Department of **Water and Environmental Regulation**

Department of **Primary Industries and Regional Development**

GOVERNMENT OF WESTERN AUSTRALIA

Catchment to Coast Science, modelling and monitoring plan 2016–2019

Revitalising Geographe Waterways

VASSE taskFORCE

Catchment to Coast science, modelling and monitoring plan 2016–2019

Department of Water and Environmental Regulation

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Cover photograph: Monitoring on the Vasse-Wonnerup Wetlands

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1 Introduction

1.1 Purpose

This plan outlines the science, monitoring and modelling components of the Revitalising Geographe Waterways program, which aims to tackle water quality problems in the Geographe catchment. The plan is designed to inform state and local government agencies, universities, catchment groups and members of the community about the program's science activities.

Management informed by the best-available science and knowledge is fundamental to ensuring healthy waterways in the Geographe catchment. The science, monitoring and modelling outlined in this plan will contribute to Revitalising Geographe Waterways by:

- **Increasing our understanding:** Through the science program we will increase our knowledge and understanding of our local waterways and their key ecological components and how they respond to changes in water levels and water quality.
- **Testing our hypotheses:** Decisions concerning the management of our waterways often rely on assumptions made on the basis of limited evidence. Hypotheses will be tested through monitoring, scientific experiments and the use of hydrodynamic models to test 'what if' scenarios for a range of complex issues.
- **Evaluating our actions:** Monitoring programs will enable us to assess the impacts of our current land management practices and evaluate how successful the management initiatives of the Revitalising Geographe Waterways program have been at improving water quality and waterways health.
- **Informing our decision making:** Information gained from the program will be used to inform the development of management plans for the Lower Vasse River, Vasse-Wonnerup wetlands and Toby Inlet. The information will also support decisions about surge barrier operation, reconnecting rivers and catchment management activities.

The plan will be implemented through collaborative partnerships between state and local government agencies, universities and catchment groups.

1.2 Geographical focus

This plan covers the waterways, wetlands and coastal waters of the Geographe catchment (Figure 1). Waterways within the catchment have been separated into five areas:

1. Geographe catchment and waterways (Section 2)
2. Lower Vasse River (Section 3)
3. Vasse-Wonnerup wetlands (Section 4)
4. Toby Inlet (Section 5)
5. Geographe Bay (Section 6)

Each section will include a snapshot of information describing the waterway(s), a brief outline of past science and monitoring, and a summary of science and monitoring projects to be conducted from 2016–19.

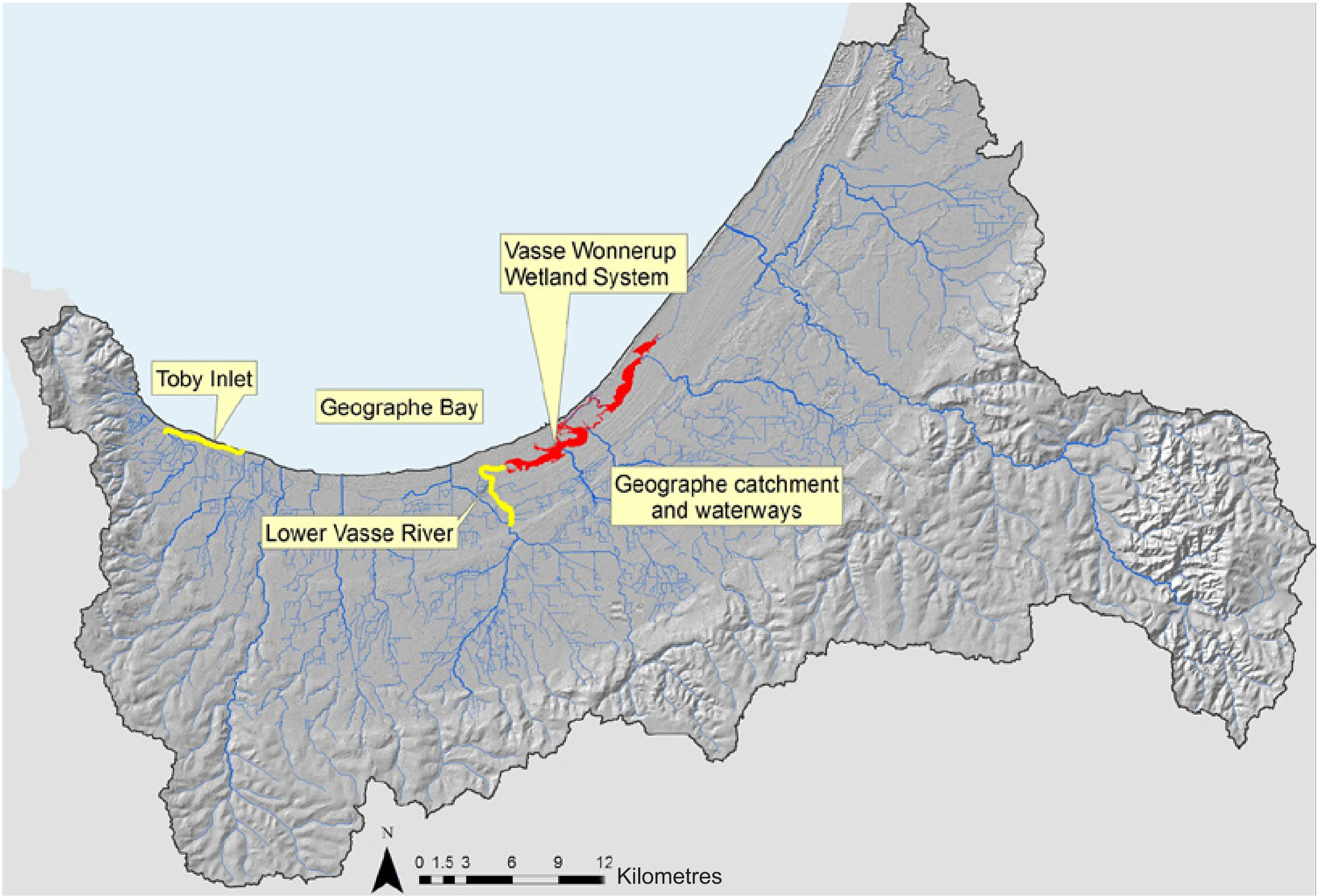

Figure 1 Overview of waterways, wetlands and coastal waters covered in this plan

2 Geographe catchment and waterways

2.1 Snapshot

The Geographe catchment is located about 250 km south of Perth, bounded by the Whicher Range to the south, Darling Range to the east and the Leeuwin-Naturaliste Ridge to the west. Sixteen waterways collect flow from across the Geographe catchment, discharging either directly to Geographe Bay or via coastal wetlands and estuaries (Department of Water 2010). Many of these waterways provide habitat for native freshwater fish, macroinvertebrates and aquatic plants, while also providing ecological linkages for terrestrial fauna. Waterways in the Geographe catchment do not flow during summer, with the exception of the Capel River.

Before European settlement very few waterways in the Geographe catchment flowed directly into Geographe Bay. In their natural state, waterways flowed into an extensive chain of wetlands stretching along the coast that flowed into the Vasse and Wonnerup estuaries. Hydrological modifications in the catchment's lower reaches began as early as the 1880s when the Capel River was diverted from the Wonnerup Inlet into Geographe Bay through the Higgins Cut. From this time until the 1950s a series of hydrological changes were made, including construction of floodgates to prevent saltwater incursion, a network of small drains to remove water from farmland, and a series of large arterial drains and river diversions for discharging surface flow directly into Geographe Bay (Department of Water 2010). The Vasse Diversion Drain was constructed in 1924 and diverts flow of about 65% of the Upper Sabina River and 90% of the Upper Vasse River directly to Geographe Bay.

Clearing in the catchment and drainage modifications have resulted in large increases in river flow and erosion problems in many of the catchment's waterways. These changes, combined with the increased nutrient loads entering the waterways from agricultural and urban land uses, have resulted in water quality issues for the receiving wetlands.

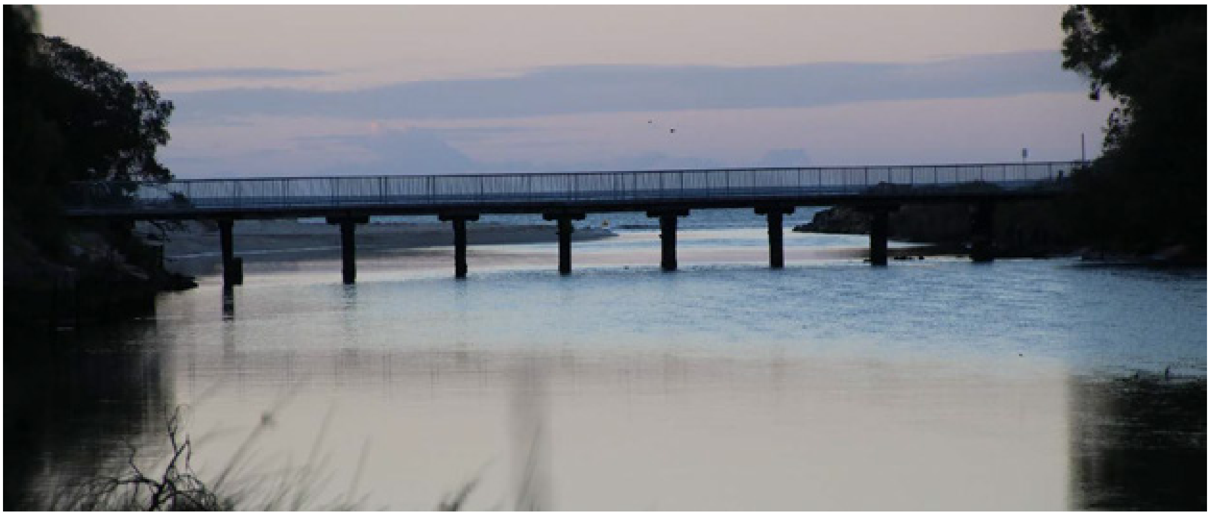

Plate 1 The Vasse Diversion Drain flowing into Geographe Bay

2.2 Past science and monitoring

The following key water quality monitoring programs and water quality initiatives have been conducted in the Geographe catchment and waterways:

- a catchment-wide sampling program: 21 sites have been sampled fortnightly since 1996 for physical parameters, nutrients and phytoplankton by the Department of Water (now the Department of Water and Environmental Regulation [DWER] – see Figure 2).
- the Greener Pastures Program: 26 sites sampled fortnightly by the Department of Agriculture and Food.
- the former Busselton Environmental Improvement Initiative (2000–06) that included snapshot water quality sampling by the Water Corporation at 63 mixed rural properties in the southern Geographe Bay catchment area.

The data from these water quality programs helped support development of the Geographe catchment model and subsequent development of the *Vasse-Wonnerup wetlands and Geographe Bay water quality improvement plan* (WQIP) (Department of Water 2010). The WQIP outlines nutrient load reduction targets for these waterways and recommends the implementation of best management practices to achieve those targets.

Between 1999 and 2010 GeoCatch developed and implemented seven River Action Plans for priority catchment waterways. These plans included foreshore assessments of main waterways, landholder surveys and capacity building, flora assessments and recommendations for management. Fish monitoring was carried out on the Capel, Vasse, Ludlow, Abba and Buayanyup rivers; Ironstone Gully, Carbunup and Naturaliste streams (Jingarmup, Dantatup, Dugulup); and Meelup Brook. Implementation of these plans is ongoing and has resulted in riparian restoration, fencing, weed control and increased awareness and understanding of riparian management by landholders.

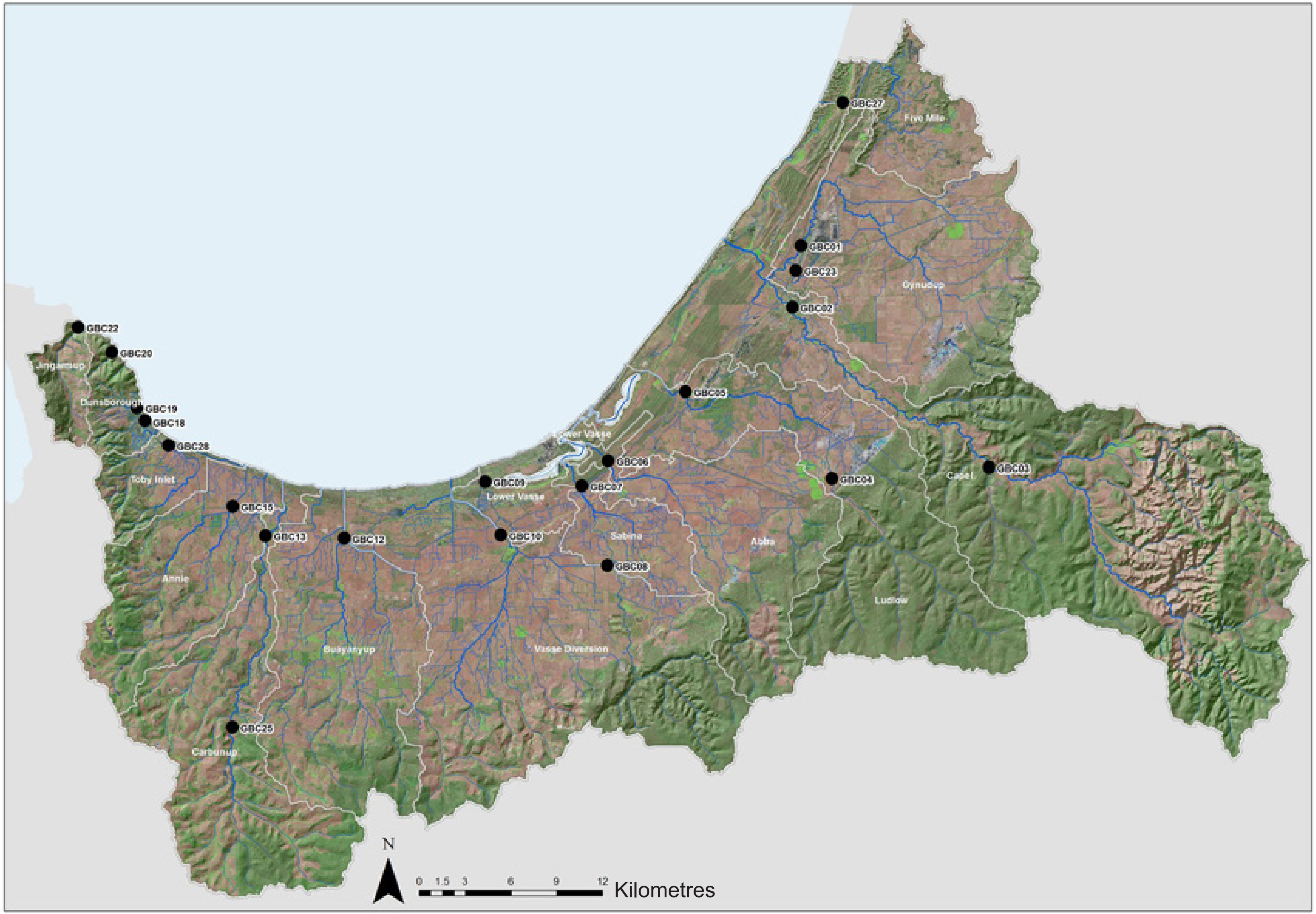

Figure 2 Current water quality monitoring sites in the Geographe catchment

2.3 Science and monitoring 2016-19

The science projects to be conducted in the Geographe catchment and waterways from 2016–19 are outlined in Table 1.

Fish surveys will be undertaken in priority waterways to provide important baseline information and to develop a better understanding of the ecological health of these waterways.

Soil amendment products and dairy effluent upgrades will be trialled and monitored, providing guidance on their effectiveness for improving water quality in catchment waterways.

A key aspect of the science program will be a continuation of fortnightly water quality monitoring across the catchment to assess water quality trends over time and support updating of the Geographe catchment model. The model will be used to update the Vasse-Geographe WQIP during the next three years. Monitoring will provide information to assess the effectiveness of trials being conducted as part of the Revitalising Geographe Waterways program (e.g. soil amendment products and dairy effluent upgrades).

These projects will provide information to support management decisions about the future of our catchment waterways.

Table 1 *Science, monitoring and modelling for Geographe catchment and waterways 2016-19*

Project	Lead agency	Why?	Timing	Parameters investigated	Further information
Catchment water quality monitoring program	DWER	To monitor trends in water quality over time and to populate the Geographe catchment model.	Ongoing Fortnightly	21 sampling sites monitored for physical parameters and nutrients (Figure 2).	The WQIP will be updated and finalised by December 2019. Water quality data is available at: http://water.wa.gov.au/maps-and-data/monitoring/water-information-reporting.
Update Geographe catchment model	DWER	To help understand the impact of changes to the system, guiding decisions related to reconnecting rivers, surge barrier operation etc. To calculate daily flows, annual loads and load reduction targets for each of the reporting subcatchments entering the Vasse-Wonnerup estuary and Geographe Bay.	Completed June 2018	Water levels, physical parameters, tidal forcing and catchment flushing using data from the catchment water quality monitoring program.	Model will be updated by June 2018.
Soil amendment trial monitoring program	DWER	To evaluate the success of soil amendment products in reducing nutrient loss from high-risk land uses such as turf and dairy farms.	June 2017–December 2018	Nutrients and physical parameters at selected farms.	A monitoring report on the effectiveness of the soil amendment trial will be developed by June 2019.
Monitoring the success of dairy effluent upgrades	DWER	To evaluate the success of dairy effluent upgrades in improving water quality.	December 2017–June 2019	Nutrients and physical parameters at selected farms.	Updates will be provided on the Revitalising Geographe Waterways website.
Fish surveys	Murdoch University	To provide baseline information on fish species and abundance in catchment waterways.	2017	Species and abundance in priority waterways.	Report June 2018

3 Lower Vasse River

3.1 Snapshot

The Lower Vasse River flows through the centre of Busselton into the internationally significant Vasse-Wonnerup wetlands. The river is highly valued by the community and has long been an iconic town feature and focal point for recreational and social events. Improving the visual amenity of and water quality in the Lower Vasse River is a priority for the wider community.

The Vasse River flows only in the winter months, with little or no flow in summer. Water levels in the Lower Vasse River during summer are maintained by check boards at the Butter Factory, which form a still pool. In recent decades poor water quality has negatively affected this section of the river, including annual blue-green algal blooms. The blooms reduce the amenity of the Lower Vasse River and often result in offensive odours.

The potential for redirecting water either back through the wetlands/estuary or down the Lower Vasse River is frequently a subject of community discussion.

Plate 2 Lower Vasse River

3.2 Past science and monitoring

Early science and monitoring in the Lower Vasse River focused on water quality and sediment characteristics, a reflection of the poor water quality and algal blooms of recent decades. Initiatives include:

- routine water quality monitoring since 1996 by the Department of Water (now DWER)
- an oxygenation trial initiated by GeoCatch in the summer of 1998–99 (White 1999)
- sediment water quality and remediation studies (Shire of Busselton 1998a, 1998b; Sinclair Knight Merz 1999)
- the 1999 Lower Vasse River Cleanup Program (LVRCP).

The LVRCP aimed to improve the Lower Vasse River's ecological health and provide a practical demonstration of integrating and coordinating technical, ecological and community input into river rehabilitation. The LVRCP included numerous trials of water quality improvement initiatives including dredging, phoslock trials, oxygenation, macrophyte trials, reed rafts, flocculating clays and revegetation. Paice (2005) provides a comprehensive review of the program. More recent scientific studies and monitoring in the Lower Vasse River include:

- aquatic macroinvertebrate diversity and abundance (Smith 2006)
- the feasibility of restoring submerged macrophytes (Paice 2008)
- the fish fauna of the Vasse River and colonisation by feral goldfish (Morgan et al. 2004)
- water quality treatment trials during the 2014–15 summer by the City of Busselton.

At present, water quality at the top of the Lower Vasse River is monitored on a fortnightly basis by DWER and includes physical parameters, phytoplankton and occasional nutrients at two sites from November to May.

Plate 3 Phoslock trials in the Lower Vasse River as part of the 1999 Lower Vasse River Cleanup Program

3.3 Science and monitoring 2016–19

The science and monitoring projects to be undertaken in the Lower Vasse River from 2016–19 are summarised in Table 2.

Fortnightly water quality monitoring will continue in the Lower Vasse River, supporting the validation and calibration of the Lower Vasse River flood and drainage model. The model has been developed to better understand the river's water movement and drainage and explore opportunities for reconnecting rivers (i.e. the implications of redirecting water either back through the wetlands/estuary or down the Lower Vasse River). Fortnightly water quality monitoring will also continue to track water quality over time and seasonal changes in river health.

Water quality treatment trials are a key aspect of the science program for the Lower Vasse River. These trials will investigate the effectiveness of various treatments to improve the river's water quality and visual aesthetics.

These projects will provide information to support management decisions about the future of the Lower Vasse River, including the feasibility of water/sediment treatment options and/or reconnecting rivers as a means of improving water quality. Technical reports will describe these options in detail, with management outcomes ultimately presented in the *Lower Vasse River water management plan.*

Plate 4 Setting up water quality treatment trials in the Lower Vasse River, December 2016

Table 2 Science, monitoring and modelling for the Lower Vasse River 2016-19

Project	Lead agency	Why?	Timing	Parameters investigated	Further information
Catchment water quality monitoring program: Lower Vasse River	DWER	To populate the Lower Vasse river flood and drainage model and monitor changes in water quality over time.	Ongoing Fortnightly	One site, located adjacent to the Peel Terrace Footbridge in the Lower Vasse River, monitored for physical parameters, phytoplankton and nutrients.	The WQIP will be updated and finalised by December 2019. Water quality data is available at: http://water.wa.gov.au/maps-and-data/monitoring/water-information-reporting.
State Algal Strategy and Public Health Program	DWER	To monitor water quality and phytoplankton during the summer high-risk fish kill and algal bloom period to provide early warning of potential fish kills and determine the health risk posed by phytoplankton.	Ongoing Fortnightly November–April	Two sites in the Lower Vasse River, located adjacent to the Strelly Street Bridge and the Peel Terrace Footbridge, monitored for physical parameters, nutrients and phytoplankton (density and type).	Water quality data is available at: http://water.wa.gov.au/maps-and-data/monitoring/water-information-reporting.
Water quality treatment trials	DWER	To investigate and report on the effectiveness of water quality treatments to improve the water quality in and visual aesthetics of the Lower Vasse River.	December 2016 – June 2019	New water quality treatments such as algae flocculants and new generation phosphorus binding clays. The potential for dredging and removal of bottom sediment. The extent and likely impact of water lilies on the water quality and ecology of the Lower Vasse River.	Technical report by June 2019
Lower Vasse River flood and drainage model	DWER	To support understanding of the water movement and drainage in the Lower Vasse River and to explore a number of scenarios whereby rivers may be fully or partially directed back to the wetlands, identifying connection opportunities.	Model complete Report by June 2017	Flood data, water levels and physical parameters using data from the catchment water quality monitoring program.	Report on scenarios by June 2017

4 Vasse-Wonnerup wetlands

4.1 Snapshot

The Vasse-Wonnerup wetlands are situated within an extensive low-lying coastal depression located 14 km north-east of Busselton in the south-west of Western Australia. The wetlands consist of the Vasse and Wonnerup estuaries and their exit channels, the Wonnerup Inlet, and the seasonal connection between the two estuaries known as Malbup Creek (Figure 3). The Deadwater and Swan Lake are associated wetlands.

Water flow into and out of the wetlands has been dramatically altered since European settlement. Drainage networks have been constructed throughout the catchment and several rivers that formerly discharged to the Vasse-Wonnerup estuary have been diverted to the sea. It is estimated that the wetlands now receive only around 20% of their original pre-modified flow. Currently the Lower Vasse, Lower Sabina and Abba rivers flow into the Vasse Estuary, while the Ludlow River flows into the Wonnerup Estuary before discharging into the Wonnerup Inlet (intermittently open to Geographe Bay).

In 1908 floodgates (surge barriers) were installed on the exit channels of the Vasse and Wonnerup estuaries to regulate flow, exclude seawater and minimise flooding of the adjoining agricultural land and Busselton township (Lane et al. 2011). In 2004 the new surge barriers were installed and include a fish gate to allow fish to move between the estuaries and the Wonnerup Inlet and to allow exchange of water between the two systems. The surge barriers automatically open when the water level in the estuary is higher than the Wonnerup Inlet.

Salinity in the Vasse and Wonnerup estuaries ranges from fresh to hypersaline over an annual cycle. Rivers flush both estuaries to fresh in winter. During summer salinities rise dramatically from fresh to saline/hypersaline due to leakage, controlled inflow through the floodgates and evaporation. Strong annual and interannual variances occur in nutrient enrichment, water quality and water depths.

Plate 5 The Vasse Estuary surge barrier

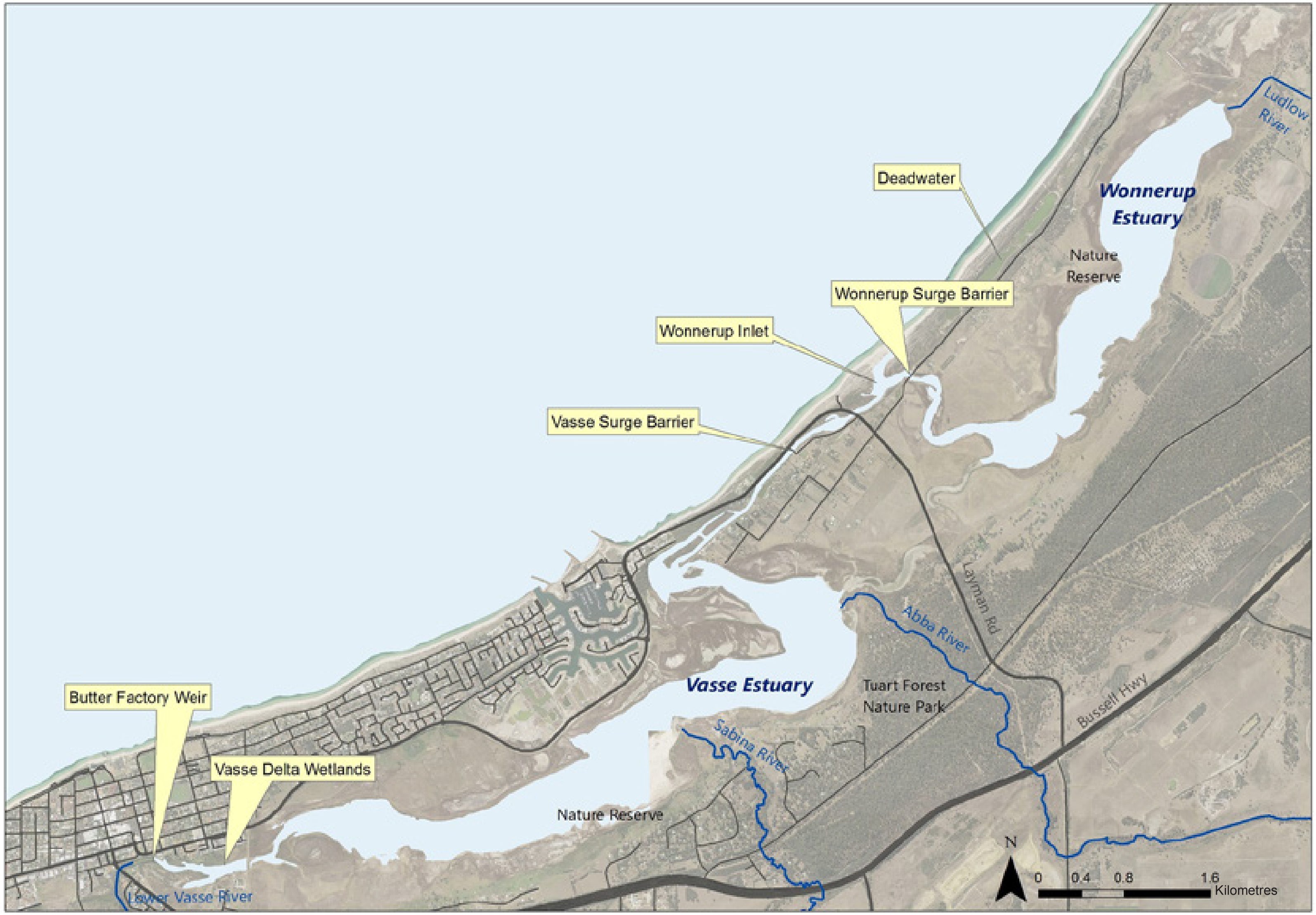

Figure 3 The Vasse-Wonnerup wetlands

The Vasse-Wonnerup wetlands have a wide range of ecological, cultural, social and economic values. The wetlands regularly support more than 20 000 birds at one time – including nationally and internationally significant populations of waterbirds and the largest regular breeding colony of the black swan, *Cygnus atratus,* in Western Australia (Lane et al. 1997). The importance of the wetlands for waterbird habitat was recognised in 1990 when the Vasse-Wonnerup wetland system was listed as a 'Wetland of International Importance' under the Ramsar Convention (Government of Western Australia 2000).

Despite their significance, the wetlands have experienced eutrophication for many years due to nutrient inputs from the catchment, reduced flows and longer water residence times. Water quality issues in the wetlands are expressed by macroalgal blooms, toxic phytoplankton, fish kills and noxious odours. These water quality issues are common upstream of the Vasse Estuary surge barriers in the summer months.

Sudden mass fish deaths at the Vasse and Wonnerup floodgates were reported as early as 1905 before the floodgates were installed, with other large kills recorded in the 1930s, 1960s, 1980s and late 1990s *(*Lane et al. 1997*).* Fish kills have occurred in recent years in January and February 2012, April 2013 and February 2014 with causes ranging from anoxia to high temperatures, algal blooms and/or toxic phytoplankton (Lane et al. 1997; Hart 2014; Tweedley et al. 2014).

In recent years management efforts to improve water quality and reduce the frequency and severity of fish kills have included the artificial opening of the Wonnerup sandbar, floodgate management, removal of algae and a plant to oxygenate the water.

4.2 Past science and monitoring

The Vasse-Wonnerup wetlands have been the focus of considerable research and monitoring during the past 10 years. Early science and monitoring associated with the wetlands focused on waterbirds and vegetation monitoring. Waterbird surveys were primarily conducted and/or commissioned by the Royal Australasian Ornithologists Union and the Department of Parks and Wildlife (now Department of Biodiversity, Conservation and Attractions [DBCA]). Past research and monitoring includes:

- aerial annual waterbird counts in the 1960s and 1970s (Halse et al. 1990)
- vegetation mapping (1980) and monitoring (1999) (Tingay & Tingay 1980; Froend 1999, 2000)
- comprehensive waterbird surveys from 1981–85 (Janensch et al. 1988, 1993)
- regional waterbird surveys from 1986–1992 (Halse et al. 1990)
- waterbird response to disturbance (Bamford & Bamford 1995)
- Vasse Estuary waterbird survey from 1998–2000 (Lane et al. 2011)
- black swans, broods and nesting effort and waterbirds in 2009 (Bennelongia 2009a, 2009b)
- monthly waterbird monitoring since 2014 by DBCA
- annual surveys by Birds Australia (the Shorebirds 2020 program).

Plate 6 Australian pelicans congregate on the lower reaches of the Vasse-Wonnerup wetlands to feed

Water quality monitoring became a focus in the late 1990s to address worsening water quality and to support waterbird data. Water quality monitoring has been conducted with increasing frequency since the mid-1990s, particularly in the Vasse Estuary where poor water quality, poor amenity and fish kills occur. Past monitoring and research includes:

- summer quality monitoring by the Department of Water (now DWER) since 1996
- fortnightly water quality monitoring at 12 sites in the Vasse and Wonnerup estuaries since 2014 (DWER) (Figure 4)
- summer water quality monitoring within the Vasse Estuary channel by DWER for the 2014–15 seawater inflow trial (Figure 4 inset)
- two in-situ telemetered buoys continuously monitoring physical parameters in the Vasse Estuary by DWER as part of the fish kill mitigation strategy (Figure 4 inset)
- monitoring of water levels at the Vasse and Wonnerup floodgates (Water Corporation)
- water quality monitoring from 1998–2000 to coincide with, and continue beyond the 1998–2000 waterbird surveys (Lane et al. 2011)
- hydrodynamic modelling by DWER.

The ecological character description by Wetland Research and Management (2007) identified a paucity of quantitative data on the ecological values of the Vasse-Wonnerup wetlands including fish, invertebrates and macrophytes, as well as a gap in knowledge of sediments and nutrient cycling. Since 2007 a considerable amount of data and research has been undertaken:

- baseline fish and crayfish surveys (Tweedley et al. 2012, 2013a; Beatty et al. 2014)
- the ecology of the black bream and acoustic fish tracking projects (Tweedley et al. 2014; Cottingham et al. 2015)
- vegetation mapping at the floristic community level (Webb et al. 2009)

- draft mapping of vegetation communities at 1:50 000 (DBCA)
- annual snapshot surveys by Murdoch University (since 2006) characterising the composition, distribution and abundance of aquatic macrophytes, phytoplankton and macroinvertebrates in relation to sediments and water quality (documented in Wilson et al. 2008a; Chambers et al. 2009, 2010, 2011, 2013a, 2013b, 2014, 2015)
- sediment characterisation and benthic nutrient cycling studies (by Wilson et al. 2008b and Smith & Haese 2008 respectively).

These studies have contributed to our knowledge of the relationship between water quality, sediments and ecological processes.

A comprehensive summary and description of ecological processes and interactions is given in *Ecological character description Vasse-Wonnerup wetlands Ramsar site south-west Western Australia* (Wetland Research and Management 2007) for work undertaken before 2007 and *The Vasse Wonnerup wetlands system research node background document* (South West Catchments Council 2013) for work undertaken from 2007–13.

Much of the recent science and monitoring for the Vasse-Wonnerup wetland system has been developed and implemented with support and advice from scientists and managers who have a strong interest and/or research involvement in the wetlands. In 2015 this group was formalised to support the management of the wetlands. The group, known as the Vasse Wonnerup Science Advisory Group, has been instrumental in setting priorities for the science, monitoring and modelling planned for wetlands for the next four years.

Plate 7 The Science Advisory Group (from left to right): Stephen Beatty (Murdoch University), Kim Williams (DBCA), Peta Kelsey (DWER), Emily Hughes-dit-Ciles (SWCC), Jane Chambers (Murdoch University), Jim Lane (DBCA), Fiona Valesini (Murdoch University), Kieryn Kilminster (DWER), James Tweedley (Murdoch University). Absent: Kathryn McMahon (Edith Cowan University), Kath Lynch and Linda Kalnejais (DWER).

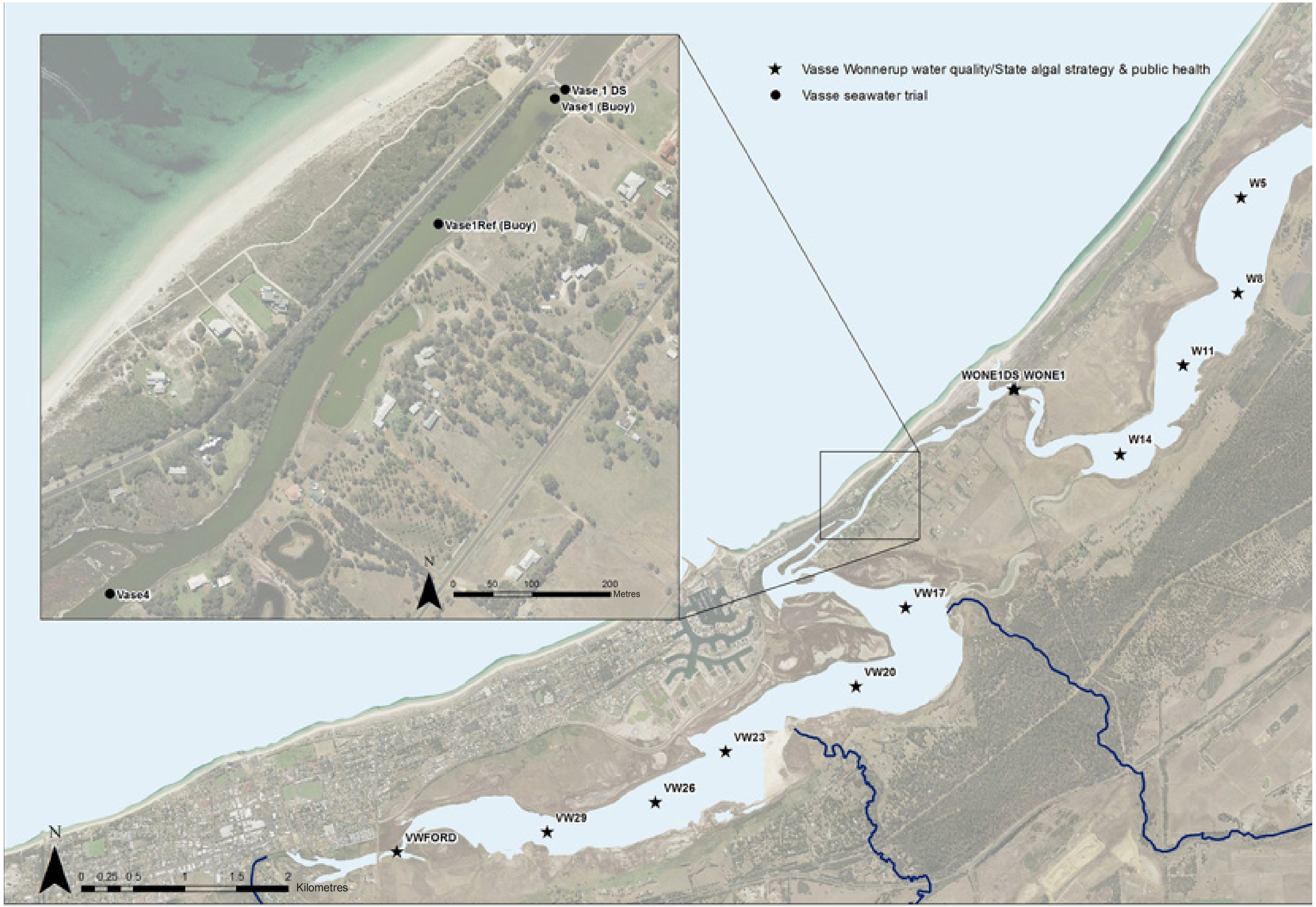

Figure 4 Water quality monitoring sites in the broader Vasse-Wonnerup wetlands and Vasse Estuary channel (inset)

4.3 Science and monitoring 2016–19

The science and monitoring projects to be undertaken in the Vasse-Wonnerup wetlands from 2016–19 are summarised in Table 3.

Underpinning the Vasse-Wonnerup science program is a comprehensive water quality monitoring program to monitor changes in water quality over time, determine the health risk posed by phytoplankton blooms and support the fish kill mitigation and response program. This program, coupled with an integrated ecological monitoring program (including fish, waterbirds, benthic invertebrates and macrophytes), will improve understanding of the linkages between ecological parameters across a range of habitats as the seasons and water levels change.

Water quality data will support the development of a hydrodynamic model for the Vasse Estuary. The model will also increase knowledge about the relationship between salinity, water levels, water movement and flushing in the Vasse-Wonnerup estuary as a result of floodgate management, bar opening and/or redirection of drains/rivers. This will help develop new operational guidelines for the Vasse Estuary surge barrier and management actions for the *Vasse-Wonnerup Estuary operational plan.*

Investigations to improve water quality of the Vasse Estuary will include seawater inflow trials, oxygenation trials and the feasibility of sediment removal.

Several undergraduate and postgraduate studies will be conducted during the next four years that will contribute to scientific knowledge of the wetlands. Key topics are food webs, nutrient sources and pathways, the genetic diversity and resilience of estuarine seagrass and key social values of the wetlands.

Table 3 Science, monitoring and modelling for the Vasse-Wonnerup wetlands 2016-19

Project	Lead agency	Why?	Timing	Parameters investigated	Further information
Vasse-Wonnerup water quality program	DWER	To monitor changes in water quality over time and to populate the wetlands' hydrodynamic model.	Ongoing Fortnightly in the Vasse Estuary (additional nutrients monthly only); monthly in the Wonnerup Estuary	Six sites in the Vasse Estuary and six sites in the Wonnerup Estuary sampled for physical parameters, phytoplankton and nutrients (see Figure 4 for site locations). Seasonal (quarterly) physical profiles of each estuary at 250 m intervals.	Water quality data is available at: http://water.wa.gov.au/maps-and-data/monitoring/water-information-reporting.
State Algal Strategy and Public Health Program	DWER	To monitor water quality and phytoplankton during the summer months to provide early warning of potential fish kills and determine the health risk posed by phytoplankton.	Ongoing Fortnightly November–April	Physical parameters, nutrients and phytoplankton (density and type). Collected simultaneously with the Vasse-Wonnerup water quality program (see Figure 4 for site locations).	Water quality data is available at: http://water.wa.gov.au/maps-and-data/monitoring/water-information-reporting.
Fish kill mitigation monitoring program	DWER	To provide continuous and instantaneous data to support the fish kill mitigation and response program. To improve understanding of the diurnal conditions of the waterbody at the Vasse Estuary floodgates to verify trigger criteria set for the fish kill period.	November to March 2016–19 Loggers are continuous	Two in-situ telemetered buoys continuously monitoring physical parameters in the Vasse Estuary. These buoys are located at VASE1 and VASE1REF (Figure 4).	Water quality data is available at: http://water.wa.gov.au/maps-and-data/monitoring/water-information-reporting. Report provided to community and stakeholders by 30 June 2019.
Vasse Estuary seawater inflow trial	DWER	To assess the water quality conditions in the Vasse Estuary channel under different surge gate management conditions and contribute to a review of surge barrier operation guidelines. To monitor changes in water quality and to provide data to validate and calibrate the Vasse wetlands hydrodynamic model.	2016–18 Summer (November to March): weekly Winter: fortnightly (additional nutrients monthly only)	Summer: four sites monitored weekly for physical parameters, nutrients, chlorophyll *a* and phytoplankton (VASE1DS, VASE1, VASE1Ref, VASE4, Figure 4). Physical profiles also done at five additional sites in the Vasse Estuary channel. Winter: four sites monitored fortnightly for nutrients, chlorophyll *a*, phytoplankton and physical parameters.	Final report December 2018

Project	Lead agency	Why?	Timing	Parameters investigated	Further information
Vasse Estuary oxygenation trial	DWER	Determine if the oxygenation plant at the Vasse Estuary channel has helped increase dissolved oxygen concentrations within the water column after low oxygen conditions. Estimate the range of influence of the artificially oxygenated water. Estimate the oxygen demand and speed of the system recovery at different oxygen delivery rates, and assess the suitability of new technology.	Late summer 2015–16 and the summer of 2016–17.	Summer 2016 and 2016–17: seven sites profiled at 20 cm depth intervals for physical parameters. Data collected simultaneously with Vasse Estuary inflow trial. Continuous monitoring of physical parameters by in-situ telemetered monitoring buoys in the Vasse Estuary.	A monitoring report on the 2015–17 oxygenation trial will be available December 2017.
Annual waterbird monitoring	Birdlife Australia (Shorebirds 2020)	To collate baseline data on shorebirds and raise community awareness through participation.	Annually (February) to 2020	Waterbird counts: species and abundance.	Newsletters and communication tools www.birdlife.org.au/projects/shorebirds-2020
2016–18 monthly waterbird monitoring program	DBCA	To monitor the temporal and spatial distribution and abundance of waterbirds within the Vasse-Wonnerup wetlands. To report on Ramsar status.	2016, 2017 Monthly	Waterbird counts: species and abundance. Behavioural observations. Observations of anthropogenic disturbance.	Monitoring report December 2018
Fine scale vegetation mapping	DBCA	To gather data on the baseline condition and composition of fringing vegetation within the Vasse-Wonnerup wetlands Ramsar site.	Spring 2017	Vegetation type and condition (surveyed at a fine scale with high accuracy and resolution).	
Vegetation risk mapping	DBCA	To assess and map the risk of salinity and/or inundation to vegetation types fringing the Vasse-Wonnerup wetlands.	2017	Inundation and salinity tolerance of fringing vegetation of the Vasse-Wonnerup wetlands.	Vegetation risk map December 2017
2017–18 fish monitoring program	Murdoch University Dr James Tweedley and Dr Stephen Beatty	To track the recovery of the black bream following the 2013 fish kill. To investigate fish movement in response to hydrodynamics and floodgate management. To investigate fish movement through the sandbar and the implications of bar opening on fish immigration and emigration.	2017, 2018 bi-annual monitoring	Number of species and densities of fish. Temporal changes in the abundance of black bream Water quality parameters (salinity, temperature, dissolved oxygen) Fish movement (passive aggressive transponder tagging and fyke netting)	Monitoring reports Final report June 2019

Project	Lead agency	Why?	Timing	Parameters investigated	Further information
2016 annual aquatic macrophyte monitoring	Murdoch University Dr Jane Chambers	To continue baseline survey (started 2007). To improve understanding of the relationship between water quality and aquatic plants.	November 2016	Water quality, phytoplankton and macrophytes	Monitoring report June 2017
The genetic diversity and resilience of seagrasses in estuaries	Edith Cowan University student: yet to be determined	To increase our understanding of the genetic diversity and resilience of estuarine seagrass species across the south-west of Western Australia.	Yet to be defined	Physiological responses, genetic diversity and connectivity among populations of seagrass	PhD thesis
Source composition of organic matter and nutrients contributing to the Vasse-Wonnerup wetland system	South West Catchments Council, Edith Cowan University student, Roisin McCallum	To further understand nutrient sources and pathways.	Completion date: March 2019	Water dissolved organic matter and nutrients, particulate organic matter and potential source material (e.g. saltmarsh, trees, pasture grasses, aquatic plants).	PhD thesis
A quantitative and predictive food web for the Vasse-Wonnerup wetlands	South West Catchments Council, Murdoch University student, Sian Glazier	To identify energy sources and trophic linkages throughout the food web.	Completion date: January 2019 Field sampling to occur over two years starting in Sept/Oct 2016.	The dietary compositions of key invertebrate, fish and bird species.	PhD thesis
Understanding community values, attitudes and adaptive management in the Vasse-Wonnerup wetlands system	South West Catchments Council, Murdoch University student, Shivani Purushothman	To identify community values and perceptions of the Vasse-Wonnerup wetlands To identify what barriers and drivers exist towards the adoption of ecosystem-based management.	Completion date: October 2018	Community values, perception and attitudes of the Vasse-Wonnerup wetlands.	PhD thesis, interim reports and presentation
Analysis of bird guild data	DBCA	To understand how water quality and water levels affect bird communities.	DBCA	Bird Guilds, water quality and water levels.	Technical paper December 2017

Project	Lead agency	Why?	Timing	Parameters investigated	Further information
Investigation of wetland sedimentation over time	DWER, Edith Cowan University and the University of Western Australia	To understand sediment accumulation rates over time in the Vasse-Wonnerup wetland system.	Dec 2016	Sediment cores from the Vasse and Wonnerup estuaries.	Technical report December 2017
Sediment removal feasibility study	DWER	To understand the volume and composition of sediment in the Vasse Estuary channel.	October 2016	Parameters monitored include sediment volumes; sediment characterisation (including presence of MBO); options for removal and disposal and potential costs.	Sediment removal feasibility report December 2017
Hydrodynamic model	Department of Water, the University of Western Australia	To understand the relationship between salinity, water levels, water movement and flushing in the Vasse-Wonnerup estuary as a result of floodgate management, bar opening and/or redirecting drains/rivers.	Dec 2016	The model will provide water levels, water movement and physical parameters (salinity, temperature etc.) for selected scenarios. The model will be calibrated with data collected by the Vasse-Wonnerup water quality program, seawater inflow trial and Vasse Estuary oxygenation trial.	Vasse-Wonnerup wetlands hydrodynamic model
Integrated ecological monitoring program	DWER, DCBA and Murdoch University	Improve our understanding of the relationship between hydrology, water quality and ecological parameters.	Seasonal monitoring 2017 and 2018	Monitoring of waterbirds, water levels, water quality, phytoplankton, aquatic plants, benthic macroinvertebrates and fish in five habitat zones throughout the Vasse and Wonnerup estuaries and Wonnerup Inlet.	Technical report June 2019

5 Toby Inlet

5.1 Snapshot

Toby Inlet is located east of Dunsborough in the south-west of Western Australia. The inlet is a narrow inter-barrier lagoon running parallel to the shore and separated from the ocean by high beach ridges (Pen 1997). The estuary is of ecological and social importance, providing habitat for fish, waterbirds and frogs, as well as a recreational area for residents and tourists.

The catchment has a long history of clearing and drainage modification to allow for productive farming in the area. The most recent drainage modification was construction of the Station Gully channel that drains from the subcatchment and flows from the eastern end of Toby Inlet to the ocean. Overall, the system's hydrology has been significantly altered from its natural state – with consequences for the water quality and ecological health in the inlet. Nutrients and sediments from the catchment and urban development surrounding the estuary have also had a significant impact on estuary health.

The current system has a fragile ecology and is eutrophic, shallow and periodically closed. Seepage from septic tanks, pollution and habitat decline are some of the immediate pressures on the inlet. Algal blooms, deoxygenation and fish kills are a regular occurrence during summer and adversely affect the ecological function and recreational use of the estuary.

The potential for permanent reconnection of waters directly to the ocean or back through the Station Gully drain is frequently a subject of community meetings.

Plate 8 Toby Inlet

5.2 Past science and monitoring

A series of baseline data, including terrestrial and aquatic fauna, vegetation, water quality and macroinvertebrate data, were collected for the Toby Inlet by the Toby Inlet Catchment Group in 1996 and 1997. The data were used to develop a management plan for Toby Inlet and associated wetlands (Comer & Clay 1999). Further work was conducted from 2000–01 supporting a second management plan (Clay 2005). These additional studies included:

- groundwater monitoring by the Department of Water (now DWER) (Water and Rivers Commission 1999)
- an entrance management study (Rogers & Associates 2000)
- ecological studies in the Toby Inlet subcatchment including vegetation and flora, landscape and bird habitats (documented in Groundlink Planning Consultants 2000; Clay 2000; Clay & Henderson 2001 respectively).

An understanding of sediment characteristics and quality was gained in 2005–07 from investigations of monosulfidic black ooze (MBO), acid sulfate soils, metals and sediment depths (documented in ENV Australia Pty Ltd 2007 and Ward 2009).

DWER has monitored phytoplankton and occasional nutrients in the Toby Inlet since 2008. Since 2014 regular monitoring has been undertaken from November to May to assess water quality trends over time as part of the Geographe catchment water quality monitoring program. Since 2010 water quality has been monitored on a fortnightly basis during the summer months as part of the State Algal Strategy and Public Health Program to provide early warning of potential fish kills and determine the health risk posed by phytoplankton.

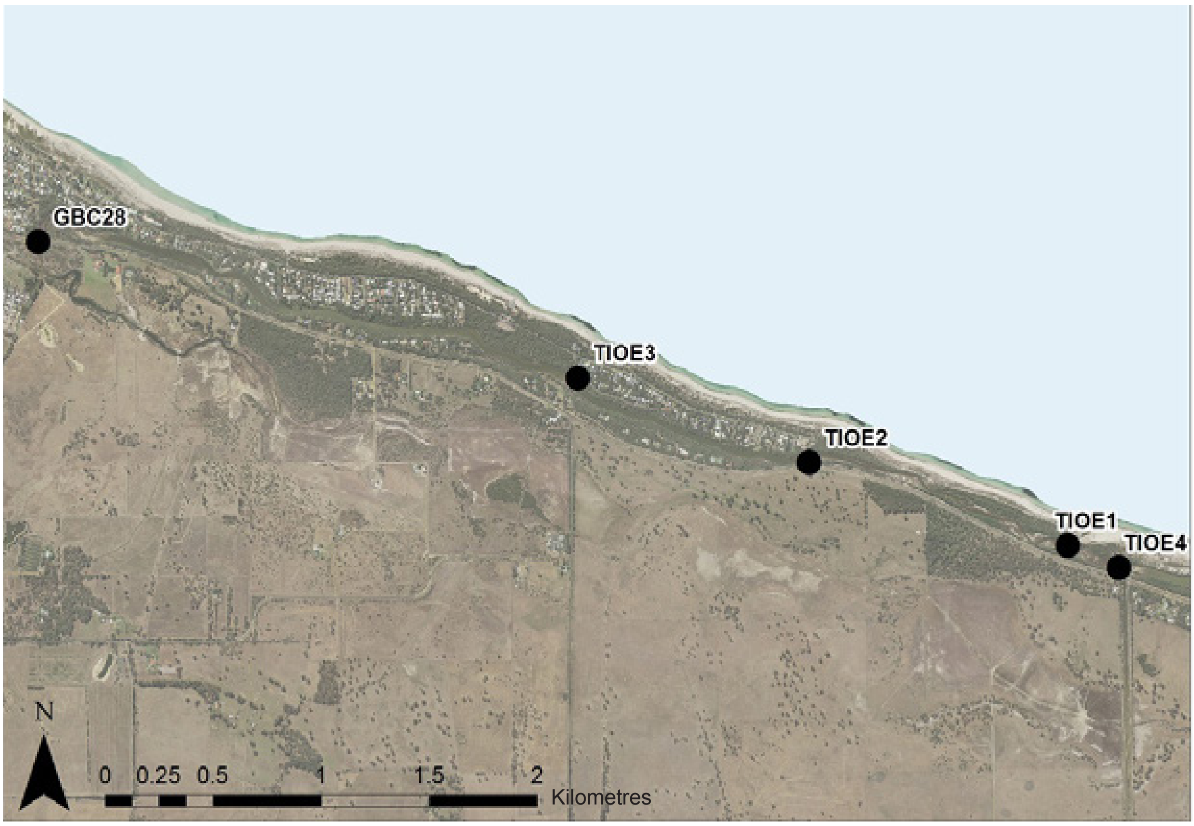

Figure 5 Water quality monitoring sites in the Toby Inlet

5.3 Science and monitoring 2016–19

Table 4 summarises the science and monitoring projects and programs to be undertaken for the Toby Inlet from 2016–19.

The Toby Inlet hydrodynamic model has been developed to better understand water movement and flushing of the inlet. Continuation of a fortnightly water quality monitoring program will support the model and help assess opportunities to reconnect Toby Inlet to maximise circulation and improve water quality. This monitoring will continue to track water quality over time, including seasonal changes in the health of the inlet.

Properties on the western side of Toby Inlet will be converted from septic tanks to deep sewage in 2017. Water quality monitoring before and after the conversion will allow us to quantify the environmental impacts of septic systems on valued water resources.

These programs will provide information to support management decisions about the future of the Toby Inlet. Outcomes will ultimately be presented in the *Toby Inlet water management plan.*

Table 4 Science, monitoring and modelling for Toby Inlet 2016–19

Project	Lead agency	Why?	Timing	Parameters investigated	Further information
State Algal Strategy and Public Health Program	DWER	To monitor water quality and phytoplankton during the summer high-risk fish kill and algal bloom period to provide early warning of potential fish kills and determine the health risk posed by phytoplankton.	Ongoing Fortnightly November–April	Four sites monitored for physical parameters, phytoplankton and nutrients. (sites TIOE1-4, Figure 5).	Water quality data is available on the DWER website: http://water.wa.gov.au/maps-and-data/monitoring/water-information-reporting.
Catchment water quality monitoring: Toby Inlet	DWER	Water quality data will be used to monitor trends in water quality over time and will be used to populate the Toby Inlet hydrodynamic model.	Ongoing Fortnightly	One site in Toby Inlet monitored for physical parameters, phytoplankton and nutrients (see Figure 5 for the location of site GBC28).	The WQIP will be updated and finalised by December 2019. Water quality data is available on the DWER website: http://water.wa.gov.au/maps-and-data/monitoring/water-information-reporting.
Toby Inlet sewage infill monitoring program	DWER Water Corporation	To verify the migration of septic tank effluent to valued water resources and to quantify environmental impacts on valued water resources.	Pre-sewage infill monitoring: late summer 2017 (following high loading of septic systems with no flushing). Post-sewage infill monitoring (similar timing to above)	The collection, storage and reporting of ground and surface water quality data monitoring after the conversion from septic to deep sewage on the western side of the inlet using data from the State Algal Strategy and Public Health Program and catchment water quality monitoring.	Monitoring report
Toby Inlet hydrodynamic model	DWER	To improve our understanding of water movement in the inlet and model a range of scenarios whereby water circulation and flushing would be increased.	Hydrodynamic model complete	Water levels, physical parameters, tidal forcing and catchment flushing data using data from the catchment water quality monitoring program.	Technical report on scenarios June 2017

6 Geographe Bay

6.1 Snapshot

Geographe Bay is highly valued by the local community and visitors to the area. The bay provides habitat for a diverse combination of tropical and temperate species, and its values have been recognised by its inclusion in the Ngari Capes Marine Park.

For the purpose of this plan, Geographe Bay is defined by the nearshore seagrass meadows within southern Geographe Bay from Dunsborough to Capel, aligning with the coastal boundaries of the Geographe catchment. Two key ecological themes are considered in this plan: water quality and seagrass meadows.

The nearshore shallow waters of Geographe Bay support extensive seagrass meadows that serve important ecological functions. Seagrasses stabilise sediments, provide habitat for fish and use nutrients in the water column (Limbourn & Westera 2006). Seagrass meadows of nearshore Geographe Bay in 2–4 m depth are dominated by *Posidonia sinuosa* (McMahon & Walker 1998). *Amphibolis antartica* is found on the edges of these meadows and on limestone outcrops (McMahon & Walker 1998).

Geographe Bay receives ephemeral surface flow from 16 waterways that dissect the catchment. Of these, only the Lower Vasse, Lower Sabina, Abba and Ludlow rivers drain into the Vasse-Wonnerup wetlands before discharging through the Wonnerup Inlet into Geographe Bay. Geographe Bay also receives flow from groundwater sources. There is concern that the nutrients flowing into Geographe Bay from the catchment may be putting the bay's nearshore water quality and marine ecosystems at risk.

Plate 9 Aerial view of nearshore Geographe Bay and the Busselton jetty

6.2 Past science and monitoring

Past research on and monitoring of seagrass, as well as water quality monitoring in nearshore Geographe Bay, includes:

- mapping of seagrass using aerial photography, and the analysis of changes in seagrass extent over time in 1993, 2004 and 2009 (documented in Conacher 1993; GEM Group School of Earth and Geographical Sciences 2004; and Van Neil et al. 2009).
- monitoring seagrass and water quality in the 1990s, primarily by the University of Western Australia Botany Department (studies include McMahon 1994; McMahon & Walker 1998; McMahon et al. 1997; DAL Science and Engineering 1995; Lord & Associates 1995; Murdoch University 1996; Searle & Logan 1978)
- a nearshore marine monitoring program (Sinclair Knight Merz 2003)
- seagrass wrack dynamics in Geographe Bay were investigated to inform the development of seagrass management approaches at Port Geographe (documented in Oldham et al. 2010).
- from 2005 to 2006 the Department of Water (now DWER) started a catchment-wide sampling program, which included a number of sites in the coastal waters of nearshore Geographe Bay at the outlets of major drains
- quantification of the distribution of benthic habitats, seagrasses, epiphytes, fishes, invertebrates and water quality over summer/autumn 2006–07 at 20 sites in the seagrass meadows of southern Geographe Bay (Westera et al. 2007).

Key monitoring programs being conducted at present include catchment water quality monitoring and water quality monitoring at one site within nearshore Geographe Bay by DWER and the ‘Keep Watch’ seagrass health monitoring program (Figure 6). The ‘Keep Watch’ program was initiated in 2012 and has been conducted annually for five years (McMahon 2012, 2013, 2014, 2015, 2016). The project is a collaborative effort between Edith Cowan University, DBCA, Department of Fisheries, DWER and the Water Corporation. The program enhances our understanding of the linkages between nutrient enrichment from the catchment and the health of Geographe Bay, using seagrass communities as indicators of change. Results from the past five years show seagrass meadows in Geographe Bay to be in good condition.

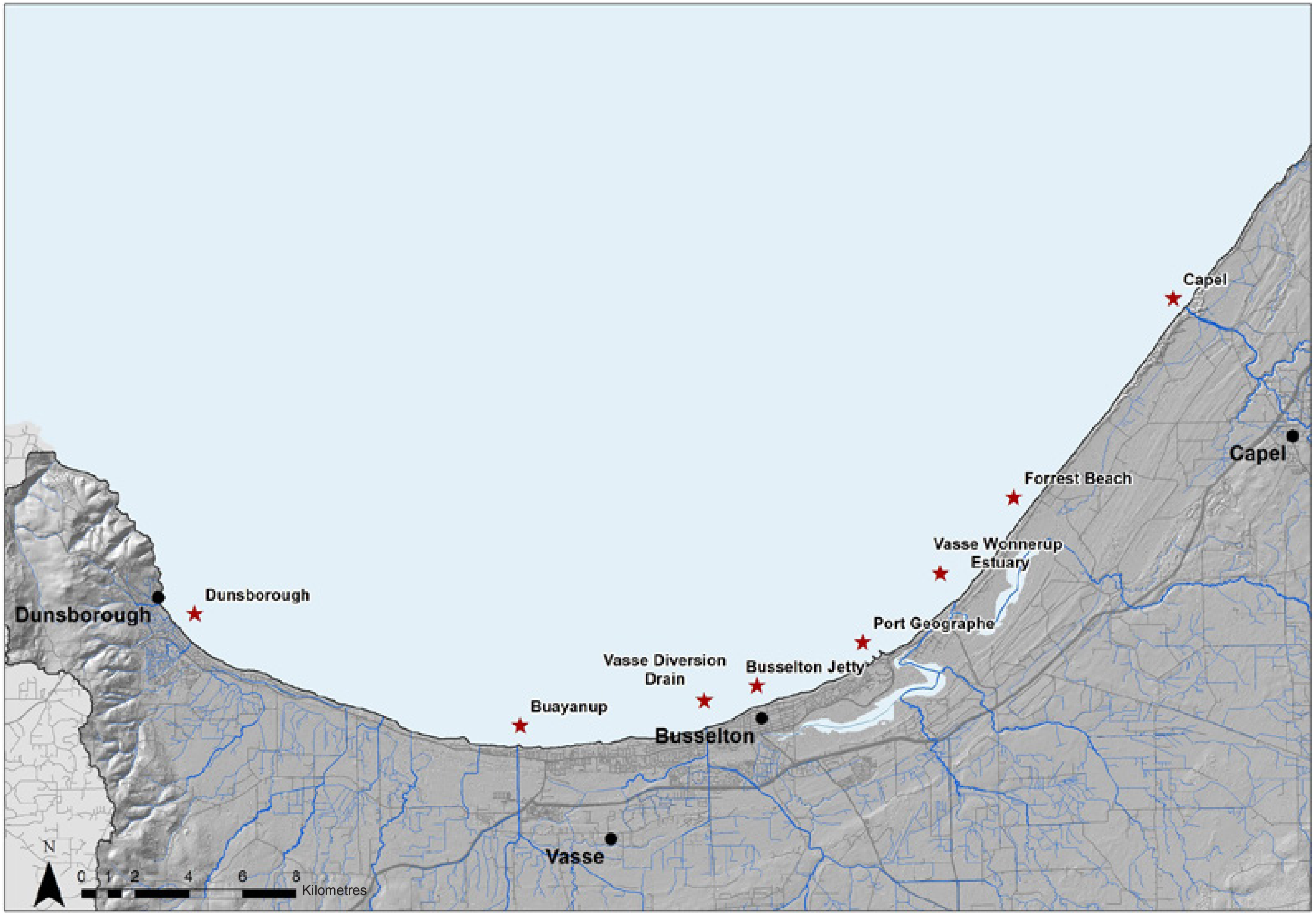

Figure 6 Map of Geographe Bay showing the 'Keep Watch' seagrass monitoring sites

6.3 Science and monitoring 2016–19

The science and monitoring projects and programs to be undertaken in nearshore Geographe Bay (seagrass and water quality) during the next four years are summarised in Table 1. The research priorities for nearshore Geographe Bay have arisen from the 'Keep watch' program and its recommendations, as documented in McMahon (2016).

The 'Keep watch' program will continue to assess the health of seagrass meadows in Geographe Bay in relation to the potential threat associated with the predicted nutrient enrichment from the catchment. Seagrasses generally respond rapidly to environmental change, providing a useful indicator to the state of the marine environment (Van Niel et al. 2009). This monitoring is an essential part of the science program, assessing potential impacts to the marine environment, linking the land to the sea.

Regular water quality monitoring across the catchment will be continued. Water quality data is critical for development of the catchment model that will be used to update the *Vasse-Wonnerup wetland and Geographe Bay water quality improvement plan* during the next three years, determining the velocities, annual loads and nutrient reduction targets for Geographe catchment waterways.

Plate 10 Monitoring Seagrass in Geographe Bay

Table 5 Science and monitoring for nearshore Geographe Bay 2016-19

Project	Lead agency	Why?	Timing	Parameters investigated	Further information
Keep Watch annual seagrass health monitoring program	Edith Cowan University Lead Scientist: Kathryn McMahon	To assess the health of seagrass meadows in Geographe Bay in relation to the potential threat associated with the predicted nutrient enrichment from the catchment, and to assess change over time at each site using a number of assessment triggers.	2017–2021 annually in summer	Eight sites in nearshore Geographe Bay monitored for *Posidonia sinuosa* health (including shoot density) and *Amphibolis antarctica* nutrient content (see Figure 6 for site locations). Parameters include shoot density seagrass leaf nutrient content and epiphytic algal cover.	Annual monitoring reports are available on the GeoCatch website: http://geocatch.asn.au/resource-category/geographe-bay/
Catchment water quality monitoring program	DWER	To monitor trends in water quality over time and to populate the Geographe catchment model. Water quality data from this program will help link land to sea.	Ongoing Fortnightly	A total of 21 sampling sites monitored for physical parameters and nutrients (see Figure 2 for site locations).	The WQIP will be updated and finalised by December 2019. Water quality data is available on the DWER website: http://water.wa.gov.au/maps-and-data/monitoring/water-information-reporting.
Water quality sampling: Geographe Bay	DWER	Water quality data will be used monitor trends in water quality over time and support seagrass monitoring data.	Ongoing Fortnightly	One site at the Busselton Jetty monitored for physical parameters, phytoplankton and nutrients.	Water quality data is available on the DWER website: http://water.wa.gov.au/maps-and-data/monitoring/water-information-reporting.

7 Communicating the plan

Both the community and asset managers require effective communication and information on the current condition of water assets and progress being made in science and monitoring. Effective communication is critical to engaging all stakeholders to work towards common objectives.

Scientific results from this plan will be reported in various formats including technical reports and papers, factsheets and theses (outlined in the 'further information' column of tables 1, 2, 3, 4 and 5). This will allow key asset managers to readily access data and information to support Revitalising Geographe Waterways projects and actions.

The following strategies will be developed to effectively communicate the findings of the science and monitoring programs and projects in this plan and inform stakeholders on the current condition of water assets:

- synthesise and communicate science and monitoring findings through various media including the Revitalising Geographe Waterways website, traditional print media and community and stakeholder briefings.
- engage the community (where possible) in science and monitoring activities to increase awareness and understanding (e.g. fish tagging).

8 Annual review and reflection

The science and monitoring research programs will be reviewed annually. The review will be a collaborative process with advice from the Science Advisory Group. A review of each program/project will be undertaken answering the following key questions:

- Is the project/program still relevant?
- Is the methodology used in the program current/working effectively to meet the program/project objectives and outcomes?
- Are there any problems with the output of the current program that may limit its use for management decisions, modelling inputs or research outcomes?
- Are there any information gaps that could be addressed by modifying the existing program?

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