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Department of **Water and Environmental Regulation**
Department of **Primary Industries and Regional Development**

Reconnecting Rivers summary report

Revitalising Geographe Waterways

VASSE taskFORCE

Reconnecting Rivers summary report

Department of Water and Environmental Regulation

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Cover photograph: Vasse Diversion Drain, Department of Water and Environmental Regulation

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Summary

The Reconnecting Rivers study was undertaken by the Department of Water and Environmental Regulation as part of the Revitalising Geographe Waterways program, which aims to improve the water quality, waterway health and management of Geographe waterways. The study was initiated in response to community interest in options to improve water quality in the Lower Vasse River and Vasse-Wonnerup wetlands by increasing flows. This report summarises the investigations into and modelling of the management options (scenarios) put forward by the community and City of Busselton for increasing flows into the Lower Vasse River and Vasse Estuary. These were:

1 Reconnecting flows from the upper catchment of the Vasse and Sabina rivers

2 Using alternative water sources from the catchment

3 Removing barriers to flow in the Lower Vasse River and Vasse Estuary

Key findings from this study include:

Reconnection options

- Flood modelling confirmed that the major structures – Vasse Diversion Drain, Sabina Diversion Drain (and associated compensation basins) and Vasse surge barrier – are necessary to prevent flooding of low-lying areas in Busselton and adjacent to the Vasse Estuary.
- Modelling identified that a large amount of additional water could be directed into the lower Vasse and Sabina rivers without increasing the flood risk by installing an additional 900 mm culvert at the Vasse Diversion Drain offtake to the Lower Vasse River or two 900 mm culverts to re-direct water to the Lower Sabina River from the Upper Sabina River. Any further increases in culvert size would increase the flood risk to the Lower Vasse and Sabina Rivers and would also substantially increase nutrient loads to the Vasse estuary.
- Reconnection scenarios only increased flows significantly during the winter months and did not reduce water residence times in spring, summer and autumn (when water quality conditions are poor).
- The two- and three-culvert Vasse Diversion Drain to Lower Vasse River re-connection scenarios showed an increase in sediment mobilisation in the Lower Vasse River; however, the sediment would flow to the Vasse Estuary. None of the reconnection scenarios are likely to ‘push’ sediment from the Vasse Estuary into the Wonnerup Inlet. Increasing flows into the Lower Vasse River also has the potential to erode the upper reaches of the river, contributing to sediment build-up.
- The potential decreases in nutrient concentrations in spring and summer associated with increasing flows (reconnection scenarios) are small and unlikely to reduce algal blooms or improve visual amenity.

- The potential increased nutrient loads associated with the increased flows following reconnection are significant and have the potential to further impact on the ecological health of the Lower Vasse River and Vasse Estuary.

Using alternative water sources from the catchment

- Options to access alternative water from the catchment to maintain summer flows are limited.
- It was estimated that a dam with the volume of 18 GL, covering an area of 9 km^2, would be required to store adequate water to maintain flows in the Lower Vasse River over summer.
- Any water stored in the catchment to maintain summer flows would be likely to experience water quality conditions similar to, or worse than the Lower Vasse River due to nutrient enrichment and algal blooms.
- It is not viable to use the flood detention basins or the Vasse Diversion Drain for storing water without compromising their flood protection roles.
- Discharge of recycled water from the wastewater treatment plant to the Lower Vasse River during summer would reduce water residence times in summer. This scenario also has the potential to reduce total phosphorus concentrations in the river over summer with only small increases in nutrient loads.

Removal of barriers

- The Vasse surge barrier is critical to Busselton’s flood protection: it is not viable to remove the barrier without compromising its flood protection role.
- Removal of the Butter Factory weir boards at the lower end of the Lower Vasse River meets the flood risk criteria, however the impacts on water quality and the Vasse Estuary were not determined in this study and would require further investigation if this action were to be pursued.

Key recommendations

Based on the major findings of this study, the key recommendations are:

- As part of the Vasse Diversion Drain works being undertaken by the Water Corporation, upgrade the current offtake structure to the Lower Vasse River to a flow capacity equivalent to two 900 mm culverts. The structure should be able to control the amount of flow that can be directed to the Lower Vasse River.
- Develop an operational strategy for the management of the culverts, including clearly defined roles and responsibilities for the relevant agencies and management of first flush and high flows.
- Further investigate the scenario of removing the Butter Factory weir boards and re-contouring the Lower Vasse River.
- Further investigate the use of recycled water from the Busselton wastewater treatment plant to increase summer flows in the Lower Vasse River.

- Further investigate raising the checkboard height of the Vasse surge barrier through the Review Surge Barrier project.
- Continue water quality monitoring in the Lower Vasse River and Vasse Estuary to monitor the impact of increasing flows on water quality.

The following scenarios are not recommended:

- Partial or full reconnection of the Sabina Diversion Drain to the Lower Sabina River due to the substantial increase in nitrogen loads to the Vasse Estuary.
- Partial (equivalent to three 900 mm culverts) or full reconnection of the Vasse Diversion Drain to the Lower Vasse River due to increased flood risk and the substantial increase in nutrient loads to the Lower Vasse River and Vasse Estuary.
- Storage of water in the Sabina and Vasse flood detention basins and removal of the Vasse surge barrier, as this would compromise the flood protection of Busselton and surrounding areas.

1 Background

The hydrology of waterways in the Geographe catchment has been substantially modified. In its natural state, the Swan Coastal Plain consisted of linked wetlands, which supported a rich and diverse ecosystem. Meandering streams and swamps conveyed water to estuaries and the ocean. Many areas were waterlogged and water residence times were long. Following European settlement in the Busselton area in 1830s, the area was developed for agricultural and urban land uses. Land clearing greatly increased water yield, so from 1900 onwards artificial drains were constructed to control waterlogging of farm land. In 1927 the Vasse Diversion Drain was constructed to reduce flooding of the Busselton township by diverting river flow to the ocean. These days, about 60% of flow from the Sabina River and 90% of flow from the Vasse River is diverted to the ocean. The Vasse and Wonnerup surge barriers were constructed in 1908 to stop salt water flooding the low-lying areas around the estuaries and to protect Busselton from storm surges. The major drainage structures are shown in Figure 1.

Many catchment waterways contain nutrient-enriched water from fertiliser used on agricultural and urban land, which is efficiently conveyed to receiving waterbodies through artificial drainage structures. Several waterways, including the Lower Vasse River in the centre of Busselton, suffer persistent algal blooms during spring, summer and autumn. The Vasse-Wonnerup wetlands have been identified as being the most nutrient-enriched wetlands in the south-west of Western Australia, characterised by annual major macroalgal blooms. The exit channel of the Vasse Estuary is also a water-quality hotspot: annual phytoplankton blooms and de-oxygenated water events are common and contribute to occasional catastrophic fish kills.

The Lower Vasse River is highly valued by the local community and the Ramsar-listed Vasse-Wonnerup wetland system has international importance as waterbird habitat. The Revitalising Geographe Waterways program has the overarching goal of improving water quality, waterway heath and management of these and other waterways in the Geographe catchment. This study is one project among those of the larger program.

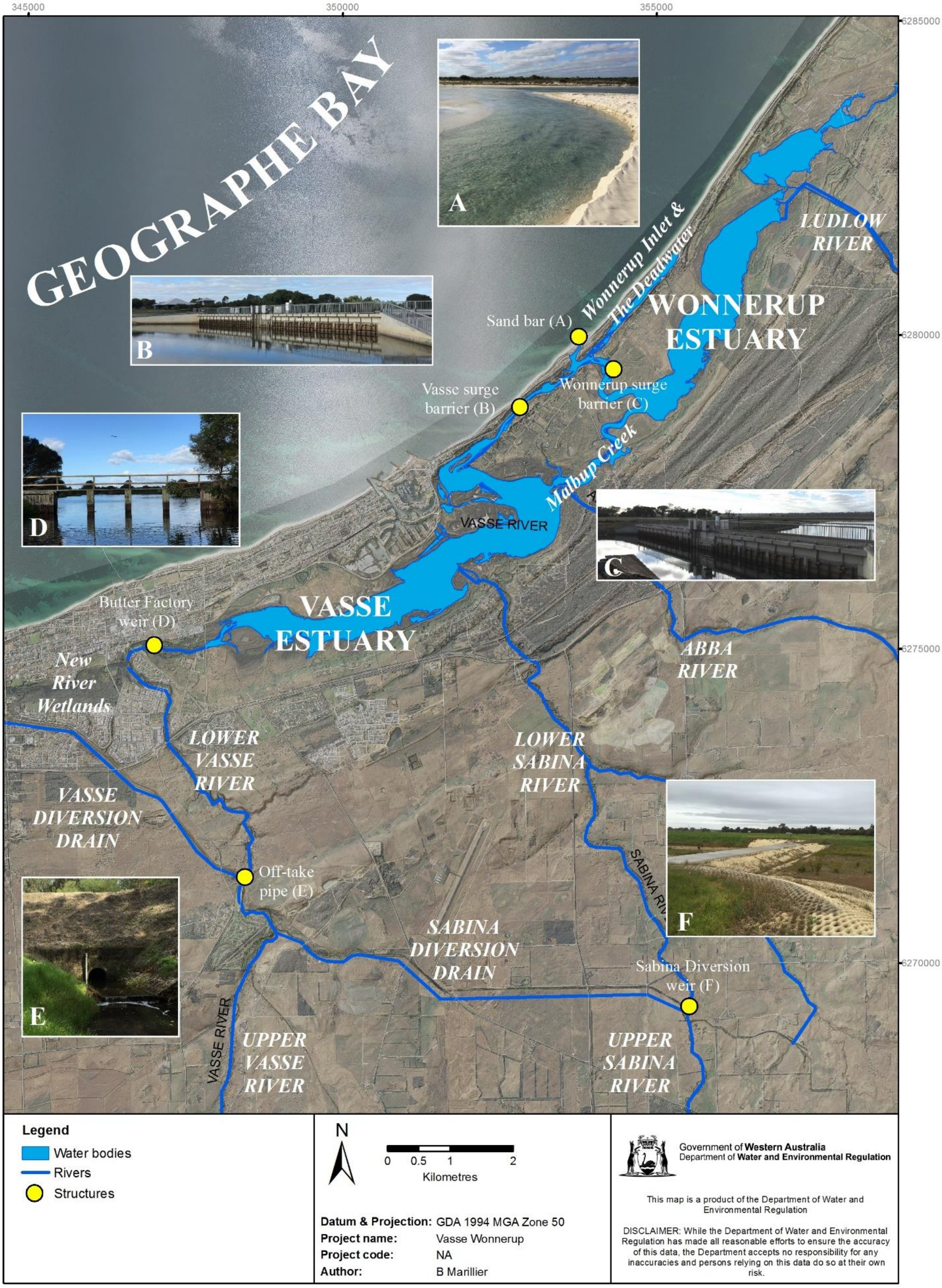

Figure 1 Major drainage structures of the Vasse-Wonnerup system

1.1 Reconnecting Rivers project

The Reconnecting Rivers project was developed in response to the community's desire to investigate how modifications to the current drainage network might benefit water quality in the Lower Vasse River and Vasse Estuary. There is a strong community belief that increasing flows would improve water quality by 'flushing' nutrient-enriched water and sediments from these waterways. High nutrient concentrations in the waterways at the end of spring contribute to algal blooms during summer. In addition, a large build-up of nutrient-rich sediments occurs in the Lower Vasse River and Vasse Estuary, which fuels algal growth during the warmer months (when inflows cease). This study investigated whether redirecting flows from the upper Sabina and Vasse rivers – which have slightly better water quality than the lower rivers – or using alternative water sources from the catchment might be able to lower nutrient concentrations and mobilise sediment away from the problem areas. The study also investigated whether decreasing water residence times in the Lower Vasse River would be beneficial, given algae does not grow readily in flowing water.

The community's proposals (scenarios) considered in this study included:

1 Reconnecting flows from the upper catchment of the Vasse and Sabina rivers

- Reconnection of the Vasse Diversion Drain to the Lower Vasse River
- Reconnection of the Sabina Diversion Drain to the Lower Sabina River

2 Using alternative water sources from the catchment

- Summer discharge of treated recycled water into the Lower Vasse River
- Storage of water in the catchment for discharge into the Lower Vasse River in summer

3 Removing barriers to flow in the Lower Vasse River and Vasse Estuary

- Removal of the Butter Factory weir and modifications to the Lower Vasse River channel to remove pools
- Removal of the Vasse surge barrier.

Also examined were two modifications to drainage infrastructure planned for the near future:

- Upgrades to the bridge at Causeway Road
- Adding a formalised spillway to the Vasse Diversion Drain to direct water to the Lower Vasse River in large floods to safeguard the drain's banks.

Another proposal was:

- Storing more water in the Vasse Estuary at the end of the flow season.

2 Methodology

This study assessed the feasibility of the proposed scenarios in terms of:

- Flood risk
- Water quality

To examine these parameters, the Department of Water and Environmental Regulation (DWER) used a MIKE11 (1D hydraulic) model of the Lower Vasse River, Lower Sabina River and Vasse-Wonnerup estuary to study water conveyance in the streams and drains. Although this study concentrates on the Lower Vasse River and Vasse Estuary, because the waterways are connected, the model domain includes the Wonnerup Estuary and Inlet (

Figure 2).

2.1 Flood risk

To assess flood risk, 1% Annual Exceedance Probability (AEP)[1] flood flows were generated using the RORB runoff routing software, which were input to the MIKE 11 model. When the estimated water levels breached the drainage channels in model simulations, a digital terrain model was used to determine flood extent and depth. The flood modelling simulations had an hourly time-step. Flooding extent and depth were compared with floodplain mapping and building levels to determine the flood risk acceptability.

2.2 Water quality

To assess water quality parameters, long-term changes to flows into the lower Vasse and Sabina rivers were estimated using the MIKE11 model with daily time-step and inputs from the Source catchment model. A simple nutrient mass balance model was then used to estimate changes to nutrient concentration and loads in the lower Vasse and Sabina rivers. Sediment mobilisation and water residence times were only considered for the Lower Vasse River and not for the Lower Sabina River.

The following parameters for water quality were considered in this study:

- *Residence time*: Algal blooms are less likely to establish in flowing waters, and flow will carry (disperse) algae downstream. Decreasing the water residence time (the amount of time that a water droplet remains in the river) in autumn and summer in the Lower Vasse River may help to prevent algal growth.
- *Sediment mobilisation*: Algal growth is fuelled by nutrients in the water and by nutrients released from sediments on the river and estuary beds. Increased flow may mobilise nutrient-rich sediments downstream of the Lower Vasse River and out of the Vasse Estuary.

[1] 1% AEP flood event is a flow event that has a 1% probability of occurring in any given year.

- *Nutrient concentration:* Winter nutrient concentrations are generally lower in the Vasse Diversion Drain and Upper Sabina River than in the lower rivers. Diverting lower-nutrient concentration water from the drain into the lower Vasse or Sabina rivers may dilute the nutrient-rich water in the lower rivers and estuary.
- *Nutrient loads*: Annual nutrient loads are an important measure of water quality and health of a waterbody. Increasing nutrient loads through increased flows may adversely affect the lower Vasse and Sabina rivers and Vasse Estuary.

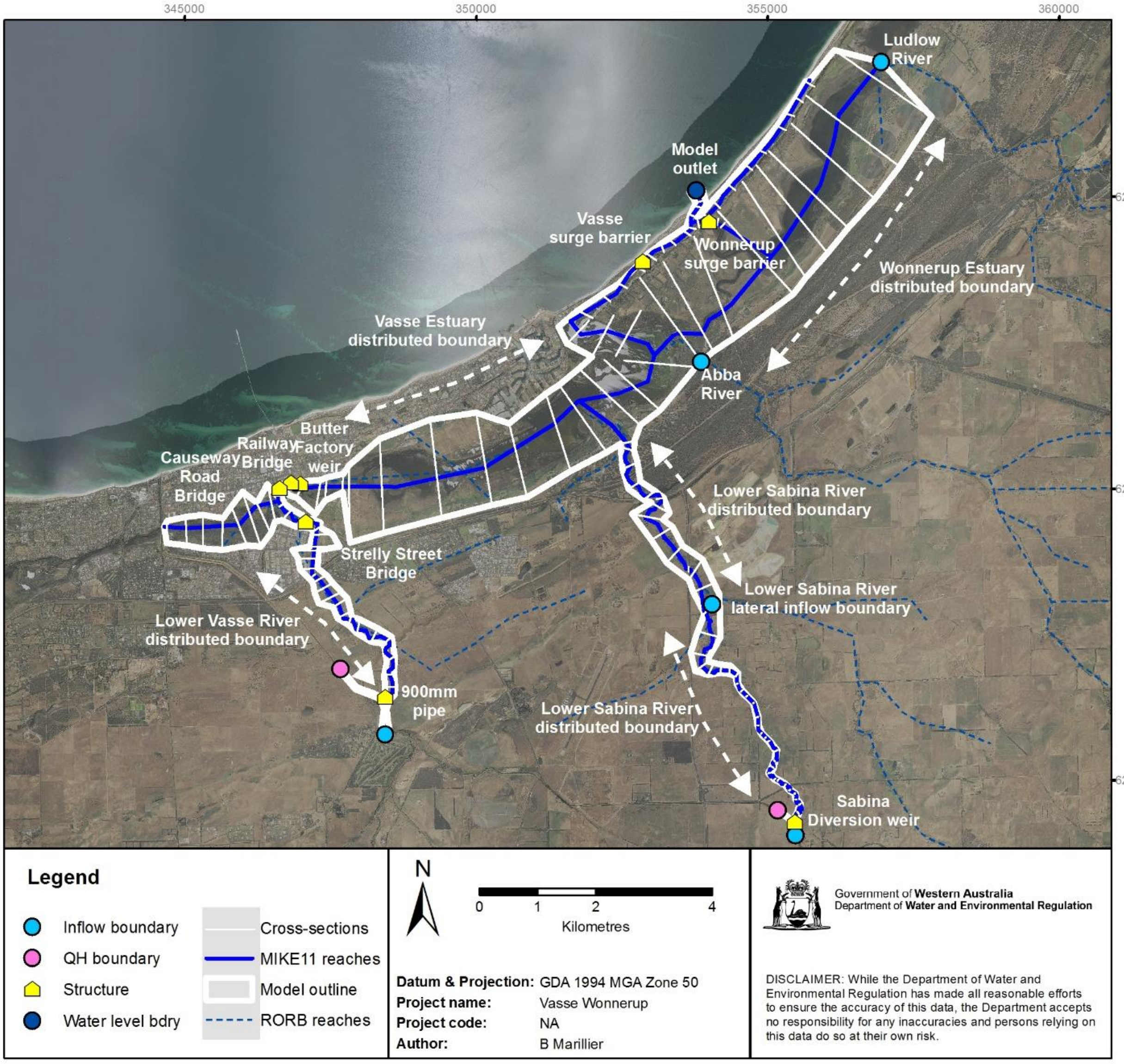

Figure 2 MIKE11 model extent for the Lower Vasse River and estuary

3 Scenarios

The scenarios modelled in this study included:

3.1 Reconnection options

- Base case: Vasse Diversion Drain offtake – one 900 mm culvert 3/4 open (S00)
- Vasse Diversion Drain offtake – two 900 mm culverts (S03)
- Vasse Diversion Drain offtake – three 900 mm culverts (S04)
- Vasse Diversion Drain offtake – three 900 mm culverts with spillway at Vasse Diversion Drain offtake in place and Causeway Road bridge upgraded (S04sb)
- Vasse Diversion Drain fully connected to the Lower Vasse River (S05)
- Two 900 mm culverts to direct flow from the Sabina Diversion Drain to the Lower Sabina River (S10a)
- Upper Sabina River fully connected to the Lower Sabina River (S11)

3.2 Alternative water sources from the catchment

- Recycled water discharged to Lower Vasse River year-round (S07)

3.3 Removal of barriers

- Butter Factory weir removed and Lower Vasse River partially filled to remove pools, with two 900 mm culverts at Vasse Diversion Drain offtake (S14)
- Estuary surge barriers removed (S12)

3.4 Other

- Vasse Estuary surge barrier check boards raised to 0.6 mAHD (S08).

The scenario ‘storage of water in the catchment for discharge into the Lower Vasse River in summer’ could not be modelled with MIKE11 without definition of storage structures and proposed summer outflow regime to the Lower Vasse River. Instead, the water volume needed to maintain flows in the Lower Vasse River during the summer dry season (December to April) was estimated. Calculations were based on the estimated volume of the river pools during summer (70 ML), the volume of water needed to replace the water in the river pools daily (11 GL) and evaporation losses (about 5.6 mm/day or 7 GL) during the five-month period.

A technical report on this study is being finalised (Department of Water and Environmental Regulation, in prep.). Scenarios with smaller capacity reconnection structures were also modelled. For clarity, these are not presented here but are included in the technical report. The scenario numbering above (S00, S03 etc.) relates to numbering in the technical report.

4 Results

Results from this study are outlined below, considering flood-risk and water-quality parameters. Table 1 summarises the model outputs.

4.1 Reconnection options

Vasse River reconnection scenarios (S03, S04, S04sb, S05)

Flood risk

Increasing the capacity of the Vasse Diversion Drain offtake to the Lower Vasse River to the equivalent of two 900 mm culverts (S03) meets the flood-risk criteria based on the current floodplain development strategy and building floor levels in the area. It is estimated that this would increase the 1% AEP flood level upstream of Causeway Road by 6 cm.

Increasing the capacity of the Vasse Diversion Drain offtake to the Lower Vasse River to three 900 mm culverts (S04) does not meet the flood risk criteria. However, if the Causeway Road Bridge is upgraded suitably (S04sb), then the three 900 mm culverts scenario would meet the flood risk criteria. Full reconnection of the Upper Vasse River to the Lower Vasse River (SO5) would pose an unacceptable flood risk.

The modelling showed that adding a formalised spillway from the Vasse Diversion Drain to the Lower Vasse River is unlikely to influence peak flood levels in the Lower Vasse River or Vasse Estuary due to differences in time-to-peak on the drain compared with the estuary. This assumes that the spillway is designed with a peak capacity of 7 m^3/s during the critical six-hour duration in 1% AEP flood event on the Vasse Diversion Drain, and does not flow in events more frequent than 5% AEP.

Water quality

Modelling of the Vasse reconnection scenarios showed that none of these scenarios changed the summer residence time appreciably, given most of the additional flows occurred during the winter months. Increasing flows did increase the bed shear stress (flow velocity), although the percentage of time that sediment could be mobilised was small in most cases. As an example, the two 900 mm culverts scenario is estimated to mobilise medium silt 1.8% of the time and fine sand 0.3% of the time (Figure 3).

Nevertheless, a simple uncalibrated HEC-RAS sediment transport model indicated that under present and increased flow conditions, the upper reaches of the Lower Vasse River would erode, with deposition occurring in the lower reaches. Additionally, any sediment mobilised out of the Lower Vasse River would flow to the Vasse Estuary.

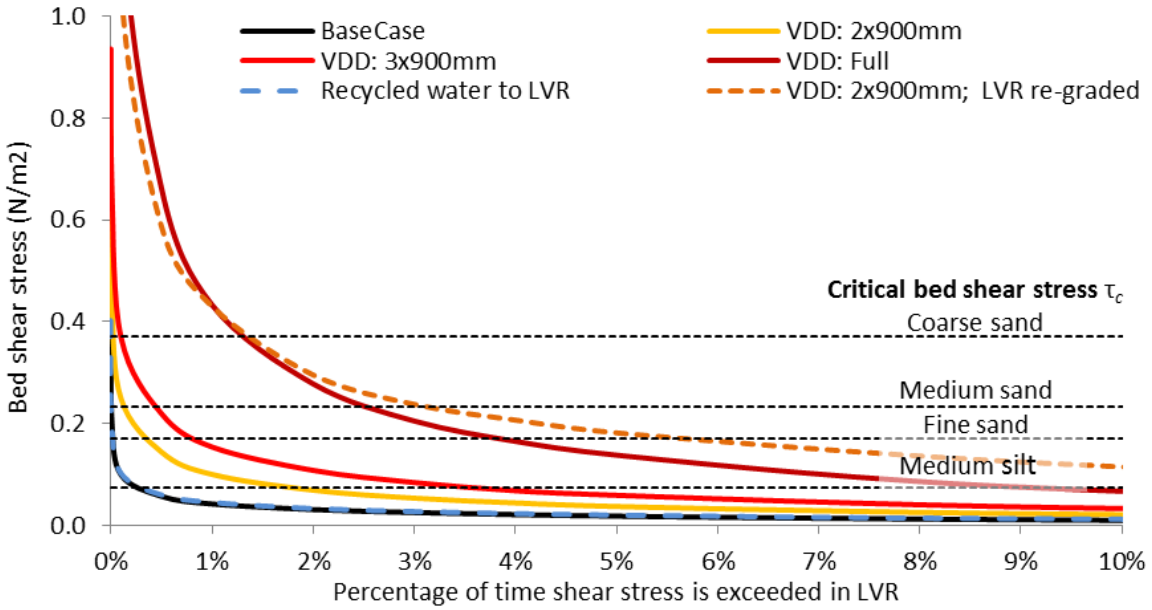

Figure 3 ***Percentage of time Lower Vasse River bed shear stress is exceeded. VDD = Vasse Diversion Drain***

Table 1 Summary of modelling results

Legend: Acceptable flood risk (blue); High risk for flood or increased nutrient pollution (orange); Potential benefit (green); Negligible change (yellow)

Scenario	Flood risk	Annual river loads (% increase)		% time medium silt is mobilised	Water residence time (days)		November nutrient concentration (% change)		Comments
		N	P		JAN–MAR	AUG–SEP	TN	TP	
LOWER VASSE RIVER SCENARIOS									
Base case				0.2	> 300	1			
2 x 900 mm culverts		45	20	1.8	> 300	1	-6	-8	Nutrient load increase
3 x 900 mm culverts		80	40	3.5	> 300	1	-8	-9	Flood risk; excessive nutrient load increase
3 x 900mm + bridge upgrade		80	40	3.5	> 300	1	-8	-9	Excessive nutrient load increase
FULL		200	90	9	> 300	< 1	-8	-9	Flood risk; excessive nutrient load increase
2 x 900 mm + remove butter boards		45	20	15	NA[2]	1	NA[2]	NA[2]	Nutrient load increase
Recycled WW to LVR		8	8	0.2	13–14	1	3	-11	Reduces water residence time in LVR in summer
SABINA RIVER SCENARIOS									
Base case									
2 x 900 mm culverts		130	8	NA	NA	NA	0	0	Excessive nutrient load increase
FULL		150	11	NA	NA	NA	0	0	Flood risk; excessive nutrient load increase
OTHER									
Check boards raised to 0.6 mAHD		NA	NA	NA	> 300	1	NA	NA	Being considered in Review Surge Barrier project
Removal of surge barriers		NA	NA	NA	NA	NA	NA	NA	Unacceptable risk of flooding farmland with salt water; increases Busselton's flooding potential

FULL = full re-connection; NA = not applicable; LVR = Lower Vasse River; NA[2] = not applicable because Lower Vasse River would dry out in summer
2 x 900 mm culverts re-grade LVR[1] -- Note that sediment mobilised from the LVR will flow to the Vasse Estuary with potential adverse impact

Changes to total nitrogen (TN) and total phosphorus (TP) concentrations from November to April in the Lower Vasse River were small for all the reconnection scenarios modelled (Figure 4 and Figure 5). All scenarios that increased flows into the Lower Vasse River resulted in increased nutrient loads (Figure 4 and Figure 5). The largest load increases were associated with full reconnection and upgrading to three 900 mm culverts with nutrient loads estimated to increase by up to 200% for TN and 90% for TP with full reconnection.

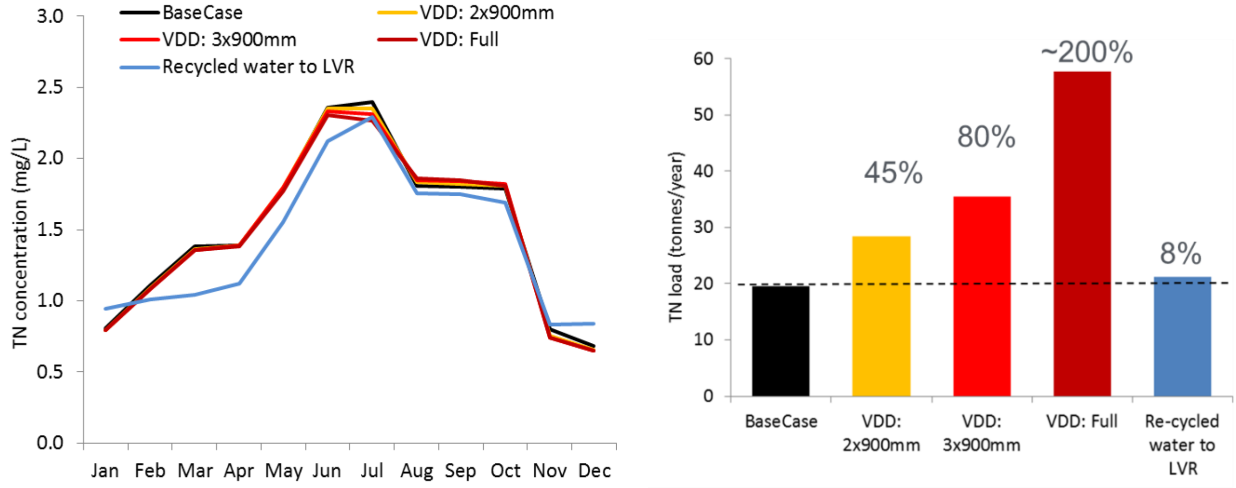

Figure 4 Average monthly TN concentrations and loads for the Lower Vasse River

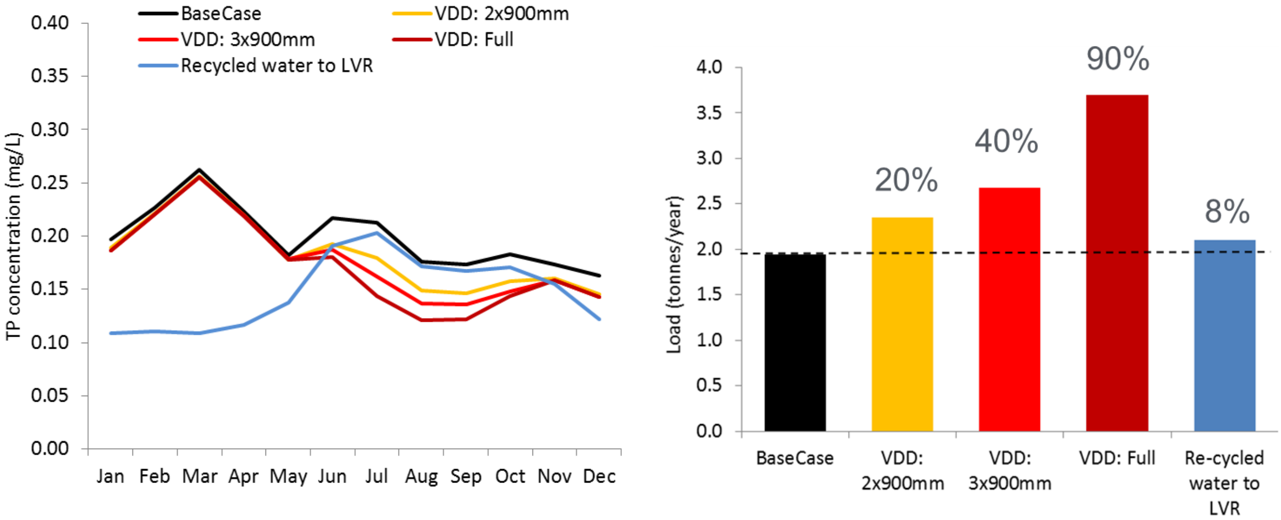

Figure 5 Average monthly TP concentrations and loads for the Lower Vasse River

Sabina River reconnection scenarios (S10a, S11)

Flood risk

Adding up to two 900 mm culverts to the Sabina Diversion weir (S10a) to divert more flow to the Lower Sabina River meets the flood risk criteria. With this structure, water would spill from the Lower Sabina River to surrounding areas: this was considered acceptable because buildings were not affected. A 4 cm increase in flood levels near residences located upstream of Tuart Drive was also predicted. The existing floodplain development strategy for the area would provide adequate protection from this increase in water level.

Full connection of the Upper Sabina River to the Lower Sabina River (S11) did not meet the flood risk criteria. Flood levels would increase by an estimated 38 cm near residences located upstream of Tuart Drive and would likely affect several properties adjacent to the river. The flood peak in the main body of the Vasse Estuary and the Lower Vasse River would also increase.

Water quality

Redirecting water from the Upper Sabina River to the Lower Sabina River would not change summer TN concentrations (Figure 6), but would increase winter TN concentrations – due to the Upper Sabina River having greater TN concentrations than the Lower Sabina River (Figure 4 and Figure 5). The outcome would be different for TP concentration, which would show no change in the dry season but a marked decrease during the flow season (Figure 7).

Redirecting more flow to the Lower Sabina River would increase nutrient loads. In the case of nitrogen, predicted load increases were substantial, increasing by 50 to 150% (Figure 6 and Figure 7).

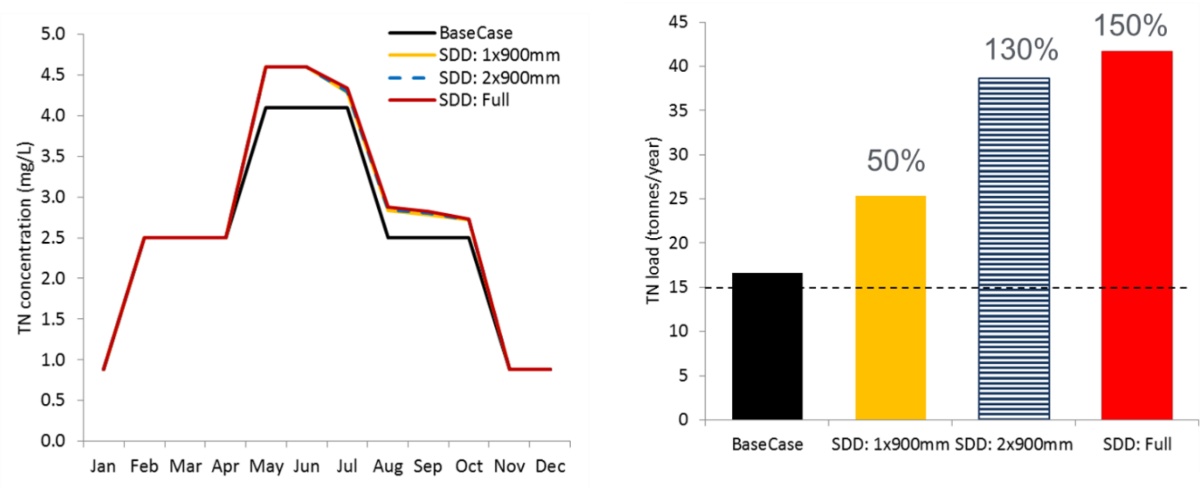

Figure 6 Average monthly TN concentrations and loads for the Lower Sabina River

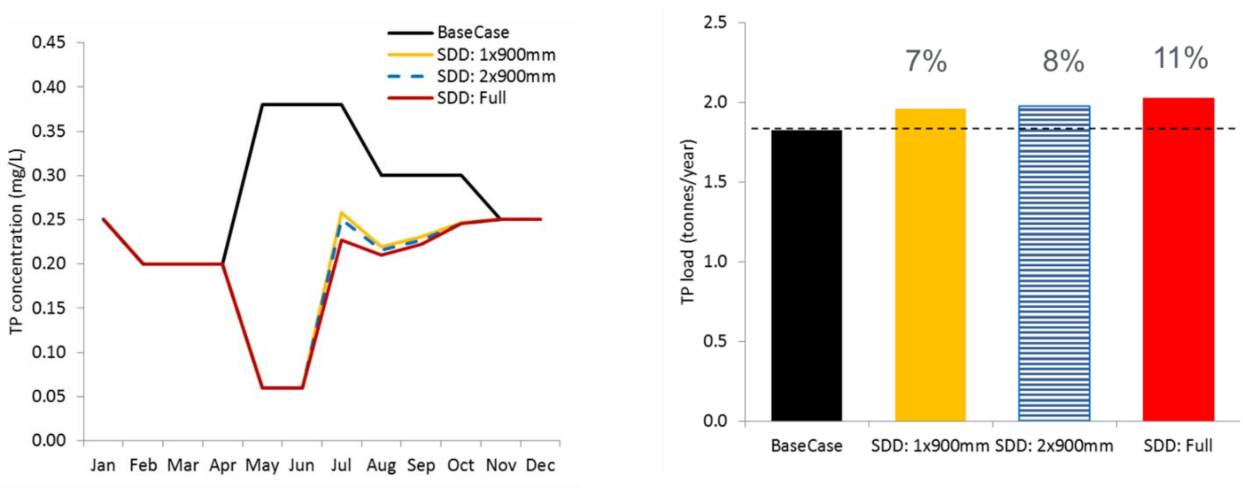

Figure 7 Average monthly TP concentrations and loads for the Lower Sabina River

4.2 Alternative water sources from the catchment

Recycled water discharged to Lower Vasse River year-round (S07)

This scenario had no impact on the flood regime, and was the only scenario modelled that was effective in increasing flow during summer, reducing summer water residence times and reducing summer nutrient concentrations. Directing recycled wastewater into the Lower Vasse River with TN and TP concentrations of 1 mg/L and 0.1 mg/L respectively would decrease dry-season (December to April) TP concentrations markedly (Figure 5). The modelling showed that this action would increase TN concentrations slightly in December and January and decrease them slightly during February to June. This scenario resulted in the lowest increase in nutrient loads to the Lower Vasse River: around 8% for both nitrogen and phosphorus (Figure 4 and Figure 5).

4.3 Removal of barriers

Storage of water in the catchment for discharge into the Lower Vasse River in summer

A major reservoir structure would be required to store adequate water to maintain flows in the Lower Vasse River during the summer months. This study estimated that the required dam volume would be 18 GL, requiring an area of around 9 km^2 with a depth of 2 m. Water for the purpose-built dam would need to be harvested from winter flows in the Vasse Diversion Drain and stored, requiring almost all of the winter in average years (annual average flow 24 GL).

Partially fill Vasse River pools, remove the Butter Factory weir and re-construct the river channel (S14)

This scenario was modelled with a reconnection structure of two 900 mm culverts at the Vasse Diversion Drain offtake. In the model the Vasse River pools were filled so that an even grade resulted and the Butter Factory weir was removed. Even with the two-culvert diversion the flooding risk was acceptable. Most of the nutrients in the increased inflows would flow to the estuary.

Removal of the estuary surge barriers (S12)

The model showed that removing the surge barriers would result in flooding (from the ocean) during significant storm surges, with a predicted 4 cm increase in the modelled flood level for the 1% AEP flood event. Seawater flooding would salinise low-lying land adjacent to the estuary. With sea level rise of 0.17–0.38 m anticipated by 2050 (IPCC 2013), the surge barriers will be of increasing importance for flood protection.

4.4 Other

Increase Vasse Estuary checkboard height to 0.6 mAHD (S08)

Increasing the Vasse Estuary surge barrier checkboard heights to 0.6 mAHD (0.2 m higher than present) would increase the risk of spring flooding. The 1% AEP flood modelling assumes that the water level in the estuary before the event is 0.6 mAHD. Even small rainfall events in September would result in slightly higher water levels than 0.6 mAHD. For example, if the estuary had a water level of 0.8 mAHD before a 1-in-100 year flood, this would result in a peak flood level of 1.49 mAHD, compared with a peak flood level of 1.45 mAHD for a 0.6 mAHD starting level.

Retaining more fresh water in the Vasse Estuary may provide ecological benefits. Increasing the height of the checkboards and the timing of their installation at the end of the flow season is being investigated in another project (Vasse Estuary Surge Barrier Management).

5 Discussion

5.1 Reconnection options

Reconnection of the upper Vasse and Sabina rivers to their lower sections was considered in this study from a flood risk and water quality perspective.

The model identified that a large amount of additional water could be re-directed into the lower Vasse and Sabina rivers without increasing the flood risk – by way of installing additional 900 mm culverts at the offtake structures from the upper rivers. Modelling also showed that the scenarios of redirecting water from the Busselton wastewater treatment plant, removing the Butter Factory weir in the Lower Vasse River and increasing the height of checkboards in the Vasse Estuary would meet flood risk criteria. The complete reconnection of the Vasse Diversion Drain to the Lower Vasse River or the Upper Sabina River to the Lower Sabina River would result in unacceptable flood risks, as would the removal of surge barriers on the Vasse Estuary.

Although a number of the scenarios modelled did meet the flood risk criteria, the study found that increasing flows by reconnecting the Vasse Diversion Drain to the Lower Vasse River was unlikely to improve water quality in the Lower Vasse River and Vasse Estuary. The increased flows after reconnection would mainly occur in winter, not in summer when water quality conditions are poor. Modelling showed that higher flows would result in little or no improvement in spring/summer nutrient concentrations and water residence times and therefore would be unlikely to reduce the duration or severity of algal blooms in the Lower Vasse River.

A simple uncalibrated HEC-RAS model showed that present and increased flows also have the potential to erode river banks in the upstream sections of the Lower Vasse River, with the mobilised sediment being deposited in river pools or the estuary. The MIKE11 modelling showed that increased flows may mobilise sediment out of the Lower Vasse River, however it is likely this sediment would deposit in the estuary. Nutrient-rich sediments deposited in either of these waterbodies have the potential to worsen their water quality as algal blooms in summer are fuelled partly by nutrient-sediment release and nutrient cycling (growing and decaying algae).

A potentially detrimental consequence of increasing flows into the Lower Vasse River and Vasse Estuary is increased nutrient loads. Any increase in nutrient loads poses a risk to these waterways. As an example, the reconnection of three 900 mm culverts at the Vasse Diversion Drain offtake to the Lower Vasse River would pose a substantial risk to the health of the Lower Vasse River and Vasse Estuary ecosystems, due to the large increases in average annual nitrogen (about 80%) and phosphorus (about 40%) loads. Although most of the nitrogen in the water would be in soluble form, more than half of the phosphorus would be in particulate form. This means the particulate phosphorus in winter inflows would be likely to deposit in river and estuary bed sediments, fuelling algal growth during the summer months. This is of particular concern in the Vasse Estuary, where phosphorus supply is thought to be the driver of algal blooms.

In 2004, sediments were removed from the Vasse Estuary in the area upstream and downstream of the surge barrier (for about 30 m) before construction of the new barrier. A recent sediment survey in November 2016 revealed that the area upstream of the barrier contained about 300 m^3 of sediment that was 50–60 cm deep, while the area downstream had little sediment. This highlights the tendency for particulate matter (whether from river inflows or dead algae) to be trapped in the estuary instead of flowing to Wonnerup Inlet. The increased flow volumes from the different reconnection options would not increase flows at the surge barrier sufficiently to 'push' accumulated sediments into Wonnerup Inlet, and would likely to contribute to further sediment build-up in the estuary.

5.2 Alternative water sources from the catchment

Recycled water from the Busselton wastewater treatment plant was the only viable alternative water source identified in this study for increasing flows into the Lower Vasse River during summer. This scenario has the potential to reduce summer residence times and nutrient concentrations and thereby improve water quality. Further investigation of this scenario is required to assess the availability and cost of recycled water, and whether its quality would be appropriate for discharge to the Lower Vasse River and estuary, taking into consideration any potential human and ecological health effects.

Storage of water in the Sabina and Vasse flood detention basins was not considered a feasible option in this study given it would compromise their flood protection roles. Constructing a purpose-built dam to enable water storage in the catchment was therefore also investigated. The size of the reservoir required would be substantial: an estimated 9 km^2 area to store about 18 GL of water. It is likely that water stored in one or more purpose-built reservoirs in the upper catchment would also suffer water quality problems similar to, or worse than the Lower Vasse River, given the water would be still, warm and nutrient-rich. It is also likely that algal growth in built reservoirs would be even greater than in the Lower Vasse River due to lack of shading. If this scenario were pursued, the potential impact of perennial summer flows on the Vasse Estuary would need to be further investigated.

5.3 Removal of barriers

The study examined scenarios to remove barriers to flow in the Lower Vasse River and Vasse Estuary.

The Butter Factory boards in the Lower Vasse River maintain permanent pools in the Lower Vasse River over summer. This study found that removing the boards would have no measurable impact on the flood regime so this would be feasible from a flood-risk perspective. There were, however, some important issues that would need to be investigated if this scenario were to be considered further. The Lower Vasse River has been substantially modified over time and is much wider and deeper than it would have been beforehand. There is also significant sediment build-up in the river. It is likely that major engineering works would be required to remove sediment and fill in the river pools.

The impact of removing the boards in the Lower Vasse River on the Vasse Estuary would also need to be considered. The Lower Vasse River suffers annual toxic algal blooms that may provide a seeding source for algae in the main estuary. The Lower Vasse River also traps and processes nutrients that would otherwise flow to the estuary. A comprehensive study to further assess flood risk, and ecological and social benefits, would be required if this scenario were to be considered further.

The main role of the Vasse Estuary surge barrier is to prevent salinisation of low-lying land surrounding the estuary during the summer. If the surge barrier were removed, the peak flood level for the 1% AEP flood would increase by about 4 cm under current sea level conditions. Importantly, the surge barrier’s role in flood prevention will increase as ocean levels increase (0.17–0.38 m anticipated by 2050).

Aside from the significant flood risk associated with removal of the surge barriers, this scenario would significantly alter the estuary’s ecological character by the introduction of large volumes of sea water. This would have implications for fringing vegetation, farm land and the estuary’s ecological function.

Further modelling of this scenario using the estuary model being developed by Department of Water and Environmental Regulation will be done to assess the potential extent of land salinisation and the predicted increase in estuary salt concentrations.

6 Conclusions

The flood modelling confirms that the major structures – Vasse Diversion Drain, Sabina Diversion Drain (and associated compensation basins) and Vasse surge barrier – are necessary to prevent flooding of low-lying areas in Busselton and adjacent to the Vasse Estuary.

A large amount of additional water could be directed into the lower Vasse and Sabina rivers without increasing the flood risk – by installing an additional 900 mm culvert at the Vasse Diversion Drain offtake to the Lower Vasse River or two 900 mm culverts to re-direct water to the Lower Sabina River.

This preliminary study showed, however, that re-connection of the Vasse Diversion Drain to the Lower Vasse River and the Upper Sabina River to the Lower Sabina River would have negligible benefits in terms of decreasing nutrient concentrations in the lower rivers and estuary from November to April. The reconnection scenarios also showed no decrease in spring, summer and autumn water residence times.

The two- and three-culvert Vasse Diversion Drain to Lower Vasse River connection scenarios showed an increase in sediment mobilisation in the Lower Vasse River; however, the sediment would flow to the Vasse Estuary. None of the reconnection scenarios are likely to ‘push’ sediment from the Vasse Estuary into the Wonnerup Inlet.

The potential increased nutrient loads associated with the higher flows following reconnection are significant, and likely to further damage the ecological health of the Lower Vasse River and Vasse Estuary. As more than half of the inflowing phosphorus is in particulate form, deposition of phosphorus in the Lower Vasse River upstream of the Butter Factory weir and in the Vasse Estuary is highly likely.

Discharge of recycled water to the Lower Vasse River during the dry season has the potential both to reduce water residence times in the Lower Vasse River and nutrient concentrations during summer, with only minor increases in nutrient loads. If this scenario were to be considered, further investigations would need to examine the potential impacts on human health and ecology of both the Lower Vasse River and Vasse Estuary.

6.1 Recommendations

- As part of the Vasse Diversion Drain works being undertaken by the Water Corporation, upgrade the current offtake structure to the Lower Vasse River to a flow capacity equivalent to two 900 mm culverts. The structure should be able to control the amount of flow that can be directed to the Lower Vasse River.
- Develop an operational strategy for the management of the culverts, including clearly defined roles and responsibilities for the relevant agencies and management of first flush and high flows.
- Further investigate the scenario of removing Butter Factory weir boards and re-contouring the Lower Vasse River.

- Further investigate the use of recycled water from the Busselton wastewater treatment plant to increase summer flows in the Lower Vasse River.
- Further investigate raising the checkboard height of the Vasse surge barrier through the Review Surge Barrier project.
- Continue water quality monitoring in the Lower Vasse River and Vasse Estuary to monitor the impact of increasing flows on water quality.

The following scenarios are not recommended:

- Partial or full reconnection of the Sabina Diversion Drain to the Lower Sabina River due to the substantial increase in nitrogen loads to the Vasse Estuary.
- Partial (equivalent to three 900 mm culverts) or full reconnection of the Vasse Diversion Drain to the Lower Vasse River due to increased flood risk and the substantial increase in nutrient loads to the Lower Vasse River and Vasse Estuary.
- Storage of water in the Sabina and Vasse flood detention basins and removal of the Vasse surge barrier, as this would compromise the flood protection of Busselton and surrounding areas.

6.2 Future studies

Monitoring of water quality in the main rivers, Lower Vasse River and Vasse and Wonnerup estuaries should continue, including the sediment concentrations of the inflows.

Little information is available on the characteristics and functioning of sediment in the beds of the Lower Vasse River and estuaries: further research in this area is needed.

It is recommended that some of the scenarios that investigated long-term hydrology and water quality are re-visited once the Vasse Estuary model being developed by the Department of Water and Environmental Regulation is complete. The estuary model should be used to:

- investigate residence times and fate of inflows
- assess the management of the Vasse Estuary surge barrier, including checkboard height
- model surge barrier removal.

If other options besides the upgrade of the Vasse Diversion Drain offtake are pursued, such as removing the Butter Factory weir and reconfiguring the Lower Vasse River or addition of recycled water to the estuary, comprehensive studies to assess possible impacts should be undertaken.

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