City of Busselton
Geographe Bay

alluvium

DESIGN REPORT:

Living Streams concept design for the Lower Vasse River

August 2021

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In addition to the report authors, an extensive design team contributed to the development of this concept: Richard McManus (Alluvium), Paul Verity, Jen Lorrimar-Shanks (Josh Byrne and Associates), Andrew Storey (Wetland Research and Management), Matt Blunt, and Alex Johnston (Tranen).

The team worked closely with an interagency working group that contributed expertise and local knowledge: Mathilde Breton, Paul Needham, Ian Ferry, Tanya Gillett (City of Busselton), Tracy Sonneman (DBCA), Kath Lynch, Krish Seewraj, and Joel Hall (DWER)

Josh Byrne and Associates deliver projects with an integrated approach to landscape architecture, environmental engineering and sustainability, community engagement and communications.

Tranen's primary focus is revegetating, rehabilitating, and restoring natural ecosystems around the southwest of Australia using native species.

Wetland Research and Management is a highly experienced environmental research and consultancy group that provides a wide range of specialist aquatic ecological services

Contents

Figures

Tables

Abbreviations

Alluvium	Alluvium Consulting Australia Pty Ltd
AHD	Australian Height Datum
CoB	City of Busselton
DBCA	Department of Biodiversity, Conservation and Attractions
DWER	Department of Water and Environmental Regulation
EDD	Extended Detention Depth
LIA	Light Industrial Area
LVR	Lower Vasse River
LVRMAG	Lower Vasse River Management Advisory Group
LVRWMP	Lower Vasse River Waterway Management Plan
NWL	Normal Water Level
TEC	Threatened Ecological Communities

1 Introduction

Alluvium Consulting Australia Pty Ltd (Alluvium) and Josh Byrne and Associates have been engaged by the City of Busselton (CoB) to develop concept design for the restoration of the Lower Vasse River (LVR) using a Living Streams approach.

This report outlines a Living Streams concept design that will enhance the ecological values, and improve public amenity, of the Lower Vasse River. This report summarises existing conditions and issues as they pertain to management of algae blooms in the project area, and outlines a staged concept design for the restoration of the Lower Vasse River.

1.1 Project background

The LVR is a 5.6 km reach of the Vasse River which flows from the Vasse Diversion Drain to the Butter Factor Museum. The Vasse Diversion Drain significantly modifies the hydrological regime of the reach; diverting approximately 90% of catchment flows directly to Geographe Bay.

The LVR flows through the centre of Busselton, and is socially and culturally important to the community of Busselton and the whole Geographe catchment. However, it is one of the most heavily nutrient-enriched waterways in the state. The LVR experiences severe blue-green algal blooms caused by toxic cyanobacteria that last for several months each summer, presenting a risk to public health and reducing amenity.

In the last two decades ongoing management activities have been undertaken to address poor water quality in the Lower Vasse River. Management approaches have included:

- river restoration (i.e. bank reprofiling and revegetation);
- installation of stormwater treatments;
- agricultural nutrient management; and
- small scale case studies for water quality improvement (e.g. application of flocculating clays, recirculation, and establishing aquatic plants)

However, water quality in the LVR remains poor, and severe blue-green algal blooms continue to occur for several months each summer.

In 2019 the LVR Waterway Management Plan (LVRWMP), developed through the Revitalising Geographe Waterways program, was released in response to community concerns regarding poor water quality. The LVRWMP was developed to guide future management strategies and actions that will work towards the vision for the Lower Vasse River:

> *"The Lower Vasse River is an icon of Busselton, valued and enjoyed by the community, as a healthy waterway linking people and nature".*

Importantly, the LVRWMP recommended further development of a Living Stream approach to future management of the LVR.

The Living Streams concept design has been driven by the LVRWMP. Strategically, the foundations of a 'clear and shared vision' have been established for the Living Streams design and provide strategic influence to this study.

1.2 Living Stream approach

This report describes a Living Streams concept design that will improve the ecological and social values of the Lower Vasse River. The concept will achieve multiple objectives, but is primarily concerned with reducing the duration, frequency, and severity of Cyanobacterial blooms.

The project aims to create a stable and sustainable ecosystem, where primary productivity is dominated by vascular plants, by restoring or enhancing ecological processes and biodiversity, and reconnecting the river with surrounding wetland habitat. Creating a stable ecosystem will achieve the concept's objectives while minimising ongoing operational expense associated with current efforts to control Cyanobacterial blooms to the maximum extent possible.

The concept design includes several interventions that address Cyanobacterial blooms, as well as other objectives, via several complimentary mechanisms (Figure 1). There are many causes of Cyanobacterial blooms, and it can be difficult to determine which one is the most important in any given situation. Therefore, adopting a multi-pronged approach to controlling cyanobacteria offers the best chance of long-term success. The concept design can be implemented in a staged approach that allows the CoB to prioritise objectives and access different funding streams now and in the future.

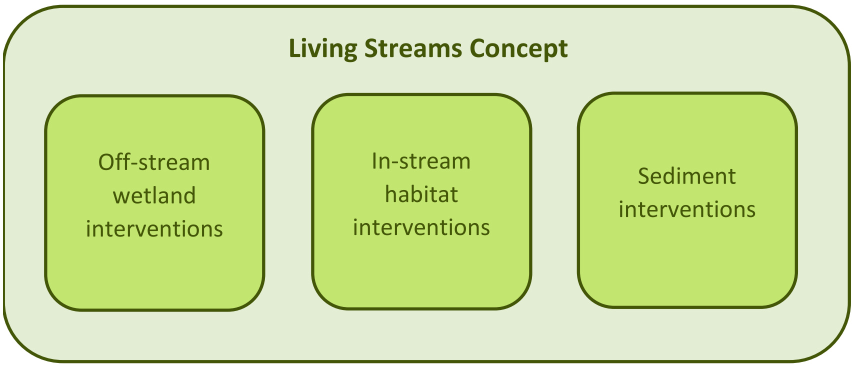


Figure 1 *Components of the Living Streams concept for the Lower Vasse River.*

The proposed interventions have been designed to sustainably reduce the frequency, severity and duration of cyanobacterial blooms over the medium term, but also allow complimentary interventions to mitigate acute problems over short time frames if required.

The concept aims to reduce Cyanobacterial blooms in a 3.3 km reach of the LVR between the Butter Factory weir and the Busselton bypass (Figure 2), beginning in the lower reach and working upstream. The lower reach is the most visible and accessible section of the river, and also experiences the most severe blooms.

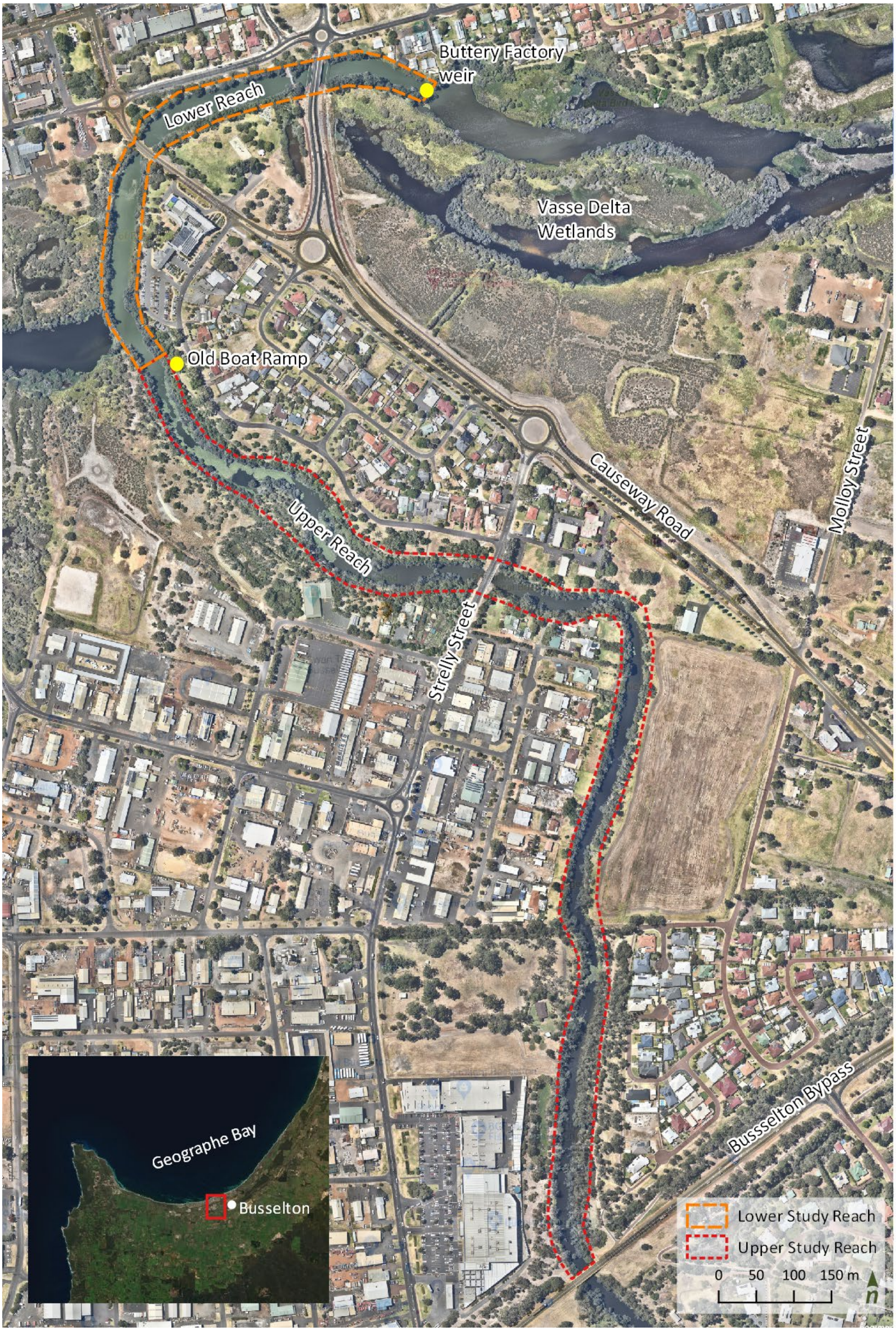


Figure 2. *Location map the Lower Vasse River Living Streams study area, showing the upper and lower study reaches, and key landmarks.*

1.3 Project aim

The project aim is to develop a concept design, with cost estimates, for the restoration of a section of LVR using a Living Streams Approach. The project area extends from the Butter Factory weir up to the Bussselton bypass (Figure 2). The design is to be gradually implemented over a decade.

The concept design has one key aim:

- Significantly reduce the extent, severity, frequency, or duration of cyanobacterial blooms in a high priority part of the reach in the short term and throughout the whole study reach in the medium term.

Objectives to meet the overall project aim have been derived through a review of the system opportunities and constraints and in consultation with stakeholders. This is further documented in Section 4.

1.4 Stakeholders

There are numerous stakeholders to this study which include:

- The City of Busselton (CoB)
- Lower Vasse River Management Advisory Group (LVRMAG)
- Traditional Owners
- Department of Water and Environmental Regulation (DWER)
- The Department of Biodiversity, Conservation and Attractions (DBCA)
- Water Corporation
- Community (includes residents, landowners, businesses, community groups etc.)

2 System understanding

2.1 Overview

The LVR is a seasonally flowing river that drains into an extensive wetland complex that includes the Ramsar-listed Vasse-Wonnerup Estuary to the east and the New River Wetlands to the west. When water levels drop in summer, it becomes disconnected from these wetlands.

Prior to widespread drainage in the Geographe catchment, this wetland complex which extends from Dunsborough to Capel would have received much greater inflows than at present. The drying climate has reduced flow as well, but to a lesser extent than drainage. The impact of drainage on the extent, inundation period and salinity of the wetland complex has been large but is not currently well understood. Water would have flowed into the wetlands during winter and spring, as is currently the case, however most of the annual flow of the LVR (90%) has now been diverted by the Vasse Diversion Drain to reduce flooding in Busselton. The seasonal inflow period of approximately June to November has remained relatively unchanged but prior to drainage, water would likely have been retained in the landscape for much longer, and outflow to Geographe Bay may have continued into late spring and early summer.

Clearing of native vegetation, high nutrient loads from the catchment, and still water during the long cease-to-flow period have led to the formation of regular toxic cyanobacterial blooms every summer that damage the river's social and ecological values.

The LVR is regionally significant from a hydrological and ecological perspective due to the presence of permanent fresh water in a landscape with highly seasonal rainfall. Together with the lower Sabina and Ludlow Rivers, it forms a summer refuge for freshwater fish (Beatty et al. 2014), which act as hosts for the threatened Carter's Freshwater Mussel.

It is likely that the LVR is connected to a regional groundwater system that supports the presence of permanent fresh water and contributes to winter baseflow. The LVR is incised into the Spearwood Dune and Vasse Estuarine formations, which directly overlie the Leederville formation. This contrasts with the seasonally dry upper reaches of the Vasse River that are separated from the regional groundwater by the alluvial Guildford formation. Hydraulic head in the Leederville aquifer near the coast has been decreasing in recent years due to reduced rainfall and/or increasing abstraction. This trend is likely to continue as the climate becomes hotter and drier.

Climate change is likely to reduce the annual discharge and the flow period of the Vasse River through changes in surface hydrology. Although the objectives of the regional drainage network are unlikely to change within the next ten years, the concept design described in this report acknowledges the possibility that the network may be managed to retain surface water in the landscape in a drier future.

2.2 Causes of blue-green algae blooms

Cyanobacteria, or blue-green algae, are highly adaptive single-celled organisms that increasingly dominate lakes and stagnant water bodies around the world. They can reproduce exponentially and form blooms when the cells accumulate to sufficient density.

To control cyanobacterial blooms in the LVR, we need to have a detailed understanding of the mechanisms that cause them. Although the factors influencing cyanobacterial growth are well understood, they operate at different scales and over different timeframes. Understanding the site-specific, bloom-forming mechanism that apply to the LVR helps us to predict the effect that a certain intervention option is likely to have on blooms. From the published literature (Raps et al. 1982, Robarts and Zohary 1987, Vezie et al. 2002, Robson and Hamilton 2003, Novak and Chambers 2014), literature provided in the brief (Paice et al. 2016, Tulipani 2019,), discussions with the project team, and analysis of routinely collected water quality data, we suggest that the severity and duration of cyanobacterial blooms are related to five casual factors:

1. initial cell count at the beginning of the growing season
2. nutrient concentration in the water
3. available light
4. water temperature
5. stagnation of the water body

Each of these factors may be limiting depending on the location within the reach and the time of year. Factors controlling the growth of cyanobacteria cells and the formation of blooms are summaried in Figure 3.

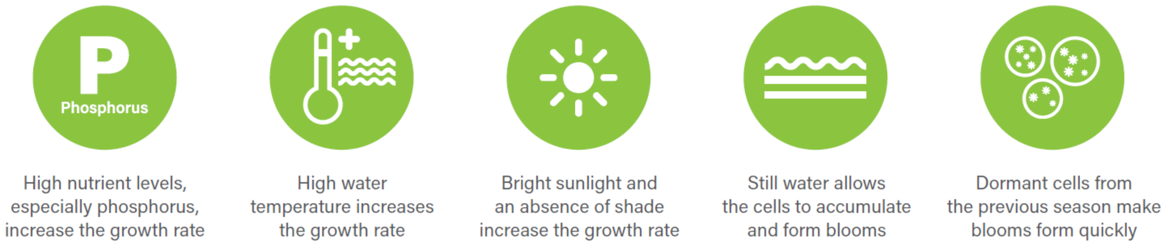
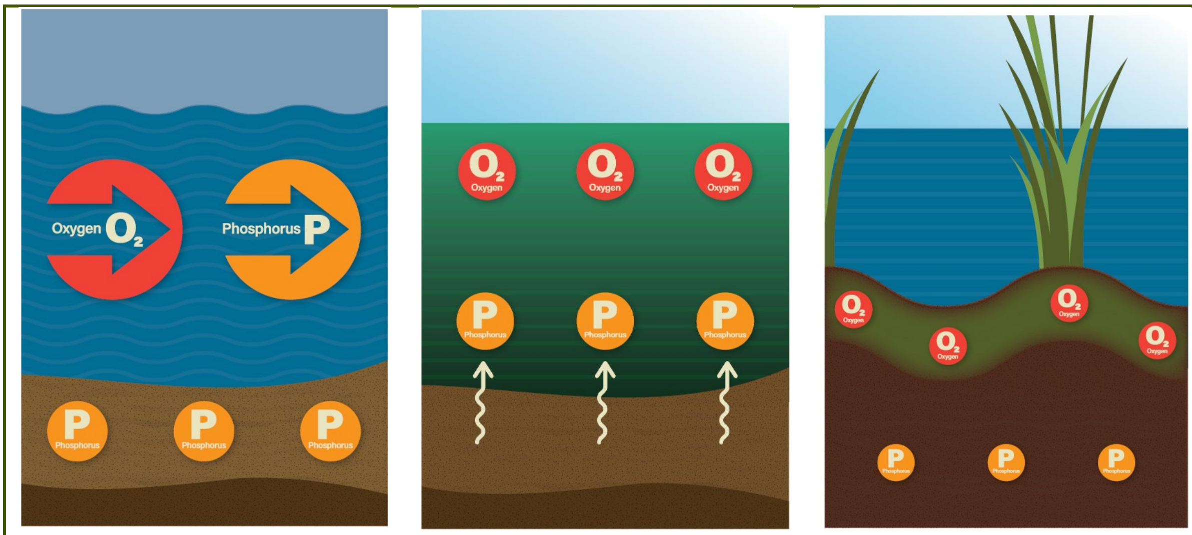


Figure 3 *Factors controlling the growth of cyanobacteria cells and the formation of blooms.*

Data gathered from the LVR suggest several pathways for blooms to form. The pathways are described below and illustrated in Figure 4.

- The nutrient concentration in the water is related to both external (catchment) and internal (sediment) loads. Both sources are probably sufficient to cause blooms on their own and both will need to be controlled to ensure long-term reductions in the severity, extent and duration of blooms. There may be further inputs of nutrient into the river from shallow groundwater. In particular, data presented by Paice et al. (2016) and supported by routine monitoring, suggest that Phosphorus levels in the waters of the LVR when it is flowing exceed the level at which algae dominate lakes (Novak and Chambers 2014) and that phosphorus levels increase further during the cease-to-flow period.
- The presence of ASS within the sediment of the LVR suggests that the bed is frequently anoxic, which can lead to remobilisation of phosphorus from sediment into the water column (Tulipani 2019). It is likely that anoxic conditions are maintained by inflow of groundwater with low levels of dissolved oxygen and internal biochemical cycles that consume oxygen.
- The cyanobacterial blooms often begin in the deepest part of the reach downstream of the causeway and expand upstream (Tulipani 2019).
- Given favourable light and temperature conditions and sufficient nutrient concentration, cyanobacteria will achieve a growth rate of around 0.35/day, meaning that residence time of water within a non-flowing waterbody of 20-30 days will result in a cyanobacterial bloom. We expect that blooms will begin to form in this system about a month after the river ceases to flow, usually in late spring (Robson and Hamilton 2003).



Current winter conditions

Phosphorus flows in from the catchment. Low light, low temperature, and turbulence prevent cyanobacterial blooms. Oxygenated water and turbulence prevents phopshorus from being released from organic sediment

Current summer conditions

Strong light, high temperature, high nutrient concentrations and still water initiate cyanobacterial blooms. Cyanobacteria create turbid and supersaturated oxygen conditions at the surface and dark, oxygen-starved conditions on the riverbed. Phosphorus is released from the organic sediments, fueling further cyanobacterial growth

Intended summer conditions

Recirculation through dense aquatic vegetation reduces cyanobacterial cells and prevents them from accumulating to bloom concentrations. Removal of organic sediments reduces phosphorus load. High light and photosynthesis on the riverbed oxygenates bottom water and prevents the release of phosphorus.

Figure 4 *Conditions leading to cyanobacterial blooms in the Lower Vasse River and intended conditions after implementation of the Living Streams design.*

Data from the LVR and studies elsewhere provide some evidence of more complex mechanisms that may be operating in the LVR:

- Phosphorus is considered to be the limiting nutrient, especially as cyanobacteria can fix nitrogen. However, high levels of nitrogen can increase the response of cyanobacteria to phosphorus, especially when both are present in high concentrations (Gobler et al. 2016).
- Photosynthetic capacity and growth of *Microcystis* are reduced at light levels below 240 μmol/m/s and 100 μmol/m/s under laboratory conditions (Raps et al. 1982). In field conditions, these light intensities would be experienced at noon beneath vegetation that intercepts around 88% and 95% of sunshine. This may explain their absence from the area infested with Mexican water lilies in the upstream part of the reach (Ottelia Ecology 2018).
- There is insufficient mixing between cooler, more saline, denser and deoxygenated groundwater and warmer, fresher oxygenated surface water in the deeper lower reach in winter/spring, creating a chemocline where cyanobacterial cells persist through the flow season. These cells are the progenitors of the new bloom each summer. The rapid onset of blooms in the LVR at the start of the growing season suggests that a substantial number of cells are more or less permanently present.

We suggest further monitoring and investigation to better understand the biogeochemical processes that lead to the formation of cyanobacterial blooms and the efficacy of potential interventions. This includes:

- Continuous physical-chemical monitoring of the water column downstream of the causeway bridge to detect potential thermal stratification and the onset of benthic anoxia. Parameters to be measured include temperature, dissolved oxygen, salinity, pH and chlorophyll. Monitoring upstream of the causeway bridge could also be beneficial.
- Isotopic identification of phosphorus and nitrogen sources throughout the growing season.

- Auto-sampling of water in the Vasse Diversion Drain to detect seasonal peak concentrations of phosphorus and nitrogen for an optimised operational strategy for the offtake structure to the LVR.

A summary of the five causes of cyanobacterial blooms and the concept's approach to preventing them is contained in Attachment 2.

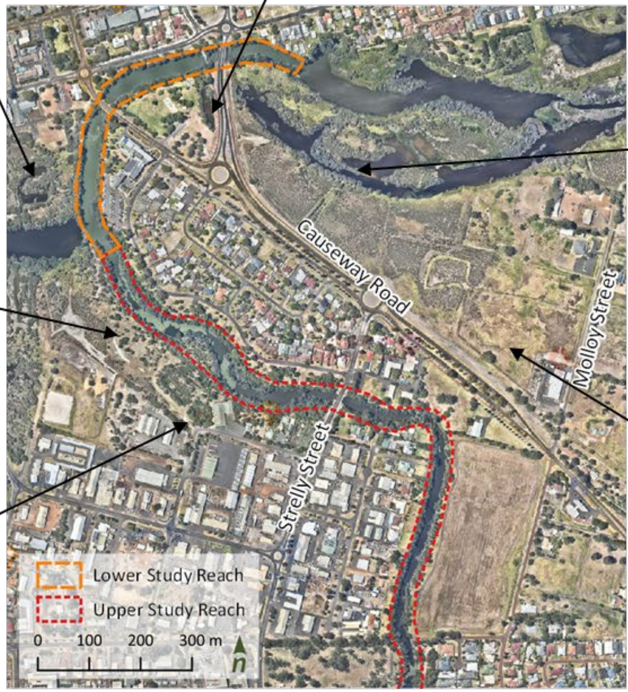
2.3 Site inspection

Two site visits were conducted in September 2020, and a third site visit in March 2021, to allow the project team to gain a better understanding of the local terrain, site constraints and opportunities. The first site visit was attended by Alex Johnston (Tranen), the second by Richard McManus (Alluvium), and the third by Bill Moulden (Alluvium).

Consideration was given to the location, landscape form(s), local features and structures (constructed and natural) including creeks, rivers, irrigation channels, overland flow paths, existing sediment basins, significant trees and natural habitat features, and existing recreational links around the site. Some key findings from the site visit are provided in Figure 5.

Rotary Park sediment basin. Large established trees.

New River wetlands. Existing wetland system.



East of the New Eastern Link Bridge. Very well vegetated. Sensitive site.

LIA site. Existing revegetation site.

Molloy Site. Existing vegetation degraded.

Bunbury Street sediment basin.

Figure 5. *Photos of sites considered and referred to in the concept design.*

2.4 Existing services

The existing underground services are shown in Figure 6. An optic fibre line runs north south through middle of the study area.

Other key infrastructure includes:

- Stormwater basin at Rotary Park
- Stormwater basin at Bunbury Street (Light Industrial Area (LIA))

Figure 6. *Existing services and infrastructure within the study area.*

3 Community Engagement

The participation of the community in this project was deemed fundamental to ensure community participation in the design process and ultimately to ensure the long-term success of the project. The key objectives of the community engagement program were to:

- Create awareness of and interest in the project amongst the local community, foreshore users, interests groups, nearby schools and businesses, regulators and other interested stakeholders.

- Provide a range of opportunities and formats for the community and other stakeholders to engage in the project through the planning and decision-making phases.

- Ensure that stakeholders have the right information, promptly and in a format that is easily understood, to provide considered feedback and constructively contribute to collaborative actions and solutions.

- Create a process and environment whereby stakeholder groups can hear and understand the needs, aspirations and concerns of other stakeholders, and participate in an informed debate to identify win-win solutions that achieve maximum benefit for all parties.

- Acknowledges and celebrates the contributions of stakeholders to the concept plan design process.

A timeline of community engagement activities is provided in Table 1. Further etail of these community engagement activities is provided below. Further community engagement should be undertaken prior to proceeding to functional and detailed design.

Table 1. Timeline of community engagement activities.

Date	Summary
September 2020	Community survey carried out on the CoB's YourSay website
September 2020	Online community forum and Q&A, which resulted in 93 comments posted on the CoB's online consultation platform.
September 2020	Community engagement workshop
September and November 2020	Traditional Owners consultation - presentations to SW Boojarah Working Group
November 2020	Community update attended by 55 people
22 June 2021	On Country Traditional Owners consultation

3.1 Community survey

A community survey was carried out on the CoB's YourSay website during September 2020. The survey had 86 participants. The purpose of engaging the community through the YourSay website was for the CoB and its partners to:

- Provide a publicly accessible summary of our understanding of the problem, the project's objectives, and the potential interventions being considered.
- Understand community views for each of the project objectives.
- Understand community views for each of the potential interventions.
- Identify high priority areas within the study reach and surrounds.

We wanted to engage as broad a cross-section of the community as possible to understand preferences for the project's objectives and potential interventions. We also wanted to engage, in a more targeted way, people who have strong attachment to the waterway and its future management. This is about incorporating as much detailed knowledge as possible and building an understanding of the constraints that may exist.

3.2 Community engagement workshop

A community engagement workshop was also carried out in September 2020. The purpose of the workshop was for the CoB and its partners to:

- Understand community views on potential wetland and in-stream works locations
- Identify other outcomes and interventions the community would like to see in the project

A summary memo for the Your Say survey, the community feedback form used during the workshop, and survey results are provided in Attachment A.

3.3 Community engagement outcomes

The outcomes from the community engagement activities were used to:

1. inform the preferred treatment intervention and location

2. inform secondary project objectives:

    - Place activation through the provision of interactive play

    - Indigenous and ecological interpretation and education

    - Connectivity through walking and cycling links

    - Enhance public open space with provision of public amenities and shade

    - Enhance habitat and nature interaction through planting/habitat elements viewing areas and boardwalks

3. Identify key issues / opportunities in each location

3.4 Aboriginal cultural heritage survey

Brad Goode and Associates undertook an Aboriginal Heritage Survey for the CoB's Captial Works program, which includes the Vasse River walking trail, in 2021. The Vasse River walking trail and the survey area incorporates the LIA site. Key outcomes from the report, relevant to the Living Stream concept, include:

- The New River is a registered DPLH site (Site ID 16807).

- Traditional Owners advised that the New River is a significant site created by the Waugal. It is part of a larger and culturally and spiritually significant interconnected system of wetlands. The wetland system was a major source of food in pre and post contact times.

- It was requested that the Local Nyungar community be offered employment and engagement opportunities in relation to the proposed works at the Vasse River Reserve.

- The walking trail should be located to the south of the LIA site as much as possible on previously disturbed ground.

4 Project objectives

4.1 Ecological principles

We have employed four overarching ecological principles to evaluate the proposed interventions. These ecological principles are summarised below:

- **Address the multiple causal factors of cyanobacterial blooms**
  We have identified five factors that promote the growth and accumulation of cyanobacterial cells to bloom concentrations. A great deal of work has been done to understand ecological processes in the LVR and all of the factors appear to be contributing to the blooms. However, it is not clear if any single factor is dominant. A design that addresses all the factors will therefore have the best chance of successfully controlling blooms. This principle directly addresses the main objective of reducing algal blooms, as well as the second objective of improving nutrient processing capacity.

- **Reconnect wetlands and river**
  This concept attempts to recreate the historical connection between a permanent water body and the surrounding seasonal wetlands within the constraints of the urban footprint of Busselton and the need to minimise flooding. This principle addresses the third objective of increasing and/or improving wetland habitat.

- **Create a diversity of habitat types**
  Prior to clearing and drainage of the Vasse River catchment, the LVR would have been connected to a large wetland complex with a diversity of hydrological and ecological habitats. Each habitat type served a unique role in supporting a healthy ecosystem. For example: wetland shrubs and trees would prevent algal dominance by shading the water column, extensive macrophyte beds would fix nutrients and provide fish spawning habitat, and permanent waterholes would provide habitat for fish that control mosquito larvae during summer. We have purposely designed a concept to recreate this complexity, with improved aquatic habitat and a range of seasonal wetland habitats to improve overall biodiversity and create a healthy, self-sustaining ecosystem.

- **Create a new stable ecosystem**
  The LVR behaves like a lake ecosystem for at least six months of the year. Currently, it is an algal-dominated system, where floating unicellular algae create supersaturated oxygen conditions in the upper levels of the water column and shade the riverbed, which starves benthic algae and submerged macrophytes of energy. This in turn leads to deoxygenation of the sediment and microbial release of nutrients into the water column, further fuelling algal growth. The Living Streams concept creates a new macrophyte-dominated ecosystem that replaces algae with emergent macrophytes and woody wetland plants as the dominant source of photosynthesis and primary productivity. As well as absorbing nutrients from the sediment, vascular plants oxygenate the sediment that they grow in, preventing the microbial mobilisation of nutrients into the water column. This principle addresses the long-term sustainability issues described in objectives four, five, and six.

4.2 Project objectives

The system understanding, community engagement outcomes, ecological principles and ongoing discussions with City of Busselton have been used to develop objectives to meet the overall project aim and enable a quantitative assessment of management options.

Project Aim:

- Visibly reduce the extent, severity, frequency, or duration of cyanobacterial blooms in a high priority part of the reach in the short term and throughout the whole study reach in the medium term.

Project Objectives:

1. Functionality
    - Reduce toxic algal blooms: visibly reduce the extent, severity, frequency, or duration of Cyanobacterial blooms in the study reach
    - Improve water quality: increase the capacity of the LVR to fix and store nutrients that are imported via inflowing water and/or decrease the amount of nutrients released from internal stores within the medium term
2. Environment
    - Create diversity of aquatic and wetland habitats
    - Improve ecological corridor: reconnection of waterways and wetlands (Ecological principle)
3. Constructability
    - Construction considerations (i.e. pipe network and pumping, access and working conditions, complexity of approvals)
4. Operation and maintenance
    - Maintenance requirements (i.e. ease of maintenance, reliability) and long-term sustainability

5 Management options

5.1 Central interventions

There are a multitude of potential interventions that can control cyanobacterial blooms. Many have already been employed in the LVR with varying degrees of success. We have assessed around a dozen possible interventions (Table 2) before selecting the four central interventions that form the core of the concept option development:

- Creating wetland habitat
- Shading the water column
- Recirculating water
- Removing sediment

Together, these interventions address the five causal factors of algal growth in the LVR. Wetland habitat, both off-stream and instream, absorbs nutrient from the water and sediment. It shades the water column, reducing the light and temperature environment that promotes algal growth. If the wetland vegetation is dense enough and the residence time of water within it is long enough (approximately 5 days), complete shading is possible, which can starve algal cells of energy and kill them. If the residence time in the open-water habitat of the LVR is reduced enough (approximately 20 days), the algal cells do not have enough time to reach bloom concentration. The concept presented in this report is intentionally conservative, adopting a long residence time in shade of 5 days and a short residence time in sun of 20 days in order to maximise the chances of success.

The wetland vegetation also reduces nutrient in the sediment and water through direct absorption and through absorption by microbial communities in the root zone. Establishing emergent wetland vegetation also oxygenates the sediment, which inhibits the release of nutrients into the water column. Removing unconsolidated and organic sediment from the bed of the river reduces an important source of nutrients in the system. It also creates better habitat for nutrient fixing organisms such as submerged macrophytes and freshwater mussels that can lodge more easily in the firmer underlying soil.

Every potential intervention has a mode of action, or mechanism by which it controls algal blooms, and each has strengths and weaknesses. Many complement each other and can be employed in a staged approach, while others must be employed together to be successful.

The complete list of interventions considered during the development of this concept is detailed in Table 2The interventions we have selected are highlighted in bold text and were chosen because together, they offered a multi-pronged approach to achieving the diverse objectives of the project in a reasonable timeframe. Importantly, most of the interventions are compatible with the ones described in this concept and can be employed in the future if desired. For example, there are large areas of existing wetland habitat within the project area that could be artificially reconnected to the river to achieve biodiversity and water quality objectives, however, the topography and hydraulics of these wetlands are uncertain, so reconnection would require a process of trial and error over many years. Traditional Owners and other stakeholders would also need to be engaged to resolve issues associated with cultural heritage and land tenure.

Table 2. Potential interventions that were considered during the development of this concept.

Intervention		How does it interfere with the cyanobacterial life cycle?	Does it support a new stable ecosystem?*	Design benefits	Design constraints
Remediate the catchment		Reduces nutrients	Yes	• Treats the source of the problem • Benefits the whole catchment	• Takes a long time to work • Requires a large number of partners
Shade the water column	**Riparian trees**	**Reduces temperature and light environment**	**No**	• **Visual and social amenity** • **Terrestrial biodiversity**	• **only slows BGA cell growth** • **doesn't remove nutrients**
	Wetland macrophytes and shrubs	**Strongly reduces light environment and temperature** **Reduces initial algal cell count**	**Yes, if connected to the river**	• **eliminates BGA cells** • **removes nutrients**	• **Visual amenity** • **Requires complimentary interventions to be fully effective**
Create wetland habitat	**In-stream**	**Reduces nutrients**	**Yes**	• **Removes nutrients** • **Creates habitat** • **Reduces the volume of water that needs to be treated**	• **Can increase nutrients by creating bird habitat**
	Off-stream	**Reduces nutrients** **Reduces residence time**	**Yes, if connected to the river**	• **Removes nutrients** • **Creates habitat**	• **Requires recirculation** • **Increases the evaporative surface**
Hydraulically isolate water bodies		N/A	no	• Can greatly reduce the volume of water that needs to be treated • Creates habitat	• Can reduce connectivity of aquatic habitat if not designed properly
Connect existing wetland habitat		Reduces nutrients	yes	• Hydrological remediation of high-value wetlands • Benefits terrestrial and aquatic biodiversity • Potentially a very large treatment area available • Inexpensive	• Many design uncertainties • Risk of eutrophication in high value wetlands
Remove sediment		**Reduces nutrients**	**Yes, in the long term**	• **Removes a large nutrient source** • **Improves aquatic habitat**	• **Increases the volume of water that needs to be treated**
Recirculate water		**Reduces residence time**	**Yes, if connected to wetlands**	• **Inexpensive**	• **Requires complimentary interventions to be fully effective**
Supplement with alternative water source		dilutes nutrients in the LVR Reduces initial algal cell count (in the LVR)	no	• Inexpensive • Visual amenity • Reduces initial agal cell count	• Doesn't fix nutrients or kill BGA cells • Potentially shifts the problem to Ramsar listed VWW
Flocculate nutrients		Reduces nutrients	no	• Proven to work • Removes nutrients from the water • Can potentially eliminate cells	• Could add to nutrient load in the sediment • Probably requires removal of sediment and remediation of the riverbed to be fully effective • Probably requires intensive control of exotic fish
Fertilise diatom community with silica		Reduces nutrients	Supports an alternative unicellular algal community.	• Can potentially shift algal community from toxic to non-toxic • Ease of application	• Presence of suitable diatom species is not known. • Long-term sustainability of the new algal community is uncertain • Nutrients from senescing diatoms may remain available
Plant submerged macrophytes		Reduces nutrients	yes	• Creates aquatic habitat • Visual amenity	• Large-scale establishment is complex • May require preliminary control of algae to be effective

*Refer to ecological principles in Section 4.1

5.2 Site selection

We identified six potential locations for constructed wetlands based on land tenure and proximity to the study reach (Figure 7). In, this section we have analysed each location against the primary project objective of reducing cyanobacterial blooms, and the secondary objectives of environmental outcomes and financial sustainability.

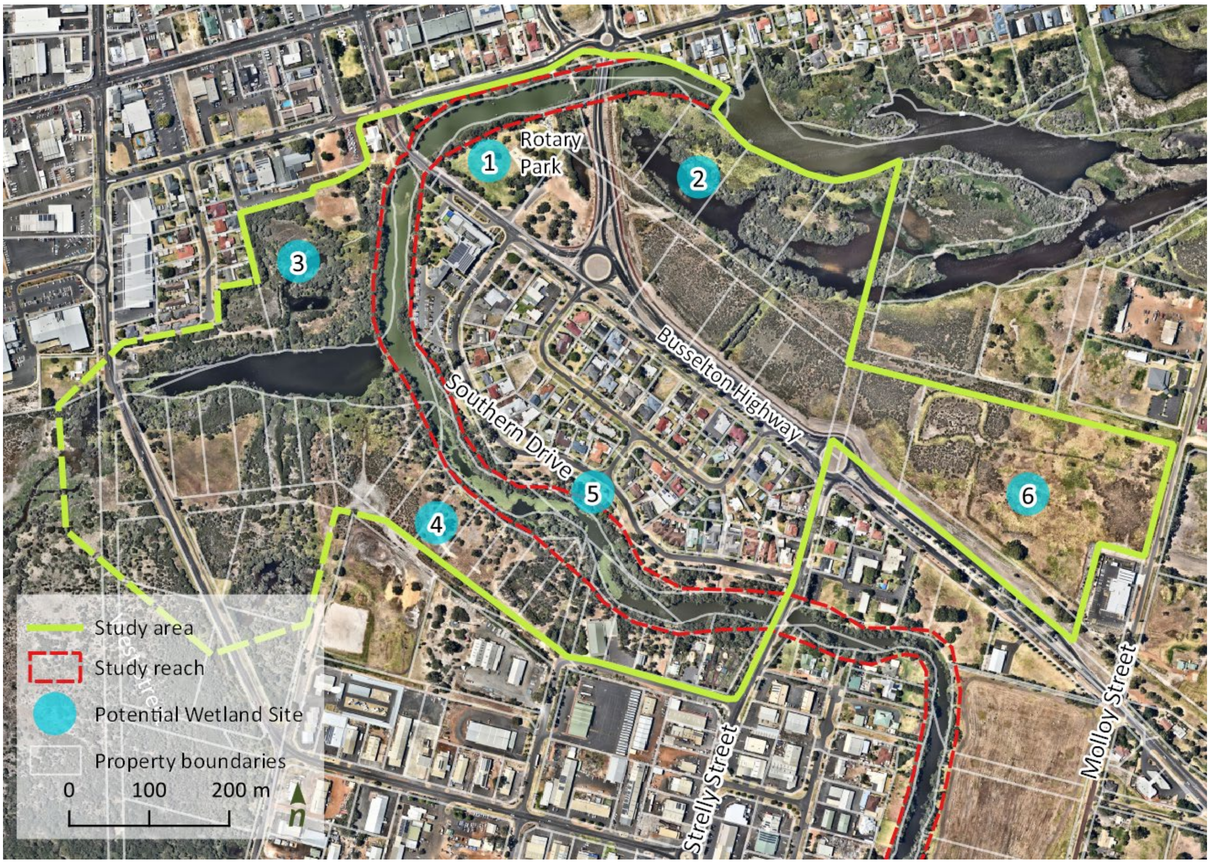


Figure 7. *Study area for the Living Stream design, Lower Vasse River: showing six potential wetland location identified based on land tenure and proximity to study reach.*

We have summarised the benefits and constraints of each wetland site in Table 3. Based on the site comparison the LIA site and the Molloy Site were identified as the preferred sites to progress to concept design. The LIA site was identified as a preferred site due to its proximity to the LVR, size, and potential for habitat and ecological corridor improvement. The Molloy site was identified as preferred site due its size, accessibility, and potential for visual amenity as an entrance statement to Busselton.

Table 3. Comparison between the relative benefits and constraints of LIA and Molloy Street constructed wetland sites.

Site	Current use	Benefits	Constraints	Neutral	Site suitability
1: Rotary Park	Recreation	• Could utilise existing stormwater detention area: create benches (fill areas) within stormwater detention area and revegetate • Site proximal to the study reach	• Limited space • Social values: current recreational use • Future use: war Memorial has progressed, likely opposition/complaints from residents		Constraints in terms using whole site. However, could utilise existing stormwater detention area.
2: East of the New Eastern Link Bridge	Crown reserve for railway purposes	• Site proximal to the study reach • Existing wetland system	• The site is already well vegetated. • Sensitive site adjacent to Ramsar-listed Vasse-Wonnerup Estuary • Constructability issues: engagement with ground water, low-lying and very wet in winter, and difficult to access		Not suitable
3. New River Wetland	Passive recreation	• Large area • Close to study reach • Existing wetland system	• Registered site •		Land tenure and potential cultural heritage constraints. However, still a potential site.
4: LIA wetland site	Passive recreation and revegetation activities	• Site proximal to the LVR, minimising capital and operational costs • Straightforward outfall system (i.e. weir structure) that minimises operational costs and improves reliability • Habitat and corridor improvement that better fulfills environmental objectives in the long term. • Option to use existing stormwater infrastructure to pulse system during winter. This will improve ecological health and visual amenity	• Existing revegetation site. Tree removal likely required. However, wetland will be planted out, therefore will be an overall net vegetation gain once established • Potential ecological constraints. Threatened Ecological communities are nearby and may constrain the site footprint. • Smaller site with more difficult access • Some loss of water through evapotranspiration	• Proximity to culturally sensitive areas. Could negatively affect construction timelines but could also drive further engagement with Traditional Owners and raise the profile of the project outside Busselton	Potential site: develop concept design
5: Southern Park Drive	Passive recreation	• Site proximal to the study reach • Minimal native vegetation • Good access	• Small narrow site • Large established vegetation • Existing amenity already good, the site is currently use by community • Proximity to residents: likely opposition/complaints from residents		Not suitable
6. Molloy Street wetland site	Nil	• Existing vegetation is generally degraded. Negligible tree removal required, which fulfills environmental objective sin the short term. • Visual amenity – entrance statement to Busselton • Larger site with easier access	• Distance from study reach: higher costs associated with outfall pumping over long distances and maintenance that increases operational costs and decreases reliability. • Pumped pulse flow may be required during winter, to maintain amenity • Potential ecological constraints (TECs) • Significant loss of water through evapotranspiration, and potentially seepage to groundwater		Potential site: develop concept design

A quantitative assessment of the two preferred sites was then carried out (Table 4). Both options have been given a score against the following criteria (informed by key project objectives and overarching ecological principles) to arrive at a preliminary preferred solution and to inform staging of the concept design:

1. Functionality
   - Reduce toxic algal blooms: visibly reduce the extent, severity, frequency, or duration of Cyanobacterial blooms in the study reach
   - Improve water quality: increase the capacity of the LVR to fix and store nutrients that are imported via inflowing water and/or decrease the amount of nutrients released from internal stores within the medium term
   - *Both sites perform equally well at improving water quality and reducing cyanobacterial blooms. We expect that losses to groundwater and evapotranspiration will be greater at the Molly St site and have rated it lower for this reason.*
2. Environment
   - Create diversity of aquatic and wetland habitats
   - Improve ecological corridor: reconnection of waterways and wetlands
   - *We have rated the LIA site higher for environmental criteria as a wetland at this site would enhance an existing habitat corridor and be more consistent with the surrounding habitat.*
3. Constructability
   - Construction considerations (i.e. pipe network and pumping, access and working conditions, complexity of approvals)
   - *We have rated the Molloy St site higher for constructability. Although it will require more pipework, site access is easier and the approvals process will be simpler.*
4. Operation and maintenance
   - Maintenance requirements (i.e. ease of maintenance, reliability) and long-term sustainability
   - *A wetland at the LIA site will be simpler to operate and maintain, requiring only one pump rather than two.*

The LIA site is preferred at this stage based on desktop assessment. It scores higher for functionality, enhancing biodiversity, and creating a sustainable long-term solution. It's physical proximity to the LVR and New River wetlands offers an opportunity to enhance existing habitat as well as create new habitat, and the need for only one pump rather than two improves the long-term financial sustainability of constructing at this site. The Molloy St site scores higher for constructability, being a larger site with fewer constraints, a simpler approvals process, and easier access.

Table 4. Wetland options assessment matrix.

All scores rated from 1 (Poor) to 5 (Very Good) **CRITERIA**	**Constructed wetland - LIA bushland**	**Constructed wetland - Molloy St**
	Score	Score
FUNCTIONALITY		
Reduce toxic algal blooms	5	5
Improve water quality in the LVR	5	5
Losses to evaporation, groundwater	4	2
Sub-total for Functionality	14	12
ENVIRONMENT		
Improve aquatic and wetland habitat	4	3
Improve ecological corridor/connectivity	4	2
Visual amenity	4	4
Sub-total for Environment	12	9
CONSTRUCTABILITY		
Pipe network and pumping	4	3
Access, working conditions	3	4
Complexity of approvals (TECs, cultural, land tenure)	3	4
Sub-total for Constructability	10	11
OPERATION & MAINTENANCE		
Energy requirement	4	3
Ease (Cost) of Maintenance	4	3
Reliability	4	3
Sub-total for Operation	12	9
Total Overall Score	48	41

5.3 Wetland sizing

The summer water volume in both the lower and upper reach of the study area was determined (using bathymetry (2015) and LiDAR data provided by CoB) in order to size the wetland treatment systems. The treatment water volume assumes an average summer water level of 0.12 m AHD (determined from 2009 – 2020 logger data downstream of the Butter Factory weir). The treatment volume accounts for dredging to a depth of 0.5 m, based on the average sediment depth in the LVR (Apex Envirocare).

The LIA wetland was sized to treat to lower reach and the Molloy site was size to treat the upper reach. The wetland size is based on a residence time of 5 days in the wetland (to maximise algal cell shedding due to shading by wetland vegetation), a residence time of 20 days in the Lower Vasse River (to prevent algal cells from accumulating to bloom conditions), and an average wetland depth of 0.4 m (assuming a constant pump rate). Design parameters of the wetland systems for the upper and lower reaches are shown in Table 5.

Table 5. Design parameters for the wetlands.

Site	River section treated	Reach volume	Average wetland depth	Normal water level (NWL) area	Pump rate
LIA	Lower reach (Butter factory weir to old boat ramp)	27,120 m^3	0.4 m	16,950 m^2	15.7 (L/s)
Molloy Street	Lower reach (old boat ramp to Busselton bypass)	25,770 m^3	0.4 m	16,105 m^2	14.9 (L/s)

6

7 Concept design

7.1 Staging

We have selected four interventions, in collaboration with the working group, to form the core of the Living Streams concept for the Lower Vasse River. The primary objective of the concept is to significantly reduce the extent, severity, frequency, or duration of cyanobacterial blooms, while also achieving significant benefits for biodiversity and sustainability. The interventions are listed as stages of a potential 3-10 year implementation process and illustrated in Table 6 and Figure 8. An overview of these interventions is provided below with a more detailed assessment provide in the following sections.

The Living Streams concept design drawings are provided in Attachment C.

Table 6. Program staging.

Stage 1	**Sediment Removal**
	Options that comprise dredging the Lower Vasse River. – Dredge lower reach – Dredge whole study reach
Stage 2	**Constructed Wetland**
	Stage 2A Light Industrial Area (LIA) bushland Site (treats lower reach) Stage 2B Molloy Street Site (treats upper reach)
Stage 3	**In-stream Structures**
	Options that comprise in-stream structures within Lower Vasse River. – Bench structures – Cross-stream structures
Stage 4	**Wetland Enhancement**
	Enhancement of the existing Rotary Park stormwater basin.

Figure 8. *Four stages of the Living Streams concept design.*

We expect that Stages 1 and 2 (sediment removal and wetland construction) will both be required if a significant reduction in algal blooms is to be achieved. Removing sediment will reduce a major source of nutrient driving the system, create better aquatic habitat for flora and fauna and reduce the incidence of algal blooms over the long term. However, the seasonal inflow of water during winter and spring likely delivers sufficient nutrient load to cause algal blooms even in the absence of nutrient released from sediment, although this may be minimised by better management of the inflow culvert. Shallow groundwater in the area has high nutrient levels (Total Phosphorus ranging from 0.11 to 4.01 mg/L within the study area) and it is likely that groundwater inflow provides a further input. Therefore, we expect the LVR to remain nutrient saturated for the foreseeable future, so we require a complementary intervention that can reduce cell count under these conditions. Off-stream wetlands that control cells by completely shading the water are the intervention that we have selected to fulfill this role.

In-stream structures could be implemented as Stage 3 of the design. They would reduce the residence time of water in the river, enhancing the efficacy of the off-stream wetlands, as well as providing habitat, shade and nutrient processing capacity to the river itself. Enhancement of existing wetland is another option that would reduce algal cells further if additional improvement in water quality is required in the future. There are several sites where this could be implemented, including the existing sediment basin in Rotary Park. This stage is more akin to an 'optional extra' and implementation would be reliant on support from a range of stakeholders. Consequently, we have described this stage in less detail than the others.

7.2 Sediment removal

Nutrient-rich sediments have built up on the bed of the LVR due to low flow, and deposition of algal blooms. These sediments smother aquatic habitat and form a sink in the system for nutrients which are released from the sediment each summer, fuelling the cycle of continued algal growth. Removing these sediments controls a key input of nutrients into the water and helps to reduce algal blooms over the long term.

The algal blooms appear to originate between the Causeway and Eastern Link bridges, so this area is a priority for sediment removal. Removing sediments throughout the study reach (from the Busselton Bypass to the Butter Factory weir) will have even greater benefits, however, this is associated with considerably high cost.

Sediment removal techniques, such as dredging, can have a negative impact on Carter's freshwater mussels. Due to their conservation status, mussels would need to be removed and relocated to a suitable aquatic environment for the duration of any dredging operations.

7.3 Constructed wetlands

The recirculation of river water through the constructed wetland habitat controls cyanobacteria via several mechanisms:

- Shading within the wetland that starves the cells of light and energy. This reduces the capacity of the cells to grow and divide when they re-enter the river, and if the shading is sufficient, can lead to senescence and sedimentation within the wetland.
- Filtering of cells along with other suspended solids by the wetland vegetation and by flow through subsurface sediments, especially at the unlined LIA site. This reduces the number of cells that flow back into the river.
- Reduction in temperature of water in the wetlands due to shading by dense vegetation reduce the growth rate of cyanobacteria in the wetlands.
- Reduction in nutrient concentration of water that flows back into the river, which reduces the growth rate of cells in the river.
- Reduction in residence time of water in the river, which reduces the opportunity for cell concentrations to reach bloom levels.

Implemented together, recirculating water through constructed wetlands addresses all five mechanisms of bloom formation: light, temperature, nutrients, residence time, and initial cell count.

The concept designs for the two different sites are presented within this section. Each option includes:

- The macrophyte treatment area NWL based on the volume of the relevant section of the study reach
- NWL identified by looking at the topography of the site, as well as the inclusion of 0.1 m extended detention depth (EDD) and 0.2 m freeboard
- An approximate overall footprint based on the selected NWL, battering up to existing surface at a 1-in-5 grade, and/or bunding around perimeter at a 1-in-5 grade
- Indicative inlet pipe, and outlet pipe locations.

Other factors that influenced the configuration of the wetlands included:

- The ability to outfall
- The requirement to meet a length to width ratio of at least 4:1 [MZ4 in the Constructed Wetlands Manual], therefore the associated maximum width, and how this fits with the surrounding terrain
- Minimising excavation requirements where possible

The configuration of these wetlands will be refined in later design stages, however these concept designs provide a conservative indication of land take and functionality.

LIA constructed wetland

The LIA wetland is created by excavating the inlet and outlet pools and using the cut material to bund the perimeter and create a shallow wetland basin. The wetland should be planted with a dense coverage of native sedges and shrubs that are adapted to periodic inundation. Vegetation should be dense enough to intercept at least 90-95% of photosynthetically active radiation to significantly impact the physiology and growth of cyanobacterial cells. This level of light interception has been achieved in annual rice crops (Kar and Kumar 2014, Gautam et al. 2019) and even greater levels have been measured in terrestrial forest ecosystems where soil moisture is non-limiting (Runyon et al. 1994). In practice, it may take several growing seasons to reach maximum light interception, with growing and senescent vegetation both shading the water surface. The existing vegetation is comprised of species typically suited to periodic inundation (e.g. *Melaleuca viminea, Eucalyptus rudis, Juncus pallidus*). These and other species should be planted in a mosaic to test the optimal structure and composition of vegetation. Where existing vegetation needs to be excavated to create optimal wetland geometry, excavated plants should be replanted elsewhere.

The wetland incorporates a recirculation system. In spring and summer, water will be pumped from the river at the Butter Factory weir and into the wetland. Treated water will then flow back into the river (opposite the old boat ramp) through a rock weir. The inlet and outlet pools are clay lined to create permanent water bodies and habitat for macroinvertebrate predators and to enable sediment to be dredged from the inlet pool following flocculation. The macrophyte zone is not clay lined, allowing seepage back into the river. Pumping into the wetland would begin in spring before the river stops flowing to enable the shallow groundwater to be recharged and minimise water losses during summer. Shallow bores that intercept the water table can be installed between the wetland and the river to measure the hydraulic gradient and estimate water flow between the wetland and the river.

An automatic dosing system for flocculating clay will be connected to the inlet pool to facilitate removal of dissolved and particulate phosphorous. The dosing system consists of a storage hopper, powder feeder and a mixing tank that creates a suspension of flocculating clay that is injected directly into the inlet pipe just before it discharges to the wetland's inlet pool. The inlet pool should be dosed at a rate of approximately 0.75g/L (Tulipani 2019, Robb et al. 2003). Application period would depend on nutrient concentration; however it would likely be for intermittent periods of approximately 20 days at the beginning of summer.

Additional benefits of the wetland are the removal of nutrients by vegetation and soil microorganisms and provision of habitat for birds, frogs, and other wetland species. The LIA constructed wetland concept schematic is shown in Figure 9.

The wetland has been positioned to minimise impacts on threatened ecological communities (TEC), to retain and enhance as much of the existing vegetation as possible, and to accommodate the existing stormwater basin and underground services (Figure 6).

Figure 9. *LIA constructed wetland concept. Showing treatment area, macrophyte zones, and proposed pipe network.*

The wetland normal water level (NWL) at the LIA site is 1.3 m AHD (approximately 0.25 - 0.3 m above the average existing ground level). The fall of the existing terrain (within the macrophyte zone) is utilised to convey flow from the inlet to the outlet pool. In addition, the NWL is set at a higher elevation than both the summer and winter average water levels in the LVR to allow treated water to flow from the wetland back into the river via gravity. Specifications for the LIA wetland are provided in Table 7. A representative cross-section of the LIA wetland is shown in Figure 10.

Table 7. LIA wetland specifications.

Specification	Unit	Value
Wetland NWL	m ADH	1.3
Wetland EDD	m	0.1
Wetland Freeboard	m	0.2
Wetland area at NWL	m^2	16,950
Approximate total footprint	m^2	20,620

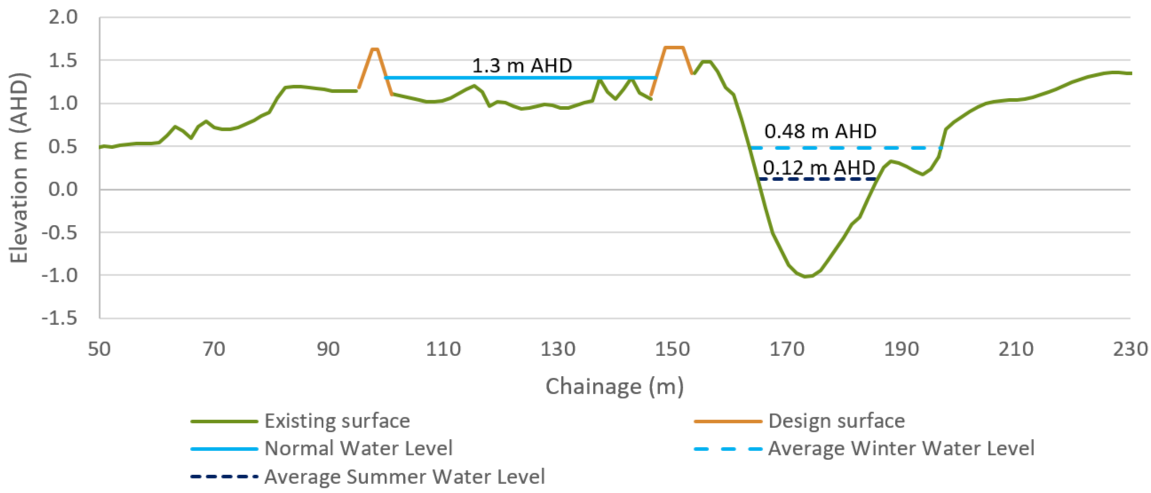


Figure 10. *A representative cross-section of the LIA constructed wetland. Showing the wetland perched above the Lower Vasse River to the east and the New River Wetlands to the west.*

Wetland habitat provides good spawning habitat for the native fish that act as hosts for mussel larvae. If possible, the outlet should be designed as a natural riffle/run sequence that allows fish to access the wetland during spawning season.

The outlet of the wetland will be a source of flowing water during summer and therefore is likely to attract fish. If the outlet cannot be designed to allow access, fish are likely to congregate and be vulnerable to predation, so vegetation will need to be established around the outlet to provide cover.

Molloy Street constructed wetland

The Molloy wetland is created by excavating to create a shallow basin and bunding of part of the perimeter (i.e. lower lying ground at the western extent of the site). The wetland incorporates a pump-in/pump-out recirculation system. In spring and summer, water will be pumped from the river at the Butter Factory weir and into the wetland. Treated water will then be pumped from the wetland and into the river (near the Busselton bypass). The Molloy Street wetland is clay lined beneath the entire extent to prevent water loss via seepage during summer.

An automatic flocculation dosing system is proposed to be connected to the inlet pool, to facilitate removal of dissolved and particulate phosphorous. The dosing system consists of a mixing tank that creates a suspension of flocculating clay that is injected directly into the inlet pipe just before it discharges to the wetland's inlet pool. The inlet pool should be dosed at a rate of approximately 0.75g/L (Tulipani 2019, Robb et al. 2003). Application period would depend on nutrient concentration; however it would likely be for intermittent periods of approximately 20 days at the beginning of summer.

Additional benefits of the wetland are the removal of nutrients by vegetation and soil microorganisms and provision of habitat for birds, frogs, and other wetland species. The Molloy Street constructed wetland concept schematic is shown in Figure 11.

The wetland has been positioned to minimise impacts on existing vegetation (including TEC), and to accommodate the underground services (Figure 6).

The wetland NWL at the Molloy site is 1 m AHD (approximately 0.15 m below the average existing ground level). The NWL has been set close to the existing average site level to minimise earthworks costs. Due to the significant distance from the wetland outlet pool and the upstream extent of the study reach (~1.6 km), and the relatively flat terrain, the treated water must be pumped from the outlet pool into the river. Specifications for the Molloy Street wetland are provided in Table 8. A representative cross-section of the Molloy Street wetland is shown in Figure 12.

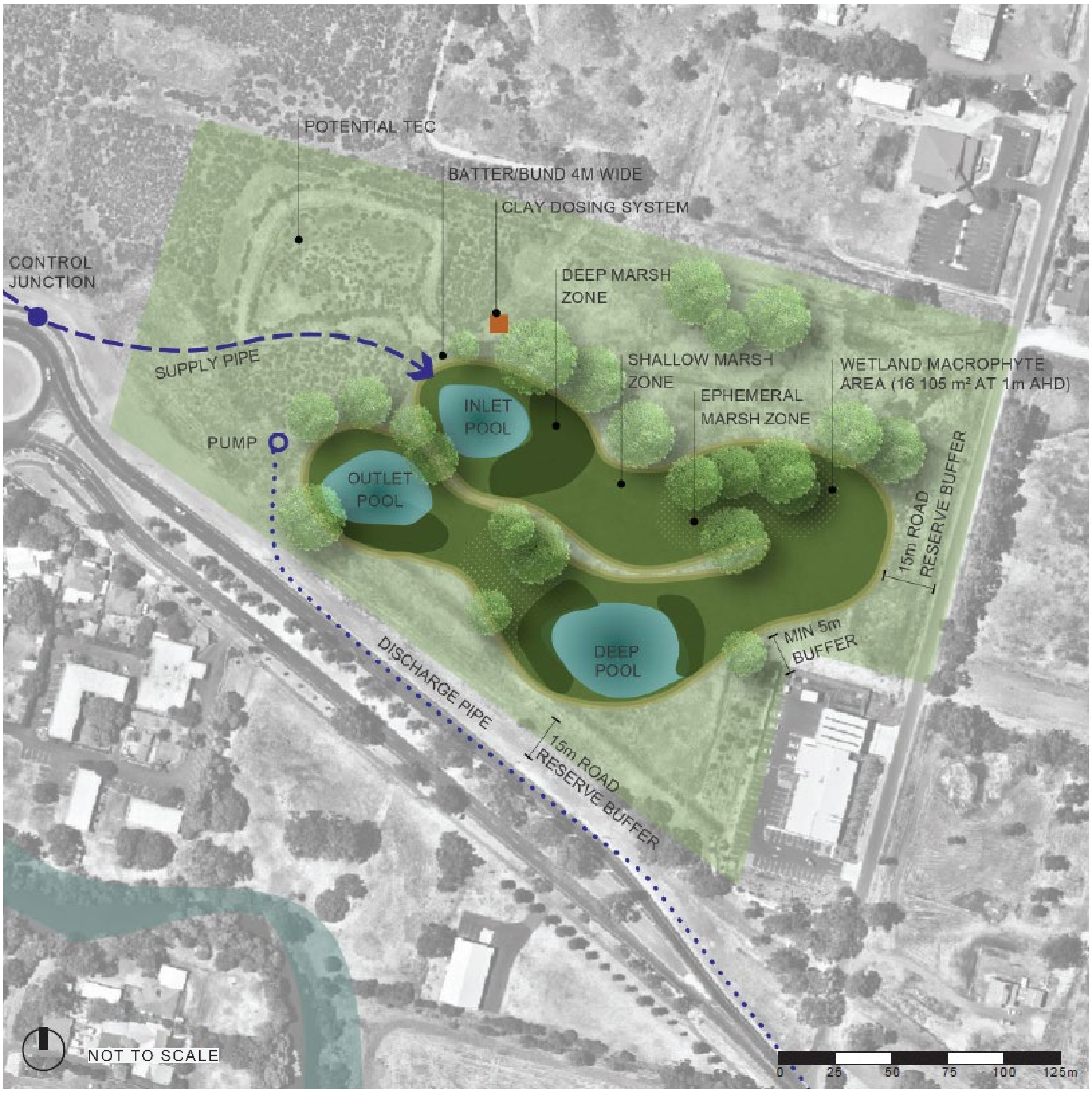


Figure 11. *Molloy Street wetland concept. Showing treatment area, macrophyte zones, and proposed pipe network.*

Table 8. Molloy wetland specifications.

Specification	Unit	Value
Wetland NWL	m ADH	1
Wetland EDD	m	0.1
Wetland Freeboard	m	0.2
Wetland area at NWL	m^2	16,105
Approximate total footprint	m^2	19,720

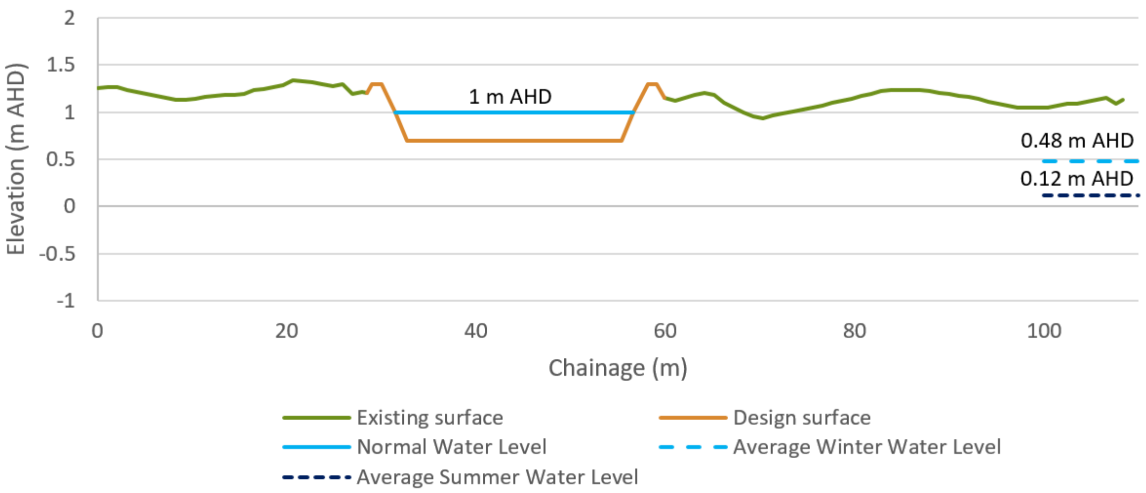


Figure 12. *A representative cross-section of the Molloy Street constructed wetland. Showing the wetland cut into relatively flat terrain.*

Pipe network

The combined pipe network for the LIA (Stage 2a) and Molloy Street (Stage 2b) wetland is shown in Figure 13. The supply pipe network should be sized for the combined LIA and Molloy Street wetlands. A control junction situated where the supply pipe separate (adjacent to the Busselton Highway and Strelly Street roundabout) builds flexibility into the design. The junction enables flow rates to each wetland to be adjusted based on system response, allowing greater control of cyanobacteria in upstream or downstream.

Figure 13. *LIA and Molloy Street wetland combined pipework.*

Flood storage

The cut/fill design approach for the wetlands will result in loss of floodplain in a small area due to bunding of the wetland perimeter. Preliminary two-dimensional hydraulic modelling indicates that the wetland footprints, at both sites, only marginally encroach on the 100 yr ARI flood extents. Therefore, loss of flood storage is likely fairly negligible. The impact on flood extents will need to be confirmed during detailed design.

7.4 In-stream structures

In-stream structures with a dense coverage of sedges and scattered wetland trees reduce cyanobacterial blooms primarily by reducing the residence time of water in the river before it is pumped into a wetland. They do this by reducing the volume of water held in the river. Larger structures will reduce the volume and residence time more than smaller structures, and the size can be optimised to meet any specified residence time. They also shade the water column and remove nutrients as water flows through the vegetation and associated biofilms, which reduces the growth of cyanobacteria further still.

Mussels are to be removed and relocated to a suitable aquatic environment for the duration of construction of in-stream structures. Rock walls will be covered with a suitable substrate to facilitate recolonisation.

Cross-stream structures

Cross-stream structures incorporate the use of two rock walls to create an area of infill across the width of the river (i.e. between the rock walls). Rocks will be covered with suitable substrate that allows the establishment of sedges and/or freshwater mussels. A plan view and long-section of the cross-stream structure is shown in Figure 14 and Figure 15 respectively.

Cross-stream structures would be implemented in pairs. The top of the cross-stream structure is set at 0.3 m AHD with a narrow invert at a lower level. The cross-stream structure is below the winter average water level (0.48 m AHD), allowing flow and migrating fish to pass over it. In summer when the water level drops (average water level 0.12 m AHD), the structure is exposed and pools either side of the structure are largely isolated, except for a narrow channel. Water in the isolated section (between the two structures) can be recirculated or treated with products such as nutrient binding clays to prevent algal blooms. Isolating this section of the river prevents the blooms that form there from spreading to the rest of the river. Each structure has a total top width of approximately 13 – 15 m. The individual rock walls have a top width of approximately 1 m and batter slopes of 1H:2V. Dimensions should be refined during the detailed design phase.

Potential locations for cross-stream structures are downstream of the Causeway Bridge and upstream of the East Link Bridge. This would isolate the part of the river subject to the most severe blooms and allow for intensive treatment of the water within the summer pool. Locations downstream of the study reach near the Vasse Delta wetlands could be suitable location to prevent the infiltration of saline water from the delta. Final locations would be subject to stakeholder consultation and hydraulic modelling during the detailed design phase.

Figure 14. *Plan view of the cross-stream structures showing isolated waterbody (between the two structures) during summer. Location is indicative only and would be finalised during detailed design phase.*

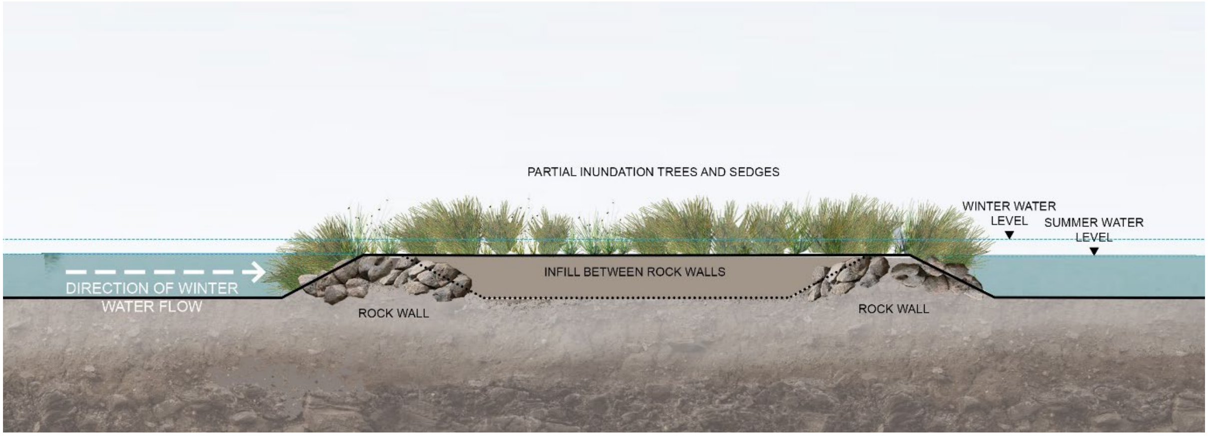


Figure 15. *Long-section of a single cross-stream structure showing infill area (between rock walls), dense planting, and average summer and winter water levels. Winter flow passes over the cross-stream structure.*

Sedges planted on the structure help to control algal blooms by removing nutrients and allowing water to flow through during winter. Shallower sections or raised islands can be incorporated to support wetland trees that further control algal blooms by shading the water column. In the longer term, enough canopy coverage can be achieved to allow possums to safely cross the river in summer and autumn, connecting habitat on both sides of the river.

Bench structures

Bench structures incorporate the use of rock walls to create areas of infill along the river bank. Rocks will be covered with suitable substrate that allows the establishment of sedges and/or freshwater mussels. Bench structures can be constructed on one or both sides of the river and are to extend approximately halfway across the river width. The top of the bench structure is set at 0.3 m AHD. The bench is below the winter average water level (0.48 m AHD), allowing water to flow across the structure and inundate vegetation in winter. When the water level drops in summer, the vegetation is exposed and allowed to partially dry. The individual rock walls have a top width of approximately 1 m and batter slopes of 1H:2V. A plan view and cross-section of the bench structure is shown in Figure 16 and Figure 17 respectively. The location of structures is indicative. Final locations would be subject to stakeholder consultation and hydraulic modelling during the detailed design phase.

Figure 16. *Plan view of the bench structure showing modified river flow. Location is indicative only and would be finalised during detailed design phase.*

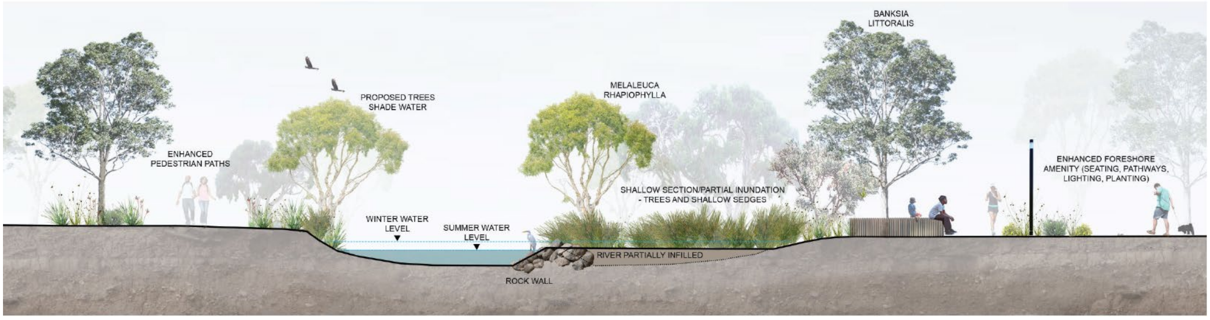


Figure 17. *Cross-section of the bench structure showing infill area, dense planting and average summer and winter water levels.*

Sedges and trees, planted on the bench structures, aim to reduce the duration, frequency, and severity of Cyanobacterial blooms by shading the water and removing nutrients. The benches also reduce the volume of water in the river, which reduces the amount of time water spends in the river before being recirculated through constructed wetlands. Additional benefits of the bench structures include more extensive riparian vegetation creating spawning habitat for frogs and fish, and nesting habitat for water birds. Native vegetation and fauna also provide a more nature-based experience for the community.

7.5 Wetland enhancement

The existing basin in Rotary Park is enhanced to create denser wetland vegetation without the need for excavation (infill is used to create shallow macrophyte zones). Dense vegetation shades the water column (maximising algal cell shedding) and absorbs nutrients.

The proposed Rotary Park wetland has a treatment area of approximately 1,900 m^2 (and average depth on 0.4 m). Water is pumped from the river near the Butter Factory weir (via the existing constructed wetland pipe network) and allowed to drain back via gravity through a vegetated treatment swale (Figure 18).

The wetland has been positioned to fit within the existing stormwater basin. The wetland NWL at the Rotary Park site is 0.6 m AHD to minimise impacts on fringing vegetation (i.e. period of inundation). In addition, the NWL is set at a higher elevation than both the summer and winter average water levels in the LVR (to allow treated water to flow from the wetland into the LVR via gravity through a treatment swale).

Figure 18. *Rotary Park enhanced wetland concept. Showing treatment area, and treatment swale.*

This option creates a smaller amount of wetland habitat than the LIA or Molloy Street sites and therefore treats a significantly smaller volume of water. On its own, it would treat approximately 10% of the lower reach. However, it could be implemented as a “value-add” option that improves the performance of one of the constructed wetlands by reducing the residence time of water in the lower reach by 3-4 days. Note that there are many areas of wetland surrounding the LVR, both large and small, that could potentially be enhanced in a similar way to reduce residence time in the river and improve water quality and biodiversity.

7.6 Optimising residence time in the river

The interventions should be implemented together to achieve a residence time of water in the river that optimises the performance of the constructed wetland(s) within the constraints of time, budget, land availability and evaporative loss of water. Each of the constructed wetlands has been sized to provide a residence time for water of 5 days in the wetland and 20 days in the reach of the river that it is treating. If increased treatment of water is required, river residence times can be reduced by implementing stages 3 and/or 4. The marginal cost of water treatment via each stage is detailed in Table 9.

A wetland at the Molloy St site could easily be made larger to reduce the residence time of water in the river. However, this is likely to increase the loss of water through evapotranspiration, potentially requiring the river to be topped up with groundwater from the Leederville aquifer.

The in-stream structures reduce residence time of water in the river without promoting loss of water through evapotranspiration. The structures described in this report reduce residence time by about a day, but they can be easily scaled up or down during the detailed design phase to theoretically achieve any target. Cross-stream structures and the location of inlet and outlet pipes could be configured to intensively treat a limited portion of the LVR using very low residence times in the river. However, it would be difficult to achieve this effect while maintaining movement for fish during the cease-to-flow period. Benches can be added to progressively reduce the residence time of water in the river using whatever budget is available. To achieve a significant reduction in residence time, they would need to fill a significant volume of the river, potentially reducing habitat for fish. The effect on fish habitat can be mitigated by sensitive design to create optimal bank habitat, reintroduce large woody debris and maximise the wetted surface area.

Enhancement of existing wetland habitat close to the LVR offers the most cost-effective way to reduce the residence time of water in the river. This option has minimal impacts on cultural heritage values, and potentially enhances them. It could potentially increase the loss of water through evapotranspiration, but this effect would be small, given that the areas are already well vegetated and close to the river. The stormwater basin in rotary park is the largest of these wetland areas, and activation of this wetland would reduce residence time by several days. Other suitable areas also exist between the confluence with the New River and Strelly St.

7.8 High-level cost estimates

A summary of high-level construction, treatment, and operation and maintenance costs for the selected interventions is provided in Table 9. Quantity and cost estimates for the recommended works are provided in Table 10 to Table 14.

Costs are provided for individual in-stream structures (bench and cross-stream structures). However, it is likely that bench structures would be implemented in sets, and cross-stream structures would be implemented in pairs, having consideration for small-scale . In-stream structure costs are based on indicative locations; cost would vary based on channel width and depth at site of implementation. A 30% contingency has been included due to the difficult nature of estimating costs at such an early stage of treatment design.

Table 9. A summary of high-level concept costs for the selected interventions.

Options	Construction Cost	Construction Cost (with contingency)	Cost of treatment ($/m³ water)	Annual operation and maintenance costs
Sediment removal				
Dredge between lower reach (Butter Factory weir to the old boat ramp) (including approvals)	$ 1,046,000[1]			
Dredge whole study reach (including approvals)	$ 2,136,000[2]			
Constructed Wetland				
Constructed wetland - LIA		$3,290,000	$130	$103,000
Constructed wetland - Molloy Street		$6,580,000	$260	$113,000
Individual in-stream structure				
Bench structure (vegetated area = 760 m²)		$420,000	$410	$3,800
Cross-stream (vegetated area = 450 m²)		$290,000	$500	$2,300
Enhanced wetland				
Constructed wetland (infill) - Rotary Park		$420,000	$140	$1,800

[1] Cost estimate provided by City of Busselton
[2] Cost estimate extrapolated from lower reach estimate

Table 10. Costing - LIA constructed wetland.

Description of works	Quantity	Unit	Unit Rate	Cost
Preliminaries				
Site establishment, sediment and erosion control	1	No	5.00%	$102,454
	Subtotal - Preliminaries			$102,454
Wetland				
Excavation (inlet and outlet pools)	1922	m^3	$30	$57,670
Excavation (for 200 mm planting media)	678	m^3	$30	$20,340
Excavation (for 300 mm clay liner)	1017	m^3	$30	$30,510
Reuse spoil for bunds (top width ~ 1m, top elevation 1.6 m AHD, 1 in 5 batter)	1170	m^3	$15	$17,555
Dispose of excess spoil (transport and disposal - clean)*	3617	m^3	$80	$289,388
Supply and place clay liner (300 mm thick)	3,390	m^3	$30	$101,700
Planting (6 plants/sqm)	15,253	m^2	$50	$762,637
Planting media (200 mm depth)	678	m^3	$40	$27,120
Supply and install inlet pipe scour pad	1	No	$5,000	$5,000
Supply and install outlet weir	1	No	$5,000	$5,000
	Subtotal - Wetland			$1,316,920
Flocculant dosing system				
Automatic flocculation dosing system (storage hopper, powder feeder and a mixing tank)	1	PC	$115,000	$115,000
	Subtotal - Dosing system			$115,000
Recirculation system				
Electrical design associated with pumps	1	No	$5,500	$5,500
Pump design	1	No	$5,500	$5,500
Pumps (pump in)(sized supply both the LIA and Molloy wetland)	1	No	$50,000	$50,000
Solar panels	10	No	$1,000	$10,000
Supply and install recirculation pipe to wetland	1351	m	$350	$472,850
	Subtotal - Recirculation			$543,850
Landscaping				
Planting (4 plants/sqm)	3,665	m^2	$20	$73,300
	Subtotal			$73,300
-	Subtotal - Wetland			$2,049,070
-	Subtotal for all items			$2,151,524
Other				
Allowance for approvals (heritage, ecology etc.)	1	No	$50,000.00	$50,000
Site investigations (geotech, survey, service detection, potholing, contam, etc)	1	No	5.0%	$107,576
Maintenance and establishment period	1	No	15.0%	$223,901
Subtotal	Subtotal - other			$381,477
	Subtotal for all items			**$2,533,001**
	Contingency		**30%**	**$759,900**
	Total Overall (EX. GST) Inc. 30% contingency			**$3,290,000**
Annual Operation and Maintenance (O & M)				
O & M - Vegetated fringe			6.59%	$4,830
O & M - Wetland			0.40%	$12,867
O & M - Flocculating clay **	20.3	tonnes	$3,000.00	$60,900
O & M - Sediment removal from inlet pool	2	No	$10,000	$20,000
O & M - Recirc pipes			0.50%	$2,364
O & M - Pumps			4%	$2,000
	Total - O & M			**$102,962**

* Disposal rate may vary based on disposal method.

** Based on a dose rate of 0.75 g/L for 20 days. Total annual clay requirement likely to be reduced significantly after a few years of application.

Table 11. Costing – Molloy Street constructed wetland.

Description of works	Quantity	Unit	Unit Rate	Cost
Preliminaries				
Site establishment, sediment and erosion control	1	No	5.00%	$203,679
	Subtotal - Preliminaries			$203,679
Wetland				
Excavation (to wetland dimensions - average depth 400 mm)	9357	m^3	$30	$280,697
Excavation (for 200 mm planting media)	3221	m^3	$30	$96,630
Excavation (for 300 mm clay liner)	4831	m^3	$30	$144,945
Reuse spoil on site for bunds (top width ~ 1m, top elevation 1.6 m AHD, 1 in 5 batter)	769	m^3	$15	$11,533
Dispose of excess spoil (transport and disposal - clean)	17409	m^3	$80	$1,392,723
Supply and place clay liner (300 mm thick)	16,105	m^2	$30	$483,149
Planting (6 plants/sqm)	12,884	m^2	$50	$644,198
Planting media (200 mm depth)	3,221	m^3	$40	$128,840
Supply and install inlet pipe scour pad	1	No	$5,000	$5,000
	Subtotal - Wetland			$3,187,714
Flocculant dosing system				
Automatic flocculation dosing system (storage hopper, powder feeder and a mixing tank)	1	PC	$115,000	$115,000
	Subtotal - Dosing system			$115,000
Recirculation system				
Electrical design associated with pumps	1	No	$7,500	$7,500
Pump design	1	No	$7,500	$7,500
Pumps (pump out)	1	No	$25,000	$25,000
Solar panels	20	No	$1,000	$20,000
Supply and install recirculation pipe to wetland	213	m	$350	$74,550
Supply and install recirculation pipe to river	1611	m	$350	$563,850
	Subtotal - Recirculation			$698,400
Landscaping				
Planting (4 plants/sqm)	3,623	m^2	$20	$72,460
Subtotal				$72,460
	Subtotal - Wetland			$4,073,574
	Subtotal for all items			$4,277,252
Other				
Allowance for approvals (heritage, ecology etc.)	1	No	$50,000	$50,000
Site investigations (geotech, survey, service detection, potholing, contam, etc)	1	No	5.0%	$213,863
Maintenance and establishment period	1	No	15.0%	$519,578
	Subtotal			$783,440
	Subtotal for all items			$5,060,693
	Contingency		**30%**	**$1,518,208**
	Total Overall (EX. GST) Inc. 30% contingency			**$6,580,000**

Annual Operation and Maintenance (O & M)				
O & M - Vegetated fringe			6.59%	$4,775
O & M - wetland			0.40%	$26,030
O & M - Flocculating clay	19.3	tonne	$3,000	$57,900
O & M - sediment removal from inlet pool	2	No	$10,000	$20,000
O & M - Recirc pipes			0.50%	$3,192
O & M - pumps			4%	$1,000
	Total - O & M			**$112,897**

* Reuse of topsoil and clay onsite, depending on geotechnical and agronomy investigation, may reduce these costs.
** Based on a dose rate of 0.75 g/L for 20 days. Total annual clay requirement likely to be reduced significantly after a few years of application.

Table 12. Costing – Individual bench structure (vegetated area = 760 m²).

Description of works	Qty	Unit	Rate ($)	Amount ($)
Preliminaries				
Site establishment, sediment and erosion control	1	item	5.00%	$11,233
Subtotal	Subtotal			$11,233
Instream structure				
Sediment removal (dredging)- site of structures (assuming silt depth 500mm)	1174	m^3	$30	$35,205
Dewatering (200 m3)	6	item	$750	$4,500
Transport and disposal to landfill	293	m^3	$80	$23,470
Supply of rock (rock wall)	467	m^3	$100	$46,734
Landscape rock (top 200 mm of wall)	22	m^3	$90	$1,976
Fill material	574	m^3	$100	$57,382
Top surface area of structure	760	-	-	
Top soil (200 mm)	152	m^3	$40	$6,080
Supply and installation of erosion matting (added 10% to exposed area)	833	m^2	$5	$4,165
Construction of rock wall	6	Days	$2,500	$15,000
Earthworks - placement of fill / topsoils	6	Days	$2,500	$15,000
	Subtotal			$209,512
Planting				
Planting top of instream structure (4 plants/m2)	757	m^2	20	$15,145
	Subtotal			$15,145
	Subtotal for all instream structure items			$224,657
	Subtotal for all items			$235,890
Other				
Allowance for approvals (heritage, ecology etc.)	1	item	50,000	$50,000
Site investigations (geotech, survey, service detection, potholing, contam, etc)	1	item	5%	$11,794
Maintenance and establishment period	1	item	10%	$23,589
	Subtotal			$85,383
	Subtotal for all items			**$321,273**
	Contingency		**30%**	**$96,382**
	Total Overall (EX. GST) Inc. 30% contingency			**$420,000**
Annual Operation and Maintenance (O & M)				
Weed control. Summer hand weeding x 4	760	m^2	2.50	$1,900
Infill planting. 1 plant/m2	760	m^2	2.50	$1,900
	Total - O & M			**$3,800**

Table 13. Costing – Individual cross-stream structure (vegetated area = 450 m²).

Description of works	Qty	Unit	Rate ($)	Amount ($)
Preliminaries				
Site establishment, sediment and erosion control	1	item	5.00%	$7,145
Subtotal	Subtotal - Preliminaries			$7,145
Instream structure				
Sediment removal (dredging)- site of structures (assuming silt depth 500mm)	444	m^3	$30	$13,310
Dewatering (200 m3)	3	item	$750	$2,250
Transport and disposal to landfill	111	m^3	$80	$8,873
Supply of rock (rock wall)	279	m^3	$100	$27,853
Landscape rock (top 200 mm of wall)	17	m^3	$90	$1,516
Fill material	310	m^3	$100	$30,996
Top surface area of structure	453	-	-	
Top soil (200 mm)	74	m^3	$40	$2,966
Supply and installation of erosion matting (added 10% to exposed area)	498	m^2	$5	$2,491
Construction of rock wall	6	Days	$2,500	$15,000
Earthworks - placement of fill / topsoils	6	Days	$2,500	$15,000
	Subtotal – Structure			$120,254
Planting				
Planting top of instream structure (4 plants/m2)	1132	m^2	$20	$22,648
	Subtotal			$22,648
	Subtotal for all instream structure items			$142,902
	Subtotal for all items			$150,047
Other				
Allowance for approvals (heritage, ecology etc.)	1	item	50,000	$50,000
Site investigations (geotech, survey, service detection, potholing, contam, etc)	1	item	5%	$7,502
Maintenance and establishment period	1	item	10%	$15,005
	Subtotal			$72,507
	Subtotal for all items			**$222,554**
	Contingency		**30%**	**$66,766**
	Total Overall (EX. GST) Inc. 30% contingency			**$290,000**
Annual Operation and Maintenance (O & M)				
Weed control. Summer hand weeding x 4	435	m^2	2.50	$1,133
Infill planting. 1 plant/m2	435	m^2	2.50	$1,133
	Total - O & M			**$2,265**

Table 14. Costing - Rotary Park infill constructed wetland.

	Quantity	Unit	Unit Rate	Cost
Preliminaries				
Site establishment, sediment and erosion control	1	No	5.00%	$10,920
	Subtotal- Preliminaries			$10,920
Wetland				
Excavation (to wetland dimensions)	0	m^3	$30	$0
Fill material (area x 0.6 m fill (minus clay liner depth and planting media depth) i.e. from -0.4 m AHD to 0.2 m AHD assuming ave depth 0.4 m)	190	m^3	$100	$18,970
Dispose of excess spoil (transport and disposal - clean)	0	m^3	$80	$0
Supply and place clay liner	1,897	m^3	$30	$56,910
Planting (6 plants/sqm)	1,897	m^2	$50	$94,850
Planting media (200 mm depth)	379	m^3	$40	$15,176
Supply and install inlet pipe scour pad	1	No	$5,000	$5,000
Supply and install outlet treatment swale	1	No	$10,000	$10,000
	Subtotal- Structure			$161,069
Recirculation system				
Electrical design associated with pumps	0	No	$5,500	$0
Pump design	0	No	$5,500	$0
Pump station - 2 pumps (duty and standby)(pump in)	0	No	$25,000	$0
Supply and install recirculation pipe to wetland	50	m	$350	$17,500
Supply and install recirculation pipe to river	0	m	$350	$0
	Subtotal			$17,500
	Subtotal for all wetland items			$218,406
	Subtotal for all items			$229,326
Other				
Allowance for approvals (heritage, ecology etc.)	1	No	$50,000	$50,000
Site investigations (geotech, survey, service detection, potholing, contam, etc)	1	No	5.0%	$11,466
Maintenance and establishment period	1	No	15.0%	$34,399
	Subtotal			$95,865
	Subtotal for all items			**$325,192**
	Contingency		**30%**	**$97,557**
	Total Overall (EX. GST) Inc. 30% contingency			**$420,000**
Annual Operation and Maintenance (O & M)				
Operation and Maintenance Estimate - wetland			0.40%	$1,680
Operation and Maintenance Estimate - Recirc pipes			0.50%	$88
	Total - O & M			**$1,768**

7.9 Concept design assumptions

In developing the concept designs for each site, a range of assumptions were used, as outlined in Table 16. All the designs were developed to concept design stage. This level of detail will ensure the concepts at each site work; however, it does not include detailed site surveys or investigations. The concept designs relied on 2015 LiDAR, 2015 bathymetry and GIS information (i.e. services layers provided by CoB), which will need to be verified during the functional and detailed design stage. This may alter the costs associated with the detailed design and construction. To allow for this, the costings include a 30% contingency.

Table 15. Concept design assumptions.

Assumption	Comment
Cut and fill	Cut and fill calculations were performed based on the treatment area, average wetland depth of 0.4 m, average existing ground level, and a batter slope of 1 in 5.
Services	Services were identified from GIS layers provided by the CoB and included water, waste-water, gas mains, electricity and optic fibre line.
Costing	Each element of the design was incorporated in the costing schedule. Landscaping was factored into each design's costs, to a maximum area of 30% of the treatment area (e.g., wetland water level and surrounding embankments). The method used for Operation and Maintenance costing was as follows: 1. Vegetated fringe O&M cost is based on the raw CapEx estimate (i.e. no contingencies) * 6.59% 2. Wetlands (0.4%) O&M cost is based on total CapEx estimate (including contingencies) minus the raw costs of vegetated fringe 3. Pipe O&M cost is based on the raw CapEx estimate (i.e. no contingencies) * 0.5% 4. Pump O&M cost is based on the raw CapEx estimate (i.e. no contingencies) * 4%
Rates	Unit rates were developed by Alluvium and other consultants for the construction of the treatment systems (e.g. pipes, filter media, excavation). The unit rates were based on previous projects undertaken in Canberra, NSW and VIC, and the Australian Construction Handbook (Rawlinsons, 2020).
Access	Access was required to each site for both construction and ongoing maintenance. Where required, 3 m access paths were accounted for to enable access from the road to the treatment system.

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Attachment A
Community engagement

YourSay Survey results

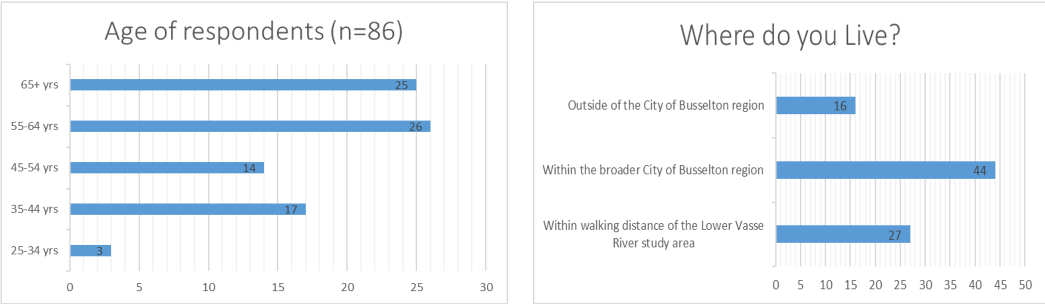

Figure A1. *Age (left) and residence location (right) of survey respondents.*

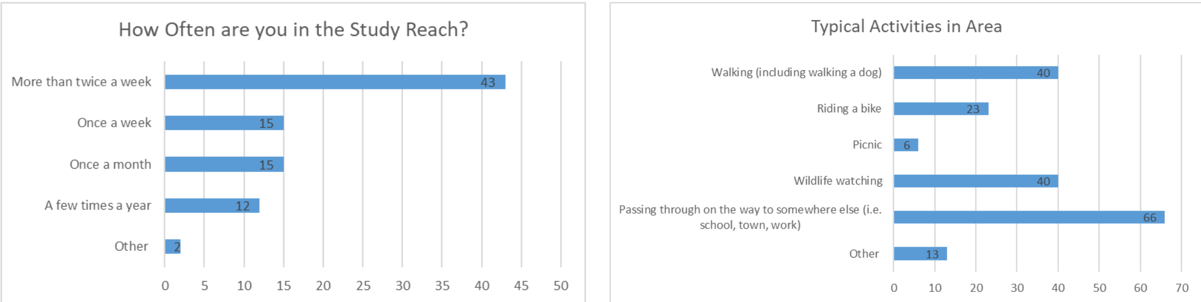

Figure A2. *How often respondents are in close proximity to the study area (left) and activities respondents undertake around the study area (right)*

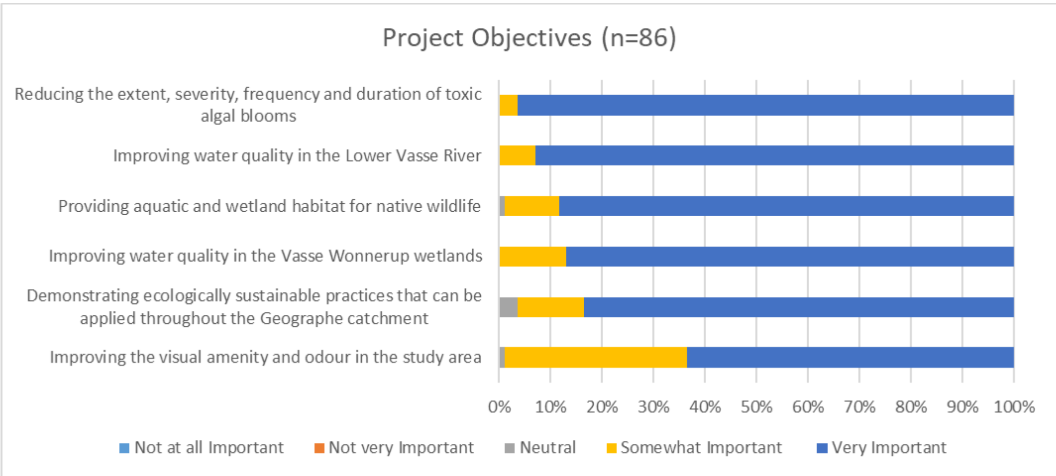

Figure A3. *Importance of key project objectives to the survey respondents.*

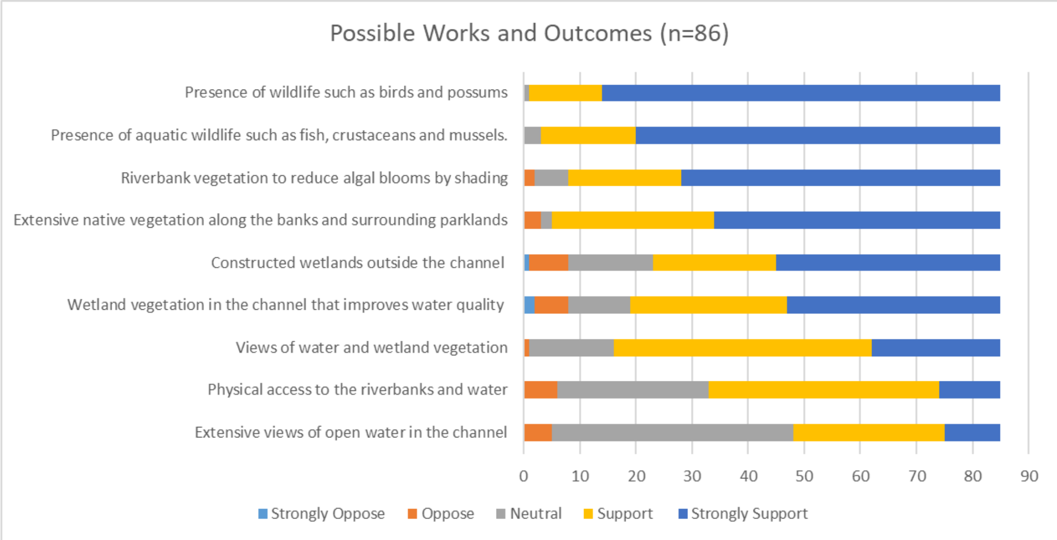

Figure A3. *Views of potential changes to the character and appearance of the Lower Vasse River and its surrounds.*

Table A1. A sample of survey comments

A sample of survey comments
• "winter stream which dries out over summer" • "Bacteria/Enzyme product….to help control the Blue Green Algae" • "some form of artificial circulation (either fountain or Volcanic mixers)" • "some form of artificial flow in the summer months by a bore or wastewater" • solar powered water fountain for aeration and aesthetics • "Restoration and beautification interventions should be mindful that this part of the waterway is part of the entrance to Busselton and include views and access statements" • The most important item that is missed in the questionnaire is - do you support the removal of sludge in the river, this is something that MUST be done to improve the flow of the river

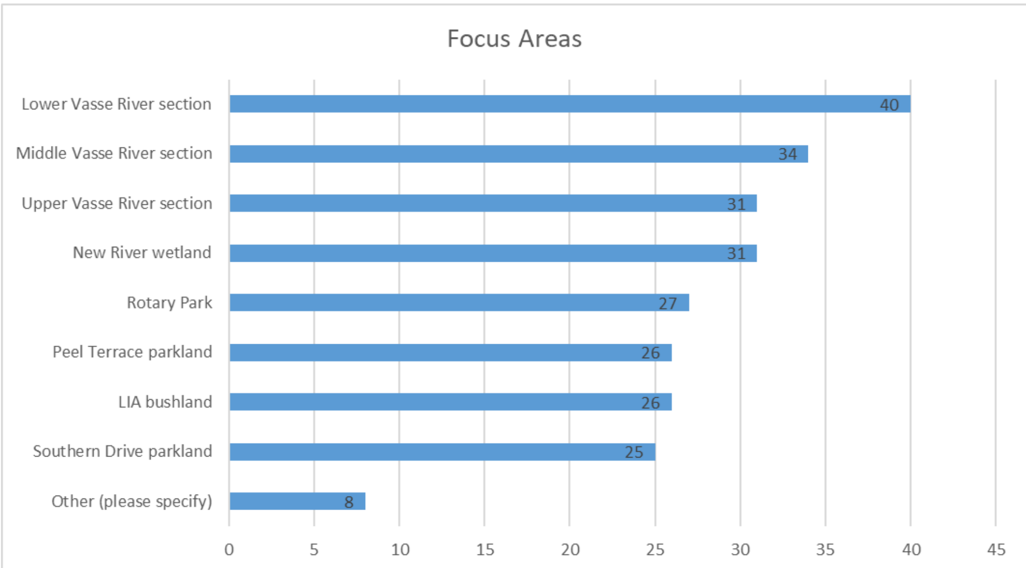

Figure A3. *Views of focus areas for the Living Streams design.*

Attachment B
Conceptual understanding of Cyanobacterial blooms

Attachment C
Concept Design Drawings