,942	-$23,754	-$22,623	-$21,546	-$20,520	-$19,543	-$18,612	-$17,726
$0	$0	$0	$0	$0	-$151,841	$0	$0	$0	$0	$0	$0	$0
-$31,833	-$30,317	-$28,873	-$27,499	-$26,189	-$176,783	-$23,754	-$22,623	-$21,546	-$20,520	-$19,543	-$18,612	-$17,726
-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$730,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200
-$31,833	-$30,317	-$28,873	-$27,499	-$26,189	-$176,783	-$23,754	-$22,623	-$21,546	-$20,520	-$19,543	-$18,612	-$17,726
-$2,169,512	-$2,199,829	-$2,228,703	-$2,256,201	-$2,282,391	-$2,459,174	-$2,482,928	-$2,505,551	-$2,527,097	-$2,547,617	-$2,567,160	-$2,585,772	-$2,603,498

37	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**
2061	**2062**	**2063**	**2064**	**2065**	**2066**	**2067**	**2068**	**2069**	**2070**	**2071**	**2072**	**2073**
0.16047	0.15283	0.14555	0.13862	0.13202	0.12573	0.11975	0.11404	0.10861	0.10344	0.09852	0.09383	0.08936
0.16444	0.15661	0.14915	0.14205	0.13528	0.12884	0.12270	0.11686	0.11130	0.10600	0.10095	0.09614	0.09156
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200
$ -	$ -	-$ 625,000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 625,000.00
-$105,200	-$105,200	-$730,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$730,200
-$16,882	-$16,078	-$15,312	-$14,583	-$13,889	-$13,227	-$12,597	-$11,998	-$11,426	-$10,882	-$10,364	-$9,870	-$9,400
$0	$0	-$93,217	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$57,227
-$16,882	-$16,078	-$108,530	-$14,583	-$13,889	-$13,227	-$12,597	-$11,998	-$11,426	-$10,882	-$10,364	-$9,870	-$66,628
-$105,200	-$105,200	-$730,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$105,200	-$730,200
-$16,882	-$16,078	-$108,530	-$14,583	-$13,889	-$13,227	-$12,597	-$11,998	-$11,426	-$10,882	-$10,364	-$9,870	-$66,628
-$2,620,380	-$2,636,457	-$2,744,987	-$2,759,570	-$2,773,459	-$2,786,686	-$2,799,283	-$2,811,281	-$2,822,707	-$2,833,589	-$2,843,953	-$2,853,824	-$2,920,452

Cost Benefit Analysis **Macrophyte Control for the purpose of improving flood flows in the Styx River**
Option 3: **Mechanical cutting**

Cost identification and estimation details	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24
Capital costs																								
Replacement equipment										-$ 625,000.00										-$ 625,000.00				
Subtotal capital costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 625,000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 625,000.00	$ -	$ -	$ -	$ -
Operational costs																								
Nil - assume absorbed by CCC and the same for all control methods	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal operational costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance costs																								
Delivery of service (2x per annum)	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00
Maintenance of equipment	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00
Subtotal maintenance costs	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00
Indirect costs																								
Subtotal indirect costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total costs per annum	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 730,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 730,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**

Costs on a total control area basis
Total control area for this method (ha)

Year 25	Year 26	Year 27	Year 28	Year 29	Year 30	Year 31	Year 32	Year 33	Year 34	Year 35	Year 36	Year 37	Year 38	Year 39	Year 40	Year 41	Year 42	Year 43	Year 44	Year 45	Year 46	Year 47	Year 48	Year 49	Year 50
					-$ 625,000.00										-$ 625,000.00										-$ 625,000.00
$ -	$ -	$ -	$ -	$ -	-$ 625,000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 625,000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	-$ 625,000.00
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00	-$ 75,200.00
-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00	-$ 30,000.00
-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00	-$ 105,200.00
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
-$ 105,200.00	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 730,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 730,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 105,200.00**	**-$ 730,200.00**

Option 3 - Mechanical Cutting

Capital costs (initial)	**Total control area**	
N/A as use existing equipment, equipment replacement costs captured below.		
Capital costs subtotal	*$*	*-*
Ongoing capital costs		
Replacement equipment		
Ongoing capital costs subtotal	*$*	*-*
Operational costs		
Nil - same for all methods		
Operational costs sub-total		
Maintenance costs		
Delivery of cutting of entire control area (twice per annum; $37,600 per time)	-$	37,600.00
Maintenance of equipment	-$	30,000.00
Disposal of material	$	-
Maintenance costs sub-total	*-$*	*67,600.00*
Indirect costs		

Assumptions

That equipment would need to be replaced once every 10 years, starting in Year 10.

That the cost of the replacement equipment is at the midpoint in the range of cost estimates provided by CCW to CCC - between $250k and $1mil (i.e. $625k)

That the delivery of the cutting would occur twice per annum, at a cost of $37,600 per delivery.

That disposal costs are not included in the delivery of the service.

Determining total control area

Length of control area (m)	7395.7	m	*This cell can be adjusted to test different scenarios*
Average river width (m)	15	m	*This cell can be adjusted to test different scenarios*
Control area (length of control area x 15m width) (ha)	11.09355	ha	

One off replacement costs once every 10 years - captured in CBA chart for Option 3.

Cost Benefit Analysis **Macrophyte Control for the purpose of improving flood flows in the Styx River**
Option 4: **Riparian Planting**
Thursday, 25 July 2024

Key Assumptions:

Public Sector Discount Rate 2011	5.00%
Appraisal period (years)	50 years

Summary of the Results of the Analysis:

Capital Costs	$1,963,908
Whole of Life Costs	$2,444,008
Present Value of Benefits	$0
Present Value of Costs	$2,392,856
Benefit Cost Ratio	0.00
Net Present Value	-$2,392,856

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Discount factor (mid-year)	0.97590	0.92943	0.88517	0.84302	0.80288	0.76464	0.72823	0.69355	0.66053	0.62907	0.59912	0.57059	0.54342
Discount factor (start of year)	1.00000	0.95238	0.90703	0.86384	0.82270	0.78353	0.74622	0.71068	0.67684	0.64461	0.61391	0.58468	0.55684
Benefits (monetised benefits not assesse	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Benefits (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits (mid-yr)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits	$0												
Operational costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance costs	$ -	-$ 192,040.00	-$ 192,040.00	-$ 96,020.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Indirect costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs (mid-year)	$0	-$192,040	-$192,040	-$96,020	$0	$0	$0	$0	$0	$0	$0	$0	$0
Capital Costs (at start of year)	-$ 1,958,808.00	$ -	-$ 5,100.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs	-$1,958,808	-$192,040	-$197,140	-$96,020	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Capital Costs	-$1,963,908												
Total Whole of Life Costs	-$2,444,008												
Present Value of Costs (mid-year)	$0	-$178,487	-$169,988	-$80,947	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs (start year)	-$1,958,808	$0	-$4,626	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs (by year)	-$1,958,808	-$178,487	-$174,614	-$80,947	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs	-$2,392,856												
Net Cash Flows	-$1,958,808	-$192,040	-$197,140	-$96,020	$0	$0	$0	$0	$0	$0	$0	$0	$0
Net Present Value (by year)	-$1,958,808	-$178,487	-$174,614	-$80,947	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cumulative NPV	-$1,958,808	-$2,137,295	-$2,311,909	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856

	13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Year	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
Discount factor (mid-year)	0.51754	0.49290	0.46942	0.44707	0.42578	0.40551	0.38620	0.36781	0.35029	0.33361	0.31773	0.30260	0.28819
Discount factor (start of year)	0.53032	0.50507	0.48102	0.45811	0.43630	0.41552	0.39573	0.37689	0.35894	0.34185	0.32557	0.31007	0.29530
Benefits (monetised benefits not assesse	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Benefits (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits (mid-yr)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits													
Operational costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Indirect costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Capital Costs (at start of year)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Capital Costs													
Total Whole of Life Costs													
Present Value of Costs (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs (start year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs (by year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs													
Net Cash Flows	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Net Present Value (by year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cumulative NPV	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856

Cost Benefit Analysis

Option 4:

Thursday, 25 July 2024

Key Assumptions:

Public Sector Discount Rate 2011

Appraisal period (years)

Summary of the Results of the Analysis:

Capital Costs

Whole of Life Costs

Present Value of Benefits

Present Value of Costs

Benefit Cost Ratio

Net Present Value

	26	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
Year	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**
Discount factor (mid-year)	0.27446	0.26139	0.24895	0.23709	0.22580	0.21505	0.20481	0.19506	0.18577	0.17692	0.16850	0.16047
Discount factor (start of year)	0.28124	0.26785	0.25509	0.24295	0.23138	0.22036	0.20987	0.19987	0.19035	0.18129	0.17266	0.16444
Benefits (monetised benefits not assesse	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Benefits (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits (mid-yr)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits												
Operational costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Indirect costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Capital Costs (at start of year)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Capital Costs												
Total Whole of Life Costs												
Present Value of Costs (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs (start year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs (by year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs												
Net Cash Flows	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Net Present Value (by year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cumulative NPV	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856

	38	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**
Year	**2050**	**2051**	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**
Discount factor (mid-year)	0.15283	0.14555	0.13862	0.13202	0.12573	0.11975	0.11404	0.10861	0.10344	0.09852	0.09383	0.08936
Discount factor (start of year)	0.15661	0.14915	0.14205	0.13528	0.12884	0.12270	0.11686	0.11130	0.10600	0.10095	0.09614	0.09156
Benefits (monetised benefits not assesse	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Benefits (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits (mid-yr)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Benefits												
Operational costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Indirect costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Capital Costs (at start of year)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Capital Costs												
Total Whole of Life Costs												
Present Value of Costs (mid-year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs (start year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs (by year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Present Value of Costs												
Net Cash Flows	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Net Present Value (by year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cumulative NPV	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856	-$2,392,856

Cost Benefit Analysis **Macrophyte Control for the purpose of improving flood flows in the Styx River**

Option 4: **Riparian planting**

Cost identification and estimation details	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22
Capital costs																						
Site preparation and planting	-$ 384,080.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Plant purchase	-$ 960,200.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Fertiliser tabs	-$ 38,408.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Plant guard	-$ 576,120.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Infill plant replacement (once in year 3)	$ -	$ -	-$ 5,100.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal capital costs	-$ 1,958,808.00	$ -	-$ 5,100.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Operational costs																						
Nil - assume absorbed by CCC and the same for all control methods	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal operational costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Maintenance costs																						
Establishment / weed control	$ -	-$ 153,632.00	-$ 153,632.00	-$ 76,816.00																		
Pest plant control	$ -	-$ 19,204.00	-$ 19,204.00	-$ 9,602.00																		
Pest animal control	$ -	-$ 19,204.00	-$ 19,204.00	-$ 9,602.00																		
Subtotal maintenance costs	$ -	-$ 192,040.00	-$ 192,040.00	-$ 96,020.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Indirect costs																						
Nil																						
Subtotal indirect costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total costs per annum	**-$ 1,958,808.00**	**-$ 192,040.00**	**-$ 197,140.00**	**-$ 96,020.00**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**

Costs on a total control area basis

Total control area for this method (ha)	9.602

Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30	Year 31	Year 32	Year 33	Year 34	Year 35	Year 36	Year 37	Year 38	Year 39	Year 40	Year 41	Year 42	Year 43	Year 44	Year 45	Year 46	Year 47	Year 48	Year 49	Year 50
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
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Capital costs (initial)	**per plant**	**per ha**	**Total control area**		
Site preparation and planting	-$ 2.00	-$ 20,000.00	-$ 384,080.00		
Plant purchase	-$ 5.00	-$ 50,000.00	-$ 960,200.00		
Fertiliser tabs	-$ 0.20	-$ 2,000.00	-$ 38,408.00		
Plant guard	-$ 3.00	-$ 30,000.00	-$ 576,120.00		
Capital costs subtotal	*-$ 10.20*	*-$ 102,000.00*	*-$ 1,958,808.00*	*Delivered once in Year 1*	
Ongoing capital costs					
Infill plant replacement (assume 5% of	-$ 10.20	-$ 5,100.00	-$ 5,100.00	Delivered once in Year 3	
Operational costs					
Nil - same for all methods					
Operational costs sub-total					
Maintenance costs (per delivery)					
Establishment / weed control	-$ 0.30	-$ 3,000.00	-$ 57,612.00		-$ 115,224.00
Pest plant control (per annum)		-$ 500.00	-$ 9,602.00		-$ 19,204.00
Animal pest control (per annum)		-$ 500.00	-$ 9,602.00		-$ 19,204.00
Maintenance costs sub-total		*-$ 4,000.00*	*-$ 76,816.00*	Delivered twice in Year 1, twice in Year 2, once in Year 3	
Indirect costs				Year 1	-$ 153,632.00
Nil		$ -		Year 2	-$ 153,632.00
		$ -		Year 3	-$ 76,816.00

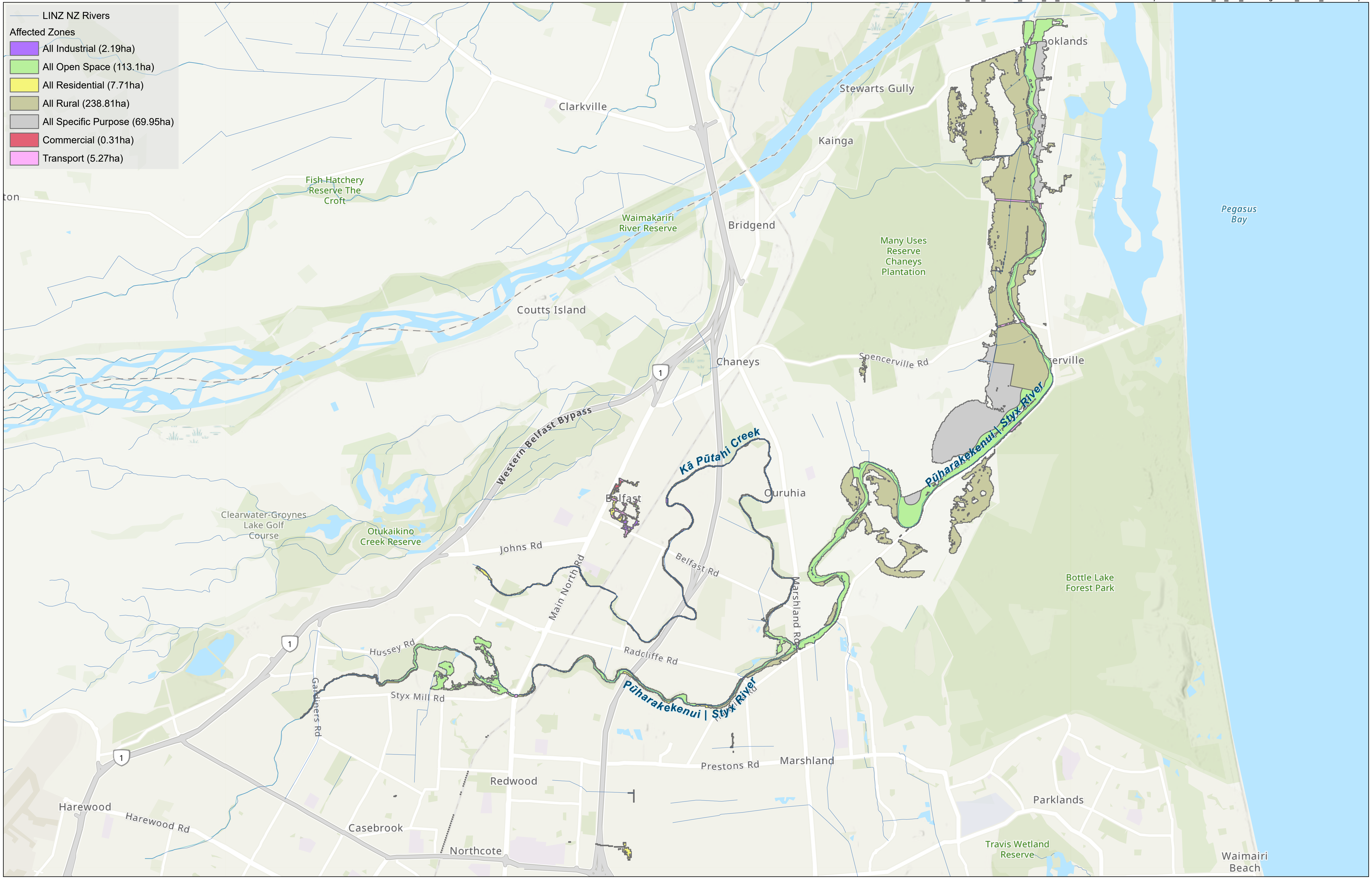
Determining total control area			
Length of control area (m)	9602	m	*This cell can be adjusted to test different scenarios*
Riparian margin (each bank) (m)	10	m	*This cell can be adjusted to test different scenarios*
Percentage reduction in riparian area for other features	0%	%	*This cell can be adjusted to test different scenarios*
Remaining riparian area	100%	%	
Riparian area (ha)	19.204		

Assumptions

Plants per m2	1
Plants per ha	10000
Excludes fencing	

Maintenance delivered twice in Year 1; twice in Year 2; and once in Year 3

Appendix 4: Maps of land zones affected by flooding



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0 1 km

1:40,000 @ A3

Data Sources: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand

Projection: NZGD 2000 New Zealand Transverse Mercator

PŪHARAKEKENUI | STYX RIVER COST BENEFIT ANALYSIS

District Plan Zoning Affected Flood Extent with No Mitigation

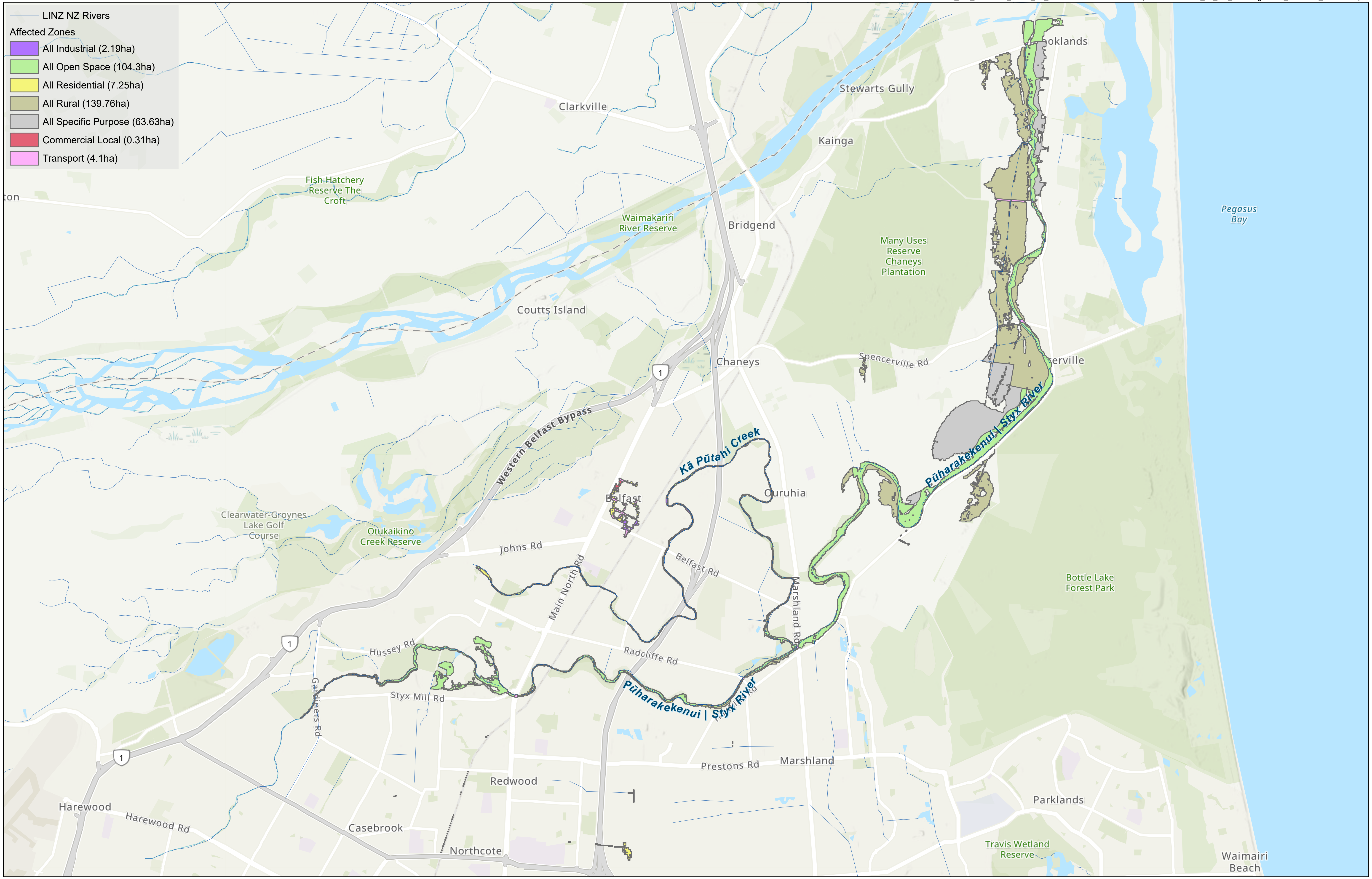
Date: 24 July 2024 | Revision: 0

Plan prepared for Christchurch City Council by Boffa Miskell Limited

Project Manager: Jourdan.Lethbridge@boffamiskell.co.nz | Drawn: LJa | Checked: JLe

Map 1

File Ref: U:\2020\BM200717G_TBI_Technical_Panel_for_CSNDC\GIS\BM200717G.aprx BM200717G_02_DP_FloodingExtent_MechCut_A3L 5:15 pm



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Data Sources: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand

Projection: NZGD 2000 New Zealand Transverse Mercator

PŪHARAKEKENUI | STYX RIVER COST BENEFIT ANALYSIS

District Plan Zoning Affected Flood Extent with Mechanical Cutting

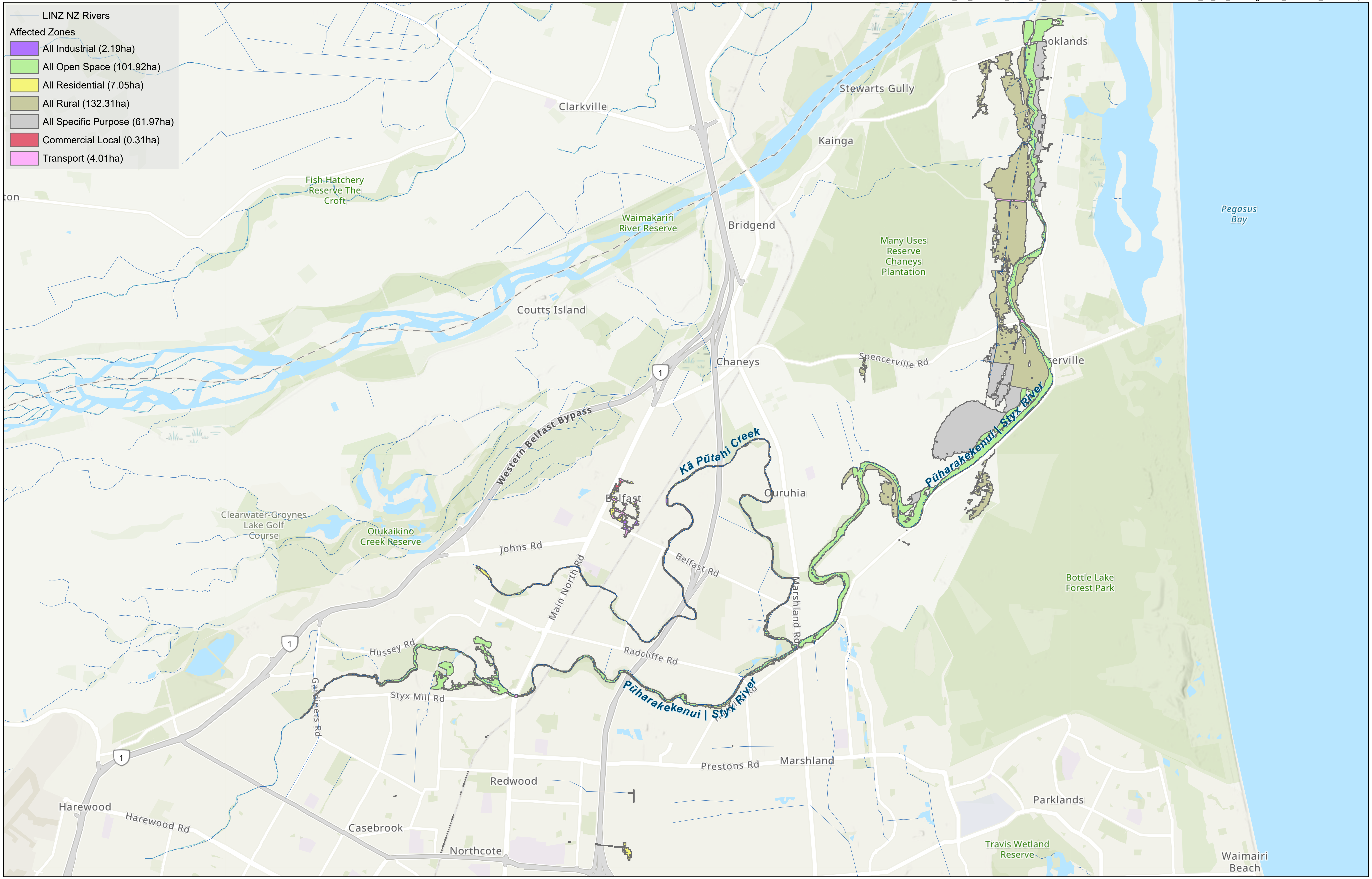
Date: 24 July 2024 | Revision: 0

Plan prepared for Christchurch City Council by Boffa Miskell Limited

Project Manager: Jourdan.Lethbridge@boffamiskell.co.nz | Drawn: LJa | Checked: JLe

Map 2

File Ref: U:\2020\BM200717G_TBI_Technical_Panel_for_CSNDC\GIS\BM200717G.aprx BM200717G_03_DP_FloodingExtent_Herbicide_A3L 5:17 pm



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0 1 km

1:40,000 @ A3

Data Sources: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand

Projection: NZGD 2000 New Zealand Transverse Mercator

PŪHARAKEKENUI | STYX RIVER COST BENEFIT ANALYSIS

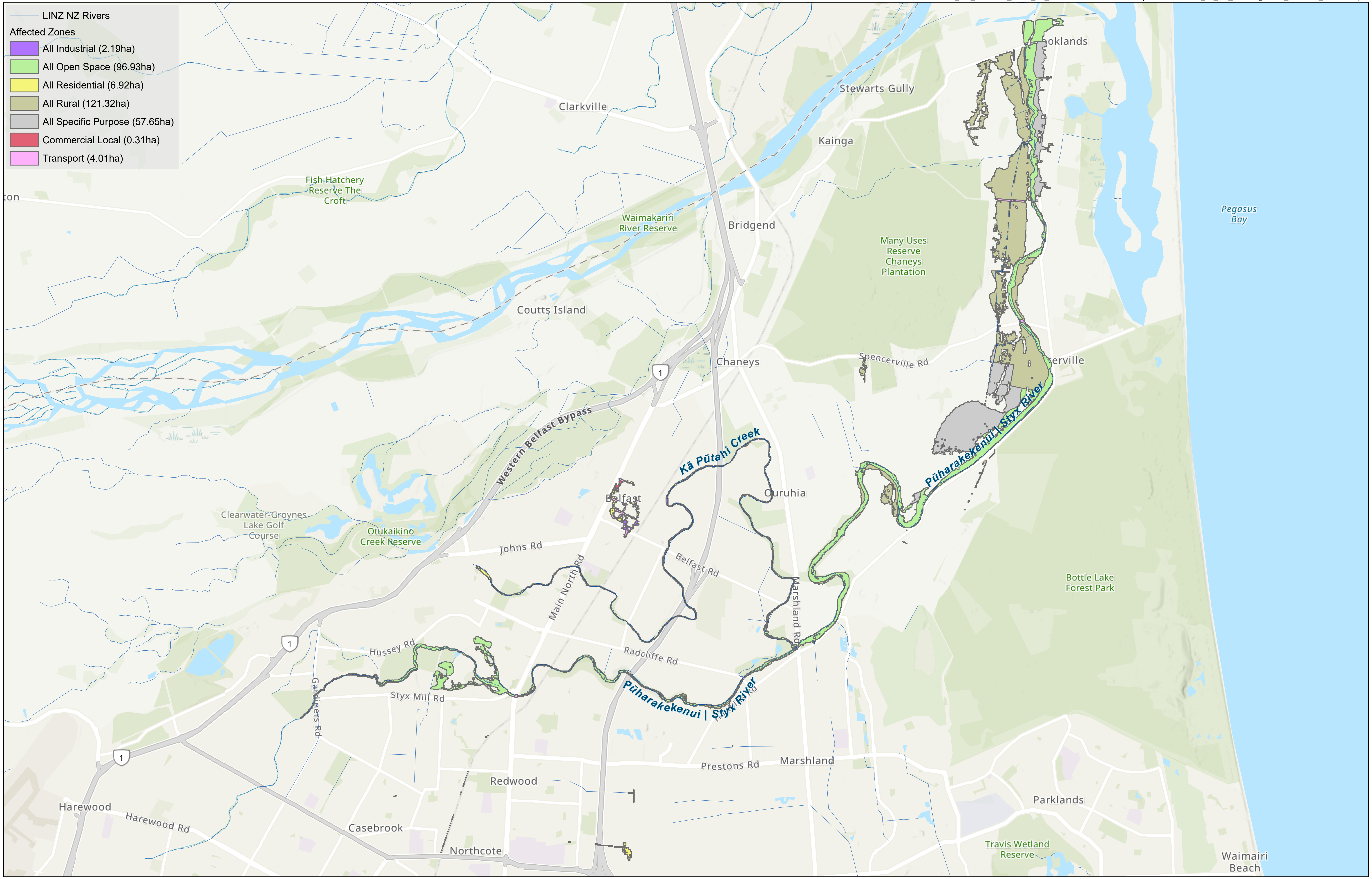
District Plan Zoning Affected Flood Extent with Herbicide

Date: 24 July 2024 | Revision: 0

Plan prepared for Christchurch City Council by Boffa Miskell Limited

Project Manager: Jourdan.Lethbridge@boffamiskell.co.nz | Drawn: LJa | Checked: JLe

Map 3



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Data Sources: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand

Projection: NZGD 2000 New Zealand Transverse Mercator

PŪHARAKEKENUI | STYX RIVER COST BENEFIT ANALYSIS

District Plan Zoning Affected Flood Extent with Hessian Matting

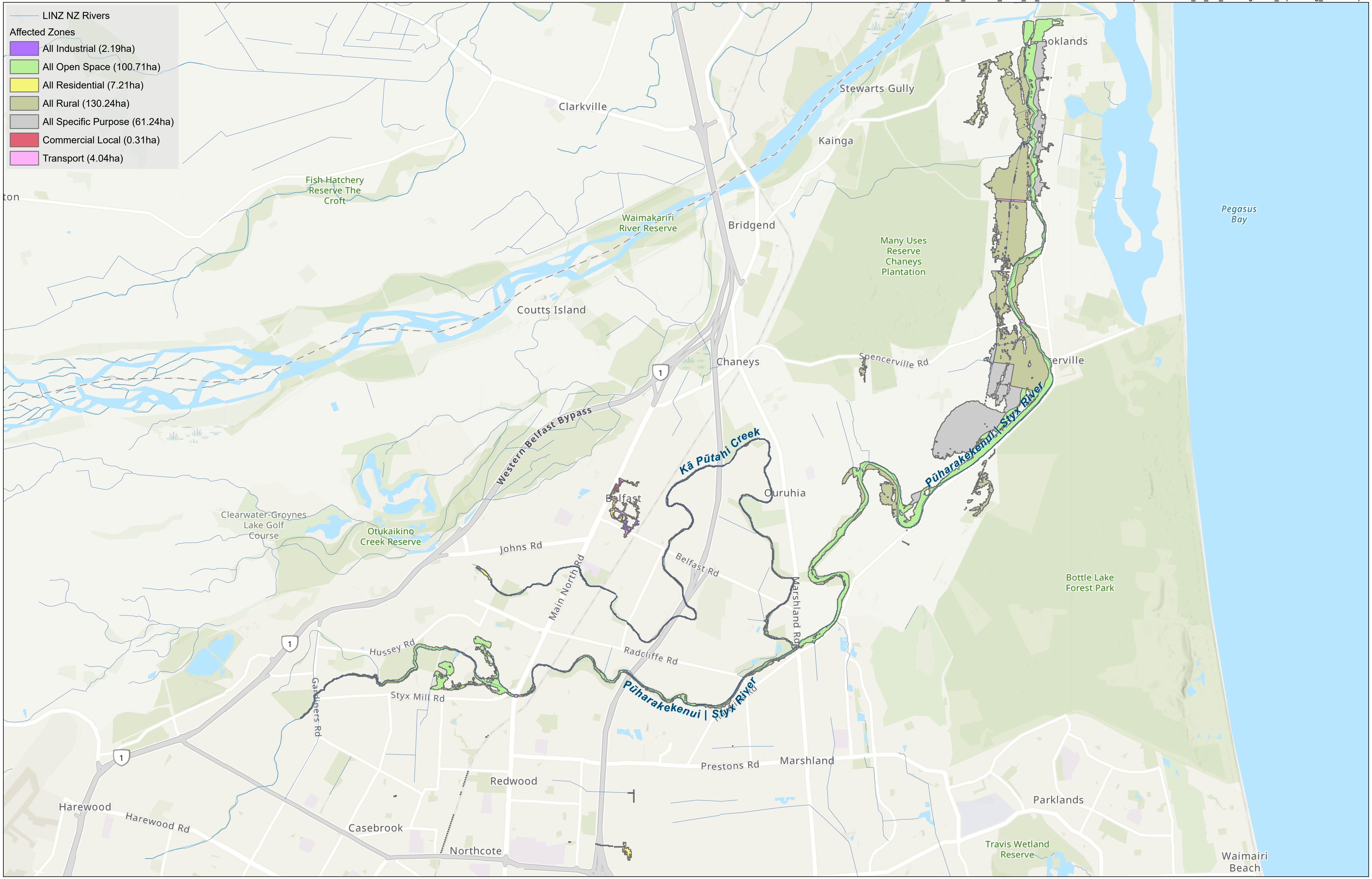
Date: 24 July 2024 | Revision: 0

Plan prepared for Christchurch City Council by Boffa Miskell Limited

Project Manager: Jourdan.Lethbridge@boffamiskell.co.nz | Drawn: LJa | Checked: JLe

Map 4

File Ref: U:\2020\BM200717G_TBI_Technical_Panel_for_CSNDC\GIS\BM200717G.aprx BM200717G_05_DP_FloodingExtent_RipShading_A3L 5:19 pm



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Data Sources: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand

Projection: NZGD 2000 New Zealand Transverse Mercator

PŪHARAKEKENUI | STYX RIVER COST BENEFIT ANALYSIS

District Plan Zoning Affected Flood Extent with Riparian Shading

Date: 24 July 2024 | Revision: 0

Plan prepared for Christchurch City Council by Boffa Miskell Limited

Project Manager: Jourdan.Lethbridge@boffamiskell.co.nz | Drawn: LJa | Checked: JLe

Map 5

Appendix 5: Analysis of the ecological effects and planning implications for macrophyte management options within the Pūharakekenui / Styx River

Boffa Miskell

Memorandum

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☐ **Nelson** 51 Halifax Street Nelson 7010 +643 548 8551	☒ **Christchurch** Level 1 141 Cambridge Terrace Christchurch 8013 PO Box 110 Christchurch 8140 +643 366 8891	☐ **Queenstown** PO Box 1028 Queenstown 9348 +643 441 1670	☐ **Dunedin** 49 Water Street Dunedin 9016 +643 470 0460	

Attention:	Florian Risse
Company:	Christchurch City Council
Date:	5 December 2023
From:	Jourdan Lethbridge (Biosecurity), Christine Hetherington (Planning), Kate Hornblow (Ecology)
Message Ref:	Analysis of the ecological effects and planning implications for macrophyte management options within the Pūharakekenui / Styx River
Project No:	BM200717G

Introduction

This memo presents a high-level summary of the potential ecological effects and planning implications for each of the suggested macrophyte management options within Pūharakekenui / Styx River. The memo has been prepared as part of the requirements of Schedule 4 clause S (vii) and (viii) of the Comprehensive Stormwater Management Consent (CRC231955) held by Christchurch City Council (CCC). This information will inform Stage 3B cost-benefit analysis and the finalised report for Stage 4 of the Boffa Miskell project.

The control of excessive macrophyte growth in the lower reaches of Pūharakekenui / Styx River is the responsibility of the CCC. To prevent flooding of the low-lying areas, the CCC currently uses mechanical cutting as the primary method for reducing the biomass of macrophytes. Previous work undertaken by the National Institute of Water and Atmospheric Research (NIWA) explored diverse approaches for controlling the growth of macrophytes within Pūharakekenui / Styx River (NIWA, 2020).

To continue on from this previous work by NIWA, the control methods analysed in this memo are as follows.

- Riparian shading
- Diver-based hand-weeding
- Aquatic herbicide spraying
- Hessian matting
- Mechanical cutting

Pūharakekenui / Styx River

Freshwater ecological values

Pūharakekenui / Styx River is listed in the Christchurch District Plan (CDP) as a Site of Ecological Significance (SES/23: Styx River; Shadbolt, 2014) (Figure 1), due to remnant wetland vegetation that is representative of the natural diversity of the Low Plains Ecological District and eight uncommon or regionally rare indigenous plant species[1]. Pūharakekenui / Styx River is also significant as it supports a representative assemblage of indigenous bird species, and the At Risk – Declining longfin eel (*Anguilla dieffenbachii*), At Risk – Declining kēkēwai or kōura / freshwater crayfish (*Paranephrops zealandicus*), and the Threatened – Nationally Critical kanakana / lamprey (*Geotria australis*) (Shadbolt, 2014). Moreover, the operative Canterbury Land and Water Regional Plan (CLWRP) (Environment Canterbury, 2018), incorporating Plan Changes 1-7, has identified various ecological overlays on the Planning Maps. Sections of the lower reaches of Pūharakekenui / Styx River are listed as 'Critical Habitat' for kākahi / freshwater mussel (At Risk, Declining; Grainger et al., 2018); upriver reaches near Styx Mill are listed as 'Critical Habitat' for kōura; and the downstream reaches, Styx River Mouth Conservation Research is listed as īnanga spawning habitat. The sections of the river identified as critical habitat for kākahi are within the area of focus of this memo.

Pūharakekenui / Styx is also an important ecological connection route for a variety of other indigenous fish species, including longfin eel, bluegill bully (At Risk – Declining), īnanga (At Risk – Declining), giant bully (At Risk – Naturally Uncommon), shortfin eel (Not Threatened) and lamprey (Dunn et al., 2018).

Planning considerations

A high-level assessment of the CDP and CLWRP requirements has been undertaken for the proposed macrophyte management options. Consideration has also been given to the global waterway enhancement consent held by CCC (CRC100750.1) and a certificate of compliance held by the CCC from the Canterbury Regional Council (ECan) for a trial of the spraying of diquat for aquatic weed management purposes within Pūharakekenui / Styx River (CRC223323). A conservative approach to the activity status of any identified consent requirements has been adopted.

Current Consents Held

Current authorisations held by CCC could be utilised for freshwater macrophyte management. The Council holds a global waterways consent (CRC146620), which provides for waterway enhancement activities. This provides for margin and berm planting and using geotextiles on riverbanks (but not on riverbeds). Reference to this consent is made later in this memo concerning some of the proposed macrophyte management techniques. It is recommended that CCC internally considers whether aspects of the works proposed could be undertaken under the ambit of this consent and discusses this with ECan if required.

A certificate of compliance is held by CCC for the spraying of diquat (CRC223323) within specified areas of Pūharakekenui / Styx River as a trial for the purpose of macrophyte management. The specified areas exclude surface water takes identified at the time (and associated buffer zones) and critical habitat areas. The certificate of compliance is valid for a period of 5 years from the date of commencement (1 March 2022). It is not considered that this certificate would permit the ongoing use of diquat for macrophyte control within Pūharakekenui / Styx River. However, it provides a useful basis upon which any similar applications for the use of diquat could be sought.

Other Authorisations and Considerations

The study area is not identified as a Statutory Acknowledgement Area under the Ngai Tahu Claims Act 1998. A silent file area identified in the Mahaanui Kurataiao Ltd Iwi Management Plan (Ōtūkaikino (Belfast)) is located at the eastern end of the study area (as shown on the plan contained in Error! Reference source not f ound.). Pūharakekenui / Styx River is identified as Ngā Wai 95 in the CDP.

[1] The eight uncommon or regionally rare indigenous plant species are: starwort (*Callitriche petriei*), mania (*Carex flagelifera*), purei (*C. flaviformis, C. maorica, C. sinclairii*), flat leaved rush (*Juncus planifolius*), swamp tussock (*Schoenus pauciflorus*), and sphagnum moss (*Sphagnum cristatum*).

Figure 1. Map of Pūharakekenui / Styx River showing key ecological and planning considerations.

File Ref: LowerStyx.aprx / BM210924_02_SiteAssessment_2023_A3L

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1:37,500 @ A3

Data Sources:
District plan data sourced fro CCC data service
CLWRP data sourced from ECan data service

Projection: NZGD 2000 New Zealand Transverse Mercator

DRAFT

LEGEND

- Surface Water Take
- Christchurch Groundwater Protection Zone
- Listed Īnanga spawning habitats (CLWRP)
- Listed Spawning Habitat (CCC)
  - Inanga
  - Trout
- Listed Critical Habitats (CLWRP)
- Sites of Ecological Significance
- Lower Styx Extent
- Cadastre
- Primary Road Parcels
- OS Water & Margins

LOWER STYX DIQUAT TRIAL

Site Assessment 2023

Date: 12 March 2024 | Revision: 0

Plan prepared for CCC by Boffa Miskell Limited

Project Manager: marcus.girvan@boffamiskell.co.nz | Drawn: BMc | Checked: CHe

Figure 1

Christchurch District Plan

The Open Space Water and Margins zone covers the majority of waterways and riparian margins within the district. The extent of the zone varies between waterways and is shown in Error! Reference source not f ound. in relation to the study area. Pūharakekenui / Styx River is also identified as a downstream waterway. The CDP contains controls on waterbody maintenance and enhancement and earthworks in these setbacks but exempts permitted activities in the Open Space – Water and Margins zone.

The study area also contains a number of ecological and other constraint overlays (which are shown in Error! R eference source not found.). These apply to various parts of the study area and include identification as an SES (described above), a Site of Significance to Māori, Nga Wai River 95, Silent file, Significant Feature, and Outstanding Natural Feature.

Canterbury Land and Water Regional Plan

The study area is located within the Christchurch – West Melton subregion[2]. It includes a number of overlays, or 'constraints' that will apply to consideration of planning requirements associated with the macrophyte management options under consideration. These are outlined below and identified in Figure 1: critical habitat areas (as described above), which include a small area at the intersection of the river and Marshland Road and two areas in the section of Pūharakekenui / Styx River adjacent to Lower Styx Road extending towards Spencerville; and groundwater protection zones, and surface water takes. The CLWRP contains controls relevant to the consideration of these macrophyte management options within the bed of a river and within riparian margins. These include the planting and removal of vegetation, the placement of structures and the discharge of agrichemicals.

Freshwater Macrophyte Management Options

Riparian shading

Increasing the presence of large-stature vegetation in the riparian margin can limit light availability to macrophytes and limit macrophyte establishment, growth, or persistence. Macrophyte growth has been shown to reduce in response to increased shading (Collins et al., 2018, 2020; Dawson & Haslam, 1983). Riparian vegetation can, therefore, act as an environmental filter, whereby a reduction in habitat suitability for macrophytes may limit nuisance growth (Photo 1).

Riparian shading ecological effects

<u>Potential adverse ecological effects</u>

The riparian margins along the lower reaches of Pūharakekenui / Styx River are primarily dominated by exotic deciduous trees (Photo 2). Exotic trees have been historically favoured when re-vegetating riparian margins, as they can reduce bank erosion and shelter adjacent farmland. However, many exotic trees commonly used (e.g., willow and poplar) are deciduous, meaning they lose their leaves in autumn and do not provide effective riparian shading in winter. In addition, seasonal inputs of leaf litter from exotic, deciduous trees can also smother in-stream habitat and adversely affect water and habitat quality.

<u>Potential ecological benefits</u>

Almost all indigenous vegetation is evergreen, which provides year-round shading and a slower, more consistent input of leaf litter, which can act as food resources for in-stream fauna. Accordingly, the use of indigenous vegetation in the riparian margin can have positive ecological outcomes for in-stream fauna and their habitat. The creation of open space (through a reduction in macrophyte cover) may create opportunities for indigenous fauna to colonise and establish in these areas. Moreover, a reduction in macrophyte biomass may improve some measures of water quality. Dissolved oxygen concentrations can fluctuate diurnally as macrophytes shift from respiration (oxygen taken up, carbon dioxide released) in hours of darkness to photosynthesis (carbon dioxide taken up, oxygen released) during daylight hours. Where macrophyte cover

[2] It is not considered that there are any specific sub regional rules which apply to this assessment.

is high, this can result in fluctuations between high dissolved oxygen levels during daylight hours (favourable for in-stream fauna) and low dissolved oxygen levels during non-daylight hours (unfavourable for in-stream fauna). Accordingly, a reduction of macrophyte cover can reduce this diurnal fluctuation, which likely has a positive effect on in-stream fauna and their persistence in an area due to more suitable water quality. The duration of any improvements to water and/or habitat quality as a result of macrophyte clearance (e.g., areas of open water column and stable DO concentrations) would be limited by macrophyte growth rates and efficacy of control works.

Riparian shading planning requirements

The provisions of the CDP provide for conservation activities (which include weed and pest control; and restoration planting) as a permitted activity within the Open Space Water Margins Zone. The term 'restoration planting' is not defined in the Plan but is considered to include riparian planting proposed for this weed management option.

Planting controls are influenced by the planning overlays that apply to the site, and that will need to be determined according to specific parts of the study area. For example, where planting is proposed within an SES, the utilisation of indigenous species that are naturally occurring and sourced from within the relevant ecological district is required.

CCC holds a global consent (CRC100750.1) from ECan for waterway enhancement purposes. This consent provides for margin and berm planting for waterway enhancement purposes. The consent requires the use of indigenous species, with new plants sourced from local stock (provenance). It is considered that the planting proposed would be covered within the ambit of this consent, however, this should be verified with CCC and ECan.

If this is not considered to be the case, any planting and the removal of existing vegetation[3], and associated discharge of sediment, would need to be considered in terms of Rule 5.163 (applies to within river beds) and 5.167 (applies to land within 5m of a river bed) of the CLWRP. Both of these rules include a condition that the vegetation clearance does not occur in any critical habitat areas. The location of critical habitats in Pūharakekenui / Styx River is shown on Figure 1. If planting is proposed, a resource consent may be required. If the required conditions can be met this is provided for as a permitted activity, or alternatively a resource consent for a restricted discretionary activity would be required.

Photo 1. Headwaters of Pūharakekenui / Styx River, with densely vegetated riparian margins providing high shading to the waterway.

Photo 2. Lower reaches of Pūharakekenui / Styx River with exotic deciduous trees that provide shade for a portion of the day on the true right bank, and seasonal influxes of leaf litter.

[3] It has been assumed that the removal of vegetation is limited to exotic species; and any replacement / riparian planting is limited to indigenous species. The extent of riparian planting proposed has also been assumed to be a maximum of 20 m from the top of the bank.

Diver-based hand-weeding

Hand-weeding is a diver-based technique that involves the removal of individual macrophytes by hand (Photo 3), either by digging the entire plant out of the sediment or cutting at the base / riverbed when macrophyte beds are denser. While hand-weeding is species-specific and can reduce the abundance of invasive macrophytes, the disturbance of the sediment beds, in which nuisance macrophyte growth typically occurs, may have short-term ecological effects.

Diver-based hand-weeding ecological effects

Potential adverse ecological effects

In the short term, hand-weeding may resuspend fine sediments into the water column. Suspended sediment can alter water chemistry (including lowering dissolved oxygen concentrations), increase turbidity, and reduce light penetration and visual clarity downstream. Elevated turbidity can have adverse ecological effects, even over a short period. Moreover, contaminants such as heavy metals and pesticides can be bound to stream-bed sediments, and the resuspension of these sediments may expose taxa, such as filter feeders, to these suspended contaminants.

The physical disturbance may temporally displace macroinvertebrates or fish from the area, but this displacement is likely short-lived, as taxa likely re-colonise the remaining habitat once the disturbance has ceased (i.e., the diver is no longer moving in the stream bed).

Potential ecological benefits

The creation of open space may create opportunities for indigenous fauna to colonise and establish in these areas. Moreover, after the initial disturbance (e.g., decomposing plant material which may lower dissolved oxygen levels) a reduction in macrophyte biomass may improve some measures of water quality (see Page 4).The duration of any improvements to water and/or habitat quality as a result of macrophyte clearance (e.g., areas of open water column and stable DO concentrations) would be limited by macrophyte growth rates and occurrence of control works.

Diver-based hand-weeding planning requirements

The provisions of the CDP provide for conservation activities (which include weed and pest control; and restoration planting) as a permitted activity within the Open Space Water Margins Zone. It is assumed that this work would not involve the removal of indigenous vegetation.

CCC holds a global consent (CRC146620) from ECan for waterway enhancement purposes that provides for the removal of plants for waterway enhancement purposes. It is considered that the removal of vegetation for macrophyte management purposes would be covered within the ambit of this consent, however, this should be verified with CCC and ECan.

If this is not considered to be the case, the removal of vegetation (macrophytes), and associated discharge of sediment, needs to be considered in terms of Rule 5.163 (applies to within river beds) of the CLWRP. This rule includes a number of conditions, including a requirement that the vegetation clearance does not occur in any critical habitat or identified spawning areas. If this is proposed a resource consent may be required as a restricted discretionary activity.

Photo 3. Diver hand-weeding *Lagarosiphon major* plants from beds of indigenous *Potamogeton* species.

Photo 4. Boat-based herbicide application from a knapsack in Pūharakekenui / Styx River.

Aquatic herbicide spraying[4]

Diquat is an aquatic herbicide approved for use in New Zealand to control submerged freshwater macrophytes. The application can be via helicopter boom, boat-based boom, trailing nozzles, or handgun (Photo 4, above). Diquat causes damage to the plant cells that come into direct contact with the herbicide, resulting in an inability for the plant to photosynthesise. However, as only exposed parts of the plant are damaged, it does not often kill the plant; it only reduces its height.

Any vegetation (macrophytes) treated with diquat would remain *in situ* and would not be physically removed.

Herbicide spraying ecological effects

<u>Potential adverse ecological effects</u>

Based on the literature, when applied in the prescribed dose (1 ppm), diquat has no identified toxic effects on non-target indigenous aquatic flora or fauna (Clayton, 2008; Hofstra et al., 2015; Tremblay, 2004; Young et al., 2004). For trout, which is one of the most sensitive fish species, the diquat LC50 (the dose that results in 50% mortality) for adults (96-hour exposure) is 6.1-18.7 ppm and for juveniles (21-day exposure) is 2.9 ppm (Clayton, 2008). These doses are above the application dose required for macrophyte management. A 3-week trial where eels were exposed to areas in Ōtākaro Avon River that received diquat treatment, no signs of acute toxicity were observed (Tremblay, 2004). Moreover, diquat has a short half-life and is biologically inactive once adsorbed. Amphipods, which are the most sensitive known taxa to diquat, have a (96-hour exposure) LP50 of 0.05 ppm. This is well below the application dose of 1 ppm (Clayton, 2008). Based on these previous ecotoxicity studies, when used at the prescribed application dose, there is expected to be a very low risk of toxicity to fish and macroinvertebrate taxa of diquat.

However, because the herbicide results in dying and decaying plant matter, when managing large macrophytes beds and with a good treatment success rate, there may be a risk to freshwater life due to changes to habitat quality from decomposing plant matter. Plant decomposition can rapidly release nutrients, such as nitrogen and phosphorus (Strange, 1976), which may create a high-nutrient environment that favours the re-growth of macrophytes (Collins, 2018). Another commonly noted effect of decomposing plant material post-herbicide application is the potential decrease in dissolved oxygen (DO) concentrations to levels that may harm aquatic fauna (James, 2013; Jewell, 1971). Conversely, Young et al. (2004) found no decrease in DO in waterways with decomposing plant material. The flow and air-water mixing occurring in the system will be an important factor in how quickly or greatly DO concentrations decline. It is also important to note that the photosynthesis-respiration cycle of macrophytes can also create extreme diurnal fluctuations

[4] Herbicide to be applied by hand / boom.

in DO. Prior to management, DO concentrations in areas with excessive macrophyte growth may drop to levels harmful to aquatic fauna.

Moreover, as with all macrophyte control methods, the habitat is altered from high plant cover to open water. For invertebrate communities in post-herbicide control environments, taxa residing in stream margins and on the streambed were unaffected, but taxa associated with macrophyte habitat (e.g., snails, some caddisfly taxa) declined or were lost entirely from the system (Brooker & Edwards, 1974). The loss of invertebrate taxa from a system is an adverse effect, and would work against CCC biodiversity goals.

<u>Potential ecological benefits</u>

The creation of open space may create opportunities for indigenous fauna to colonise and establish in these areas. Moreover, after the initial disturbance (e.g., decomposing plant material which may lower dissolved oxygen levels) a reduction in macrophyte biomass may improve some measures of water quality (see Page 4). The duration of any improvements to water and/or habitat quality as a result of macrophyte clearance (e.g., areas of open water column and stable DO concentrations) would be limited by macrophyte growth rates and occurrence of control works.

Herbicide spraying planning requirements

ECan is the regulatory agency responsible for the discharge of contaminants into and onto water. Rule 5.22 of the CLWRP controls the discharge of agrichemicals. This is a permitted activity provided that certain conditions are met. These conditions control the location and the manner in which agrichemicals are mixed but also require that the discharge is not within a community drinking water protection zone or within 250 m upstream or 100 m downstream of any other surface water intake. The certificate of compliance held by CCC for the spray of diquat (CRC223323) in stretches of Pūharakekenui / Styx River was granted on 1 March 2022. It authorises the use of diquat within specified areas of Pūharakekenui / Styx River as a trial for the purpose of freshwater macrophyte management. The specified areas exclude surface water takes identified at the time of application (and associated buffer zones) and critical habitat areas. The certificate of compliance is valid for a period of 5 years from the date of commencement, however, was sought only to permit the use of diquat as a trial. On this basis, this permit could not be utilised for the ongoing use of diquat for weed management purposes.

A resource consent may be required for the use of diquat in some areas of Pūharakekenui / Styx River depending on specific compliance with the various conditions of Rule 5.22, in particular those areas identified as critical habitat areas, community water protection zones, or within the specified buffer distances from surface water intakes. If the conditions in Rule 5.22 are met this would be assessed as a permitted activity. Alternatively, consent would be required as a discretionary activity.

At the time of the application for the certificate of compliance, ECan confirmed that Rule 5.163 in the CLWRP relating to vegetation clearance from the bed of a waterway did not apply as the vegetation will remain in situ[5].

Hessian matting

The installation of biodegradable hessian matting to the bed of a waterbody is a form of benthic barrier that is intended to smother and shade out macrophytes, preventing nuisance regrowth. While benthic barriers can decrease the abundance of invasive macrophytes, their installation and persistence in the benthic environment can have short- and long-term effects on indigenous macrophytes and freshwater fauna.

Hessian matting ecological effects

<u>Potential adverse ecological effects</u>

[5] Email from J Weston (Ecan) to C Hetherington (BML), 2 March 2022.

The use of benthic barriers, by design, smothers areas of the waterway bed, which could cause the mortality of non-target species, and may restrict the movement of mobile fauna and reduce habitat quality.

Benthic barriers can kill all macrophyte species (indigenous and non- indigenous) where, through the exclusion of light, macrophytes under the barrier are often dead within months (Caffrey et al., 2010) (Photo5). Hessian matting may restrict movement and smother some in-stream fauna (e.g., macroinvertebrates and fish – particularly less mobile species). For highly mobile taxa, occurrences of becoming ‘stuck’ under the matting may lessen due to their ability to quickly move away from the disturbance (i.e., move from the area where matting is being laid to an area of open habitat). However, the response of some highly mobile taxa to disturbance can be to burrow into sediment rather than move away, such as juvenile eels. This response may result in some taxa becoming ‘trapped’ under the matting, which could stress the animals, reduce their access to food resources and oxygenated water and, where individuals cannot navigate out of the barrier, may result in mortality. Sessile macroinvertebrates (e.g., kākahi) could become ‘trapped’ under the hessian matting.

For synthetic benthic barriers, densities of macroinvertebrates beneath the barrier have been found to decline by c.70-90% (Ussery et al., 1997), likely due to a decline in DO. As previously mentioned, the decomposition of plant material can cause a reduction in DO levels (James, 2013) and the use of a barrier to smother macrophytes could drive hypoxic conditions. It is important to note that as hessian matting is more permeable than synthetic fibres, it can allow for the transfer of gasses and water (Caffrey et al., 2010), and as it breaks down within months, gas and water transfer would likely increase over time.

<u>Potential ecological benefits</u>

The size of the fabric weave in the hessian matting used can favour the growth of indigenous macrophytes specifically, where smaller indigenous plants can grow through gaps in the weave, while the growth of larger exotic macrophytes is prevented (Caffrey et al., 2010; Hoffmann et al., 2013; Hofstra et al., 2015) (Photo 6). The ability of hessian matting to prevent the growth of larger invasive macrophytes can lead to positive outcomes for the macrophyte community, where dominance is shifted to smaller indigenous species.

The removal of macrophytes may improve some measures of water quality in the water column above the hessian matting (see Page 4). The duration of any improvements to water quality as a result of hessian matting would be limited by the decomposition of the fabric, where the transfer of potentially hypoxic conditions from under the barrier may degrade water quality above.

Hessian matting planning requirements

ECan is the regulatory agency responsible for the erection of structures within the bed of a river. Previous advice received from ECan is that hessian matting is considered to be a structure in terms of the definition contained in the CLWRP[6]. This type of structure is not specifically provided for in the Plan, and, therefore, consent would be required as a discretionary activity under the provisions of Rule 5.141A. This rule also provides for the associated disturbance of the bed and discharge associated with the placement of a structure.

A global consent for waterway enhancement is held by CCC (CRC146620) and authorises a number of works within waterways in the Canterbury region. This consent covers the use of geotextiles, but only in the context of bank stabilisation/ enhancement works. Previous discussions with ECan have indicated that it is not likely that the use of hessian matting for weed control purposes within the bed of a river would fall within the ambit of this consent.

[6] This has been discussed with a Principal Consents Planner at ECan.

Photo 5. Benthic barrier installed over *Lagarosiphon major* in Lake Wānaka. Photo credit: Mary de Winton, NIWA.

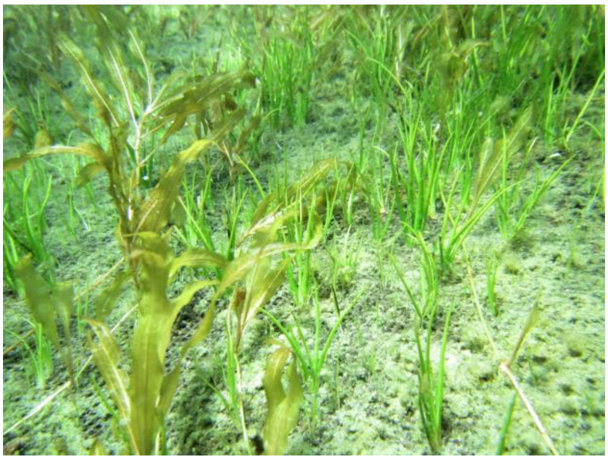

Photo 6. Indigenous macrophytes growing through hessian matting. Photo credit: Mary de Winton, NIWA.

Mechanical cutting

Mechanical weed harvesters (Photo 7) are vessels that have cutter bars and conveyer belts and have been a commonly used macrophyte management method in Pūharakekenui / Styx River since the 1990s. The harvesters cut macrophytes (usually around 300 mm above the riverbed; Photo 8) and gather the cut plant material onto the conveyor belt, which can then be removed from the waterway.

Mechanical cutting ecological effects

<u>Potential adverse ecological effects</u>

Harvesting by mechanical weed cutter is coarse and non-specific, making it difficult to select macrophytes of interest. Indigenous and/or other macrophytes that are not the subject of control may be cut by this method.

Stream bed disturbance during mechanical excavation has resulted in localised, short-term increases in suspended sediment immediately after macrophyte removal (Greer et al., 2017). This may reduce water column visibility and have local effects on fish and / or benthic fauna. The mechanical removal of macrophytes also continues the sediment resuspension after excavation, which may drive disturbance in fish communities (Greer et al., 2017).

The disturbance of fauna may be immediate and adverse for any fauna living in the macrophyte stands. The gathering and removal of cut macrophyte material and placing into a pile on the bank risks that there will be fauna in the material that cannot return to the stream. Mortality from desiccation is possible (species potentially at greatest risk include kōura, other macroinvertebrates, juvenile eels). Additionally, where removed macrophytes are left to decay on the river margins, this may result in nutrients being removed due to macrophyte removal (a benefit) being leached back into the system, essentially reversing the ecological benefit (NIWA, 2020). However, usually macrophytes piled on the banks are removed within a short period of time, in accordance with consent conditions. Noise from the mechanical action of the weed cutter may also temporarily disturb fish.

Remnant stalks or mats of plants left behind risk the likelihood of reestablishment (Hudson & Harding, 2004). If used at early stages in a macrophyte weed infestation, the harvester may produce fragments that increase the risk of weed population spread (de Winton et al., 2013). There is also a biosecurity risk that the use of the mechanical harvester in multiple different waterways without strict biosecurity controls may result in the spread of macrophytes or other pests between waterways. This is a risk that must be carefully considered in Christchurch as *Egeria densa,* an invasive aquatic weed, is present in sections of Ōtākaro Avon River where a harvester is used.

<u>Potential ecological benefits</u>

The cut height of the harvester (i.e., 300 mm above the riverbed) means macrophyte beds remain for fauna to utilise (e.g., for habitat and food resources). The open space provided by clearing macrophytes may create opportunities for indigenous fauna to colonise and establish in these areas. Moreover, after the initial disturbance (e.g., increased turbidity which can lower dissolved oxygen levels) a reduction in macrophyte biomass may improve some measures of water quality (see Page 4). The duration of any improvements to water and/or habitat quality as a result of macrophyte clearance (e.g., areas of open water column and stable DO concentrations) would be limited by macrophyte growth rates and occurrence of control works.

Mechanical cutting planning requirements

It is considered that ECan is the principal consent authority for activities on the bed of rivers. If the provisions of the City Plan are considered in this context, the Open Space Water and Margins zone provides for conservation activities (which include weed control) as a permitted activity.

CCC holds a global consent (CRC146620) for waterway enhancement purposes, but it is not considered that this consent authorises the mechanical removal of weed. However, correspondence with CCC has indicated that current mechanical weed cutting within the bed of a river is permitted under the provisions of the CLWRP. The provisions of Rule 5.163 of the CLWRP provide for vegetation clearance in the beds of rivers subject to specified conditions (including that this does not occur within a critical habitat area, within identified inanga spawning areas during spawning periods and that required suspended sediments and visual clarity levels are met. If these conditions cannot be met, a resource consent is required for a restricted discretionary activity.

Photo 7. Weed harvester operating in Pūharakekenui / Styx River. Photo credit: NIWA.

Photo 8. Bed of *Potamogeton crispus* (indigenous macrophyte) clipped by a weed harvester. Photo credit: NIWA.

Summary

Ecology

The management of dense macrophyte beds may offer some ecological benefits, such as reduced diurnal fluctuations in dissolved oxygen concentrations. However, there are a number of potential adverse ecological effects associated with macrophyte management options within Pūharakekenui / Styx River. Careful consideration should be given to what potential effects can be managed and what effects should be avoided (e.g., avoid mortality of sessile macroinvertebrates such as kākahi by not applying hessian matting within critical habitat for kākahi).

Option	Potential adverse ecological effects	Potential ecological benefits
Riparian Shading	• Seasonal inputs of leaf litter from exotic deciduous vegetation.	• Opportunity to increase shade provision, biodiversity, and resource

		input through planting indigenous vegetation. • Increased open space for in-stream fauna to establish. • Reduced diurnal fluctuations in dissolved oxygen concentrations.
Diver Based Hand Weeding	• Increased turbidity. • Short-term displacement of fauna.	• Increased open space for in-stream fauna to establish. • Reduced diurnal fluctuations in dissolved oxygen concentrations.
Herbicide Spraying	• Risk of toxicity to instream fauna if prescribed application dose is exceeded. • Changes to water quality from decaying plant matter. • Mortality or displacement of taxa associated with macrophyte habitat.	• Increased open space for in-stream fauna to establish. • Reduced diurnal fluctuations in dissolved oxygen concentrations.
Hessian Matting	• Mortality or displacement of taxa. • Complete loss of macrophyte habitat. • Changes to water quality from decaying plant matter under the barrier.	• Small indigenous macrophyte species may be able to grow through larger gaps in the weave. • Reduced diurnal fluctuations in dissolved oxygen concentrations above the barrier.
Mechanical Cutting	• Increased turbidity. • Mortality or displacement of taxa associated with macrophyte habitat. • Spread of weed species within or between waterways.	• Increased open space for in-stream fauna to establish. • Reduced diurnal fluctuations in dissolved oxygen concentrations.

Planning

There are a number of planning requirements that may limit the undertaking of macrophyte management options within Pūharakekenui / Styx River as permitted activities. It may be possible to work around some of the remaining consenting requirements if there is flexibility in the options adopted in specific areas (i.e., avoiding works in īnanga spawning areas within spawning periods; hand removal of vegetation within critical habitat areas; limitation of use of some methods over others in particular stretches). The current global waterways consent held by CCC may cover a number of the options identified in this memo. It is recommended that further discussions are held within CCC and between CCC and ECan to verify this. Alternatively, a specific resource consent could be obtained for this purpose to enable flexibility in approach.

Option	CCC Requirements	ECan LWRP Requirements Other
Riparian Shading	Permitted activity (conservation activity)	Potentially covered by global waterways consent (CRC146620). Alternatively: In the bed of a river – permitted activity (Rule 5.163) /restricted discretionary activity (Rule 5.164) In riparian margins – permitted activity (Rule 5.167/ restricted discretionary activity (Rule 5.169).
Diver Based Hand Weeding	-	Permitted activity (Rule 5.163)/ restricted discretionary activity (Rule 5.164)
Herbicide Spraying	-	Permitted activity (Rule 5.22)/ discretionary activity (Rule 5.23).
Hessian Matting	-	Clarification is sought as to the scope of global waterways consent (CRC146620). Discretionary activity (Rule 5.141A)
Mechanical Cutting	Permitted activity (conservation activity)	Permitted activity (Rule 5.163)/ restricted discretionary activity (Rule 5.164)

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Appendix 6: Multi Criteria Analysis Results

MCA EVALUATION - AQUATIC HERBICIDE

Criteria		Rankings and scores				Adjusted and aggregate scores			Weighting scenarios				Sensitivity testing - additional weighting scenarios											
Criteria Category	Criteria	Excellent (4)	Good (3)	Moderate (2)	Poor (1)	Raw Score	Adjusted scores to balance differences in number of criteria per category	Aggregate score per category	Scenario 1 (Effectiveness and deployment prioritised over ecological)		Scenario 2 (Ecological prioritised over effectiveness and deployment)		ST 1		ST 2		ST 3		ST 4		ST 6		ST 6	
Effectiveness and deployment	Time to take effect		0-3 months			3	3	8	Second priority Weighting x 3	24	Third priority Weighting x 2	16	Third priority Weighting x 2	16	Second priority weighting x5	40	Third priority Weighting x 2	16	Highest priority weighting x 10	80	Second priority weighting x5	40	Highest priority weighting x 10	80
	Duration of solution			3-6 months		2	2																	
	Effectiveness			Moderate		2	2																	
	Number of conditions that limit deployment				10-12 conditions	1	1																	
Ecological	Water quality effects				Adverse impact	1	2	6	Third priority Weighting x 2	12	Second priority Weighting x 3	18	Second priority weighting x5	30	Third priority Weighting x 2	12	Highest priority weighting x 10	60	Second priority weighting x5	30	Highest priority weighting x 10	60	Third priority Weighting x 2	12
	Physical harm to fauna			Potential adverse impact		2	4																	
Floodplain reduction	Extent of reduction in flooding levels (mm)		440mm			3	12	12	Highest priority Weighting x 4	48	Highest priority Weighting x 4	48	Highest priority weighting x 10	120	Highest priority weighting x 10	120	Second priority weighting x5	60	Third priority Weighting x 2	24	Third priority Weighting x 2	24	Second priority weighting x5	60
								OVERALL METHOD SCORE - SCENARIOS		84		82		166		172		136		134		124		152

MCA EVALUATION - HESSIAN MATTING																								
Criteria		Rankings and scores				Adjusted and aggregate scores			Weighting scenarios				Sensitivity testing - additional weighting scenarios											
Criteria Category	Criteria	Excellent (4)	Good (3)	Moderate (2)	Poor (1)	Raw Score	Adjusted scores to balance differences in number of criteria per category	Aggregate score per category	Scenario 1 (Effectiveness and deployment prioritised over ecological)		Scenario 2 (Ecological prioritised over effectiveness and deployment)		ST 1		ST 2		ST 3		ST 4		ST 6		ST 6	
Effectiveness and deployment	Time to take effect	Immediate				4	4	15	Second priority Weighting x 3	45	Third priority Weighting x 2	30	Third priority Weighting x 2	30	Second priority weighting x5	75	Third priority Weighting x 2	30	Highest priority weighting x 10	150	Second priority weighting x5	75	Highest priority weighting x 10	150
	Duration of solution		6-12 months			3	3																	
	Effectiveness	Extremely effective				4	4																	
	Number of conditions that limit deployment	0-3 conditions				4	4																	
Ecological	Water quality effects			Potential adverse impact		2	4	6	Third priority Weighting x 2	12	Second priority Weighting x 3	18	Second priority weighting x5	30	Third priority Weighting x 2	12	Highest priority weighting x 10	60	Second priority weighting x5	30	Highest priority weighting x 10	60	Third priority Weighting x 2	12
	Physical harm to fauna				Adverse impact	1	2																	
Floodplain reduction	Extent of reduction in flooding levels (mm)	575mm				4	16	16	Highest priority Weighting x 4	64	Highest priority Weighting x 4	64	Highest priority weighting x 10	160	Highest priority weighting x 10	160	Second priority weighting x5	80	Third priority Weighting x 2	32	Third priority Weighting x 2	32	Second priority weighting x5	80
OVERALL METHOD SCORE - SCENARIOS										121		112		220		247		170		212		167		242

MCA EVALUATION - MECHANICAL CUTTING

Criteria		Rankings and scores				Adjusted and aggregate scores			Weighting scenarios				Sensitivity testing - additional weighting scenarios											
Criteria Category	Criteria	Excellent (4)	Good (3)	Moderate (2)	Poor (1)	Raw Score	Adjusted scores to balance differences in number of criteria per category	Aggregate score per category	Scenario 1 (Effectiveness and deployment prioritised over ecological)		Scenario 2 (Ecological prioritised over effectiveness and deployment)		ST 1		ST 2		ST 3		ST 4		ST 6		ST 6	
Effectiveness and deployment	Time to take effect	Immediate				4	4	9	Second priority Weighting x 3	27	Third priority Weighting x 2	18	Third priority Weighting x 2	18	Second priority weighting x5	45	Third priority Weighting x 2	18	Highest priority weighting x 10	90	Second priority weighting x5	45	Highest priority weighting x 10	90
	Duration of solution				<3 months	1	1																	
	Effectiveness				Limited effectiveness	1	1																	
	Number of conditions that limit deployment		4-6 conditions			3	3																	
Ecological	Water quality effects				Adverse impact	1	2	4	Third priority Weighting x 2	8	Second priority Weighting x 3	12	Second priority weighting x5	20	Third priority Weighting x 2	8	Highest priority weighting x 10	40	Second priority weighting x5	20	Highest priority weighting x 10	40	Third priority Weighting x 2	8
	Physical harm to fauna				Adverse impact	1	2																	
Floodplain reduction	Extent of reduction in flooding levels (mm)		400mm			3	12	12	Highest priority Weighting x 4	48	Highest priority Weighting x 4	48	Highest priority weighting x 10	120	Highest priority weighting x 10	120	Second priority weighting x5	60	Third priority Weighting x 2	24	Third priority Weighting x 2	24	Second priority weighting x5	60
OVERALL METHOD SCORE - SCENARIOS										83		78		158		173		118		134		109		158

MCA EVALUATION - RIPARIAN SHADING																								
Criteria		Rankings and scores				Adjusted and aggregate scores			Weighting scenarios				Sensitivity testing - additional weighting scenarios											
Criteria Category	Criteria	Excellent (4)	Good (3)	Moderate (2)	Poor (1)	Raw Score	Adjusted scores to balance differences in number of criteria per category	Aggregate score per category	Scenario 1 (Effectiveness and deployment prioritised over ecological)		Scenario 2 (Ecological prioritised over effectiveness and deployment)		ST 1		ST 2		ST 3		ST 4		ST 6		ST 6	
Effectiveness and deployment	Time to take effect				Poor	1	1	13	Second priority Weighting x 3	39	Third priority Weighting x 2	26	Third priority Weighting x 2	26	Second priority weighting x5	65	Third priority Weighting x 2	26	Highest priority weighting x 10	130	Second priority weighting x5	65	Highest priority weighting x 10	130
	Duration of solution	>1 year				4	4																	
	Effectiveness	Extremely effective				4	4																	
	Number of conditions that limit deployment	0-3[1]				4	4																	
Ecological	Water quality effects	Delivers positive benefits				4	8	16	Third priority Weighting x 2	32	Second priority Weighting x 3	48	Second priority weighting x5	80	Third priority Weighting x 2	32	Highest priority weighting x 10	160	Second priority weighting x5	80	Highest priority weighting x 10	160	Third priority Weighting x 2	32
	Physical harm to fauna	Delivers positive benefits				4	8																	
Floodplain reduction	Extent of reduction in flooding levels (mm)		450mm			3	12	12	Highest priority Weighting x 4	48	Highest priority Weighting x 4	48	Highest priority weighting x 10	120	Highest priority weighting x 10	120	Second priority weighting x5	60	Third priority Weighting x 2	24	Third priority Weighting x 2	24	Second priority weighting x5	60
OVERALL METHOD SCORE - SCENARIOS										119		122		226		217		246		234		249		222

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