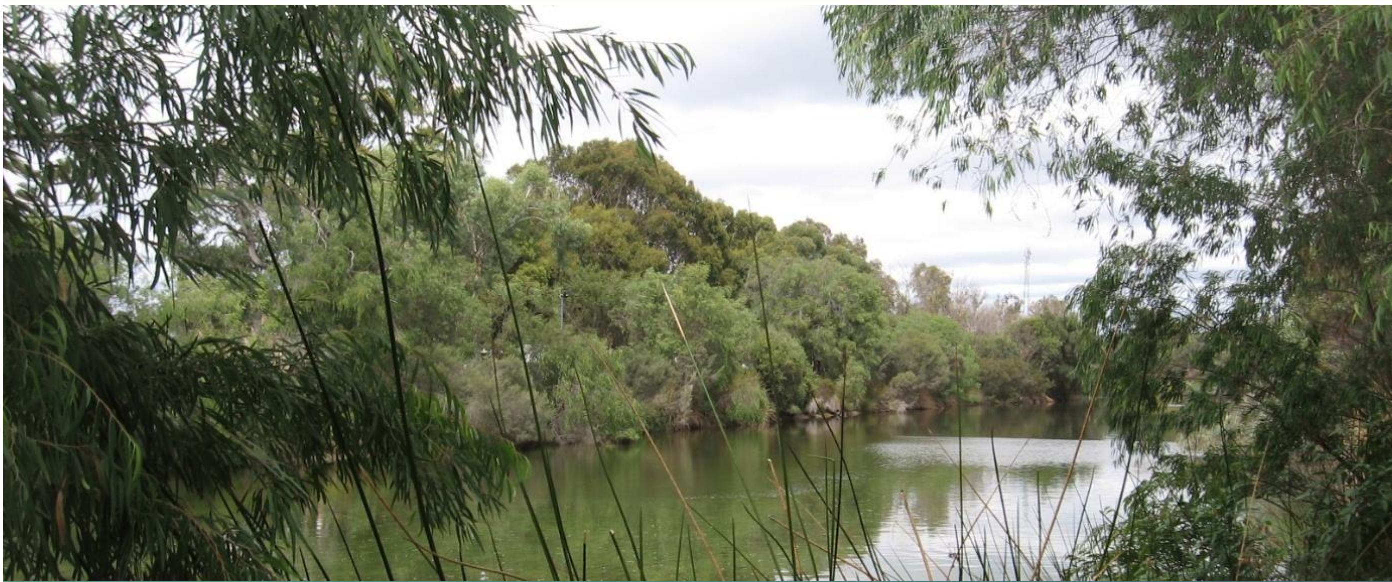
Department of Water and Environmental Regulation
Department of Primary Industries and Regional Development
GOVERNMENT OF WESTERN AUSTRALIA

# Lower Vasse River Waterway Management Plan

May 2019



City of Busselton
Geographe Bay

Revitalising Geographe Waterways

VASSE taskFORCE

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# Acknowledgement of Wadandi people and country

The Vasse River has great spiritual, environmental, customary and social significance to the Wadandi Nyungar people. From its headwaters at Chapman Hill through to the Vasse-Wonnerup Wetlands, the Bilya (river) carries their songline. The Wadandi people are the traditional custodians of the Lower Vasse River, and this connection will be recognised in its future management.

*All systems and beliefs have water as life, blood. We can't survive without fresh water: it's blood, life.*

(Isaac Webb, 2018, cited in BGA 2018)

# Executive Summary

## Background

The Lower Vasse River is a reach of the Vasse River approximately 5.5km in length from the Vasse Diversion Drain to the weir structure at the Old Butter Factory. It flows through the centre of Busselton, about 250km south of Perth.  This reach is greatly modified, with an estimated 90% of catchment flows diverted to Geographe Bay, and impoundment by the weir structure at its downstream end. The river is highly eutrophic, with severe algal blooms occurring each year during the warmer months.

Isolation in terms of flow; the conditions of extremely poor water quality experienced; and the high-profile location have led to the need for specific management of this area. This is the focus of this Water Management Plan. It was initiated though the Revitalising Geographe Waterways program, in response to community concerns about water quality issues in key water assets in the Geographe Bay Catchment. The Water Management Plan has been developed using a collaborative approach that has allowed for extensive consultation to work towards future management of the Lower Vasse River that aligns with community priorities, is well-understood and accepted, and has significant commitment to implementation by stakeholders.

## Purpose and scope

The City of Busselton (the City) has developed this Waterway Management Plan (WMP) 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.*

The Plan includes a description of the characteristics and management issues for the Lower Vasse River, and provides objectives for the future. Through a review of available management options and consideration of stakeholder input, a comprehensive series of management strategies, each with specific actions, has been developed to guide works that will contribute to the objectives and overall vision for The Lower Vasse River.

## Management focus areas

Management issues for the Lower Vasse River have been grouped into the following seven focus areas, with 16 associated management objectives, summarised here in order of importance as rated during community consultation. The table below provides management strategies and actions for each focus area.

### 1. Water Quality

Nutrients are a key driver of algal blooms, so ongoing load reduction actions are a fundamental part of management. However, it often takes a long time to achieve load reductions, and they may be counteracted by new developments and changes to land use. Algal blooms can also be addressed through interventions that limit nutrient availability or directly target algal blooms. They may also be managed by creating less favourable physical conditions for phytoplankton; or restoring ecosystem functions such as nutrient cycling and food web processes.

*Objectives:*

- Reduce nutrient contributions to the Lower Vasse River from all existing sources to improve water quality and reduce the frequency and severity of toxic algal blooms.
- Minimise any additional nutrients flowing into the Lower Vasse River from new developments and agricultural intensification.
- Utilise science and innovative technologies to improve water quality in the Lower Vasse River.

## 2. Ecology

Although degraded, the Lower Vasse River still provides habitat for native freshwater fish, frogs, turtles and invertebrates, and open water areas for waterbirds. The riparian vegetation contributes to aquatic habitats and also supports a range of terrestrial fauna and birds. The permanent fresh waters of Lower Vasse River provide a unique habitat in a landscape of seasonal wetlands and estuaries. There is significant scope to enhance ecological values through managing invasive species and restoring habitat.

*Objectives:*

- Protect and enhance native aquatic and terrestrial habitats in the Lower Vasse River and the foreshore reserve.
- Reduce the impact of threatening processes on the natural values of the Lower Vasse River and the foreshore reserve.
- Balance mitigation of fire risks with the protection of natural values of the Lower Vasse River foreshore reserve.

## 3. Water Flow

There have been substantial changes to the hydrology of the Lower Vasse River and its catchment through physical changes, diversion and impoundment. There is a strong perception in the community that increasing flows from the Vasse Diversion and removal of the Butter Factory weir boards will improve water quality and mobilise sediments. This approach is limited by flow regimes, flood risks and influence on nutrient loads; and a lack of defined management responsibilities for operation of flow control infrastructure.

*Objective:*

- Optimise water flow in the Lower Vasse River to balance improvement of water quality, protection of natural values and public amenity, while maintaining flood protection.

## 4. Sediments

The Lower Vasse River system has accumulated a layer of nutrient rich organic sediments, which contribute nutrients to the water column over summer, driving algal blooms. These sediments provide habitat for beneficial aquatic plants and benthic invertebrates. Sediments are therefore are a key consideration in addressing water quality problems in the Lower Vasse.

*Objectives:*

- Strategically manage accumulated sediments to protect the natural, cultural and social values of the Lower Vasse River.

## 5. Amenity, Recreation and Education

A number of trails and public open space areas adjoin the Lower Vasse and these are still regularly used by the community. Poor water quality has greatly reduced the opportunities for recreational activities in and around the river during the warmer months. Access and recreation was rated the highest and the focus area requiring change. There is significant potential for improving amenity and recreational and educational opportunities through enhancing ecology, improving facilities, addressing water quality problems, and developing information material.

*Objectives:*

- Improve visual amenity, public health and odours for residents and visitors to enjoy the Lower Vasse River.
- Facilitate recreational and educational opportunities, which are compatible with protection of the key values of the Lower Vasse River and enhance community stewardship.
- Enhance public access to the Lower Vasse River and within the foreshore reserve, with a focus on creating linkages to the town centre and surrounding areas while protecting the river's natural values.

## 6. Culture and Heritage

The river has historically been an iconic feature of the town and focal point for recreational and social events. There is a strong Aboriginal cultural connection to the river and a need for greater recognition of the role of Aboriginal people in future management.

*Objective:*

- Promote understanding of the Aboriginal and European history and culture of the Lower Vasse River.

## 7. Governance

The need for a designated manager of the Lower Vasse River was recognised by the independent review of waterways management, and also highlighted during community consultation. The lead role of the City in the future management of the Lower Vasse River will be recognised through endorsement and adoption of this WMP. This will task the City with responsibility for coordinating implementation, however key stakeholders and the community will have ongoing roles in many aspects of the WMP.

*Objectives:*

- Develop and maintain partnerships and a collaborative approach between key stakeholders and the community when managing the Lower Vasse River.
- Maximise opportunities for protection of the Lower Vasse River as part of future development proposals and changes in land uses.
- Manage the Lower Vasse River with consideration to other water assets, including the Vasse-Wonnerup Wetlands and Geographe Bay.
- Improve knowledge and understanding of key values and management issues of the Lower Vasse River to support adaptive management.

## Living Streams

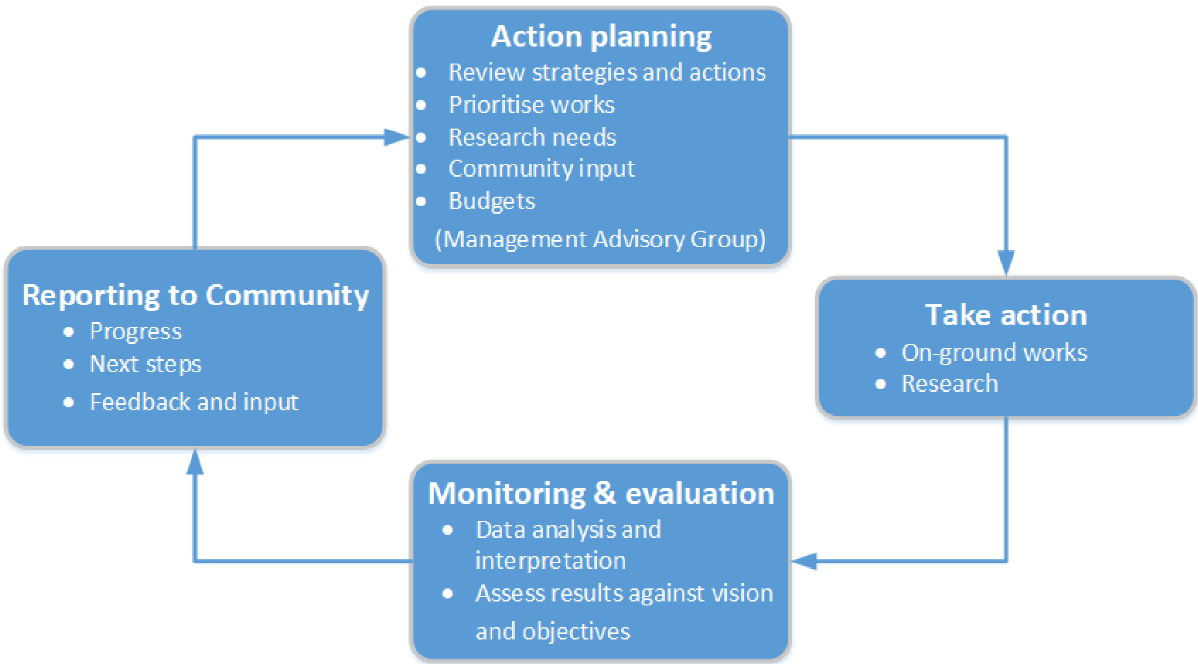
This WMP recommends further development of a Living Stream approach to future management of the Lower Vasse River. The term *Living Streams* describes an approach to managing urban stormwater that creates a complex ecosystem with outcomes for ecology, water quality, water conveyance and amenity. For the Lower Vasse River, this would involve altering the morphology to restore ecological processes and create physical conditions that provide greater resilience to high nutrient conditions. It may also facilitate intervention actions, such as water treatment and sediment removal, in specific areas of the river.

## Implementation

The lead role of the City in the future management of the Lower Vasse River will be recognised through endorsement and adoption of this WMP. Other key stakeholders will continue to have important roles in many aspects of implementation, and there is an ongoing need for community reporting and feedback.

There are many management actions recommended in the WMP and currently there is no guaranteed funding mechanisms or timeline for implementation. A framework for implementation is provided that defines the roles and responsibilities of key stakeholders and a process for action planning, works, evaluation and reporting. This will allow ongoing prioritisation and implementation of actions in line with available funding, and building on new information from research, monitoring and outcomes as management progresses.

Implementation process for the Lower Vasse River Waterway Management Plan:



## Management strategies and actions for the Lower Vasse River.

Strategies and actions are grouped for the Living Streams approach (LS) and each focus area: Water Quality (WQ); Ecology (E); Water Flow (WF); Sediments (S); Amenity; Recreation and Education (ARE); Culture and Heritage (CH); Governance (G).

| Management Strategies | Management Actions | |
|---|---|---|
| Living streams approach | LS.1 | Continue to develop Living Streams planning as a pathway for implementing ecological restoration and water quality improvement works, and assess community support for this approach. |
| | LS.2 | Incorporate the key principles into restoration planning as part of the Living Streams approach. |
| Protecting water quality from urban sources | WQ1.1 | Quantify nutrient and pollutant exports from Busselton Light industrial area (LIA) to the Lower Vasse River to inform a case for deep sewerage. |
| | WQ1.2 | Explore options to secure deep sewerage for the Busselton LIA in partnership with Water Corporation. |
| | WQ1.3 | Assess opportunities for greater connection to existing sewerage infrastructure within the LVR catchment. If there a significant opportunity exists, investigate options and incentives to increase connectivity. |
| | WQ1.4 | Planning decisions to include appropriate sewerage management requirements and best practice water management, through implementing the *Better Urban Water Management* framework. |
| | WQ1.5 | Develop a prioritised program for stormwater upgrades to maximise nutrient reduction outcomes. |
| | WQ1.6 | Support educational campaigns that aim to reduce nutrients in runoff through individual and community actions (e.g. Bay OK). |
| | WQ1.7 | Support implementation of the Vasse-Wonnerup Wetlands and Geographe Bay Water Quality Improvement Plan (WQIP). |
| Reducing nutrient inputs from the rural catchment | WQ2.1 | Support projects focussed on reducing nutrient exports from rural catchment of the LVR, as recommended in the Vasse-Wonnerup Wetlands and Geographe Bay WQIP (DoW 2010; noting future updates of this document): |
| | WQ2.2 | Explore opportunities for enhanced nutrient assimilation in rural drains in the LVR catchment, particularly those in reserves. |
| Water treatment | WQ3.1 | Incorporate outcomes from the Water Quality Treatment Trials (2016-2018) into future management planning. |
| | WQ3.2 | Undertake seasonal water treatments in priority amenity area/s prior to algal bloom establishment, ensuring physical isolation to maximise effectiveness (dependent on outcomes Water Quality Treatment Trials, 2016-2018). |
| | WQ3.3 | Maintain research partnerships to identify and investigate new technologies to treat water in the future. |
| Riparian vegetation management | E1.1 | Develop and implement a revegetation program for City-managed foreshore reserves, considering recommended rehabilitation areas reported in Ecoedge (2017). |
| | E1.2 | Continue to impose appropriate conditions on new developments adjacent to the Lower Vasse River that ensure future vesting and revegetation of foreshore reserves. |
| | E1.3 | Include creation and improvement of habitat for birds and possums in planning riparian revegetation. |
| | E1.4 | Update the Vasse River Action Plan in partnership with adjacent landholders, and extend this throughout the Lower Vasse River study area. |

| | | |
|---|---|---|
| | E1.5 | Minimise fire risks associated with foreshore reserves by: reducing growth of annual grassy weeds; and considering species type, height and planting density when planning revegetation. |
| Understanding and protecting waterbirds | E2.1 | Undertake a survey of waterbirds of the Lower Vasse River and identify important habitat zones, with strong involvement from the community. |
| | E2.2 | Protect identified important bird habitat zones through revegetation and weed control, recognising the current role of weeds as habitat. |
| | E2.3 | Create additional habitat zones for birds by placing large woody debris emerging from the water. |
| | E2.4 | Avoid identified important bird habitat zones when planning future infrastructure, and consider nesting season when planning works. |
| Controlling invasive species | E3.1 | Prevent of further spread of Mexican waterlily through herbicide control and/or shading. |
| | E3.2 | Undertake strategic control of Mexican waterlily to progressively reclaim areas of open water, while minimising adverse impacts and preventing a return to algal blooms in these areas. |
| | E3.3 | Undertake regular feral fish eradication activities in partnership with Murdoch University. |
| | E3.4 | Undertake targeted control of arum lily and Brazilian pepper trees throughout the Lower Vasse River study area. |
| Optimising flows | WF1.1 | Increase flushing of the river by installing a second 900mm culvert at outflow point from Vasse Diversion Drain, in accordance with recommendations from the Reconnecting Rivers Report (DWER 2018). |
| | WF1.2 | Monitor impacts of increasing flows into the Lower Vasse River. |
| | WF1.3 | Undertake intensive monitoring water quality in the Vasse Diversion to support operational guidelines for managing the culvert. |
| | WF1.4 | Develop operational guidelines for the Vasse Diversion culvert that defines responsibilities and provides formal guidance for manipulation of the valve to maximise water quality benefits and minimise risk of flooding. |
| | WF1.5 | Review function of the Butter Factory weir boards to inform their future use and need for replacement. |
| | WF1.6 | Investigate potential for increasing internal circulation in the system during summer to reduce residence time for phytoplankton. |
| Sediment Removal | S1.1 | Undertake a small-scale sediment removal project, using geotextile bags for dewatering and disposal, to assess cost and logistics of this approach. |
| | S1.2 | Determine feasibility of disposal options for future sediment removal: landfill, composting, soil conditioner. |
| | S1.3 | Depending on outcomes of small scale removal, undertake staged removal of sediments in the Lower Vasse River as a component of Living Streams design. |
| Improving facilities and information | ARE1.1 | Review existing facilities and develop a concept plan for strategic pathways and viewing points that connect people with the river. |
| | ARE1.2 | Update the interpretive signage around the river to provide information on of the history, ecology, hydrology and management of the Lower Vasse River. |
| | ARE1.3 | Develop online and printed resources with interesting and important information on ecology, water quality, history and management of the Lower Vasse River. |
| | ARE1.4 | Establish bird watching areas and hides in appropriate places with informational material. |
| | ARE1.5 | Encourage opportunities for citizen science to contribute to understanding and appreciation of the Lower Vasse River. |
| Public health management | ARE2.1 | Continue monitoring phytoplankton species and densities to inform public health notifications. |

| | | |
|---|---|---|
| | ARE2.2 | Review algal bloom warning sign protocol and prepare a communication program to inform the community when harmful algal blooms occur. |
| | ARE2.3 | Develop a policy for use of recreational watercrafts in the Lower Vasse River, including consideration of public health constraints. |
| Recognising Wadandi custodianship | CH1.1 | In partnership with Wadandi people, include reference to traditional custodianship of the waterways and land in development of information resources. |
| | CH1.2 | Manage future access in a way that avoids additional disturbance and considers protection of potential sites of significance – however Wadandi activities such as fishing, camping, the gathering of bush foods and family recreational and educational activities, should not be restricted by implementation of this plan. |
| | CH1.3 | Seek to improve partnerships with the Wadandi community to increase their involvement in the management, protection and restoration of the Lower Vasse River. |
| | CH1.4 | Consult further with Wadandi representatives in regards to specific works which result from this plan. |
| | CH1.5 | Support programs that engage the Wadandi community in implementation of works associated with this plan. |
| Preserving historical values | CH2.1 | Identify and ensure appropriate maintenance of sites of historical importance. |
| | CH2.2 | Develop interpretive material to increase understanding of local history, and to promote, appreciate and access historical sites. |
| Collaborative and adaptive management | G1.1 | The City to consider securing management orders over the waterway and adjacent public lands in Lower Vasse River study area, to facilitate implementation of this plan. |
| | G1.1 | Establish a Management Advisory Group comprised of representatives from the City, Department of Water and Environmental Regulation, Department of Biodiversity, Conservation and Attractions, Water Corporation, GeoCatch, Wadandi representatives, and other community representatives. |
| | G1.2 | Continue water quality monitoring in the Lower Vasse River. |
| | G1.3 | Ensure adequate monitoring and reporting of outcomes from management actions, and feedback results into future management actions. |
| | G1.4 | Maintain and develop partnerships with research organisations to improve knowledge and management of the Lower Vasse River. |
| Optimising planning tools | G2.1 | Improve clarity of planning approval requirements for changes to land use and new developments in the agricultural sector (e.g. horticulture, dairies, feedlots). |
| | G2.2 | Assess future development proposals and changes of land-use on adjoining lands with consideration of impacts on the Lower Vasse River. |
| | G2.3 | Include 50m wide foreshore reserves as part of future development adjacent to the river. |

# 1 Introduction

The City of Busselton (the City) has developed this Water Management Plan (WMP) to recommend management actions that will lead to improved water quality and ecological health for the Lower Vasse River. The vision for the Lower Vasse River, developed for this Water Management Plan in partnership with the community and stakeholders, is:

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

## 1.1 Background to this Waterway Management Plan

The Lower Vasse River is a high profile waterway in Busselton, flowing through the entrance to the town centre, and is a strong part of local history. It has extremely poor water quality as a result of increased nutrient loads form the catchment and changes to hydrology. Seasonal blooms of harmful phytoplankton are a major concern for the community and management. The river has been greatly modified from its original state and ecological health has declined, however it remains an important freshwater habitat supporting aquatic fauna and waterbirds.

This WMP is part of Revitalising Geographe Waterways (RGW), a $15 million program encompassing 30 projects to improve water quality and ecosystem health in key water assets. Within the RGW program, the City was given responsibility to prepare WMPs for the Lower Vasse River and Toby Inlet. The Department of Biodiversity, Conservation and attractions was given responsibility to develop an Operational Plan for the Vasse-Wonnerup Wetlands system.

The RGW program is one of five focus areas of the Vasse Geographe Strategy, a State Government initiative to address water quality in the Geographe Bay catchment (Figure 1). The program also includes three projects directly related to the Lower Vasse River WMP: the Reconnecting Rivers hydrological modelling project; the stormwater upgrades project for Busselton; and water treatment trials in the Lower Vasse River.

The Vasse Geographe Strategy was initiated by an independent review of waterways management (Hart 2014), commissioned by the State Government in response to serious community concerns about water quality issues. The Vasse Geographe Strategy is overseen by the Vasse Taskforce, comprising representatives from:

- Department of Water and Environmental Regulation (DWER)
- City of Busselton (the City)
- Shire of Capel
- Geographe Catchment Council (GeoCatch)
- Department of Biodiversity, Conservation and Attractions (DBCA)
- Department of Primary Industries and Regional Development (DPIRD)
- Department of Planning, Land and Heritage (DPLH)
- South West Catchments Council (SWCC)
- Water Corporation (WCorp)
- Busselton Water (BW)

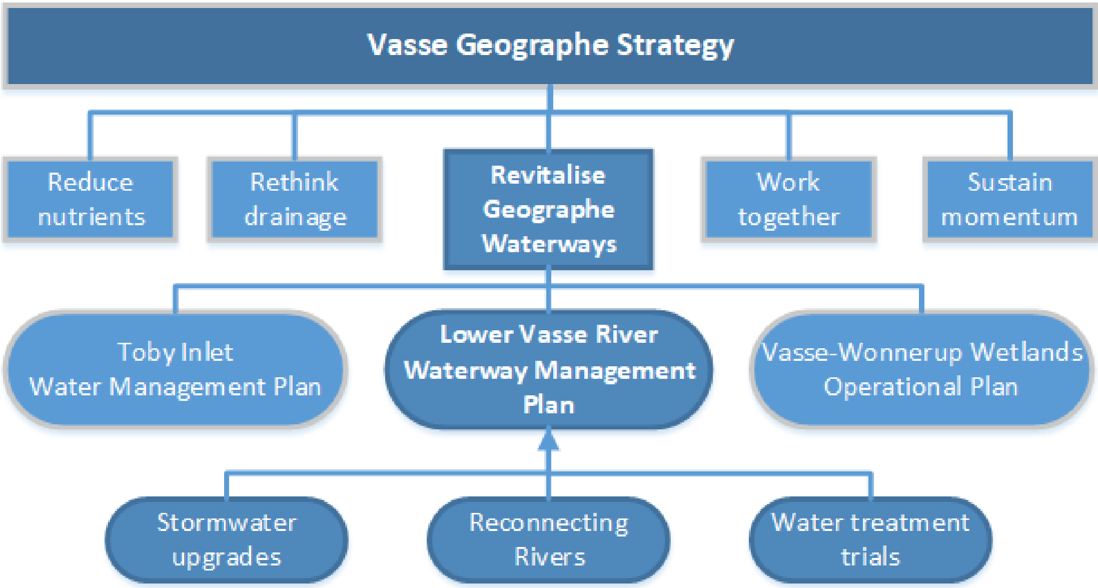



Figure 1. Framework for developing the Lower Vasse Waterway Management Plan.

## 1.2 Study area description

The study area includes the reach of the Vasse River approximately 5.5km in length, from the Vasse Diversion Drain to the weir boards at the Old Butter Factory, flowing through the centre of Busselton. The river discharges through a wetland area into the upper reach of the Vasse Estuary, which is part of the internationally significant Vasse-Wonnerup Wetland System. The study area includes the river itself and some adjacent areas of public land (Figure 1). Areas of water and unallocated crown land have no management responsibility designated, other areas are foreshore reserves managed by the City.

The lower section of the Vasse River is within Busselton's urban area, with a mix of residential and light industrial uses in the catchment. Upstream of the Busselton Bypass the surrounding land is agricultural, aside from the golf course. Upstream of the intersection with the Vasse Diversion, dairy and beef grazing are the dominant uses in the catchment and are intensifying.

The Vasse River catchment has ephemeral headwaters in the Whicher Scarp to the south, and lowland reaches crossing the Swan Coastal Plain. Extensive clearing and construction of the artificial drainage network during the early 1900s facilitated agricultural development across the Swan Coast Plain areas of the catchment. Native vegetation in these areas is very limited, and much of what remains is therefore of high conservation value. The upper parts of the catchment in the Whicher Scarp still retain substantial areas of remnant vegetation.

The Vasse Diversion diverts flow from approximately 90% of the Vasse River catchment to Geographe Bay. It was constructed in the early 1900s to provide flood protection for Busselton. Flow from this region of the catchment is restricted to a 900mmm pipe at the intersection, which may be open or closed by a manually-operated valve. This diversion drain physically separated the lower reach of the Vasse River, known as the Lower Vasse River, substantially changing the natural hydrological regime. At the downstream end of the study area the river is impounded by a weir, established in the early 1900s to maintain higher summer water levels through the town section for amenity and recreation purposes. Removable weir boards are installed at the end of winter and removed in autumn. The effect of flow diversion and impoundment is essentially an elongated "lake" area from late spring to late autumn. In recent years, the weir boards have become degraded and gradual leaking of water during summer leads to water levels defined by land to the east near Ford Road.

Owing to increased inputs of nutrients from catchment sources, and the still conditions created by impoundment, the Lower Vasse River is eutrophic. Extremely high nutrient concentrations, particularly phosphorus, and ideal physical conditions drive severe seasonal algal blooms for up to seven months from November to May. Algal blooms cause unsightly water discoloration and scums and unpleasant odours. These blooms are often dominated by blue-green algae (cyanobacteria) which are potentially toxic and close the waters to public use.

Despite seasonally poor water quality, the Lower Vasse River retains social and natural values. It provides permanent freshwater habitat and vegetated foreshore areas that support native fauna, including many waterbirds, native fish, oblong turtles, freshwater mussels and western ringtail possums. Many people in the community still enjoy the ecological characteristics amenity of the river.

The isolation of the Lower Vasse River by diversion and impoundment; the conditions of extremely poor water quality experienced; and the high profile location have led to the need for specific management of this area. This is the focus of this WMP.

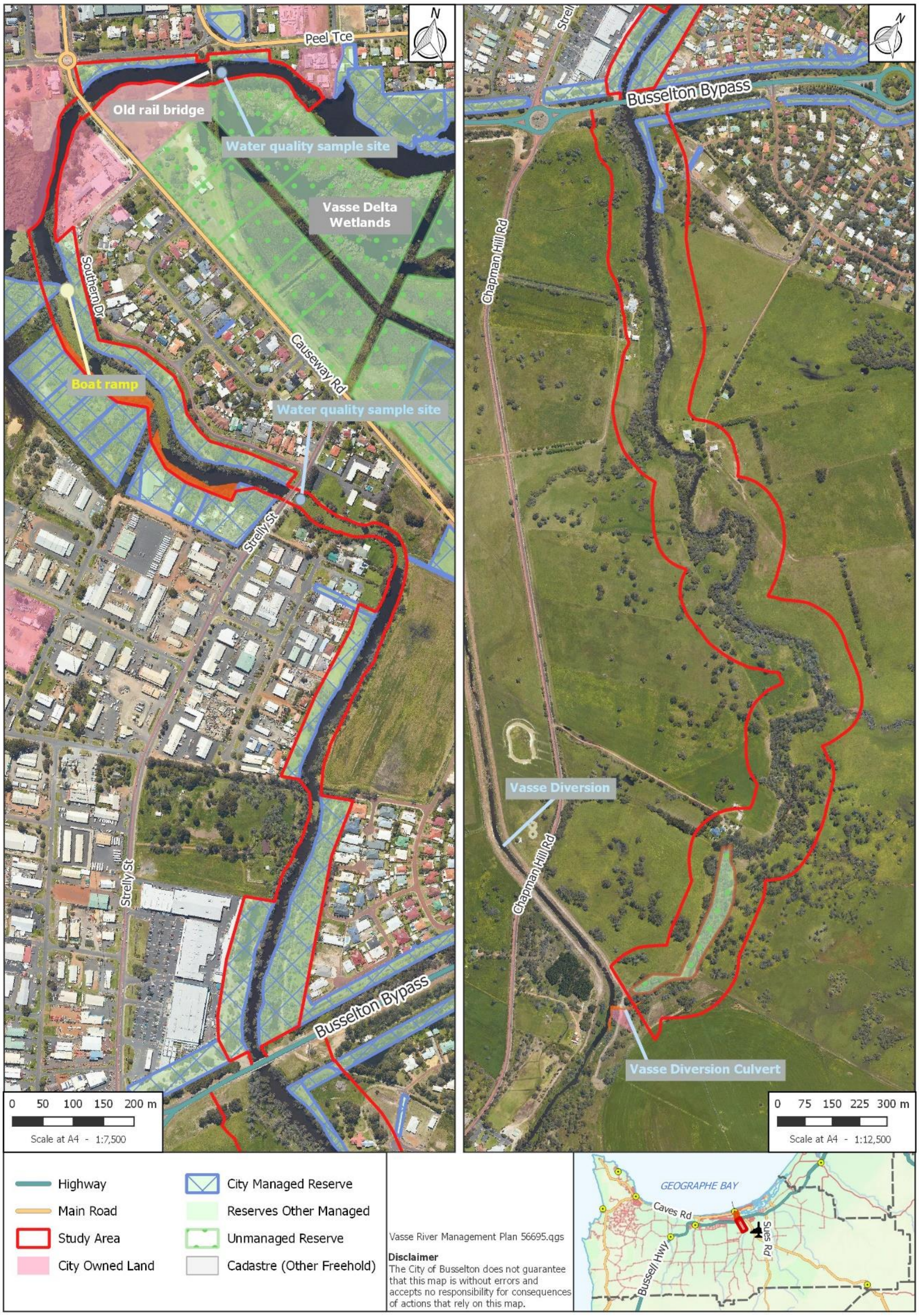



Figure 2. Study area for the Lower Vasse River Waterway Management Plan, showing tenure and landmarks.

## 1.3 History of management

Poor water quality in the Lower Vasse River has been a focus of management activities for at least two decades. The Lower Vasse River Cleanup Program (LVRCP) commenced in 1999, which implemented a range on-ground works and trials to improve the ecological health of the system (Paice 2005). Key components of the LVRCP were:

- sediment treatment and removal;
- restoring river ecology;
- rural catchment management; and
- urban catchment management.

These approaches had some success and have provided useful information for future work. The revegetation undertaken through this project has doubtless enhanced the ecological values of the river. However water quality remains extremely poor with severe algal blooms recurring each year during the warmer months. A review of the LVRCP recommended priority areas for action as:

- continued partnerships to assess appropriate sediment remediation options;
- maintenance of revegetated areas in terms of weed control;
- continued revegetation with emergent and submerged plants;
- formalise agreed management of water flows through the river to maximise flushing;
- management of the feral goldfish population;
- identifying and addressing point source problems in particular septic tank leachate; and
- ongoing monitoring and evaluation to measure progress towards long term objectives (Paice 2005).

Since the Lower Vasse River Cleanup program, managers have continued to implement nutrient reduction actions in the rural and urban catchments, including river restoration, implementation of best management practices and installation of stormwater treatments. There have also there have been small scale studies to assess potential for improving water quality using other measures such as enzyme treatments, floating islands and establishing aquatic plants.

The independent review of the waterways management (Hart 2014) highlighted the lack of an obvious lead agency. It made the distinction between long-term reduction of nutrients from the overall catchment, and short-term management of the impounded reach Lower Vasse River. It highlighted the need for an operational management plan for this section of the river that would address the dual objectives of achieving good water quality while also preventing flooding in Busselton.

## 1.4 Process for developing the Waterway Management Plan

The WMP has been developed using a collaborative approach that has allowed for extensive consultation to work towards future management of the Lower Vasse River that aligns with community priorities, is well-understood and accepted, and has significant commitment to implementation by stakeholders. Key stakeholders that contributed to this WMP are:

- City
- Community members
- Aboriginal People
- GeoCatch
- Department of Water and Environmental Regulation
- Department of Biodiversity, Conservation and Attractions
- Water Corporation

The process for developing the WMP is shown in Figure 3. The consultation process has contributed directly to the management issues, vision, management objectives, management strategies and actions for the WMP. Activities undertaken for consultation are outlined in the following sections. The consultation process and the overall WMP have been informed by review of existing information about the Lower Vasse River and new information gained through projects undertaken during the planning process. It is important to note the adaptive nature of this WMP. It has been prepared at a point in time, using the information currently available. Implementation will require an ongoing process of monitoring and evaluation to determine future actions.

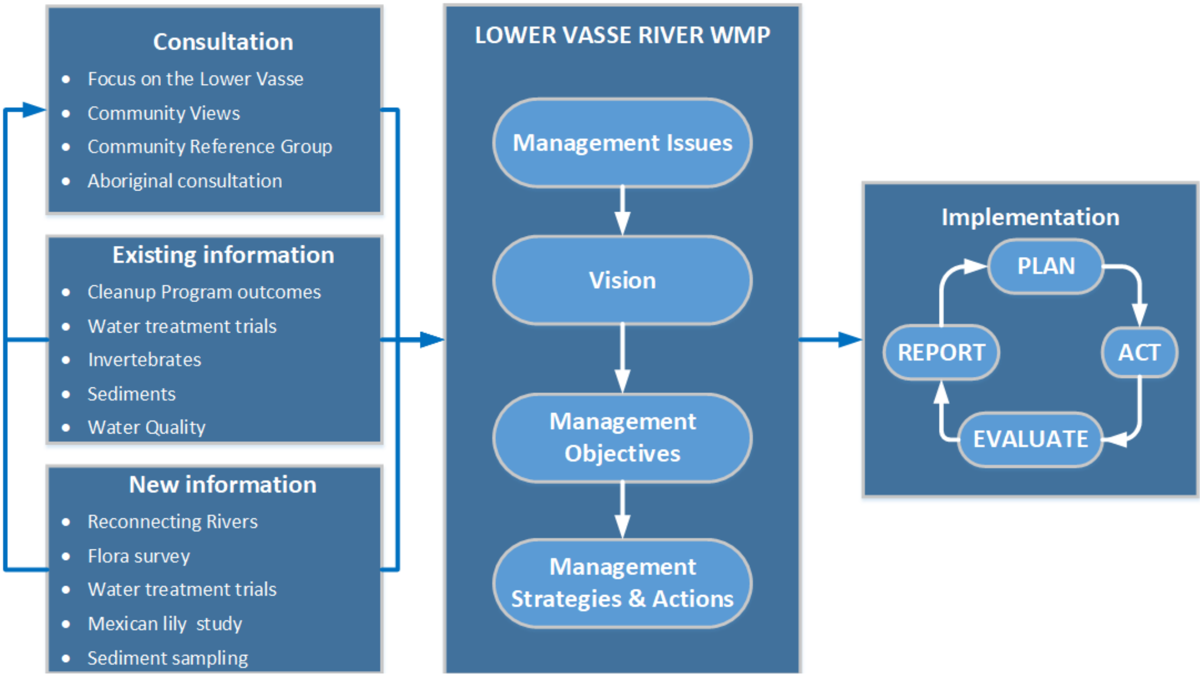



Figure 3. Process for developing the Lower Vasse River Waterway Management Plan

### 1.4.1 Community consultation

Consultation with stakeholders was an integral part of preparing this WMP. The aims of consultation were:

- To understand community issues and concerns on the Lower Vasse River;
- Gain input, ideas, feedback into future management of the Lower Vasse River;
- To get support from the community on proposed actions; and
- To raise community awareness and understanding of local water quality issues.

Early consultation events were widely advertised to attract a broad representation from the community. The first of these, *Focus on the Lower Vasse* in June 2015, provided current information and sought to identify issues of most importance to the community. The *Community Views* event in March 2016 was also open to whole community and facilitated rating of management issues valued characteristics and desired change (Figure 4; AHA 2016). These results reflected a high level of importance on issues related to the health of the Lower Vasse River and associated amenity (82%). Other issues rated as important were recreation and access, heritage, flood and management. The outcomes of this consultation were used to formally identify key management issues, as outlined in Section 2 of the WMP. Information provided by the community regarding their understanding of the system and suggested management actions were used to develop draft management objectives, and were considered when reviewing management options.

Following initial consultation, the Lower Vasse River Community Reference Group (CRG) was formed to provide ongoing input to WMP. This group was formed by inviting participants of earlier events to nominate for ongoing involvement. It also included representation from the Department of Water and Environmental Regulation and GeoCatch, as key supporting partners in development of the WMP. Facilitated workshops with this group were held to develop the vision, management objectives (AHA 2017a, 2017b) and management strategies and actions (AHA 2018) for the WMP.

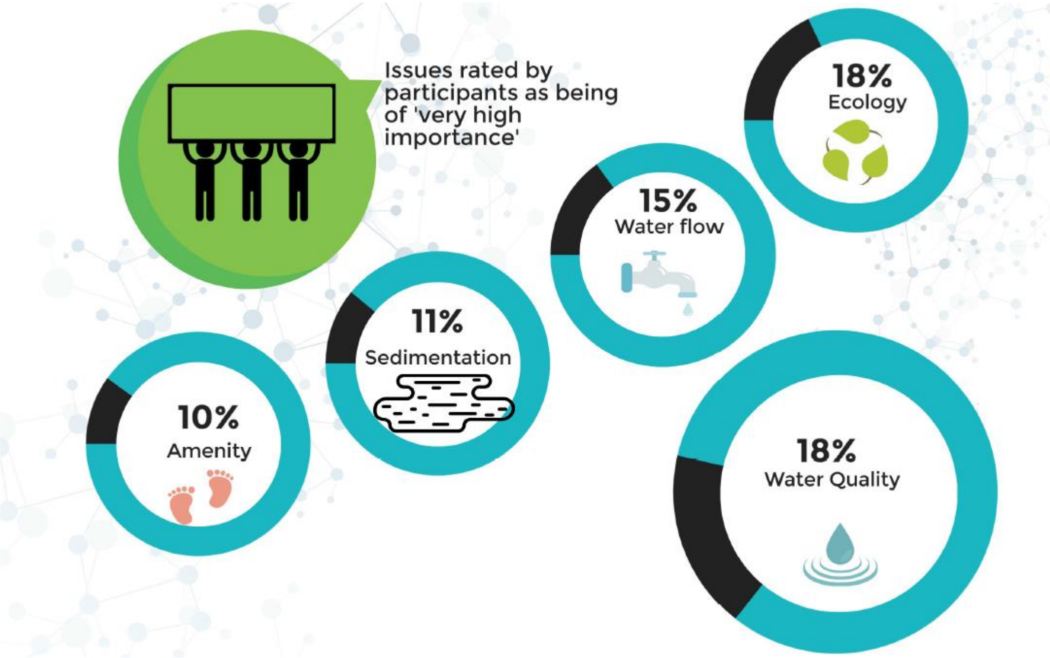



Figure 4. Outcomes of identifying and rating management issues for the Lower Vasse River from the *Community Views* consultation session, March 2016.

### 1.4.2 Aboriginal consultation

In recognition of Aboriginal (Wadandi) people as the traditional custodians of country, and understanding the significance of waterways to Aboriginal people, additional consultation was undertaken with the South West Boojarah (SWB) and Harris Family native title claim groups to allow their input to the WMP.

The study area is within the South West Boojarah Indigenous Land Use Agreement area which is one of six Agreement areas that form part of the South West Native Title Settlement Area[1].

Presentations were given to the South West Boojarah (SWB) Working Party and subsequent during an Aboriginal heritage survey. An overview of the RGW program and the draft management objectives were presented to the SWB Working Party.

An aboriginal heritage survey was undertaken with representatives of the SWB and the Harris family native title groups in February 2018, encompassing the study areas of the Lower Vasse River and Toby Inlet water management plans and the Vasse Wonnerup Operation Plan. The survey was facilitated by Brad Goode and Associates (BGA) and included briefings and a bus tour of key sites for discussion of scientific investigations, future management actions and the content of the plans (BGA 2018). On-site discussions were held on key potential management actions including sediment removal, water treatment, reshaping and revegetation, Mexican waterlily control.

The representatives highlighted the importance of connectivity of waterways in the landscape from both spiritual and ecological perspectives. They highlighted the importance of managing the headwaters of the river to address the real cause of poor health in the lower reach, relating problems in the Lower Vasse to disruption of connectivity with its catchment. They also acknowledged that it is not practical to return the river's hydrology to its natural state. The group supported specific works to address sediment and water quality problems, including sediment removal and waterlily control. Information from this consultation has been considered in the development of management strategies and actions in this WMP.

[1] Current information on the South West Native Title Settlement: http://www.noongar.org.au

# 2 Management Issues

Through the consultation process, management issues were grouped into the following eight key focus area for management:

1. Water quality
2. Ecology
3. Water flow
4. Sedimentation
5. Amenity
6. Recreation and Education
7. Heritage
8. Governance

The most important issues for management the Lower Vasse River as rated through community consultation are water quality, ecology, water flow, and sedimentation. These are key river health issues, which are interconnected and fundamental to ongoing management of the river.

Management strategies which provide outcomes for river health will contribute directly to social issues by improving amenity and increasing opportunities for recreation and education. In turn, facilities to provide for these activities will allow for promotion of cultural heritage values. Governance relates to policy and management responsibilities, which will underlie the implementation of strategies to improve river health.

A summary of key management issues and available information for these focus areas is provided in this section.

## 2.1 Water quality

### 2.1.1 Nutrients and algal blooms

The Lower Vasse River is a eutrophic waterway, with very high nutrient concentrations resulting in extremely high densities of phytoplankton (microscopic algae), commonly referred to as algal blooms. These algal blooms persist for up to seven months each year, generally between December and May, resulting in discoloured water, unsightly scums and unpleasant odours. The blooms are dominated by blue-green algae (cyanobacteria), which are potentially toxic to animals and humans (Figure 5). Not surprisingly, water quality is the most significant management issue for the Lower Vasse River.

It is interesting to note that "thick algae" was observed in the river in 1940 (Mouritz, Elphick and Anderson).

Nitrogen and phosphorus are the main nutrients contributing to eutrophication. Nutrients have been regularly sampled by DWER at two sites in the Lower Vasse River (Figure 2):

i. Strelly Street Bridge from 1996 – 2010, and since January 2017 (excluding winter since 2000);
ii. Old rail bridge from 1996 – 2010.

Total nitrogen (TN) concentrations have often exceeded ecosystem protection guidelines in the past (Figure 6a). However, sampling in recent years has lower TN concentrations, particularly at the Strelly Street site. Monthly data for the old rail bridge site shows high TN in winter and a gradual decrease during spring, followed by an increase to very high levels in summer (Figure 6b). Peak TN in summer corresponds to peak algal growth (Figure 6e), and is likely related to the ability of blue-green algae to fix nitrogen from the atmosphere. Very little nitrogen is present in dissolved available forms, which limits the amount available for growth or other types of algae.

Total phosphorus (TP) concentrations in the lower Vasse River are extremely high with annual and monthly means consistently exceeding ecosystem protection guidelines, often by an order of magnitude (Figure 6c, d). Phosphorus concentrations show a seasonal increase from spring to summer and then remain high (Figure 6d). Unlike nitrogen, the phosphorus concentrations are higher at the Strelly St Bridge site upstream, where algal blooms have been less severe in recent years (Figure 6e). This is unusual, as phosphorus is known to promote algal growth. Dissolved phosphorus is consistently high at the Strelly Street site, accounting for an average 48% of TP. At the old rail bridge site, dissolved phosphorus accounts for an average 17% of TP, and decreases over the duration of the season. Dissolved oxygen concentrations are much lower at the Strelly Street site than downstream and this may be linked to higher phosphorus concentrations, as phosphorus is released from sediments under low oxygen conditions.

Chlorophyll a is an indicator of phytoplankton growth, and very high concentrations throughout the river until 2010 reflect seasonal algal blooms. Chlorophyll a has been much lower at the Strelly St Bridge site since sampling recommenced in the 2016-17 season (Figure 6e). It has remained high at the old rail bridge in recent years, showing a seasonal increase in correspondence to increasing algal growth in the summer (Figure 6f). This is also reflected in monitoring of phytoplankton cell densities and species (Figure 8), which shows continuing dominance by blue-green algal blooms at the old rail bridge; but a substantial reduction at Strelly Street. There has been a shift at the Strelly St site to harmless species of green algae, with occasional 'bloom' densities. Lower phytoplankton growth at the Strelly Street site is no doubt due to the recent presence of Mexican waterlily at this site. The waterlily prevents light entering the water column, preventing algal growth. However, as discussed in Section 2.2.3, Mexican waterlily appears to reduce algal growth more broadly.

### 2.1.2 Nutrient sources

Nutrients in the Lower Vasse River come from surface runoff and groundwater infiltration; and are also released into the water column from the sediment (0). Nutrient sources include residential, commercial, industrial and rural sources in its local catchment area (downstream of the Vasse Diversion), as well as some flows from the Vasse Diversion. In addition to ongoing inputs to the river, nutrients accumulate in the sediments from the ongoing cycle of algal growth and decay, providing an internal source of nutrients (2.4).

Water quality analysis and modelling for the Water Quality Improvement Plan (WQIP) estimated that septic systems in the Busselton light industrial area (LIA) contribute 0.45 tonnes (9.4%) of phosphorus 1.3 tonnes of nitrogen 3.7% to the river annually (DoW 2010). This modelling also predicted that urban expansions in the catchment could result in a 41% increase in phosphorus load and a 23% increase in nitrogen load. Importantly, the WQIP also identified one feedlot as being the largest contributor of phosphorus in the Lower Vasse River catchment (since converted to irrigated horticulture, and likely to remain a significant phosphorus source). Dairy sheds also contribute a significant proportion of nutrients from broader agricultural areas.

Nutrient concentrations in the Vasse Diversion vary widely from acceptable to extremely high, with mean annual concentrations since 2008 of 1.6-2.4 mg/L for TN and 0.03-0.23 mg/L for TP. Nutrient inputs to the Vasse River depend on the operation of the culvert valve connection to allow water to flow through the 900mm pipe at the upper end of the river (Section 2.3). Opening of the valve connection is not formally managed and flows are not formally recorded. There may be potential to optimise management of the valve connection to reduce flows when nutrient levels are high. Community perception is that water flow from the Vasse Diversion to the Lower Vasse River should be maximised to improve water quality by flushing the river.

### 2.1.3 Downstream impacts

In addition to problems associated with nutrient enrichment within the river itself, high loads of nutrients flowing through the river influence the wetlands and the Vasse Estuary downstream. The WQIP reports that the Lower Vasse River contributes very high nutrient loads to downstream waters relative to its catchment size (DoW 2010); and recommends long-term load reductions of 67% for phosphorus and 70% for nitrogen to meet acceptable loadings for the Vasse-Wonnerup Wetlands. Management actions for the Lower Vasse River need to consider downstream impacts. For example, increasing flows from the Vasse Diversion to the Lower Vasse River would increase nutrient loads from this source to the Vasse Estuary (Section 4.8).

Figure 5. Blue green algal bloom in the Lower Vasse River.

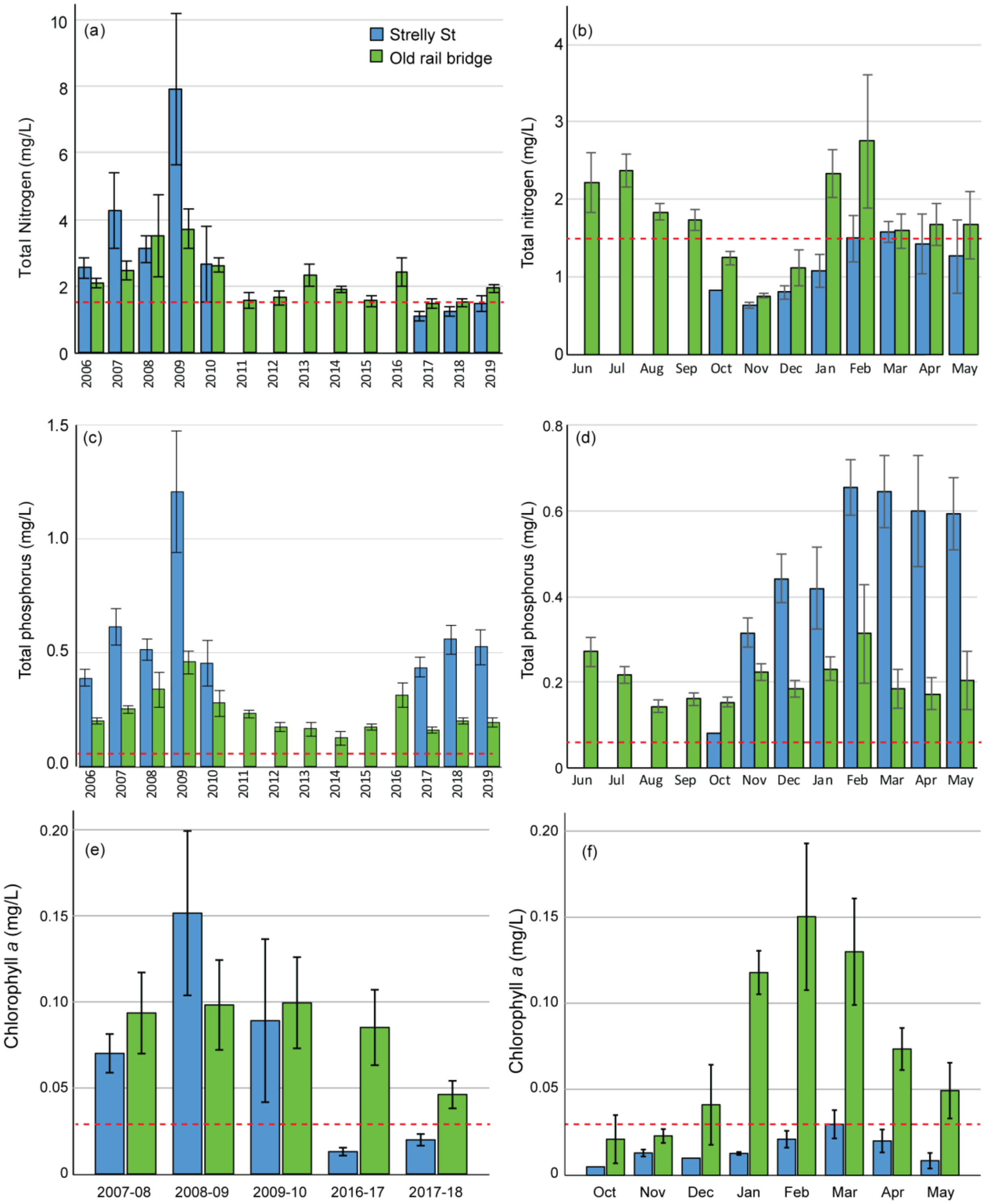



Figure 6. Mean annual and monthly concentrations of total nitrogen (a, b) and total phosphorus (c, d); and mean chlorophyll a across annual spring-summer-autumn sampling seasons (e) and for each month (f). Red dashed lines are guidelines for protection of wetland ecosystems (ANZECC and ARMCANZ 2000). Monthly nutrient data from 2011-2018; monthly chlorophyll *a* data since 2017 (DWER 2018a). Error bars are +/- standard error.

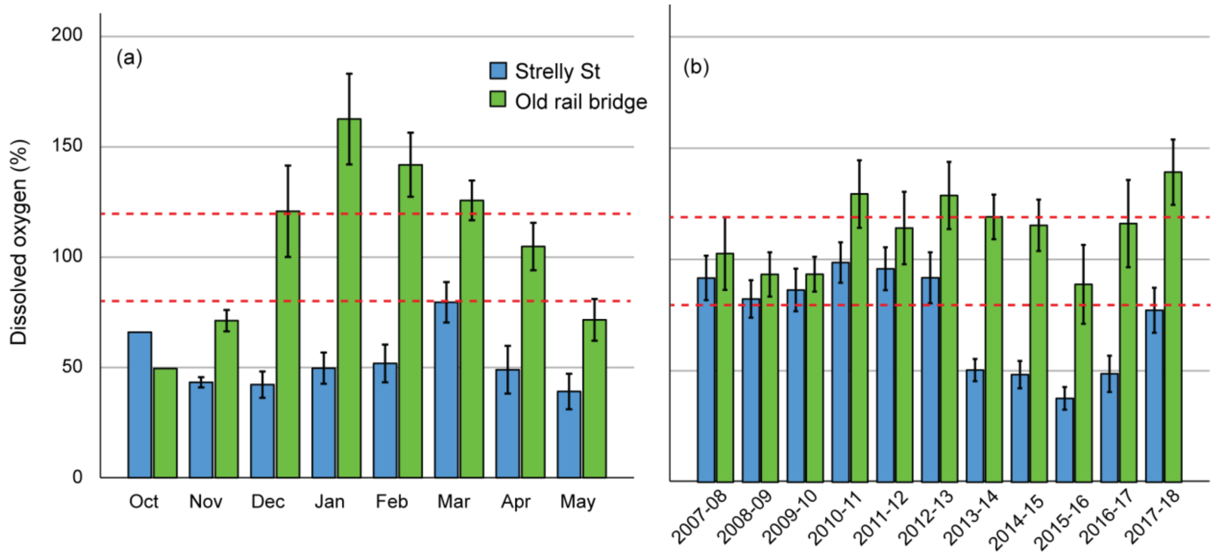



Figure 7. Dissolved oxygen concentrations in the Lower Vasse River: average monthly means for 2016-2018 centred around summer (a); and annual means since 2007-08 (spring-autumn sampling) (DWER 2018a).

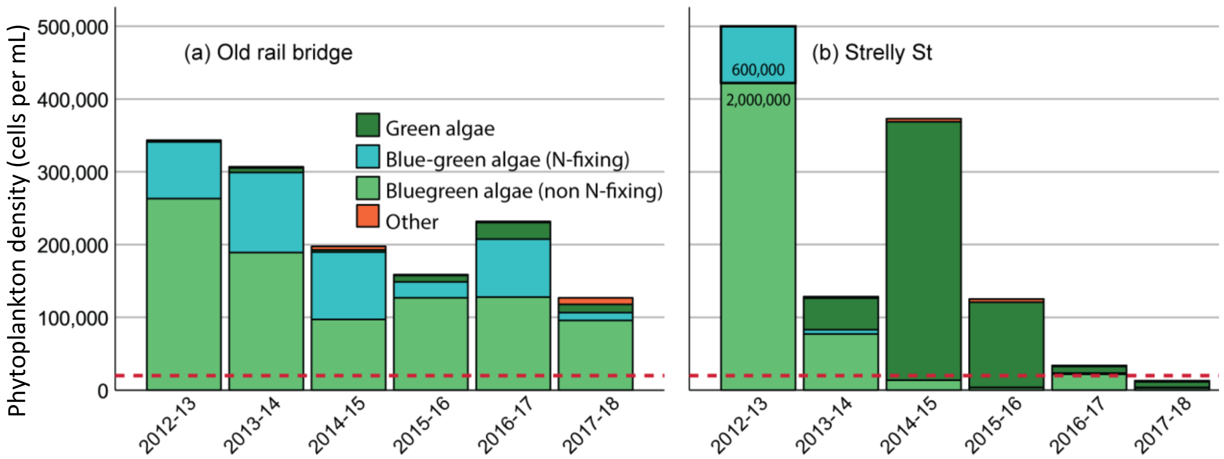



Figure 8. Mean cell densities for main phytoplankton species groups at sampling sites in the Lower Vasse River during spring-summer-autumn seasons since 2012 (DWER 2018b). Red dashed line is the guideline value of 20,000 cells per millilitre for recreational use.

## 2.2 Ecology

The Lower Vasse River has undergone substantial physical changes through widening and de-snagging, and clearing of surrounding vegetation. This includes a “clean out” by the Public Works Department around 1939 using a dragline. It has also been impacted by altered hydrology and nutrient enrichment. These changes have dramatically affected the river’s ecology. Aboriginal people have stories of fishing and hunting along the Vasse River when water quality was better. However it now has little in-stream habitat and the dominance of phytoplankton during the warmer months supports limited diversity.

Although degraded, it still provides habitat for native freshwater fish, frogs, turtles and invertebrates, and open water areas for waterbirds. The riparian vegetation contributes to aquatic habitats and also supports a range of terrestrial fauna and birds. The permanent fresh waters of the Lower Vasse River provide a unique habitat in a landscape of seasonal wetlands and estuaries.

Ecology was rated as the most important management issue by 18% of *Community Views* participants (AHA 2016). The river environment contributes to local amenity and the birdlife is particularly enjoyed. The study area has been identified as a regional ecological linkage (Molloy et al. 2009, Ecoedge 2017). A summary of the main ecological components of the Lower Vasse River study area and implications for management is provided below.

### 2.2.1 Vegetation

Native fringing (riparian) vegetation of the Lower Vasse River has been largely cleared, leaving a narrow strip of remnant trees with limited understorey and extensive weed invasion. There are opportunities to enhance vegetation in the study area through weed control and revegetation.

Vegetation along the river provides important habitat for terrestrial fauna, with overhanging trees offering many roosting and nesting sites for waterbirds. In addition to providing habitat benefits, fringing vegetation is a vital component of river health. The important functions include:

- supporting terrestrial and aquatic food webs;
- habitat for terrestrial and aquatic fauna;
- foreshore stabilisation;
- maintaining cooler temperatures
- interception of nutrients and sediments in runoff; and
- nutrient uptake and processing.

The extent and diversity has been increased downstream of the Busselton bypass by revegetation work done for the Lower Vasse River Cleanup program and in new foreshore reserves adjacent to subdivided land. A vegetation survey in the study area in 2017 found only 5.6% of vegetation in good condition, occurring mainly within these revegetated areas (Ecoedge 2017).

The current vegetation includes only 28 native species, including some species in revegetated areas that would not have occurred there naturally. The Ecoedge (2017) survey found no occurrences of threatened or priority flora, although there are nearby occurrences of the Coastal Saltmarsh threatened ecological community (TEC); and the *Eucalyptus rudis*, Marri and Peppermint forest ecological community (Priority 1).

At least 20 species of weeds are present, including 10 of environmental concern, which are mapped in the Ecoedge (2017) survey report. The most widespread problem weeds are Arum Lily, Brazilian pepper tree and Kikuyu (Ecoedge 2017). Kikuyu and other grassy weeds form an extensive component of the understory in much of the study area. Less widespread but potentially invasive weeds include Blue periwinkle, Weeping willow and Watsonia. Within the waterway, Mexican waterlily has infested large areas.

### 2.2.2 Fire Risk

Management of vegetation needs to address current and future risk of fire, particularly in areas close to buildings and infrastructure. A Bushfire Attack Level assessment can be used to determine suitable setbacks (Calibre 2018). Adequate setbacks to sensitive infrastructures, strategic gaps between vegetated areas limiting width of vegetation can be used to reduce fire risk where required. Selection of species for revegetation that have lower flammability and maintaining moisture content through irrigation can also mitigate risk (Calibre 2018).

### 2.2.3 Mexican waterlily

Mexican waterlily (*Nymphaea Mexicana*) covers large areas of the Lower Vasse River (Figure 9a,b). Although present in small patches in the river for several years, it underwent rapid expansion during the 2013-2014 spring-summer growing season and has continued to spread gradually since then. In 2017 it covered 23% and 1.15 hectares of water between the Busselton Bypass and the Butter Factory weir.

This is a serious concern for the community and management authorities owing to impacts on visual amenity, loss of open water habitat and possible flow obstruction. Overhanging fringing vegetation supports many roosting and nesting sites for birds. Growth of lilies beneath these sites prevents diving from these platforms and creates a risk for fledglings that may get trapped in the lilies beneath nests. Loss of open waters reduces space for birds to swim and dive and reduces available habitat for fish and turtles.

A study on the impacts of Mexican waterlily in the Lower Vasse River in 2017 investigated the effects of these plants on water quality and ecology (Paice 2018). In addition to the obvious problem of loss of open waters, the lilies result in very low oxygen levels in the water (Figure 10a), presenting a risk for aquatic fauna. Despite this, the structural habitat provided by the lilies supports greater abundance and diversity of aquatic invertebrates than other parts of the river. However this invertebrate population does include large numbers of non-biting midge larvae, which can contribute to nuisance insect problems.

The extensive root mass of the lilies and ongoing growth and decay contributes to a build-up of organic material, creating shallower conditions. This has allowed additional colonisation of semi aquatic plants. Currently, this has been seen the native (though prolific) Slender knotweed, *Persicaria decipiens*), but there is a risk of colonisation by wetland weeds. The reduced depth is now evident upstream of Strelly Street where waterlilies have died back from herbicide use.

Mexican waterlily has also had an effect on nutrient levels and growth of phytoplankton. Since the period of expansion in 2013-14, algal blooms have been greatly reduced in waters upstream of the point of infestation (near the boat ramp area along Southern Drive) (Figure 9c, d, Figure 10c). This is despite very high phosphorus concentrations in these areas; much higher than downstream Figure 10b). The reasons for reduced algal blooms between patches of waterlily are not fully understood. It may be a combination of greater low residence time in sunlit areas owing to lilies and riparian shading; nitrogen limitation; or chemical inhibition.

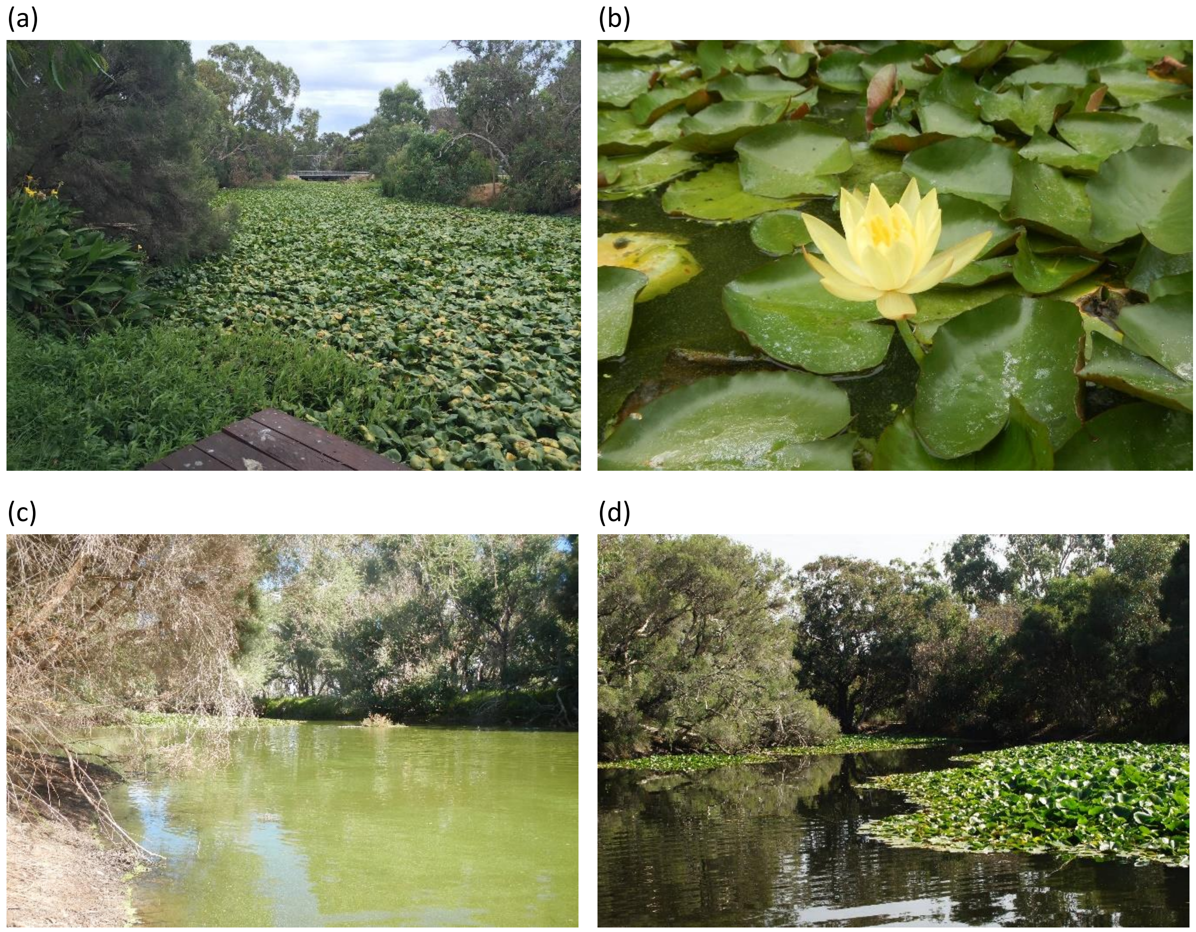



Figure 9. Mexican waterlily in the Lower Vasse River: (a) extensive growth upstream of Strelly Street in March 2017; (b) flower; (c) downstream of infestation in April 2014 showing obvious algal bloom; (d) upstream of infestation in April 2014 (same day) with no algal bloom.

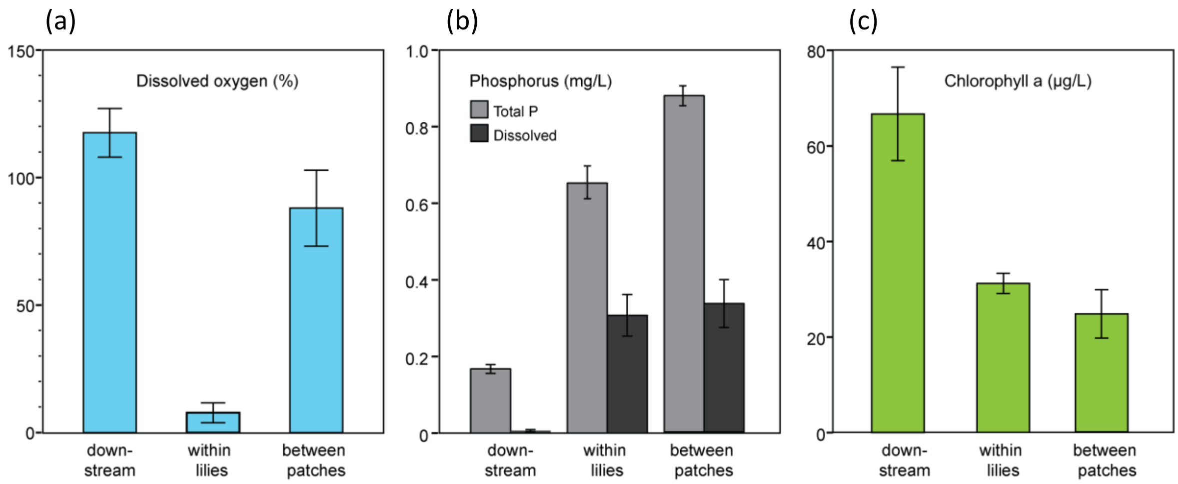



Figure 10. Comparison of water quality in relation to Mexican waterlily in the Lower Vasse River: downstream of the waterlily infestation, within dense waterlily growth, and in areas of open water between patches of waterlily (200-300m reaches) (Paice 2018).

## 2.2.4 Birds

The birdlife in and around the Lower Vasse River was rated by the community as the most liked characteristic (AHA 2016). Protecting and enhancing habitat for birds and providing opportunities for enjoyment of birdlife should be part of future management.

Table 1 provides a list of bird records available for the Lower Vasse River. There are probably more than this, however limited data is available. There is little formal published information about the birdlife of the Lower Vasse River, and there is scope to improve understanding and to share knowledge. Fostering existing community efforts in birdwatching to capture data would be a good step towards achieving this.

Remnant fringing rushes and overhanging trees provide important nesting and roosting sites. Secluded sections of the river and the southern bank adjacent to Southern Drive support some very dense nesting areas for cormorants, darters, Night heron and Yellow-billed spoonbills. In addition to the areas of remnant native rushes, grassy weeds also provide habitat for birds on the banks of the river, and this should be considered when undertaking weed control.

Threats to birds of the Lower Vasse River include predation by dogs, cats (domestic and feral) and foxes; degradation of vegetation through declining tree health, weed invasion and clearing; and loss of open water habitat by expansion of Mexican waterlily.

Table 1. Bird species recorded in the Lower Vasse River (Birdlife Australia 2018, Birdlife Western Australia 2017; Paice et al. 2016).

| Common Name | Scientific Name |
|---|---|
| Australasian grebe | *Tachybaptus novaehollandiae* |
| Australasian shoveler | *Anas rhynchotis* |
| Australian pelican | *Pelecanus conspicillatus* |
| Australian reed-warbler | *Acrocephalus australis* |
| Australian spotted crake | *Porzana fluminea* |
| Australian white ibis | *Threskiornis molucca* |
| Australian wood duck | *Chenonetta jubata* |
| Black swan | *Cygnus atratus* |
| Black-fronted dotterel | *Elseyornis melanops* |
| Black-winged stilt | *Himantopus himantopus* |
| Blue-billed duck | *Oxyura australis* |
| Buff-banded rail | *Gallirallus philippensis* |
| Darter | *Anhinga melanogaster* |
| Dusky moorhen | *Gallinula tenebrosa* |
| Eastern great egret | *Ardea alba modesta* |
| Eurasian coot | *Fulica atra* |
| Great egret | *Egretta garzetta* |
| Grey teal | *Anas gracilis* |
| Hoary-headed grebe | *Poliocephalus poliocephalus* |
| Little black cormorant | *Phalacrocorax sulcirostris* |
| Little grassbird | *Megalurus gramineus* |
| Little pied cormorant | *Phalacrocorax melanoleucos* |
| Musk duck | *Biziura lobata* |
| Nankeen night heron | *Nycticorax caledonicus* |
| Pacific black duck | *Anas superciliosa* |
| Purple swamphen | *Porphyrio porphyrio* |
| Spotless crake | *Porzana tabuensis* |
| White-faced heron | *Egretta novaehollandiae* |
| Yellow-billed spoonbill | *Platalea flavipes* |

## 2.2.5 Aquatic fauna

The key management issue for aquatic fauna is degraded habitat, in terms of limited structural habitat and poor water quality. Although a range of aquatic fauna occur in the Lower Vasse River, the degraded conditions no doubt limit the populations it can support. While management should therefore focus on enhancing habitat and reducing threats, such actions may have short term impacts on existing individuals. Nevertheless the Lower Vasse River has been found to have high ecological value worthy of protection, including a fish and crayfish community dominated by native species and with evidence of successful recruitment (DWER 2019).

### Fish

Eight native fish species have been recorded in the Lower Vasse River during a fish survey in 2003-2004 and during subsequent goldfish control work: four freshwater species and four estuarine species (Table 2). These species have been heavily impacted by alteration and loss of habitat in the south west region, requiring structural habitat and refuge in permanent freshwaters. These species are generally only found in low numbers in the Lower Vasse River; although higher numbers of the Western pygmy perch and the occurrence of the Mud minnow (listed as vulnerable under Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice 2017) at a site just downstream of the Vasse Diversion outflow suggest better habitat there (Morgan and Beatty 2004). The estuarine Western hardyhead was most abundant downstream of the Butter Factory weir and the survey reported that this structure may impede migration of native fish (Beatty *et al*. 2011).

Two introduced fish species are widespread in the Lower Vasse River: mosquitofish and goldfish. Mosquitofish are small and commonly seen in very large numbers in the river. Significant numbers of large goldfish occur in the Lower Vasse River. They have been noted as being common in the river near town in 1956; and trout were released in the river in 1957 (Mouritz, Elphick and Anderson), but have not been reported since then.

The presence of goldfish is an important issue owing to their contribution to poor water quality and algal blooms. Their benthic foraging disturbs nutrient-rich sediments and there is evidence that growth of blue-green algae is stimulated following ingestion and passage through goldfish (Kolmakov and Gladyshev 2003). A program of annual removal from 2003 to 2013 removed 842 goldfish, some exceeding 40cm in length, from the Vasse River (Beatty et al 2014).

### Other aquatic fauna

Southwestern snake-neck turtles (*Chelodina oblonga*, Oblong turtles, Western long-necked turtle) are regularly observed in the Lower Vasse River, although they have not been specifically studied. There is no published information about frogs in the study area. Decapods recorded in the study area are the endemic Gilgie (*Cherax quinquecarinatus*) and the introduced Yabbie (*Cherax destructor*) (Beatty *et al*. 2011).

Carter's freshwater mussel (*Westralunio carterii*) is common in the Lower Vasse River, showing a preference for structured benthic habitats such as bridges (Beatty et al. 2017). It is listed as vulnerable fauna (Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice 2017; IUCN Red List).

Aquatic invertebrates are commonly used as indicators of ecological health. The open waters of the river contain little structural habitat and supports very low diversity of invertebrates, dominated by zooplankton (mostly copepods) and highly mobile predators (of zooplankton) such as backswimmers (Notonectidae) and water boatmen (Corixidae) (Paice et al. 2016). The presence of aquatic plants and waterlilies greatly increases diversity and abundance of aquatic invertebrates in the river, owing to increased structural habitat and alternative food sources. In the case of waterlilies, this included mainly robust species tolerant of poor water quality and low oxygen conditions (Paice et al. 2016). However, growth of submerged plants (as transplants) has been shown to support significantly higher abundance and diversity across a range of functional groups (Paice 2018).

### 2.2.6 Other fauna

A range of other fauna are known to occur in remnant vegetation in the study area, but have not been formally surveyed. Importantly this includes the Western ringtail possum (Ngwayir, *Pseudocheirus occidentalis*), which is listed as critically endangered fauna (Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice 2017). Grey kangaroos are common in some parts of the study area and adjacent land and the river may provide a corridor for their movement within and increasingly developed landscape. Water rats (Rakali, *Hydromys chrysogaster*) have been anecdotally observed but are not common.

Table 2. Fish in the Lower Vasse River (Morgan and Beatty 2004, Beatty et al. 2011)

| Type / Common name | Species | Notes |
|---|---|---|
| **Native freshwater fish** | | |
| Western pygmy perch | *Edelia vittata* | Widely distributed, low numbers |
| Western minnow | *Galaxias occidentalis* | Few sites, low numbers |
| Nightfish | *Bostockia porosa* | Few sites, low numbers |
| Mud minnow | *Galaxiella munda* | Headwater site only, vulnerable |
| **Native estuarine species** | | |
| Western hardyhead | *Leptatherina wallacei* | Downstream sites |
| Swan River goby | *Pseudogobius olorum* | Widely distributed |
| Sea Mullet | | Downstream, low numbers |
| Black bream | *Acanthopagrus butcheri* | One fish |
| **Introduced fish** | | |
| Goldfish | *Carassius auratus* | Widely distributed, |
| Mosquitofish | *Gambusia holbrooki* | Widely distributed, large numbers |

## 2.3 Water flow

There have been substantial changes to the hydrology of the Lower Vasse River and its catchment. The coastal plain area of the catchment has been modified by a drainage network constructed during the 1920s to facilitate settlement, transport infrastructure and agricultural development (English 1994). This involved widening, straightening and de-snagging of water courses, and construction of artificial channels. Approximately 90% of catchment flows are diverted via the Vasse Diversion Drain, creating a distinct separation of the section known as the Lower Vasse River. Water flow to the Lower Vasse River from the Vasse Diversion is controlled by a manually operated valve on a 900mm pipe.

At the downstream end of the study area the river is impounded by a weir, established around the 1920s to maintain higher summer water levels through the town section for amenity and recreation purposes. Removable weir boards are usually installed at the end of winter and removed in autumn. In recent years, the weir boards have become degraded and gradual leaking of water during summer leads to water levels defined by land to the east near Ford Road.

The Lower Vasse River flows via a wetland area known as the Vasse River Delta into the Vasse Estuary. A surge barrier on the Vasse Estuary exit channel, first constructed in 1908, allows outflow of water but prevents inflow of tidal and storm surge waters. This provides flood protection but has reduced tidal exchange throughout the estuary and the lower reaches of the river.

The modified water flow regime of the Lower Vasse River contributes to poor water quality. The effect of flow diversion and impoundment is essentially an elongated "lake" area from late spring to late autumn. Reduced flow velocity contributes to accumulation of nutrients and organic material from the catchment, and the still conditions during summer promote algal blooms. Recurring algal blooms contribute to the build-up of nutrients in sediments, creating an internal source of nutrients.

There is a perception in the community that increasing flows from the Vasse Diversion and removal of the Butter Factory weir boards will create a flushing effect that will improve water quality and mobilise the accumulated sediments. Management of these structures has been restricted by limited understanding of the outcomes and constraints of this approach; and a lack of defined management responsibilities for operation.

(a) (b)

Figure 11. Flow management structures for the Lower Vasse River: (a) the valve controlling flow from the Vasse Diversion to the Lower Vasse River via a 900mm pipe; (b) the weir and removable boards at the Butter Factory.

## 2.4 Sediments

**Sediments**

The Lower Vasse River has, over several decades, accumulated a layer of nutrient rich organic sediments, generally about 0.5m thick but up to 1m in some parts (Apex 2012). Sediments accumulate from inputs of organic material from the catchment and from ongoing growth and decay of phytoplankton cells within algal blooms. Low oxygen levels and resuspension of sediments when disturbed releases nutrients to the water column over summer, contributing to algal blooms. Sediments are therefore are a key consideration in addressing water quality problems in the Lower Vasse.

There is a perception by the community that the soft organic sediments in the Lower Vasse River contribute to poor water quality, and general support for sediment removal. However there are many constraints to this management option relating to the pollution content of sediments and potential for acidification; and the high costs associated with removal and disposal. Sediment removal is discussed further in Section 4.11.

The presence of soft organic sediments impacts ecology in other ways. They provide a poor substratum for growth of beneficial aquatic plants, and poor habitat for benthic invertebrates other than worms and midge larvae. This limits biodiversity within the river system and contributes to the dominance of phytoplankton in primary production. Sediment accumulation has reduced the depth of the river over time, filling in deeper habitats and contributing to warm conditions that favour algal growth.

The bathymetry of the river (Figure 12) shows the gradual increase in depth moving downstream. There are two areas that are notably deeper: downstream of the Causeway Road bridge and downstream of the Butter factory weir. This suggests scouring of sediments downstream of these constrictions, which may indicate some potential for controlling sediment using flow regimes.

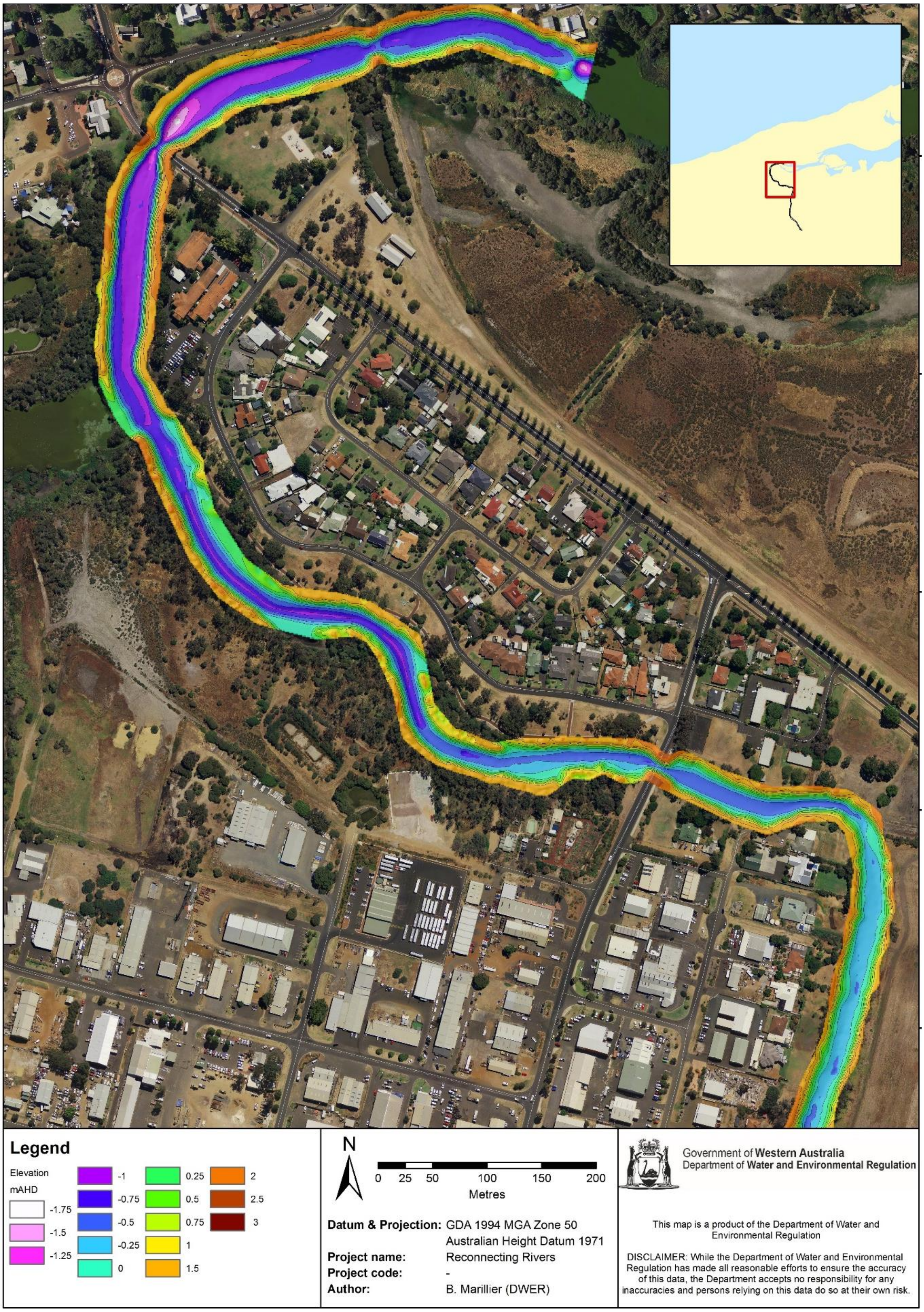



Figure 12. Lower Vasse River bathymetry from Butter Factory weir boards to Isaac Street reserve.

## 2.5 Amenity

Amenity describes the attractiveness of a place, and for the Lower Vasse River this is directly related to water quality. Algal blooms cause obvious green discoloration of the water, unsightly scums and unpleasant odours. There is concern that the poor amenity of the river during peak the tourist season creates a poor impression at the entrance to Busselton.

Despite poor water quality, natural values of the river environment, particularly the bird life, are still enjoyed by many in the community. Amenity is closely linked to the adjacent reserve and opportunities for recreation and access, which can enhance enjoyment of the Lower Vasse River.

## 2.6 Recreation and education

Poor water quality has greatly reduced the opportunities for recreational activities in the river during the warmer months. Persistent and severe algal blooms, often dominated by harmful blue-green species (cyanobacteria), cause closure of the water to public use. Access and recreation was rated highest as the focus area requiring change (AHA 2016.

Although algal blooms are seasonal, permanent warning signs are in place to advise against contact with the water. There is potential for recreational use of the water when there are no algal blooms, however signage does not indicate any safe period for contact.

In the past, the waters were used more extensively for recreation. In the 1940s the paddle wheel steamer *Jumna* carried passengers between the town and the Cattle Chosen homestead (Mouritz, Elphick and Anderson). There are anecdotes of canoeing, swimming and fishing and in the past. Whiting, Mulloway, Bream and Mullet have been anecdotally caught in the lower reach. Mullet and Black bream were caught during recent fish sampling but people no longer fish for them.

The Busselton Festival started in 1964, and crowning of the Festival Queen on the river bank opposite the City Administration building. The Festival Queen travelled on a barge from the boat ramp upstream and the community gathered on the banks to watch. At some point this ceremony ceased, though it is not clear when, probably due to poor water quality during the summer festival. In the 1970s there were paddle-boats on the river in town.

Regardless of water quality and restrictions on recreation within the river, a number of trails and public open space areas adjoin the Lower Vasse, which are still regularly used by the community. Rotary Park provides good public infrastructure near the river. Algal blooms and associated odours associated with a do impact use of these areas at times. There is significant potential for improved recreational, amenity and cultural connection with the river through enhancing and protecting natural values and improving facilities. Clearly though, addressing water quality is essential for improving recreational opportunities.

## 2.7 Culture and heritage

The river is highly valued by the local community and has historically been an iconic feature of the town and focal point for recreational and social events. There is a strong Aboriginal cultural connection to the river and many historical features. Heritage was rated as an issue of very high importance by the community.

### 2.7.1 Aboriginal heritage

The Lower Vasse River holds significant value for the local Wadandi people. There is a strong spiritual connection with all waterways in the area associated with the Waugul, and they are seen as a fundamental part of all life (Huxtable 2018). In pre European times, Aboriginal People used the Vasse River and its natural resources extensively.

With European settlement and alterations to the landscape, traditional uses of the river have been substantially impacted.

> *Before all the drains were put in the Vasse River was a system of walk trails. The old people would follow the river down to here, singing songs of the elders. We utilised the bush for medicine and food. It's a supermarket, everything we need is right here, the country provides everything we need.*
>
> (I. Webb, as cited in Huxtable 2018)

During consultation, Aboriginal representatives highlighted the importance of connectivity of waterways in the landscape from both spiritual and ecological perspectives. They highlighted the importance of managing the headwaters of the river to address the real cause of poor health in the lower reach, relating problems in the Lower Vasse to disruption of connectivity with its catchment. Representatives also acknowledged the need for intervention to improve the health of the river.

In a formal management sense, the study area is within the South West Boojarah Indigenous Land Use Agreement area within the South West Native Title Settlement Area[2]. An area encompassing the New River wetland area, including part of the study area, is a registered site under the *Aboriginal Heritage Act 1972.* In addition, there may be sites of cultural significance which are not reported or registered for cultural and political reasons. This will necessitate further consultation as specific management actions are developed.

### 2.7.2 European history

The presence of the Vasse River influenced the decision for settlement, and the development of Busselton and many aspects of social life have long been centred around it (Mouritz, Elphick and Anderson). Prior to settlement the Vasse River was one waterway from its headwaters to Wonnerup, but has been dramatically altered. History shows a connection to the river for many people. Some important historical features and activities associated with the Lower Vasse River are listed below (from Mouritz, Elphick and Anderson).

- Early settlers moved north from the Blackwood River and via the Vasse River towards Busselton.
- The old rail bridge was constructed in 1890, with rail connections to Bunbury, Nannup and Karridale, servicing the timber industry.

[2] Current information on the South West Native Title Settlement: http://www.noongar.org.au

- During the 1830s, the river was used to move goods from the jetty site, via what is now Queen Street, to Cattle Chosen to build the homestead. The small paddle replica paddle steamer *Jumna* transported people from St Mary's Church to Cattle Chosen; this included voyages for many prominent visitors to Busselton.
- The Busselton Festival commenced in 1964, with the crowning ceremony on the banks of the Vasse River a special event.
- The Butter Factory was transferred from Strelly Street to its current site in the banks of the river in 1918, and ceased production in 1975.
- The footbridge near Peel Terrace was built by the local council in 1972.

## 2.8 Governance

There are two key issues for the Lower Vasse River with regards to governance:

- defining roles and responsibilities for future management; and
- minimising impacts from planning for future developments and land use change.

Management of diffuse and point sources of nutrients from agricultural and urban catchments of the Lower Vasse River is a shared responsibility across GeoCatch, DWER, DPIRD, the City and industry groups. The independent review of water asset management (Hart 2014) recognised this joint responsibility. The Water Quality Improvement Plan (WQIP) provides load reduction targets, management recommendations and identifies key organisations responsible for implementation.

The independent review identified a clear need for a designated manager of the Lower Vasse River 'lake' section. There has been a lack of leadership and funding since the Lower Vasse River Cleanup Program, and thus little progress with management since this program was completed. This issue was also evident during community consultation (AHA 2016). One of guiding principles of the Vasse Geographe Strategy is the appointment of designated lead managers for key water assets. The independent Review (Hart 2014) recommended the City becomes the lead management agency, with continuing assistance from DWER.

The Lower Vase River catchment area will undergo considerable expansion of urban and industrial areas in the future, as identified in the current Draft Local Planning Strategy (CoB 2016). This could result in significant increases in nutrient loads to the Lower Vasse River, and downstream environments (Section 2.1). The City will have an important role in minimising nutrient exports from future developments and land use change; and effectively managing foreshore reserve areas with regard to the vision for the Lower Vasse River. Development is also expected to result in considerable new areas of foreshore reserve being managed by the City (i.e. areas identified as Parks and Recreation in Figure 13).


Figure 13. Draft Local Planning Strategy (2016) land use within the Lower Vasse River study area.

# 3 Management Objectives

This section presents sixteen management objectives across the eight the focus areas. These were developing in partnership with community members and provide good guidance on the expectations of future management of the Lower Vasse River.

## 3.1 Water quality

1. Reduce nutrients flowing into the Lower Vasse River from all existing sources to improve water quality and reduce the frequency and severity of toxic algal blooms.

2. Minimise any additional nutrients flowing into the Lower Vasse River from new developments and agricultural intensification.

3. Utilise science and innovative technologies to improve water quality in the Lower Vasse River.

## 3.2 Ecology

4. Protect and enhance native aquatic and terrestrial habitats in the Lower Vasse River and the foreshore reserve.

5. Reduce the impact of threatening processes on the natural values of the Lower Vasse River and the foreshore reserve.

6. Balance mitigation of fire risks with the protection of natural values of the Lower Vasse River foreshore reserve.

## 3.3 Water flow

7. Optimise water flow in the Lower Vasse River to balance improvement of water quality, protection of natural values and public amenity, while maintaining flood protection.

## 3.4 Sediments

8. Strategically manage accumulated sediments to protect the natural and social values of the Lower Vasse River.

## 3.5 Amenity

9. Improve visual amenity, public health and odours for residents and visitors to enjoy the Lower Vasse River.

10. Facilitate recreational and educational opportunities, which are compatible with protection of the key values of the Lower Vasse River and enhance community stewardship.

## 3.6 Recreation and education

11. Enhance public access to the Lower Vasse River and within the foreshore reserve, with a focus on creating linkages to the town centre and surrounding areas while protecting the river's natural values.

## 3.7 Culture and heritage

12. Promote understanding of the Aboriginal and European history and culture of the Lower Vasse River.

## 3.8 Governance

13. Develop and maintain partnerships and a collaborative approach between key stakeholders and the community when managing the Lower Vasse River.

14. Maximise opportunities for protection of the Lower Vasse River as part of future development proposals and changes in land uses.

15. Manage the Lower Vasse River with consideration to other water assets, including the Vasse-Wonnerup Wetlands and Geographe Bay.

16. Improve knowledge and understanding of key values and management issues of the Lower Vasse River to support adaptive management.

# 4 Review of Management Options

Development of management strategies for the Lower Vasse River has involved consideration of a range of potential initiatives. Some are fundamental approaches such as catchment nutrient reduction and riparian vegetation management. Intervention options have also been considered to directly manage water quality problems. These options are important due to the long-term nature of achieving nutrient load reductions, and the potential for ongoing release of nutrients from accumulated sediments.

The independent review identified the need for solutions that directly reduce nutrient availability for algal growth, alter physical conditions to make it more difficult for algae to grow, or dredging the sediments (Hart 2014). In addition, the *Community Views* session also provided suggestions for future management options (Figure 14). These reflect long-held community opinions and are aligned well with the options considered for inclusion in the management strategies and actions in this WMP.

This section outlines existing information, challenges and likely outcomes from potential management options. This review was an integral step in the development of strategies and actions for the WMP, outlined in Section 5.

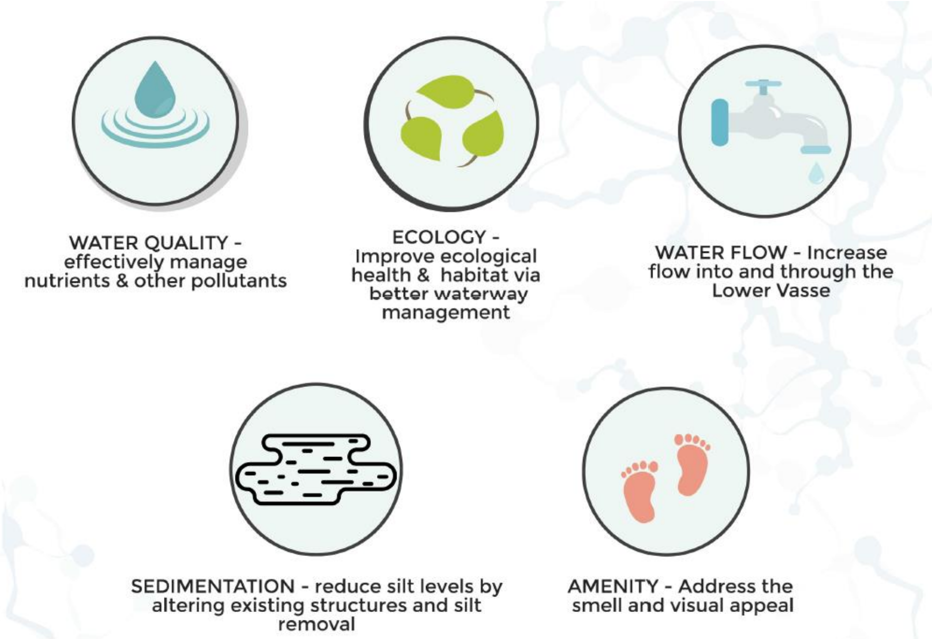



Figure 14. Suggestions for the future management of the Lower Vasse River from the *Community Views* session (AHA 2016).

## 4.1 Living Streams

The term *living streams* describes an approach to managing urban stormwater that creates a complex ecosystem with outcomes for ecology, water quality, water conveyance and amenity. Although traditionally applied to urban stormwater drains, this approach of restructuring the ecosystem is also relevant to restoration of the Lower Vasse River. In this case it would involve altering the morphology to restore ecological processes and create physical conditions that provide greater resilience to high nutrient conditions.

A living streams approach would see creation of diverse habitats including seasonally dry areas, river pools, channels, floodplain areas, riffle zones and islands (floating and grounded). Creation of these habitats would have clear outcomes for ecology, and the potential to provide significant water quality benefits. Compartmentalising the river by creating seasonally dry areas during summer also provides opportunities to stage works and target intervention actions. Figure 15 provides an example of changes to river form with a living streams approach.

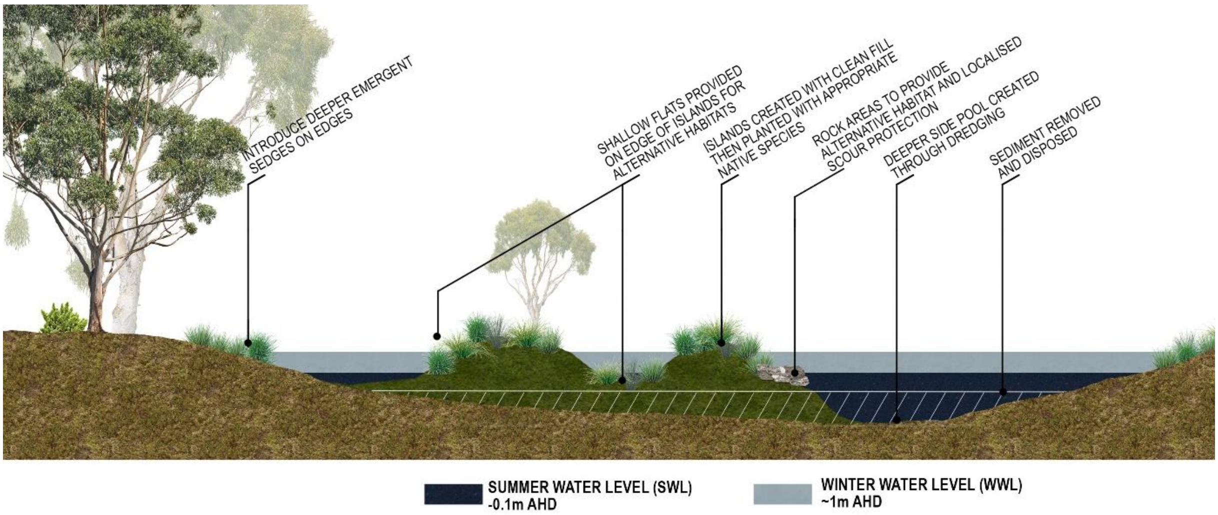



Figure 15. An example of altered river morphology with a living streams approach. More diverse habitats would be created including channels, pools, islands and seasonally dry areas.

### 4.1.1 Ecological outcomes

As outlined in Section 0, the Lower Vasse River supports many terrestrial and aquatic fauna despite its degraded status. The living stream approach would create new riparian habitat to support birds and possible other terrestrial fauna. Within the river, the increased surface area and diversity of aquatic habitats and food sources is likely to have a profound effect on aquatic invertebrate communities. This has been shown in the river in regard to aquatic plants (Paice et al. 2016, Paice 2018). Physical substrates (e.g. rocks, sand, and logs) and varied flow conditions will also support greater diversity. The plant and invertebrate communities in turn provide food resources for fish and birds.

### 4.1.2 Water quality outcomes

Potential water quality benefits of ecosystem restructuring through a living streams approach are summarised below. While these mechanisms may not achieve significant water quality improvements individually, combined they have potential to create a more complex ecosystem that is less prone to seasonal dominance by phytoplankton. Enhanced nutrient processing capacity may also benefit downstream wetlands.

a) Aquatic plants: Modifying the depth profile and enhancing substrate can provide more favourable sediment and depth conditions for anchorage and growth of beneficial aquatic plants (macrophytes). These plants may re-establish naturally or can be transplanted. A macrophyte restoration trial in the river in 2012 did not result in water quality improvement (Paice et al. 2016), however the mechanisms by which these plants contribute to water quality are well known throughout the world (Van Donk and Van de Bund 2002; Davis et al. 2010). Interestingly the Mexican waterlily has shown water quality benefits, although it is not clear how. Aquatic plants contribute to improved water quality through:
   - competing with algae for nutrients, both directly and by supporting biofilm;
   - stabilising and oxygenating the sediments;
   - supporting organisms that graze on algae; and
   - chemical inhibition (allelopathy).

b) Freshwater mussels: Carter's Freshwater Mussel (*Westralunio carteri*) is a listed threatened species known to occur in the river. Modifying substrate or providing additional substrate could increase mussel populations. They are thought to play an important role in maintaining water quality in refuge pools through filtration (Caraco et al. 2006). Mussels in the Lower Vasse River have a habitat preference for bridge sites and river edges, which are more shaded and stable.

c) Benthic algae: Increasing surface area by creating a more complex river form with greater rock and wood surfaces would allow benthic algal populations to establish. These communities are alternative primary producers to phytoplankton, competing for nutrients and providing an important food source for aquatic fauna, so that nutrients are incorporated into the food web. Emergent wood and rock materials also provide habitat for birds.

d) Emergent plants: Reshaping river banks could provide ledges for establishment of more emergent plants through revegetation. These plants use up nutrients, shade the water, trap sediments and provide excellent habitat and food for waterbirds. They are more beneficial than rushes on the upper banks because of stronger interaction with river sediment and water column. Some emergent plant beds have been created in previous restoration efforts, but they are confined to very thin riparian strips.

e) Floating islands: There have been a number of vegetated floating islands trialled in the Lower Vasse River. These islands provide habitat, both above and below the water and may contribute to nutrient uptake and processing through growth of plants and associated biofilm. Some products include a nutrient holding media in the island structure, although effectiveness is uncertain. These structures also provide an immediate shading benefit, restricting algal growth. This shading function may also be useful in restricting the spread of waterlilies (4.5).

f) Changing morphology: Physical modifications that increase surface area and creates seasonal separate wetland compartments may have several advantages, including:

- greater resilience to higher nutrient loading due to greater surface area for beneficial processes;
- higher levels of shading, providing less favourable conditions for algal blooms;
- reduced wind fetch and thus nutrient-release and turbidity from resuspension of sediments;
- potential for water circulation within or between pools, reducing residence time for development of algal blooms; and
- opportunities for targeted interventions to address water quality such as sediment removal (Section 4.11) and water treatment (Section 4.3).

### 4.1.3 Challenges

Modification of river morphology as part of a living stream approach would involve extensive earthworks that affect hydrology (and flooding) and existing riparian and aquatic habitats. Design will need to address constraints of these issues, and several approvals will be required (Calibre 2018). In particular, Carter's Freshwater Mussels occur in the river. This is a recently listed (2018) threatened species[3] and so will require approval and management of in-river works to minimise mortality and create a net benefit for this species.

Implementation of living streams works would involve considerable cost associated with sediment removal and infill. It has been difficult to develop reliable costings for this approach, owing to variation in potential designs; and uncertainty in volumes and methodology for sediment removal and disposal, and materials used for infill. Costs and uncertainty can be addressed through staging of works, allowing development of reliable methods and better understanding of materials. Adaptive implementation in stages based on results will improve overall outcomes.

## 4.2 Reducing nutrient sources

Management of nutrient inputs from urban and agricultural catchment areas is addressed in the Water Quality Improvement Plan (WQIP, DoW 2010), which is currently being reviewed. The WQIP outlines management measures and provides recommendations, which are included in the Management Strategies for this WMP (WQ1 and WQ2).

A large proportion of the catchment with agricultural landuse (approximately 90%) is currently diverted via the Vasse Diversion. Nonetheless, flows from the broader rural catchment do impact water quality in the Lower Vasse River. Increasing flows from the Vasse Diversion to the Lower Vasse River (Section 4.8) would increase nutrient loads from this source. There are also some rural land use activities remaining in the Lower Vasse River catchment area.

GeoCatch, supported by DWER, has a strong focus on nutrient reduction in agricultural areas, supporting implementation of best management practices for fertiliser use and dairy effluent management, and soil amendments. They also promote and assist riparian management and stock control on waterways. There are opportunities to improve management of the extensive modified drainage networks, which rapidly convey nutrients and sediments within the catchment. This is the

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[3] Listed as threatened under Wildlife Conservation Act 1950 (Western Australia); listed as vulnerable under Environmental Protection and Biodiversity Conservation Act (1999) (Commonwealth); listed as vulnerable under Global IUCN Red List of Threatened Species.

focus of the *Rethink Drainage* action area for the RGW program. These management initiatives are important to the long-term reduction of nutrient contributions to the Lower Vasse River from rural sources.

Much of the Lower Vasse River catchment is urban, and these areas will continue to expand with future development, creating new sources of nutrients. In existing urban areas, the City has worked in partnership with GeoCatch to implement significant stormwater management upgrades throughout the Busselton CBD and LIA areas (Appendix 3). These include:

- biofiltration beds
- rain gardens (Figure 16)
- enhancement of natural wetlands
- constructed wetlands
- vegetated swales
- biofiltration swales
- detention basins

There may be more opportunities for stormwater upgrades in the Lower Vasse River catchment, and a process to identify and prioritise future projects would be beneficial.

Inclusion of best practice water management technologies in new developments will be essential to minimise future nutrient inputs. The City has a key role through its planning and development approvals processes to ensure this occurs. The *Better Urban Water Management Framework* (BUWMF) provides guidance ensure consideration of water resource management in the planning process (Section 4.13).

Sewerage infrastructure has a major role in protecting water quality in the Lower Vasse River, diverting nutrient- and pollutant-rich waters to the Busselton Wastewater Treatment Plant. Not all properties are connected to existing sewerage infrastructure, and there may be opportunities to increase connections within the Lower Vasse River urban catchment areas, reducing nutrient exports from these areas.

The Busselton Light Industrial Area (LIA) is currently not connected to sewerage infrastructure. Septic tanks in the LIA are estimated to contribute about 10% of the phosphorus load and 4% of the nitrogen load to the Lower Vasse River annually (DoW 2010). However, there is limited data available to base these estimates on. Development of infill sewerage infrastructure in the LIA has a high potential cost and requires clear evidence to be progressed. This would be assisted by investigation of nutrient and pollutant exports, and an audit of waste in relation to acceptable criteria.

Figure 16. Example of a rain garden for stormwater quality management, at the City Administration building.

## 4.3 Water treatment

Reducing nutrient inputs is a fundamental management approach, but significant reduction in nutrient loading from diffuse sources in the catchment is difficult to achieve and takes many years. In highly eutrophic systems, such as the Lower Vasse River, reducing nutrient inputs alone is unlikely to prevent algal blooms because of the ongoing supply of nutrients form the sediments. Intervention options to limit nutrients available to algae and to treat algal blooms may be necessary to achieve short term water quality improvement. The main limitations of these options are uncertainty in effectiveness, costs of large scale treatment, and short-term effectiveness.

### 4.3.1 Water treatment using specialised clays

"Water treatment trials" in the Lower Vasse River have focussed on specialised clays. Covering the sediments with specially-developed material can prevent nutrient release and reduce nutrients available for algal growth. These products are applied as a slurry and settle through the water column to form a layer on the surface of the sediments. Applied in this way, these products can bind to and sink nutrients and algal cells as they settle through the water column (Figure 17). There are a number of clay products used commercially and experimentally in a global context. Three have been trialled in the Lower Vasse River: Phoslock™, flocculating clays, and hydrotalcite clay.

From 2001-2004, three trials of Phoslock$^{TM}$ were completed. Application during an existing algal bloom can substantially reduce available phosphorus but had no effect on the algal bloom. Application prior to establishment of the algal bloom reduced both phosphorus levels and limited algal growth by 80%, although a less severe algal bloom still occurred (Robb et al. 2003). Application rates for Phoslock$^{TM}$ are well-understood and it is a commercially available product. It needs to be applied prior to establishment of an algal bloom, to restrict growth by reducing phosphorus availability.

Two types of flocculating clays have been trialled in the Lower Vasse River. Application of a clay mixture containing polyaluminium chloride in April 2000 had no overall positive effect on river appearance. An experimental clay product was applied to a small contained area in February 2002, which did show visible improvement in water quality, but little monitoring was done.

Hydrotalcite clay (HT clay) has been the focus of more recent trials in the Lower Vasse River. Like Phoslock, this product is applied as a slurry and designed to strip phosphorus from the water column and trap phosphorus by forming a layer on the sediment surface. A mesocosm study was undertaken during 2006-17; followed by a larger scale field experiment in 2017-18. The results of these trials indicate reductions in phosphorus concentrations and algal growth (DWER 2018c). Unfortunately observed water quality remained poor in the trial areas, with the water still having a green appearance. More work is required to determine appropriate dosage levels, and this product is not widely available.

In general terms, these products have not demonstrated prevention of algal blooms, but have shown some success in reducing algal growth. Their effectiveness is limited by ongoing external nutrient inputs, so ongoing applications are needed and they are costly. DWER currently recommend annual treatment of the lower reach of the river with Phoslock$^{TM}$, at an estimated cost of $120,000 per year.

Targeted treatment may be possible in smaller, seasonally-isolated areas following implementation of living streams works. This would make multiple applications more affordable. An ongoing interest in future development of these products should be maintained as they are improved and developed commercially.

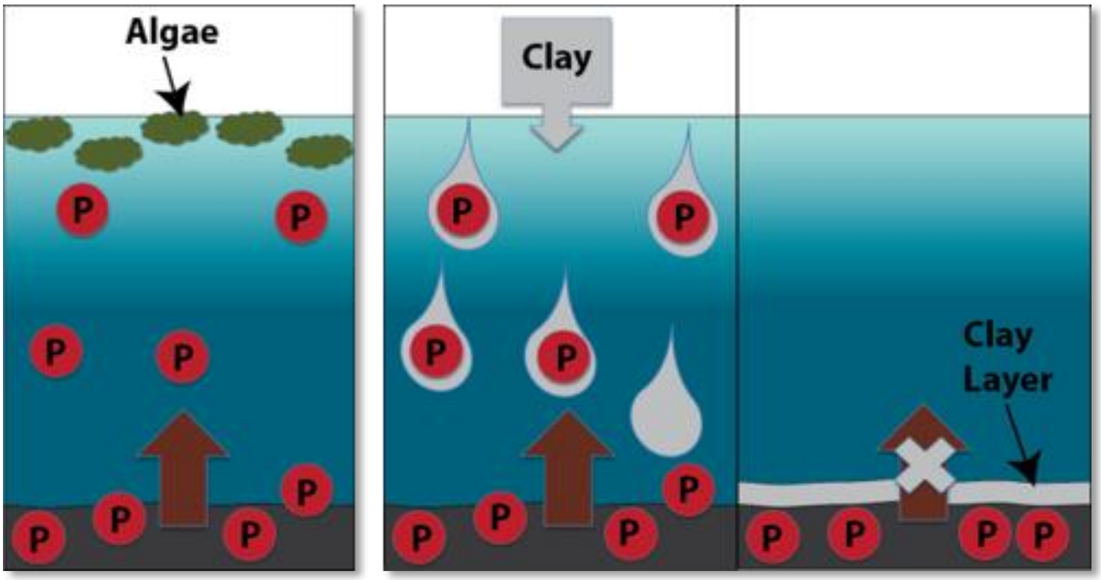


Figure 17. Phosphorus-binding clay products such as Phoslock® or the new HT-clay lock up phosphorus, making it unavailable to algae. Phosphorus is removed as the clay settles through the water and it also forms a protective layer on the sediments, reducing phosphorus release. Figure Courtesy DWER.

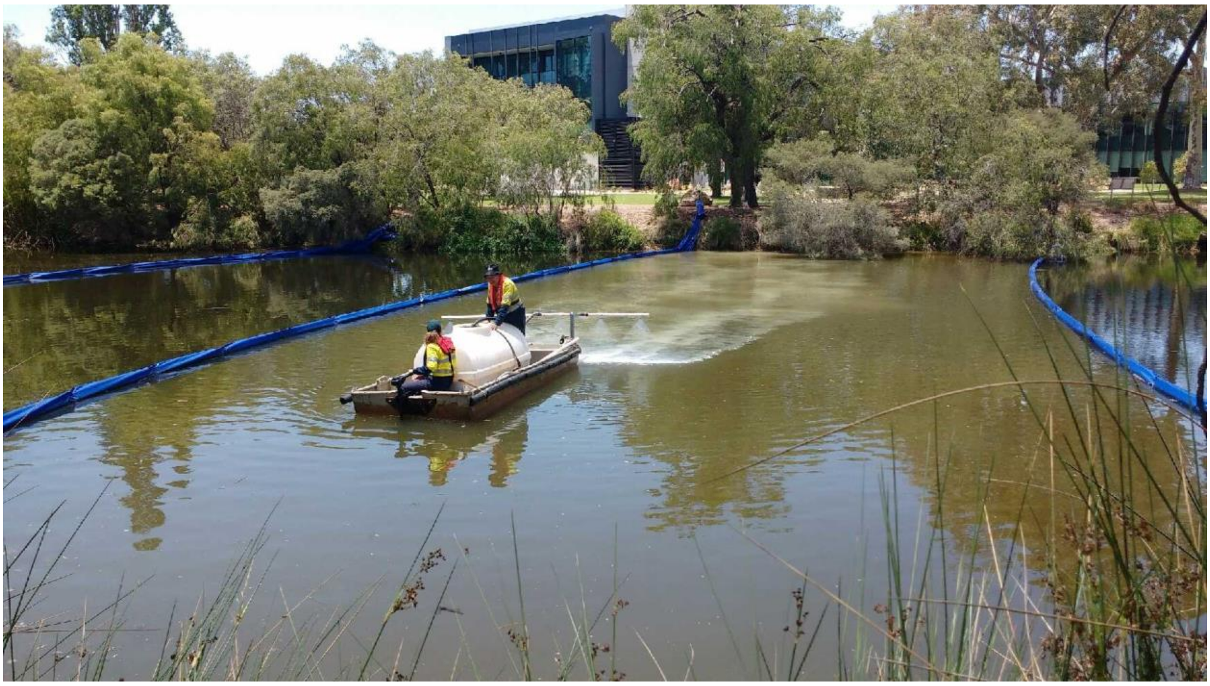

Figure 18. HT clay being applied in the Lower Vasse River during the 2017-18 trial.

### 4.3.2 Oxygenation and aeration

Oxygen is important for aquatic fauna and also influences nutrient availability. Low oxygen levels can be artificially increased by pumping oxygen gas into the water and by aeration. Both these methods will result in increased oxygen levels in the water, although oxygenation is more effective and aeration may increase nitrogen concentrations (due to nitrogen content of air). Increasing oxygen levels improves conditions for aquatic fauna and promotes aerobic biological processes, which can address odour issues.

Low oxygen conditions at the bottom of the water facilitate release of phosphorus from the sediments, which contributes to algal blooms (Boulton et al. 2014). This situation occurs when there is little mixing and the water column is stratified. In this situation, oxygenation, aeration or artificial circulation can reduce phosphorus release from sediments into the water.

The Lower Vasse River is not stratified, and has high oxygen levels throughout the water column during summer when the algal bloom is established. Algal blooms increase oxygen levels to above 100% during the day through photosynthesis. Although respiration at night consumes oxygen, it does not cause deoxygenation. The water is shallow enough to be mixed by the wind. Oxygenation and aeration of the water column would therefore not address nutrient problems in the Lower Vasse River when an algal bloom is established. The sediment is anoxic, but these methods do not oxygenate the sediments, and an attempt to do so would cause considerable resuspension of sediments.

Oxygenation was trialled in the Lower Vasse River during the summer of 1998-99 to determine the effectiveness of the process and water quality outcomes. There was no effect on the established algal bloom, although increased oxygen levels were observed and considered beneficial for aquatic fauna. Greater understanding of oxygen fluctuations prior to the onset of the algal bloom when oxygen levels would help assess potential advantages of oxygenation lower in the Lower Vasse River.

In addition to increasing oxygen levels, mixing of the water through aeration combined with sufficient circulation may influence algal growth by reducing the residence time. Phytoplankton thrive in the still conditions of the Lower Vasse River during summer. Movement of water within the system has potential to limit algal blooms by physical disturbance and reducing water temperatures (Cha et al. 2017). Artificial mixing is a common management practice in lake restoration, both to address stratification problems and to restrict growth by entraining phytoplankton in flow, and can restrict growth of scum-forming blue-green algae (Visser et al. 2016).

### 4.3.3 Water treatment using microbiological products

A number of commercial products exist that claim to improve water quality through the introduction or enhancement of micro-organisms. There are no scientific studies available on the effectiveness of these products. Current evidence is anecdotal only and while some benefits may have been observed in small-scale situations they have not been formally reported.

The City supported trials of two such products in the Lower Vasse River during the summer of 2012-2013:

- A microbiological culture pad product that provides high surface area and trace elements to increase the population of beneficial microbes (*Archaea* microbes and *Bacillus* bacteria).
- An enzyme protein product designed to promote bacterial growth and activity.

Water quality monitoring over three months did not show any significant effects of these treatments, however there were several limitations of the trials. There was no aeration, which is generally recommended in combination with these treatments. The trials did not take place under conditions of severe algal blooms expected, owing to the effect of Mexican waterlily downstream.

Enhanced nitrification and denitrification is described as the beneficial process by which these products improve water quality, and some effect on available nitrogen was found for the enzyme product. The Lower Vasse River generally has very low available nitrogen, which favours blue green algae because they can obtain nitrogen from the atmosphere through fixation. This product may influence the phytoplankton community by increasing available nitrogen. Reducing phosphorus availability is very important for limiting algal growth, and these products do not achieve this.

There are no published studies of the effective use of microbiological products to control algal blooms at the lake scale. They may be more effective in small isolated systems such as ponds and dams.

### 4.3.4 Barley Straw

Addition of barley straw is considered a preventative method for algal control that has been used extensively in farm dams and canals. Decomposing straw has been shown to inhibit algal growth in laboratory conditions (Gibson et al. 1990) and reduce filamentous algal growth in canals in years following placement (Welch et al. 1990). Barley straw bales and extracts are marketed for use in algae prevention.

In April 2000, straw bales were placed in the Lower Vasse River upstream of the Causeway Rd bridge to assess their effect on algal blooms. No effect on water quality was observed, however it is uncertain that Barely straw was used. Potential future use should consider it may be most effective at small scales; in a preventative approach; and that straw must be decomposing. It may be more effective for filamentous algae rather than phytoplankton.

### 4.3.5 Algaecides

A number of algaecides are marketed for treating algae, usually copper-based, but are generally not recommended for natural systems due to their toxicity to non-target plants and aquatic fauna. Hydrogen peroxide is marketed as an algaecide which has high specificity for blue-green algae and no residual impacts on the environment as it breaks down to hydrogen and oxygen gases. Some research supports its potential as a management tool for algal blooms (Matthijs et al. 2012, Bauza et al. 2014). It has been used to control blue-green algae in small lakes and wastewater treatment ponds, but is not widely used for larger systems for a number of reasons:

- difficulty in achieving and maintaining required concentrations throughout water body;
- potential impact of hydrogen sulphide on other organisms, mainly zooplankton;
- potential for release of toxins such as microcystins from dying algal cells;
- lack of residual effect (regrowth of algae following treatment).

Trials of hydrogen peroxide in Lake Torrens[4] in South Australia have not been formally reported. Information provided suggests effective reduction of blue-green algae at $H_2O_2$ concentrations of 2-5 mg/L, with no impacts on aquatic fauna. However these trials were conducted at low algal cell densities (below algal bloom levels), and the current recommendation is for small scale use in combination with other methods. SA Water continues to investigate this method for reservoir management.

### 4.3.6 Ultrasound

Ultrasonic control of phytoplankton is commonly used for pond environments and works by destruction of algal cells. Its effectiveness has been demonstrated in small scale studies and laboratory experiments, but upscaling this treatment to field conditions is challenging (Park et al. 2017). Frequency, intensity and exposure are important factors in effectiveness, and may have variable effects on different algal species. There has been a successful trial in a 9000m$^3$ pond in combination with pumping, but could not differentiate the effects of ultrasound and the pumps (Ahn et al. 2007).

## 4.4 Riparian vegetation management

In addition to the conservation value of the flora itself, fringing vegetation of wetland areas is a vital component of river health. Functions include:

- supporting terrestrial and aquatic food webs;
- habitat for terrestrial and aquatic fauna;
- foreshore stabilisation;
- shading and maintaining cooler temperatures
- interception of nutrients and sediments in runoff; and
- nutrient uptake and processing.

Riparian vegetation along the Lower Vasse River provides important bird habitat and forms part of a regional ecological linkage mapped along the length of the study area (Ecoedge 2017). However the vegetation is mostly degraded with low species diversity and extensive weed invasion. There has been

[4] Information from unpublished report and discussions with local NRM group Natural Resources Adelaide and Mt Lofty Ranges.

considerable riparian revegetation on the Lower Vasse River banks since 1999, and these areas provide the best condition riparian vegetation. This demonstrates successful revegetation, but these areas need more active weed control and could be enhanced with infill planting.

Extensive areas of public lands provide good opportunities for revegetation. Ecoedge (2017) suggests five key areas for rehabilitation based on size, accessibility and level of competition with existing plants (Appendix 3. Additional areas of City-managed foreshore reserve are being created through new developments, providing new opportunities for improving riparian vegetation. The littoral zone[5] could be expanded in some areas through a living streams approach, including zones of seasonal and permanent inundation, requiring a specialised suite of species. A species list for revegetation for terrestrial and aquatic areas is provided in Appendix 4.

Outside of urban areas there is still stock access to some foreshore areas, damaging fringing vegetation and directly contributing wastes to the river. The *Vasse River Action Plan* study area extends from the headwaters in the Whicher Range to Fairlawn Road (Scott 2000). It provides an assessment of foreshore condition and identifies areas requiring management of stock access, weed control, erosion control and revegetation. A review of implementation of the Action Plan and an update of the foreshores assessment and associated management recommendations for the Lower Vasse River WMP study area would assist in planning and undertaking restoration activities. This would also set a baseline for future monitoring of progress and outcomes. River action planning should also include consideration of future development and provide information to assist in planning for additional foreshore reserves.

Figure 19. Improving riparian revegetation through weed control and infill planting.

Figure 20. Floating island on the Lower Vasse River installed in 2002.

[5] The ecological zone in freshwater systems close to the shoreline where sufficient light extends to the bottom for plant growth (Boulton et al. 2014).

## 4.5 Floating Islands

Floating islands are also known as constructed floating wetlands, as they are designed to provide the ecological engineering benefits of constructed wetlands designed for water quality improvement. They are used in water treatment systems, particularly in China, and can contribute to restoration of natural waterbodies, however their effectiveness in pollutant removal is lower at larger scales (Bi et al. 2019). Floating islands have potential to remove nutrients from the water column, and they provide ecological benefits of habitat and shading.

Islands consist of a floating frame or structure supporting a contained media within which plant roots can grow. The plants and media combined enhance microbial processes that have potential to reduce nutrients in the water column. They may be more effective at nitrogen reduction than phosphorus: nitrogen is removed via enhanced nitrification and denitrification, while phosphorus is stored internally and remains potentially available. As plants grow they take up nutrients from the water, however this only contributes to ongoing nutrient removal plants are regularly harvested.

The shading effect of floating islands has immediate benefits of reducing lower water temperatures and light availability to algae, although the scale of islands needed for this to limit algal blooms may be unfeasible. The structures have potential for use in restricting growth of Mexican waterlily by shading, while retaining beneficial biological processes. Islands and the roots below provide structural habitat for aquatic invertebrates, increasing biodiversity and improving food resources for other aquatic fauna. They also provide refuge from heat and predation from waterbirds.

Some small floating islands have been placed in the river in the past. In 2002 a small reed raft was made from a PVC frame with plastic mesh base (Figure 20). Plant growth was rapid, and the structure was subsequently used for nesting. This ‘island’ remains in the river today and has become rooted to the bottom of the river. Swans have recently been observed nesting on it. In 2012 floating islands were installed in a curtained off area to assess water quality benefits. The trial did not take place under conditions of severe algal blooms expected, owing to the effect of Mexican waterlily downstream. No significant effects on water quality were found in this trial, however the beneficial ecological processes associated with floating islands are well-established.

## 4.6 Managing waterlilies

The extensive cover of waterlilies in the river has negative impacts on oxygen levels and open water habitat; however they appear to have had a beneficial effect on water quality, inhibiting the development of algal blooms in open water areas upstream of the point of infestation (near the boat ramp) (Paice 2018). The structural habitat of the waterlilies also supports aquatic invertebrates, despite low oxygen levels.

Although unintentional, this is an example of “ecological engineering”, whereby a change in the ecology has provided water quality benefits. The reasons for reduced algal blooms between patches of waterlily are not fully understood. It is not a result of reduced phosphorus concentrations, as phosphorus was actually extremely high in areas with low algal growth. It may be a combination of greater low residence time in sunlit areas owing to lilies and riparian shading; nitrogen limitation; or chemical inhibition (allelopathy). Understanding the mechanisms by which waterlilies inhibit algal growth may provide important insights to future management, and warrants further research. It would also be valuable to investigate the potential to achieve similar inhibition using native aquatic plant species, such as *Cycnogeton* spp., *Potamogeton* spp., *Liparophyllum* spp. and *Ottelia ovalifolia*.

Reduced algal growth was observed following a rapid expansion of waterlily cover in 2013-2014 (Figure 9), at considerably lower levels of cover than subsequent years. This suggests that water quality benefits can be maintained with some control of waterlily. Large scale control would likely see a return to widespread seasonal algal blooms; and also presents risks of widespread deoxygenation following plant die-off. Paice (2018) recommends strategic control of waterlily to gradually reclaim open waters between lily patches, targeting important waterbird habitat, and to prevent invasion of new areas. Although outside the study area of the WMP, the downstream Lower Vasse River delta wetlands are at particular risk and should be targeted for waterlily control.

## 4.7 Controlling feral fish

The two main feral fish species in the Lower Vasse River are goldfish and mosquitofish. There is little that can be done to control mosquitofish populations. Goldfish are known to feed in at the bottom of the river, disturbing sediments and so contributing to nutrient release and turbidity. There is also evidence that passage through goldfish stomachs can increase the growth rate of blue-green algal cells.

Although eradication of goldfish is difficult, population numbers were successfully reduced through an annual electrofishing program from 2003 to 2013 (Beatty et al 2014). The resumption of this program should be considered. Compartmentalising the river may provide opportunities for effective targeted goldfish removal.

## 4.8 Increasing flow inputs from the Vasse Diversion

Reduction in catchment flows due to interception by the Vasse Diversion, together with impoundment by the Butter Factory weir boards have substantially altered hydrology of the Lower Vasse River. The effect on nutrient concentrations is complex due to variation in nutrient concentrations and the combined results of flow volume and velocity, assimilation within the system and outflows. Although nutrient loads may have decreased due to lower volumes, this does not translate to lower nutrient concentrations.

The impounded conditions and accumulated sediments in the lower 'lake' section of the river promote algal blooms which causes a seasonal increase in nutrient concentrations over summer when there is negligible flow (Section 2.1.1). Flushing of the river may be important for removing nutrients and organic material that accumulate in during summer (Figure 6).

There is strong support from the community for increasing flow into the Lower Vasse River from the Vasse Diversion with the aim of improving water quality. Altering flows has potential to improve water quality where it dilutes nutrient concentrations or reduces residence time for growth of algal blooms. But outcomes need to be considered in the context of flood protection and impacts on nutrient loads to downstream wetland ecosystems. This option of altering flows was investigated by the *Reconnecting Rivers* study (DWER 2018b), which used hydrological modelling to determine the outcomes from a range of reconnection scenarios. The main findings of the *Reconnecting Rivers* study in relation to the Lower Vasse River were:

- the Vasse surge barrier is essential for flood prevention in Busselton;

- additional flows from the Vasse Diversion would increase nutrient loads to the Lower Vasse River and Vasse Estuary;
- an additional 900mm culvert at the Vasse Diversion offtake to the Lower Vasse River is feasible without increased flood risk and without unacceptable additional nutrient loads to the Vasse Estuary;
- the equivalent of three 900mm culverts or full reconnection of the Vasse Diversion would cause unacceptable flood risk and increase in nutrient loads to the Vasse Estuary;
- additional flows from the Vasse Diversion only has a significant effect on flows during winter;
- the potential effect of an additional culvert on summer water quality in the Lower Vasse River is small because of a lack of flow;

The study recommended that the Vasse Diversion Drain offtake structure be upgraded to an equivalent of two 900mm culverts (i.e. double its current capacity), with the ability to control flow. This infrastructure has been designed and works are currently scheduled for 2019. *Reconnecting Rivers* also recommended the development of an operational strategy to manage the culverts, with defined roles and responsibilities and consideration of how nutrient concentrations could be minimised. A greater understanding of relationships between water flow and water quality wold be beneficial to inform optimal operation of the culvert with regard to nutrient management.

## 4.9 Improving summer flows

There is no flow from the Vasse Diversion in the warmer months to address water quality problems during the algal bloom season through dilution and water movement (DWER 2018b). There are limited other options for creating summer flows with other water sources. These are summarised as follows:

- Storage of water for summer release: A dam to hold water for summer release would need a capacity of 18GL and cover an area of 9km$^2$. Water stored in such a reservoir is at risk of experiencing similar water quality problems to the Lower Vasse River. Using the Vasse Diversion or existing flood detention basins is not viable as it would compromise their flood protection function (DWER 2018b).

- Busselton Wastewater Treatment Plant discharge: This option would reduce water residence time and may decrease phosphorus concentrations with limited increase in loads to downstream wetlands (DWER 2018b). This option may be considered further, but its practicality is limited by need for substantial infrastructure and future competition for this water resource.

- Busselton Water operations: There may be potential for backwash inputs, but this has not yet been assessed.

- Internal artificial circulation: Movement of water within the system has potential to limit algal blooms by physical disturbance, reducing water temperatures. Temperature and residence time can be key factors controlling algal blooms in impounded rivers suggests (Cha et al. 2017). This approach may provide opportunities for external treatment techniques associated with recirculation (e. g. filtration via treatment wetlands). This option has not been assessed.

## 4.10 Removal of the Butter Factory weir boards

The Butter Factory weir structure and boards were installed around 1918 to retain water levels in Busselton for amenity and recreation outcomes. There are mixed perceptions regarding their necessity: that removal would improve water quality in the river through flushing; that they are not necessary and greater drying would be beneficial; and that maximising depth is important to improve water quality by creating cooler conditions.

Current management practice is to remove the weir boards in winter, and reinstall them in October to maintain water levels. However, the wooden boards currently leak, so higher water levels are only maintained temporarily. From around December, the extent of water is determined by land elevation, and currently restricted by a point further downstream near Ford Rd.

Modelling through the Reconnecting Rivers project indicated that removal of the weir functionality would not create a flooding risk; and would not result in drying out of the river. This approach may have the following outcomes:

- water levels in the Lower Vasse River would become lower earlier, by up to eight weeks;
- water would continue to flow into the downstream wetlands for a longer period, rather than being held back, influencing nutrient load;
- potential effects on goldfish movement.

An important operational issue at present is the safety of City staff during the installation and removal of the weir boards. A decision is required as to their future use, because if they are necessary part of river management they will need to be replaced and the mechanism for their installation and removal upgraded.

## 4.11 Sediment removal

Regardless of potential reductions in nutrient loads, the organic sediment in the Lower Vasse River provides an ongoing internal source of nutrients loading that can continue to drive algal blooms. Phosphorus is released from the sediments under low-oxygen conditions, and nutrients are also resuspended from the sediments when disturbed by flows and wind. Increasing phosphorus concentrations over the summer months may be a result of sediment-nutrient release. Note that specialised clay products are a form of sediment treatment that prevents phosphorus release (Section 4.3).

Sediment removal has long been viewed by many stakeholders as an essential part of future management. It was highlighted as a key management action during community consultation (AHA 2016). As a stand-alone method it would probably not prevent algal blooms, because nutrient concentrations in surface and groundwater inputs are sufficient for excessive algal growth. However, "resetting" the river through removal of organic sediments does have potential outcomes for water quality and ecology.

Outcomes of sediment removal for river health are complex. Increasing depth may create cooler temperatures but can also result in stratification if there is little mixing of the water, so there may be little temperature-related control of algae. Deeper waters may also reduce resuspension of nutrients from the riverbed. However, shallow waters may also be less prone to algae blooms owing to more favourable conditions for aquatic plants and benthic algae. Rather than removing all soft sediments from the river, creation of deeper pools and channel habitats in some areas as part of a living stream approach is considered more feasible (Section 0).

A section of the river upstream of Causeway Rd Bridge was dredged in March 2001. This work has increased the depth of the river in this section, however a large amount of soft sediment remains, at thickness similar to other parts of the river, and water quality remains poor (Paice 2005). In this case a mini-dredge was used to pump material to a holding dam, allowed to settle overnight and then overlying water was returned to the river. Sediment from the dam was disposed of at a gravel pit.

### 4.11.1 Removal method

Sediments in the Lower Vasse River are very fine and contain a high moisture content, and so require pumping from the river rather than excavation. The method used in 2001 was effective in removing some sediment and allowing it to dry out sufficiently for excavation. However drying took a considerable length of time and the total amount removed was dependent on the capacity of the holding dam. A more recently developed option is pumping sediments into porous geotextile bags placed nearby (Figure 21); with addition of a polymer to expel the water from the bags, which flows back into the river. This approach allows additional sediment to be pumped from the river as the volume of water is removed from collected sediments. This is considered the most feasible option for sediment removal from the river, and a proposal for a trial is currently being developed.

### 4.11.2 Disposal options

Disposal of dredged sediment is challenging in terms of potentially very large volumes, involving considerable transport costs; and limitations on disposal site owing to potential acidification and nutrient and pollutant content. To inform disposal options, the City undertook sampling of between the boat ramp on Southern Drive and the Butter Factory weir in March 2018, with assistance from DWER.

Levels of heavy metals and organic and inorganic contaminants were below threshold levels for disposal at a Class I landfill facility, with the exception of lead (Table 3). Although lead content levels were above threshold values for waste not requiring a leach test, subsequent leachate testing results showed levels were well below the Class I concentration limit.

The average depth of soft sediment in core samples was 488mm, with these sediments dominated by fine silts and clays (71.4%). Sample analysis found no existing acidity (mean pH 7.0), and low acid volatile sulphur (<0.005 %S) but indicated sulfidic soils with very high potential acidity. Net acidity varied greatly, ranging from 449 to 1511 with a mean value of 980 mole H+/Tonne dry weight. This is well above the acid sulphate soils 'action criterion' of 62 mole H+/T for fine texture materials (DER 2015). When sulfidic soils are exposed to air, oxidation can result in acidification. This has been demonstrated for the dredged material from 2001 at the gravel pit, which has a pH of around 4. The average lime dosing required to buffer potential acidification is 74kg/Tonne dry weight.

Soil characteristics do show that dredged material could be disposed of at a Class I landfill facility, such as the City's Vidler Road Waste Facility. However the high nutrient and organic content of the material suggests potential for reuse of the material as a component of compost. Composting can further dilute concentrations of pollutants. This approach would require a trial and further testing of the material to ensure it is safe for any proposed end use.

### 4.11.3 Risks

The main risks associated with sediment removal are:

- potential impact on benthic organisms;

- short term effects on water quality;
- acidification of sulfidic sediments; and

In the Lower Vasse River the soft sediment layer general provides poor habitat for benthic organisms. However the threatened Carter’s Freshwater Mussel (*Westralunio carteri*) is known to occur. Mussels in the Lower Vasse River have a habitat preference for bridge sites and river edges, which are more shaded and stable. Key habitat areas could be avoided and work could be offset by overall habitat improvement; but nonetheless sediment removal work would need to consider and manage impacts on this species and be approved under state and federal legislation.

There is some risk of increased nutrient concentrations in the vicinity of dredging operations disturbance of nutrient rich sediments. Given the severe water quality problems currently experienced in the river this is not considered to be a serious risk. However the connectivity to the Vasse Estuary downstream does raise the issue of impacts on nutrient loads. This could be avoided by undertaking work when the river is disconnected from the downstream system.

The soft sediments in the Lower Vasse River are sulfidic and laboratory analysis and the pH of the old dredge spoil do indicate that oxidation would cause acidification. Severe acidification can have direct impacts on aquatic flora and fauna, lead to contamination of water resources, and cause corrosion of infrastructure. Exposure of the sediments to oxygen in the water column or air would be avoided using the geotextile bag method, preventing oxidation during the removal process. The sediments are not monosulfidic (indicated by low acid volatile sulphur); so do not pose the risk of rapid acidification and associated deoxygenation of the water column with potential heavy metal release. Sediments would require lime dosing for disposal.

Table 3. Comparison of pollutant content of Lower Vasse River sediments to threshold values for Class I landfill (sampling by City, March 2018).

| Analyte | mean | Class I landfill threshold[1] | Units |
|---|---|---|---|
| Arsenic | <5 | 14 | mg/kg |
| Beryllium | 0.1 | 2 | mg/kg |
| Cadmium | 0.34 | 0.4 | mg/kg |
| Chromium | 6.6 | 10 | mg/kg |
| Lead | 35 | 2 | mg/kg |
| Lead leachate | <0.01 | 0.1 | mg/L |
| Mercury | 0.04 | 0.2 | mg/kg |
| Molybdenum | <2 | 10 | mg/kg |
| Nickel | 2.00 | 4 | mg/kg |
| Silver | <1 | 20 | mg/kg |
| Fluoride | 137 | 300 | mg/kg |
| Cyanide - Total | <1 | 16 | mg/kg |
| Petroleum hydrocarbons $C_{6\text{-}9}$ | <0.2 | 2800 | mg/kg |
| Petroleum hydrocarbons – other | 19.5 | 450[2] | mg/kg |

[1] Landfill Waste Classification and Waste Definitions (DEC 2009)
[2] minimum threshold value for range of petroleum hydrocarbons
< indicates value below limit of detection
Phenol and pesticide suite also analysed, all results below limit of detection

### 4.11.4 Costs

There is uncertainty around costs for sediment removal, related to volumes of material and potential shrinkage, method of removal and options for disposal. Further work is required to provide accurate estimates of sediment and determine sound methods for removal and disposal. Removal also needs to consider appropriate locations and whether it could be staged in association with a living streams design approach. The removal trial currently being developed (see 4.11.1) will inform future costings of this management option.

Figure 21. Geotextile bags used for sediment removal via dredging.

## 4.12 Recreation and access management

Recreational opportunities for the Lower Vasse River are mainly walking and riding along the river and bird watching. Feeding of ducks and other birds near Peel Terrace is also common, but is discouraged owing to potential impacts on water quality and bird behaviour. Recreation is clearly limited by water quality problems. Algal blooms pose a health risk that prevents direct contact activities such as swimming and use of paddle craft; and at times cause poor odours that limit activities near the water. Management actions that address water quality are thus essential to improve recreational opportunities.

There is potential to improve access and facilities for recreation and enjoyment during periods where algal blooms do not occur, or do not cause offensive odours. Community consultation indicated access and recreation as the area of management where the community would most like to see change (AHA 2016). Examples include additional pathways, boardwalks, viewing platforms, seating, bird hides and picnic areas. Upgrading of interpretive signage would also encourage people to the river and enhance their experience. There are existing pathways along the river in the vicinity of Peel Terrace and

Southern Drive, and among the nearby New River Wetlands: the City is currently developing plans for an extension to this network.

There is also a need to review the use of permanent warning signs around the river, which discourage activities when there is no public health risk. This is particularly important if water quality improvements are achieved.

There is significant potential for improved recreational, amenity and cultural connection with the river. Although poor water quality does limit these outcomes, it does not prevent it. Enhancing ecological values of the river and opportunities for community connection can be achieved independent of water quality improvement. Furthermore, there are many months of the year when water quality does not pose a health risk. Clearly though, water quality improvement is a key aspect of enhancing recreational opportunities.

Interpretive signage along the Lower Vasse River between the old Rail Bridge and Rotary Park was developed as part of the Lower Vasse River Cleanup Program, in the early 2000s. These signs are still in place but are outdated: some are no longer visible and some are no longer relevant. Improved interpretive facilities and information would engage more of the community and enhance appreciation and understanding of the river and its management.

## 4.13 Governance options

The independent review of water asset management (Hart 2014) highlighted the need for the Lower Vasse River to have a designated manager. The City was recognised as the most appropriate manager, and this has been supported by the Western Australian Government in its response to the review. It is sensible that the City adopts this role given the high public profile of the river as a part of Busselton's town centre; and the large areas of foreshore reserves under the City's management control. Although the City is responsible for overall implementation of management actions, several key stakeholders also have important roles, outlined below. These roles and responsibilities are also summarised in Table 4, in Section 6.

The flow control structures at the Vasse Diversion connection and the Butter Factory, considered vital components of river management, are generally operated by the City. However, this infrastructure is owned by the Water Corporation. The Water Corporation has given the City permission to operate these mechanisms for water quality purposes, however some uncertainty remains in relation to flood protection.

The City also has an important role in its planning capacity. The *Optimising Planning Tools* project was completed by the City, for the RGW Program, to review the potential role of planning in water resource protection (Hosken 2018). Proposals for changes in land use and new developments can trigger the imposition of new environmental protection requirements at the approval stage. This applies to both urban and rural development.

The Lower Vasse River catchment area will undergo considerable expansion of urban and industrial areas in the future, which will increase potential nutrient and pollutant sources. Continued implementation of best practice stormwater management designs, and long term maintenance of infrastructure by the City is essential to minimise water quality impacts from future developments. Future residential development will provide opportunities for improving foreshore environments as new reserves are vested in the City. Consideration of water quality protection and surface water management in the planning process is guided by *Better Urban Water Management* document (WAPC 2008). There is potential to require new developments to demonstrate that nutrient and contaminant levels will not exceed background levels, but this would require amendment of the City's Local Planning Scheme and is restricted by a lack of water quality standards.

In rural areas, the current trend of intensification of agriculture is likely to continue into the future. Although there is a requirement for planning approval for intensive agricultural uses such as horticulture and feedlots, development applications for these land use changes are generally not submitted to the City. Improved clarity of planning approval requirements for changes in agricultural land use and new agricultural developments may increase opportunities for waterway protection requirements. The development of industry best management practices (BMPs) would provide useful criteria for planning assessment.

The City's management responsibility is generally limited to the study area and does not extend into the broader catchment. Ongoing management initiatives in the catchment, in particular to address issues of nutrient enrichment and sedimentation, are a fundamental component of waterways management. GeoCatch, with the support of DWER, is the lead manager for catchment management. The Water Corporation has management responsibility for its rural drainage network.

DWER has an ongoing role in providing support for the management of the Lower Vasse River through continued involvement in water science, modelling and monitoring. If the implementation of this WMP is to be funded through ongoing investment in a broader program for Geographe Bay catchment waterways, DWER is likely to continue to have an important project management and networking role.

The community is also an important stakeholder with potential roles in management decisions, advocacy, implementation of on-ground works and contribution to community science. Many interested community members have provided valuable assistance during the preparation of this WMP and would be valuable in ongoing collaboration during implementation. The City has a strong 'Friends of' approach to reserves management, which may facilitate volunteer involvement in actions and monitoring. Aboriginal people have expressed a desire to participate in management decisions and on-ground projects.

## 4.14 Research and monitoring needs

Research and monitoring are needed to enable assessment and reporting on progress of management initiatives and to fill knowledge gaps. Research outcomes need to feed back into management planning through an adaptive process. The key research areas for the Lower Vasse River are summarised below.

**Water quality**: Ongoing water quality monitoring is an essential part of long-term assessment and reporting for waterway health. Future research into different water treatment options to reduce nutrient availability and reduce algal growth may provide important management tools. Short-term Intensive monitoring of nutrient concentrations and flows to the river from the Vasse Diversion Drain to improve understanding of the first flush dynamics of the system would inform operation of culverts.

**Water flow**: Investigation of the relationship between nutrient and flows in the Vasse Diversion will help inform management decisions around operation of the culvert connection. When the culvert is upgraded, inclusion of flow monitoring in the design would support future decisions in optimising flow. Better understanding of the effects of the Butter Factory weir on water levels and water quality is also needed to determine the need for upgrading this structure.

**Birds:** Despite being one of the most valued characteristics of the river, bird populations and key habitat areas are not well understood. Better knowledge of birds would assist in prioritising management actions (e.g. habitat restoration) and in developing information resources for visitors. There is an opportunity for development of community-based sampling to address this gap.

**Mussels:** Freshwater mussels occur in the river, and have recently been added to specially protected fauna lists at the state, federal and global levels. A better understanding is needed of the mussel population, habitat requirements, potential contribution to water quality and potential impacts of management initiatives.

**Mexican waterlily:** The reasons for reduced algal blooms between patches of waterlily are not fully understood, and research into the mechanisms for this would provide insights for broader river management.

**Sediments:** Sediment removal is potentially a major part of future management of the river to address internal nutrient sources. More work is needed to develop methods of removal, determine costs, and examine potential outcomes for water quality and impacts on existing ecological values.

# 5 Management Strategies and Actions

The management strategies and actions included here have been developed to work towards meeting the management objectives and vision for the Lower Vasse River. Specific actions have been grouped into strategies for each of the management focus areas, although many have potential outcomes for several objectives. Living Streams is included separately, because it is an approach to management that influences implementation of actions for a number of focus areas. A framework for implementation of the WMP is provided in Section 6, including the roles and responsibilities of key stakeholders; definition of management areas; and a process for ongoing action planning, reporting and review.

## 5.1 Living Streams

Living Streams is separated from the management focus areas because it provides an overarching pathway for implementing management actions related to water quality and ecology. It involves altering the morphology and physical characteristics of the river to restore ecological processes and create less favourable conditions for algal blooms. It may also facilitate intervention actions, such as water treatment and sediment removal, in specific areas of the river.

### 5.1.1 Strategy LS1: Living streams approach

A living streams approach would see creation of diverse habitats including seasonally dry areas, river pools, channels, floodplain areas, riffle zones and islands (floating and grounded). In addition to outcomes for biodiversity in the river, these habitats would be designed to maximise potential benefits to water quality.

**Management actions:**

LS.3 Continue to develop Living Streams planning as a pathway for implementing ecological restoration and water quality improvement works, and assess community support for this approach.

LS.4 Incorporate the following principles into restoration planning as part of the Living Streams approach:

- maximise shading;
- enhance substrate to provide more favourable sediment and depth conditions for anchorage and growth of beneficial aquatic plants;
- modify depth contours to support more in-stream vegetation, including emergent and submerged plants, to enhance nutrient uptake and cycling;
- provide greater surface area for benthic algal populations to develop as alternative primary producers to phytoplankton;
- reduce the size of open water areas to increase resilience to nutrient loading;
- enhance habitat for freshwater mussels to maximise their role in maintaining water quality;
- reduce residence time for algal growth through flow management.

## 5.2 Water quality

Nutrients are a key driver of algal blooms, so ongoing load reduction actions are a fundamental part of management. However, it often takes a long time to achieve load reductions, and they may be counteracted by new developments and changes to land use. Algal blooms can also be addressed through interventions that limit nutrient availability or directly target algal blooms. They may also be managed by creating less favourable physical conditions for phytoplankton; or restoring ecosystem functions such as nutrient cycling and food web processes.

Catchment management actions in this section are closely linked with recommendations in the Water Quality Improvement Plan (WQIP: DoW 2010), which are included for reference.

### 5.2.1 Strategy WQ1: Protecting water quality from urban sources

The Busselton Light Industrial Area (LIA) has been identified as a potentially significant source of nutrients and pollutants to the Lower Vasse River. This strategy is focussed on improving understanding of this problem to guide future management. It also includes actions to maintain and expand best practice stormwater management to improve water quality.

***Management actions:***

WQ1.8 Quantify nutrient and pollutant exports from Busselton LIA to the Lower Vasse River to inform a case for deep sewerage.

WQ1.9 Explore options to secure deep sewerage for the Busselton LIA in partnership with Water Corporation.

WQ1.10 Assess opportunities for greater connection to existing sewerage infrastructure within the Lower Vasse River catchment. If there a significant opportunity exists, investigate options and incentives to increase connectivity.

WQ1.11 Planning decisions to include appropriate sewerage management requirements and best practice water management, through implementing the *Better Urban Water Management* framework.

WQ1.12 Develop a prioritised program for stormwater WSUD upgrades to maximise nutrient reduction outcomes.

WQ1.13 Support educational campaigns that aim to reduce nutrients in runoff through individual and community actions (e.g. Bay OK).

WQ1.14 Support implementation of the Vasse-Wonnerup Wetlands and Geographe Bay WQIP (DoW 2010).

### 5.2.2 Strategy WQ2: Reducing nutrient inputs from the rural catchment

Agricultural activities in the Vasse River catchment influence nutrient inputs via the Vasse Diversion culvert, which may increase when the culvert capacity is increased (see Water Flows). There are also some rural land use activities remaining in the Lower Vasse River catchment area. This strategy reflects catchment management initiatives recommended in the WQIP, and future management direction in improving rural drainage.

***Management actions:***

WQ2.3 Support projects focussed on reducing nutrient exports from rural catchment of the Lower Vasse River, as recommended in the Vasse-Wonnerup Wetlands and Geographe Bay WQIP (DoW 2010):

- *Improve fertiliser management throughout the catchment*
- *Improve effluent management at dairy sheds and feedlots*
- *Implement riparian management and stock control on streams and drains*
- *Use soil amendments on sandy soils*
- *Use perennial pastures when suitable*

WQ2.4 Explore opportunities for enhanced nutrient assimilation in rural drains in the Lower Vasse River catchment, particularly those in reserves.

### 5.2.3 Strategy WQ3: Water treatment

Even when substantial reductions in nutrient loads are achieved, algal blooms often persist owing to ongoing internal nutrient supply. This strategy includes remediation approaches that address in-situ water quality, by treating water to reduce nutrient levels and algal blooms.

***Management actions:***

WQ3.4 Incorporate outcomes from the Water Quality Treatment Trials (2016-2018) into future management planning.

WQ3.5 Undertake seasonal water treatments in priority amenity area/s prior to algal bloom establishment, ensuring physical isolation to maximise effectiveness (dependent on outcomes Water Quality Treatment Trials, 2016-2018).

WQ3.6 Maintain research partnerships to identify and investigate new technologies to treat water in the future.

## 5.3 Ecology

### 5.3.1 Strategy E1: Riparian vegetation management

Riparian vegetation provides important habitat and supports ecosystem functions that maintain water quality. This strategy directs weed control and revegetation to improve and expand vegetated areas.

***Management actions:***

E1.6 Develop and implement a revegetation program for City-managed foreshore reserves, considering recommended rehabilitation areas reported in Ecoedge (2017).

E1.7 Continue to impose appropriate conditions on new developments adjacent to the Lower Vasse River that ensure future vesting and revegetation of foreshore reserves.

E1.8 Include creation and improvement of habitat for birds and possums in planning riparian revegetation.

E1.9 Update the Vasse River Action Plan in partnership with adjacent landholders, and extend this throughout the Lower Vasse River study area.

E1.10 Minimise fire risks associated with foreshore reserves by: reducing growth of annual grassy weeds; and considering species type, height and planting density when planning revegetation.

### 5.3.2 Strategy E2: Understanding and protecting waterbirds

Although there is high community appreciation of waterbirds in and around the Lower Vasse River, there is little formal understanding of bird populations and key habitats. This strategy will improve knowledge to guide protection and enhancement of bird habitat. There is potential for community contribution to this through a citizen science approach.

***Management actions:***

E2.5 Undertake a survey of waterbirds of the Lower Vasse River and identify important habitat zones, with strong involvement from the community.

E2.6 Protect identified important bird habitat zones through revegetation and weed control, recognising the current role of weeds as habitat.

E2.7 Create additional habitat zones for birds by placing large woody debris emerging from the water.

E2.8 Avoid identified important bird habitat zones when planning future infrastructure, and consider nesting season when planning works.

### 5.3.3 Strategy E3.1 Controlling invasive species

Mexican waterlily and feral goldfish are significant invasive species in the Lower Vasse River, impacting substantially on ecology and water quality. This strategy supports ongoing control programs for these species, but recognises the role of waterlily in reducing algal blooms.

***Management actions:***

E3.5 Prevent of further spread of Mexican waterlily through herbicide control and/or shading.

E3.6 Undertake strategic control of Mexican waterlily to progressively reclaim areas of open water, while minimising adverse impacts and preventing a return to algal blooms in these areas.

E3.7 Undertake regular feral fish eradication activities in partnership with Murdoch University.

E3.8 Undertake targeted control of arum lily and Brazilian pepper trees throughout the Lower Vasse River study area.

## 5.4 Water flow

### 5.4.1 Strategy WF1: Optimising flows

This strategy considers potential for water quality outcomes by manipulating flow inputs from the Vasse Diversion Drain, and by increasing summer flows. Increased flow inputs from the Vasse Diversion Drain require careful consideration of nutrient loads and flood protection. While there are limited sources of summer flow, there is scope to further investigate options and benefits of internal water circulation. This could be made more feasible through the Living Streams approach.

***Management actions:***

WF1.7 Increase flushing of the river by installing a second 900mm culvert at outflow point from Vasse Diversion Drain, in accordance with recommendations from the Reconnecting Rivers Report (DWER 2018).

WF1.8 Monitor impacts of increasing flows into the Lower Vasse River.

WF1.9 Undertake intensive monitoring water quality in the Vasse Diversion to support operational guidelines for managing the culvert.

WF1.10 Develop operational guidelines for the Vasse Diversion culvert that defines responsibilities and provides formal guidance for manipulation of the valve to maximise water quality benefits and minimise risk of flooding.

WF1.11 Review function of the Butter Factory weir boards to inform their future use and need for replacement.

WF1.12 Investigate potential for increasing internal circulation in the system during summer to reduce residence time for phytoplankton.

## 5.5 Sediments

### 5.5.1 Strategy S1: Sediment removal

The accumulated organic sediment in the Lower Vasse River provides an ongoing internal source of nutrients that drive algal blooms. These sediments also create a hostile environment for beneficial native aquatic plants and benthic aquatic fauna. This strategy includes removing sediment through an adaptive approach over time and considers alternatives to removal.

***Management actions:***

S1.4 Undertake a small-scale sediment removal project, using geotextile bags for dewatering and disposal, to assess cost and logistics of this approach.

S1.5 Determine feasibility of disposal options for future sediment removal: landfill, composting, soil conditioner.

G2.4 Depending on outcomes of small scale removal, undertake staged removal of sediments in the Lower Vasse River as a component of Living Streams design.

## 5.6 Amenity, recreation and education

### 5.6.1 Strategy ARE1: Improving facilities and information

***Management actions:***

ARE1.6 Review existing facilities and develop a concept plan for strategic pathways and viewing points that connect people with the river.

ARE1.7 Update the interpretive signage around the river to provide information on of the history, ecology, hydrology and management of the Lower Vasse River.

ARE1.8 Develop online and printed resources with interesting and important information on ecology, water quality, history and management of the Lower Vasse River.

ARE1.9 Establish bird watching areas and hides in appropriate places with informational material.

ARE1.10 Encourage opportunities for citizen science to contribute to understanding and appreciation of the Lower Vasse River.

### 5.6.2 Strategy ARE1: Public health management

There are many months of the year when algal blooms are not present and some areas do not experience regular summer algal blooms. The current approach of leaving warning signs in place throughout the year contributes to poor public perception of river health, and is not appropriate in terms of actual risk.

***Management actions:***

ARE2.4 Continue monitoring phytoplankton species and densities to inform public health notifications.

ARE2.5 Review algal bloom warning sign protocol and prepare a communication program to inform the community when harmful algal blooms occur.

ARE2.6 Develop a policy for use of recreational watercrafts in the Lower Vasse River, including consideration of public health constraints.

## 5.7 Culture and Heritage

### 5.7.1 Strategy CH1: Recognising Wadandi custodianship

Wadandi people have a strong connection to the Lower Vasse River and have considerable interest in its future management. This strategy will improve involvement of the Wadandi community in decisions and actions on river health and cultural connection.

***Management actions:***

CH1.6 In partnership with Wadandi people, include reference to traditional custodianship of the waterways and land in development of information resources.

CH1.7 Manage future access in a way that avoids additional disturbance and considers protection of potential sites of significance – however Wadandi activities such as fishing, camping, the gathering of bush foods and family recreational and educational activities, should not be restricted by implementation of this plan.

CH1.8 Seek to improve partnerships with the Wadandi community to increase their involvement in the management, protection and restoration of the Lower Vasse River.

CH1.9 Consult further with Wadandi representatives in regards to specific works which result from this plan.

CH1.10 Support programs that engage the Wadandi community in implementation of works associated with this plan.

### 5.7.2 Strategy CH2: Preserving historical values

Working towards the vision will improve community perception of the Lower Vasse River as an iconic and historical feature of the Busselton. The history of the river should be preserved in terms of physical structures and records of information.

***Management actions:***

CH2.3 Identify and ensure appropriate maintenance of sites of historical importance.

CH2.4 Develop interpretive material to increase understanding of local history, and to promote, appreciate and access historical sites.

## 5.8 Governance

### 5.8.1 Strategy G1: Collaborative and adaptive management

The City has coordinated the development of this WMP and has overall responsibility for implementation, but partnerships with other stakeholders will be essential to achieve many management actions and assess their outcomes. This strategy provides for a collaborative approach to management and will ensure outcomes of actions and new research inform future decisions. Roles and responsibilities of key stakeholders are defined in Table 4.

***Management actions:***

G1.2 The City to consider securing management orders over the waterway and adjacent public lands in Lower Vasse River study area, to facilitate implementation of this plan.

G1.5 Establish a Management Advisory Group comprised of representatives from the City, Department of Water and Environmental Regulation, Department of Biodiversity, Conservation and Attractions, Water Corporation of WA, GeoCatch, Wadandi representatives, and other community representatives.

G1.6 Continue water quality monitoring in the Lower Vasse River.

G1.7 Ensure adequate monitoring and reporting of outcomes from management actions, and feedback results into future management actions.

G1.8 Maintain and develop partnerships with research organisations to improve knowledge and management of the Lower Vasse River.

### 5.8.2 Strategy G2: Optimising planning tools

There is potential for the City to facilitate improved management through the planning and development framework. This strategy builds on the *Optimising Planning Tools* project, which outlines the potential use of planning tools in water quality protection.

***Management actions:***

G2.5 Improve clarity of planning approval requirements for changes to land use and new developments in the agricultural sector (e.g. horticulture, dairies, feedlots).

G2.6 Assess future development proposals and changes of land-use on adjoining lands with consideration of impacts on the Lower Vasse River.

G2.7 Include 50m wide foreshore reserves as part of future development adjacent to the river.

# 6 Implementation

## 6.1 Roles and responsibilities

The lead role of the City in the future management of the Lower Vasse River will be recognised through endorsement and adoption of this WMP. This will task the City with responsibility for coordinating implementation, however key stakeholders will have ongoing roles in many aspects of the WMP. These roles and responsibilities are defined in Table 5.

As captured in action G1.1 a Management Advisory Group is recommended to oversee implementation of this WMP, comprised of representatives from the City, Department of Water and Environmental Regulation, Department of Biodiversity, Conservation and Attractions, Water Corporation of WA, GeoCatch, Wadandi representatives and broader community representatives.

## 6.2 Management areas

In planning for implementation of management actions, it is helpful to define specific management areas of the catchment and river/foreshore, based on the characteristics of the areas and thus the actions that will be applicable. These are described as follows:

River and foreshore areas:

A. From the Butter Factory weir to Strelly Street, with significant areas of public reserve
B. From Strelly Street to Busselton Bypass, with adjacent residential and commercial areas and less prominent reserves
C. From Busselton Bypass to the Vasse Diversion, with adjacent rural properties

Catchment areas:

A. Busselton light industrial area
B. Other residential and commercial areas
C. Rural areas downstream of the Vasse Diversion
D. Rural catchment upstream of the Vasse Diversion

## 6.3 Implementation process

An adaptive process of action planning, works, evaluation and reporting is recommended for the WMP, summarised by Figure 22. The strategies and actions presented provide the basis for planning actions for a specified period of time, dependent on achievable priority works and research within available budgets. This would be a key role of the Management Advisory Group. Outcomes of these actions are measured through adequate monitoring, with results assessed in terms of progress towards the management objectives and vision. Reporting of outcomes to the community is essential to maintain community support and this forum would provide an opportunity to gain input to the next action planning cycle.

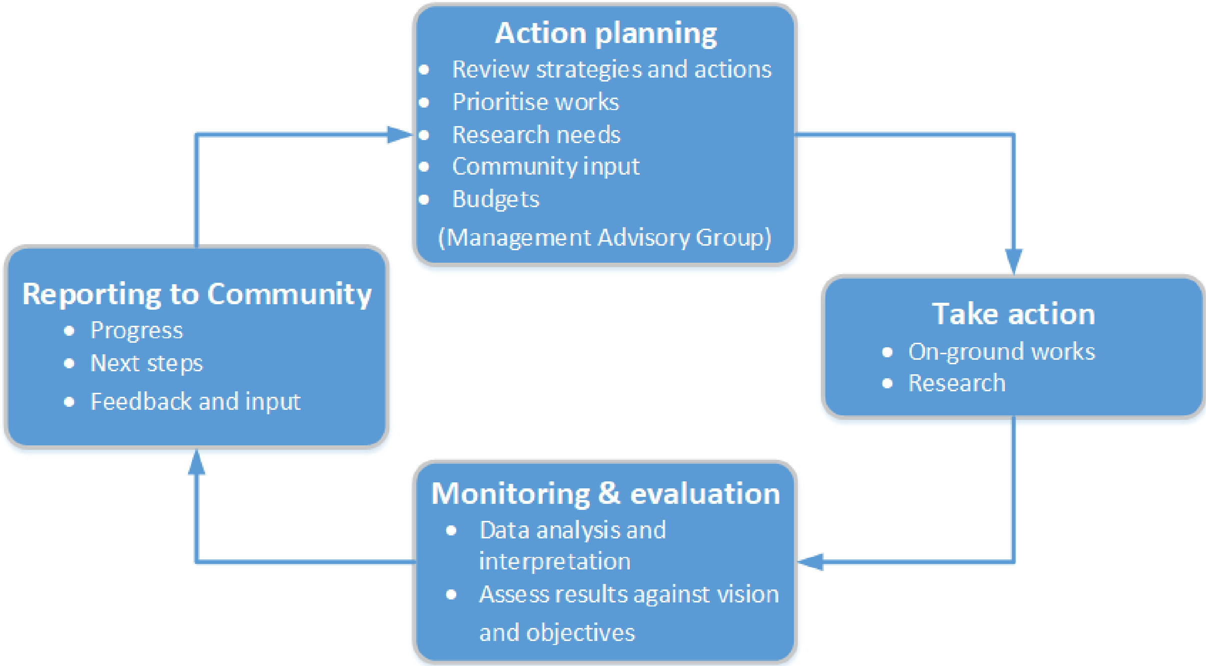


Figure 22. Implementation process for the Lower Vasse River Waterway Management Plan.

Table 4. Roles and responsibilities of key stakeholders for implementation of the Lower Vasse River Waterway Management Plan.

| Stakeholder | Roles and Responsibilities |
|---|---|
| City | Overall implementation of the WMP.<br>Management of reserves.<br>Stormwater infrastructure upgrades and maintenance.<br>Operation of the Vasse Diversion culvert.<br>Operation of the Butter factory Weir boards.<br>Support to community groups. |
| Department of Water and Environmental Regulation | Monitoring of water quality.<br>Technical contributions to management decisions.<br>Coordination of future investment in waterways management through Revitalising Geographe Waterways. |
| GeoCatch | Support to private landholders to improve land and waterway management in the catchment.<br>Educational programs to minimise nutrient and sediment loads.<br>Education, habitat restoration, and community group support for protection of Western Ringtail Possums. |
| Water Corporation | Managing flooding risk.<br>Support to operational decisions for the Vasse Diversion culvert.<br>Sewerage infrastructure development.<br>Rural drainage maintenance, with potential to improve sediment trapping and nutrient assimilation. |
| Department of Biodiversity, Conservation and Attractions | Coordinate native wildlife management programs and implement recovery plans for native flora and fauna of conservation significance.<br>Provide guidance and direction to community group in relation to the protection and conservation of Western Ringtail Possums.<br>Providing information about native flora and fauna. |
| South West Boojarah Working Party | Advocating protection and enhancement of the Vasse River.<br>Providing input to management decisions that affect environmental and cultural values.<br>Engagement and participation of Aboriginal people in management decisions and actions. |
| Friends of reserves groups | Future role in local-level advocacy and management actions. |

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# 8 Appendices

## Appendix 1. List of vascular flora found within the Survey Area of the Lower Vasse River (Ecoedge 2017).

| FAMILY | LATIN NAME | COMMON NAME | NATURALISED | PLANTED |
|---|---|---|---|---|
| Anacardiaceae | *Schinus terebinthifolius* | Pepper Tree | * | |
| Apiaceae | *Centella asiatica* | Centella | | |
| Apocynaceae | *Vinca major* | Blue Periwinkle | * | |
| Araceae | *Zantedeschia aethiopica* | Arum Lily | * | |
| Asteraceae | *Lactuca saligna* | Wild Lettuce | * | |
| Asteraceae | *Sonchus asper* | Rough Sowthistle | * | |
| Casuarinaceae | *Allocasuarina fraseriana* | Sheoak | | |
| Cyperaceae | *Carex divisa* | Divided Sedge | * | |
| Cyperaceae | *Ficinia nodosa* | Knotted Club Rush | | |
| Cyperaceae | *Gahnia trifida* | Coast Saw-sedge | | |
| Cyperaceae | *Lepidosperma gladiatum* | Coast Sword-sedge | | |
| Dennstaedtiaceae | *Pteridium esculentum* | Bracken | | |
| Dilleniaceae | *Hibbertia cuneiformis* | Cutleaf Hibbertia | | |
| Euphorbiaceae | *Euphorbia terracina* | Geraldton Carnation Weed | * | |
| Fabaceae | *Acacia saligna* | Orange Wattle | | |
| Fabaceae | *Lupinus cosentinii* | Blue Lupin | * | |
| Fabaceae | *Vicia sativa* | Common Vetch | * | |
| Fabaceae | *Viminaria juncea* | Swishbush | | |
| Goodeniaceae | *Dampiera alata* | Winged-stem Dampiera | | |
| Haemodoraceae | *Anigozanthos flavidus* | Tall Kangaroo Paw | | |
| Juncaceae | *Juncus kraussii* | Sea Rush | | |
| Juncaceae | *Juncus pallidus* | Pale Rush | | |
| Menyanthaceae | *Liparophyllum lasiospermum* | | | |
| Moraceae | *Ficus carica* | Common Fig | * | |
| Myrtaceae | *Agonis flexuosa* | Peppermint | | |
| Myrtaceae | *Astartea scoparia* | Common Astartea | | |
| Myrtaceae | *Calothamnus quadrifidus* | One-sided Bottlebrush | | x |

| FAMILY | LATIN NAME | COMMON NAME | NATURALISED | PLANTED |
|---|---|---|---|---|
| Myrtaceae | *Corymbia calophylla* | Marri | | |
| Myrtaceae | *Eucalyptus citriodora* | Lemon-scented Gum | * | x |
| Myrtaceae | *Eucalyptus rudis* | Flooded Gum | | |
| Myrtaceae | *Kunzea glabrescens* | Spearwood | | ? |
| Myrtaceae | *Melaleuca cuticularis* | Saltwater Paperbark | | |
| Myrtaceae | *Melaleuca huegelii* | Chenille Honeymyrtle | | x |
| Myrtaceae | *Melaleuca rhaphiophylla* | Swamp Paperbark | | |
| Myrtaceae | *Melaleuca viminea* | Mohan | | |
| Myrtaceae | *Taxandria parviceps* | | | |
| Papaveraceae | *Fumaria muralis* | Wall Fumitory | * | |
| Poaceae | *Bromus diandrus* | Great Brome | * | |
| Poaceae | *Cenchrus clandestinus* | Kikuyu Grass | * | |
| Poaceae | *Cortaderia selloana* | Pampas Grass | * | |
| Poaceae | *Cynodon dactylon* | Couch | * | |
| Poaceae | *Ehrharta calycina* | Perennial Veldt Grass | * | |
| Poaceae | *Ehrharta longiflora* | Annual Veldt Grass | * | |
| Poaceae | *Holcus lanatus* | Yorkshire Fog | * | |
| Poaceae | *Phleum pratense* | Timothy | * | |
| Polygonaceae | *Persicaria hydropiper* | Water Pepper | | |
| Polygonaceae | *Rumex conglomeratus* | Clustered Dock | * | |
| Proteaceae | *Banksia grandis* | Bull Banksia | | |
| Proteaceae | *Banksia littoralis* | Swamp Banksia | | |
| Salicaceae | *Salix babylonica* | Weeping Willow | * | |
| Solonaceae | *Solanum linnaeanum* | Apple of Sodom | * | |
| Typhaceae | *Typha orientalis* | Typha | | |

# Appendix 2. Summary of Water Sensitive Urban Design infrastructure

**WSUD infrastructure implemented in the Lower Vasse River Catchment**

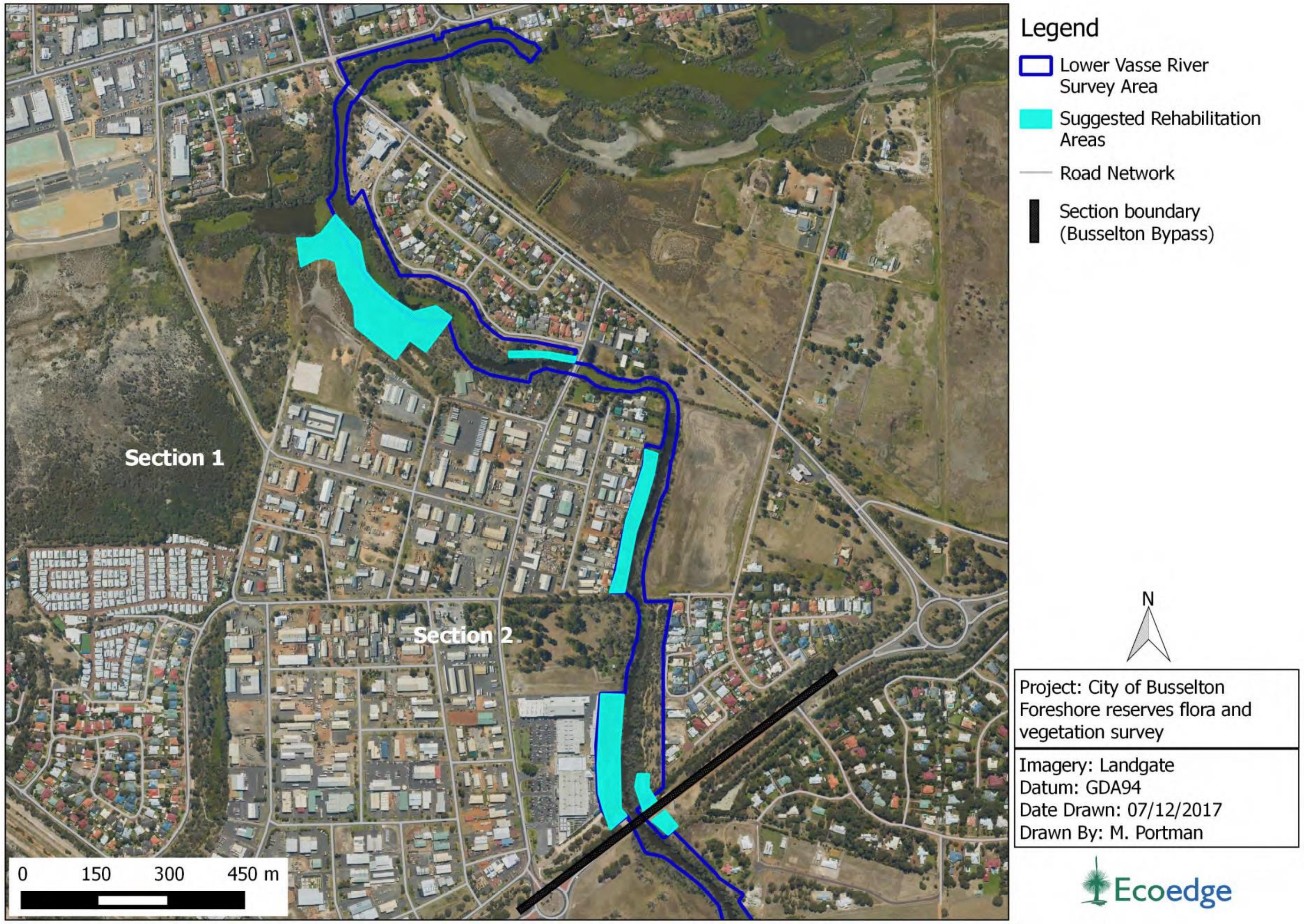
| **Description** |
|---|
| **CBD area** |
| Kent Street streetscaping<br>Kent Street biofiltration bed |
| Coles Carpark Bio-filtration Gardens |
| Woolworths carpark – Rain Gardens and soak wells |
| Queen Street/Prince Street Bio-filtration beds |
| Busselton Community Resource Centre Rain Gardens |
| Busselton Community Youth  Centre Rain gardens– High and Jolliffe Street Busselton |
| Queen Street Outfall – Natural wetlands |
| **Busselton LIA** |
| Frederick Street – Artificial ponds and vegetated swales |
| College Avenue – Constructed wetland |
| College – Cook connector drain |
| Bunnings Carpark – detention ponds |
| Fairlawn road – Vegetated Swale |
| Strelly Street – Demonstration – Biofiltration swales and rain gardens<br>Urban Drainage Pilot Project - Details on Strelly Street biofiltration swales |
| Community Garden – Vegetated swales and detention ponds |
| Bunbury Street/Roe Terrace – Vegetated detention pond and constructed wetland |
| Roe Terrace – Vegetated Swale |
| Bunbury/Barlee Street – Bio-filtration basin |

**Locations of WSUD in Busselton CBD:**


**Locations of WSUD in Busselton LIA:**

# Appendix 3. Recommended revegetation areas for the Lower Vasse River Study area

Recommended rehabilitation areas identified the 2017 vegetation survey (Ecoedge 2017). Note the western foreshore area to the south was revegetated in June 2018.



# Appendix 4. Suggested species for revegetation of the Lower Vasse River

**Revegetation species list for damp and terrestrial areas (Ecoedge 2017).**

| Family | Species | Common Name | Habitat | Form |
|---|---|---|---|---|
| Cyperaceae | *Ficinia nodosa* | Knotted Club Rush | Damp | Rush |
| Cyperaceae | *Gahnia trifida* | Coast Saw-sedge | Damp | Sedge |
| Cyperaceae | *Lepidosperma gladiatum* | Coast Sword-sedge | Damp | Sedge |
| Cyperaceae | *Lepidosperma squamatum* | | Dry | Sedge |
| Dennstaedtiaceae | *Pteridium esculentum* | Bracken | Dry | Herb |
| Dilleniaceae | *Hibbertia cuneiformis* | Cutleaf Hibbertia | Dry | Shrub |
| Dilleniaceae | *Hibbertia diamesogenos* | | Dry | Shrub |
| Ericaceae | *Astroloma ciliatum* | Candle Cranberry | Dry | Shrub |
| Fabaceae | *Acacia saligna* | Orange Wattle | Damp | Shrub |
| Fabaceae | *Hardenbergia comptoniana* | Native Wisteria | Dry | Climber |
| Fabaceae | *Jacksonia gracillima* | | Dry | Shrub |
| Fabaceae | *Viminaria juncea* | Swishbush | Damp | Shrub |
| Goodeniaceae | *Dampiera alata* | Winged-stem Dampiera | Damp | Shrub |
| Haemodoraceae | *Anigozanthos flavidus* | Tall Kangaroo Paw | Dry | Herb |
| Hemerocallidaceae | *Agrostocrinum scabrum* | Blue Grass Lily | Dry | Herb |
| Juncaceae | *Juncus kraussii* | Sea Rush | Damp | Rush |
| Juncaceae | *Juncus pallidus* | Pale Rush | Damp | Rush |
| Myrtaceae | *Agonis flexuosa* | Peppermint | Dry | Tree |
| Myrtaceae | *Astartea scoparia* | Common Astartea | Damp | Shrub |
| Myrtaceae | *Calothamnus sanguineus* | Silky-leaved Blood flower | Dry | Shrub |
| Myrtaceae | *Eucalyptus rudis* | Flooded Gum | Damp | Tree |
| Myrtaceae | *Hypocalymma angustifolium* | White Myrtle | Damp | Shrub |
| Myrtaceae | *Kunzea glabrescens* | Spearwood | Dry | Shrub |
| Myrtaceae | *Melaleuca cuticularis* | Saltwater Paperbark | Damp/ Saline | Tree |
| Poaceae | *Austrostipa flavescens* | | Dry | Herb |
| Proteaceae | *Conospermum caeruleum* ssp. *marginatum* | Blue Brother | Dry | Shrub |
| Proteaceae | *Xylomelum occidentale* | Woody Pear | Dry | Tree |
| Santalaceae | *Exocarpos odoratus* | Scented Ballart | Damp | Shrub |
| Thymelaeaceae | *Pimelea angustifolia* | Narrow-leaved Pimelea | Dry | Shrub |

**List of emergent and submerged species for restoration of seasonally and permanently inundated areas (littoral zone).**

| Species | Common Name | Habitat | Form |
|---|---|---|---|
| *Centella asiatica* | Native celery, Gotu-cola | seasonally emergent | groundcover |
| *Cotula coron* | | | |
| *Melaleuca raphiophylla* | Swamp paperbark | seasonally emergent | tree |
| *Eleocharis acuta* | Common spike-rush | seasonally-permanent emergent | Rush |
| *Schoenoplectus vallidus* | | seasonally-permanent emergent | rush |
| *Baumea articulata* | Jointed twigrush | seasonally-permanent emergent | rush |
| *Baumea juncea* | | seasonally emergent | rush |
| *Baumea rubiginosa* | | seasonally emergent | |
| *Liparophyllum sp* | | seasonally emergent | broad leaf |
| *Cycnogeton huegelii* | Water ribbons | submerged – seasonally emergent aquatic | narrow leaves |
| *Cycnogeton procera* | Water ribbons | submerged aquatic | narrow leaves |
| *Potamogeton crispus* | Curly pondweed | submerged aquatic | branched macrophyte |
| *Potamogeton ochreatus* | | submerged aquatic | branched macrophyte |
| *Potamogeton drummondii* | | submerged aquatic | submerged and floating leaves |
| *Ottelia ovalifoloa* | Swamp lily | submerged aquatic | submerged and floating leaves |
| *Stuckenia pectinatus* | | submerged aquatic | branched macrophyte |