Samson Brook Carter's Freshwater Mussel Targeted Survey

July 2023

Alcoa of Australia

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Basis of Report

This report has been prepared by SLR Consulting Australia (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Alcoa of Australia (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

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Executive Summary

Alcoa are planning to expand the existing Residue Storage Area (RSA 10) at the Wagerup alumina refinery, in the southwest region of Western Australia (WA). The development will involve construction of a new storage area RSA 10 (to the north of existing RSA 9) and the development of one or more clay borrow pits to the north of the residue storage areas (RSAs) to provide material to line RSA 10 (the Project). Samson Brook South Drain ("SBS") flows east to west along the northern boundary of the proposed RSA 10 location. Another branch of Samson Brook Drain flows north to south between the two borrow pit option areas, to the east of Samson Brook South Drain and north-east of the RSAs ("SBE").

A large population (200+ individuals) of the Vulnerable Carter's freshwater mussel (*Westralunio carteri*; "CFM") was documented during the spring 2022 aquatic fauna baseline survey for RSA 10 at Samson Brook surface water sampling site SP012. SP012 is located approximately 2.8 km downstream of the proposed RSA 10 location adjacent to Samson Brook. This population may meet the criteria as an "important population" under the *Environment Protection and Biodiversity Conservation Act 1999* Significant Impact Guidelines, as a key source population for breeding and dispersal in Samson Brook and Harvey River.

Following this discovery, Alcoa engaged SLR Consulting (previously Wetland Research and Management; "WRM-SLR") to conduct a targeted survey to determine the possible extent and density of CFM populations in Samson Brook directly adjacent to, and downstream of, the proposed RSA 10 location and new borrow pit options. The survey, carried out in July 2023 under appropriate weather and flow conditions, did not detect any CFM along the SBS drain from SBS4 through to SBS10, which included the area directly adjacent to the northern boundary of the RSA 10 proposed location. A low-density population was detected at SBS11, located 700 m upstream of the higher-density population at SP012. Small populations were also present at SBS sites 1 to 3, adjacent to Borrow Pit option 2. No CFM were recorded along SBE.

As the known, large CFM population at SP012 is located 2.8 km downstream of the RSA 10 proposed location, it is theoretically considered to be potentially exposed to Project-related disturbances (i.e., changes in water quality and sedimentation). However, the high density of in-stream vegetation (mostly *Typha* sp. bullrush) present along approximately 2 km of that 2.8 km distance would most likely serve as a significant buffer for any potentially contaminated water originating from the RSA 10 site. It is likely that this vegetation also inhibits dispersal of CFM between the SP012 population and the SBS drain east-west stretch. The area of SBS drain running south-west adjacent to the Alcoa Farmlands office contained a low-density population of CFM, which may have colonised the area via fish moving in from hydrologically-connected upstream reaches of Samson Brook. The very fine, sludgy substrate along SBE may represent unsuitable CFM habitat and might explain their non-detection along that drain. Habitat conditions in these drains where CFM were not detected are not related to Alcoa Wagerup activities, which occur downstream of these areas.

A review of previous desktop and field studies carried out by WRM-SLR was also conducted as part of the current scope of work. It was determined that the ecological values of aquatic habitats adjacent to and downstream of the Project area have been adequately characterised, with survey effort to-date appropriately addressing the gaps in knowledge identified in the initial desktop literature review. The potential risks to aquatic fauna in potential receiving

aquatic environments from the proposed development have been analysed in regard to possible adverse changes in water quality. Baseline data have also been collected to document current ecological condition of aquatic values and facilitate monitoring for any potential Project-related changes.

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1.0 Introduction

Alcoa are planning to expand the existing Residue Storage Area (RSA 10) at the Wagerup alumina refinery, approximately 130 km south of Perth metropolitan area, and 35 km south of the Pinjarra refinery, in the southwest region of Western Australia (WA). The development will involve construction of a new storage area RSA 10 (to the north of existing RSA 9) and the development of one or more clay borrow pits to the north of the residue storage areas (RSAs) to provide material to line RSA 10 (the Project) (Figure 1). Samson Brook South Drain flows east to west along the northern boundary of the proposed RSA 10 location. Samson Brook, including the South Drain branch, flows into the Harvey River approximately 5.8 km downstream of the proposed RSA 10 location. TheSamson Brook South Drain has been highly modified into trapezoidal drains, with varying levels of maintenance, in the vicinity of the RSAs. The natural hydrology of the lower Harvey River catchment, in general, has been significantly altered since the 1900s by the construction of extensive irrigation and drainage systems for agriculture on the coastal plain.

The coastal plain sumplands and drains adjacent to the footprint of the proposed RSA 10 and borrow pit locations were considered highly unlikely to provide significant habitat for conservation-significant aquatic species (WRM 2022a). However, a large population (200+ individuals) of the Vulnerable Carter's freshwater mussel (*Westralunio carteri*; "CFM") was documented during the spring 2022 aquatic fauna baseline survey at surface water sampling site SP012 (WRM-SLR 2023; Figure 2). SP012 is located on Samson Brook, approximately 2.8 km downstream of the proposed RSA 10 location adjacent to Samson Brook.

The Department of Water & Environmental Regulation (DWER) and Environmental Protection Authority (EPA) consider these drains to be ecological systems under the Inland Waters key environmental factor. Water is released from Samson Pipehead Dam (~8 km upstream of the RSA), operated by the Water Corporation of Western Australia, to maintain ecological flow and support aquatic fauna populations in lower Samson Brook. Therefore, the channel is likely to hold water throughout the year.

Following the detection of a notable population of CFM at SP012, Alcoa sought to document the presence, extent and density of possible CFM populations along a ~5.6 km section of Samson Brook South Drain, and ~1.6 km section of the eastern branch of Samson Brook (Figure 1), located to the north and west of the Wagerup Refinery's RSAs.

The SLR Consulting aquatic ecology team (previously Wetland Research and Management, "WRM-SLR") were engaged to conduct the CFM targeted survey in Samson Brook South Drain and the eastern branch of Samson Brook in July 2023. This report presents the results of that survey and summarises previous desktop and field survey efforts characterising the aquatic fauna values of the Wagerup area, to support the Works Approval application for RSA 10.

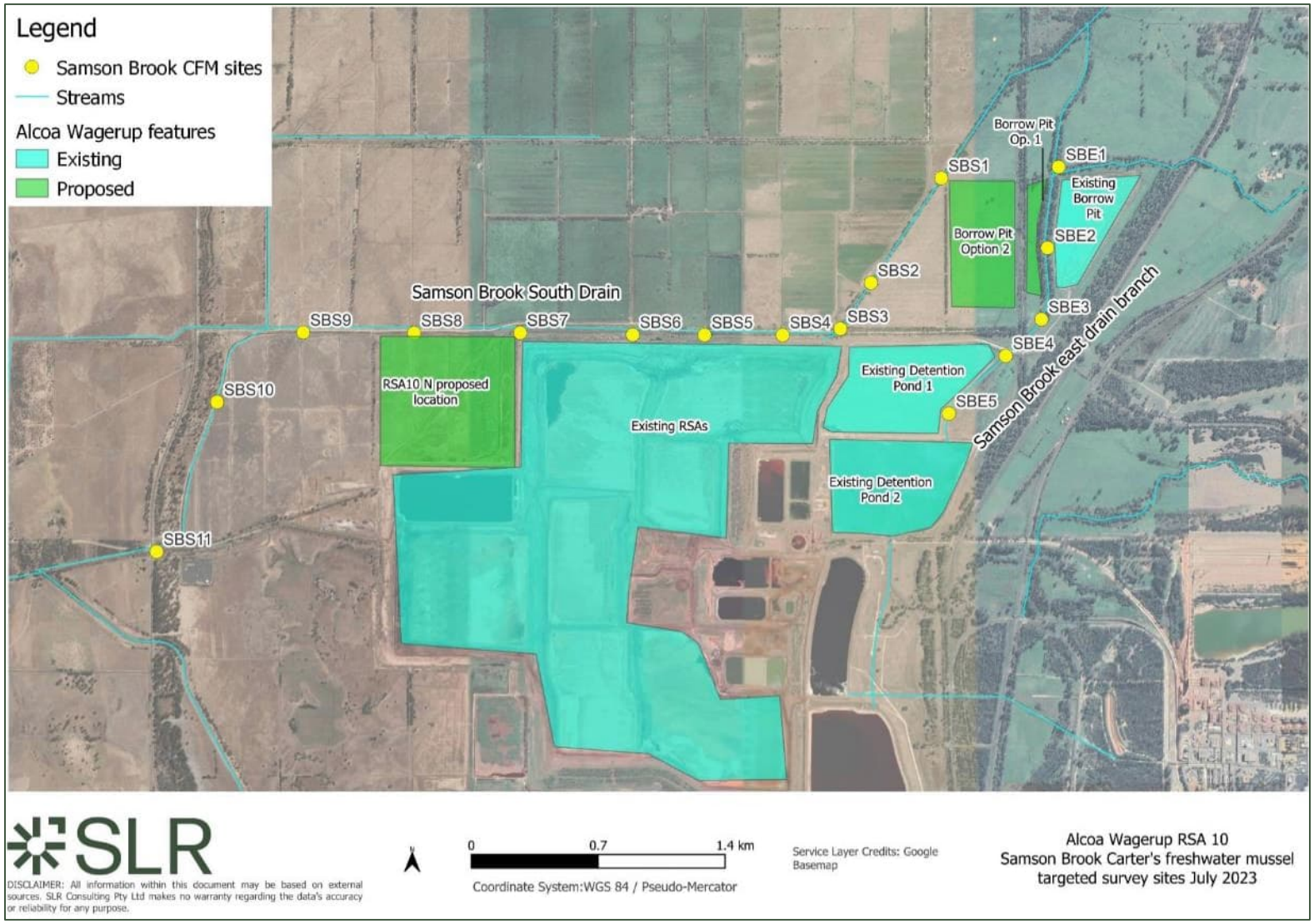

Figure 1. CFM targeted survey sites.

1.1 Scope of works

The scope of work for the survey and desktop review was:

- Conduct a desktop review of previously completed reports Aquatic Fauna Desktop Review for Wagerup RSA 10 (WRM 2022a), Wagerup Residue Storage Area Water Quality Hazard Analysis for Potential Inputs to Aquatic Environments, 2022 (WRM 2022b) and Wagerup RSA 10 Aquatic Fauna Survey Spring 2022 (WRM-SLR 2023) to summarise previous desktop and field survey efforts characterising the aquatic fauna values of the Wagerup area, to support the Works Approval application.
- Conduct a targeted field search for Carter's freshwater mussel along Samson Brook South Drain and Samson Brook east branch reaches, located to the north and east of the RSAs.
- Prepare a memorandum suitable for Alcoa to use to inform environmental approvals.
- Provide any Geographic Information System (GIS) data in accordance with Index of Biodiversity Surveys for Assessments (IBSA) requirements.

2.0 Legislative framework

Aquatic ecosystems and their dependent fauna are protected under a range of State and Federal policies and acts. The Western Australian Environmental Protection Authority's (EPA) environmental objective for *Inland Waters* is to maintain the hydrological regimes and quality of groundwater and surface water so that environmental values are protected (EPA 2018). Inland Waters are considered to include groundwater systems, wetlands, estuaries, and any river, creek, stream or brook (and its floodplain), including systems that "flow permanently, for part of the year or occasionally, and parts of waterways that have been artificially modified" (EPA 2018). Environmental value is defined under the *Environmental Protection Act 1986* (EP Act) as a beneficial use or an ecosystem health condition. Aquatic fauna and flora and the ecological processes that support them are specifically listed in the Inland Waters Environmental Factor Guideline as one of the ecosystem health values that must be considered as part of the environmental impact assessment process (EPA 2018).

Impacts to the factor Inland Waters can impact the factor *Terrestrial Fauna* which encompasses freshwater fish (EPA 2016). The EPA's objective for the factor Terrestrial Fauna is: "To protect terrestrial fauna so that biological diversity and ecological integrity are maintained" (EPA 2016a).

The previous desktop review and aquatic fauna survey conducted for the proposed RSA 10 works considered the aquatic habitats and fauna values that may potentially be affected by the Project:

- Threatened fauna species or communities listed as matters of National Environmental Significance (MNES) under the commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and ecosystems that support them;
- Threatened and Priority fauna species or communities listed under the state WA's Biodiversity Conservation Act 2016 (BC Act), and ecosystems that support them;
- Wetlands of international importance as listed under the Ramsar Convention;
- Wetlands of national importance as listed in the Directory of Important Wetlands in Australia (DIWA);
- Wetlands protected by Environmental Protection Policies (EPP) under Part 3 of the EP Act;
- Conservation Category or Resource Enhancement wetlands as mapped by the Western Australian Department of Biodiversity, Conservation and Attractions (DBCA) Geomorphic Wetlands of the Swan Coastal Plain dataset (DBCA-19);
- Wetland types which may be poorly represented in the conservation reserves system;
- Springs and permanent pools which act as refugia;
- Short-range endemic (SRE) aquatic fauna.

Aquatic fauna is encompassed by the EPA's Terrestrial Fauna factor, and their habitat is encompassed by the Inland Waters factor. Despite the Environmental Factor relating to Inland Waters being updated in 2018 (EPA 2018), there are still no prescriptive guidance statements

at the state or Commonwealth level outlining surface water quality and aquatic fauna sampling design and methods. Therefore, the aquatic fauna sampling conducted by by WRM-SLR employed methods and general approaches / rationale consistent with the following:

- EPA Technical Guidance: Terrestrial vertebrate fauna surveys for environmental impact assessment (EPA 2020);
- EPA Technical Guidance: Sampling of short-range endemic invertebrate fauna (EPA 2016b);
- the National Monitoring River Health Program (NRHP) Australia River Assessment Scheme (AusRivAS);
- Wetlands of the Swan Coastal Plain: wetland classification on the basis of water quality and invertebrate community data (Davis *et al.* 1993);
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018), developed as part of the National Water Quality Management Strategy (NWQMS) (Australian Government 2018).

3.0 Study area

The Samson Brook South Drain and eastern branch is located on the Pinjarra Plain, in the south-eastern margin of the Swan Coastal Plain, and in the Perth sub-region (SWA02) of the Swan Coastal Plain Interim Biogeographic Regionalisation of Australia (SWA IBRA) region as defined by the Department of Water and Environmental Regulation (DWER). Samson Brook is a tributary of the lower Harvey River catchment and is surrounded by agricultural lands. The majority of natural watercourses and wetlands in the Harvey River catchment are highly modified by vegetation clearing and by drains constructed for winter flood relief and irrigation in the early 1900's (Streamtec 2000, Environ 2005). Many of the natural seasonal and perennial wetlands were drained, while riverine flats and riparian vegetation were preferentially cleared for agriculture, and are some of the most heavily cleared and degraded habitats in the catchment. Vegetation clearing and drain construction has significantly altered the hydrology of the catchment. Runoff from the catchment is considered to be much greater than under pre-European conditions (by an estimated 300% for the lower Harvey sub-catchment) (Environ 2005), though reduced rainfall due to climate change has reduced catchment runoff and streamflow by up to 40% since the 1970s.

Surface water flows into the refinery area from the east, via North and South Yalup brooks, and from the north, via Samson Brook South Drain and Black Tom Brook through the Wagerup Diversion Drain (Figure 1). The volume of surface water in the Samson Brook drains can vary by orders of magnitude depending on a number of factors, including, rainfall, agricultural irrigation demands during summer and associated environmental releases/compensation flows from upper dams on the Darling Scarp, i.e., Samson Pipehead Dam (~8 km upstream of the RSA), Samson Brook Dam (12 km ENE), Drakesbrook Weir (6.5 km NE) and Waroona Dam (9.3 km NE).

The study area experiences a Mediterranean climate of hot, dry summers and cool, wet winters. The major drainage catchment is the Pinjarra-Waroona-Harvey Drainage Catchment which receives an average annual rainfall of 850mm (1981 - 2021; BOM 2022). Typically, highest rainfall occurs between May and September (highest average monthly rainfall in July - 159 mm), and lowest rainfall occurs between October and April (lowest monthly average in December - 13 mm).

Under conditions of the refinery lease, run-off from residue and the refinery areas must be strictly controlled to prevent contamination of adjacent streams and downstream receiving systems (Alcoa 2017). The understanding is that the water management systems are designed to cope with extreme rainfall events to ensure surface runoff and discharge is contained. All dewatering and runoff water from Project construction area are expected to be captured and retained on-site as process water.

4.0 Review of previous desktop studies and field surveys for the RSA 10 project

One desktop review (WRM 2022a; Appendix A) and one aquatic fauna field survey (WRM-SLR 2023; Appendix B) have been conducted to support the RSA 10 works approval, to date. The key findings of these reports have been reviewed below.

The 2022 desktop literature review (WRM 2022a) focused on documenting the known aquatic ecological values of Samson South Drain and Wagerup Diversion Drain that traverse the Project area, together with all relevant available information within a 50 km radius of the Project. The review synthesised 11 consultancy reports, three state agency reports, and data from several publicly available government and scientific databases. The review found there had been only one previous aquatic fauna study for the Project area; *Wagerup Refinery: Yalup Brook and South Samson Brook Environmental Water Requirements* (Streamtec 2000). This study included fish and aquatic macroinvertebrate sampling at six sites on local drains and brooks within and around the Project. However, Streamtec (2000) provide very little information on fish species, and no information on the aquatic invertebrate species recorded. Potential aquatic ecological values were therefore broadly inferred from several other studies conducted in similar lowland systems of the Coastal Plain; *i.e.* Samson Brook, Logue Brook, Bancell Brook, Drakesbrook-Waroona-Upper Mayfields Drain, Henty Brook, lower Collie River, and North and South Dandalup rivers. Significant aquatic fauna habitats were identified; discussed in further detail in Section 4.1 below.

As WRM (2022a) found no suitable records in existence for the Project area, field surveys for aquatic fauna were recommended to determine the importance of drain and wetland (sumpland) habitat occurring within and around the Project area. Targeted surveys for conservation significant species were also recommended. Alcoa Wagerup accepted these recommendations, and the Wagerup RSA 10 Aquatic Fauna Baseline Assessment (WRM-SLR 2023) was successfully completed between 17th – 21st October 2022 (spring 2022). Aquatic fauna sampling was conducted at six creekline and three wetland sites in the Wagerup area (Figure 2). The survey included sampling of water quality, zooplankton, macroinvertebrates, fish, and targeted surveys for potential listed species such as freshwater mussel and black-stripe minnow.

The finding of greatest significance to the RSA 10 project from the spring 2022 survey was a population of the conservation-listed Carter's freshwater mussels, *Westralunio carteri*, at surface water sampling site SP012, located on Samson Brook, immediately downstream of where Yalup Brook enters Samson Brook. This population and its significance are discussed in further detail in Section 4.2.1 below.

Water quality analyte levels recorded from the study area in spring 2022 were generally below or within the Australian and New Zealand default water quality guidelines for the protection of freshwater ecosystems (ANZG 2018), and the Wagerup RSA interim site-specific guideline values (SSGVs) derived in the 2022 hazard analysis (WRM 2022b; Appendix C).

The seasonally-inundated wetland area (a largely cleared, inundated paddock) to the west of the RSAs was sampled due to being identified as potential habitat for the black-stripe minnow, *Galaxiella nigrostriata*, which is listed as Endangered under the EPBC Act. No black-stripe minnows were captured at the three wetland sites sampled in this area. The wetland area

supported at least two native and widespread fish species (western minnow and western pygmy perch), 93 aquatic invertebrate taxa, a large number of tadpoles (species not determined), the introduced fish species Eastern gambusia and the introduced crayfish species, the yabby. While no listed conservation-significant aquatic fauna species were recorded in the wetland area, two cladoceran taxa (water fleas) recorded from these sites are likely to be new to science (Dr Russel Shiel, pers. comm., 14th December 2022).

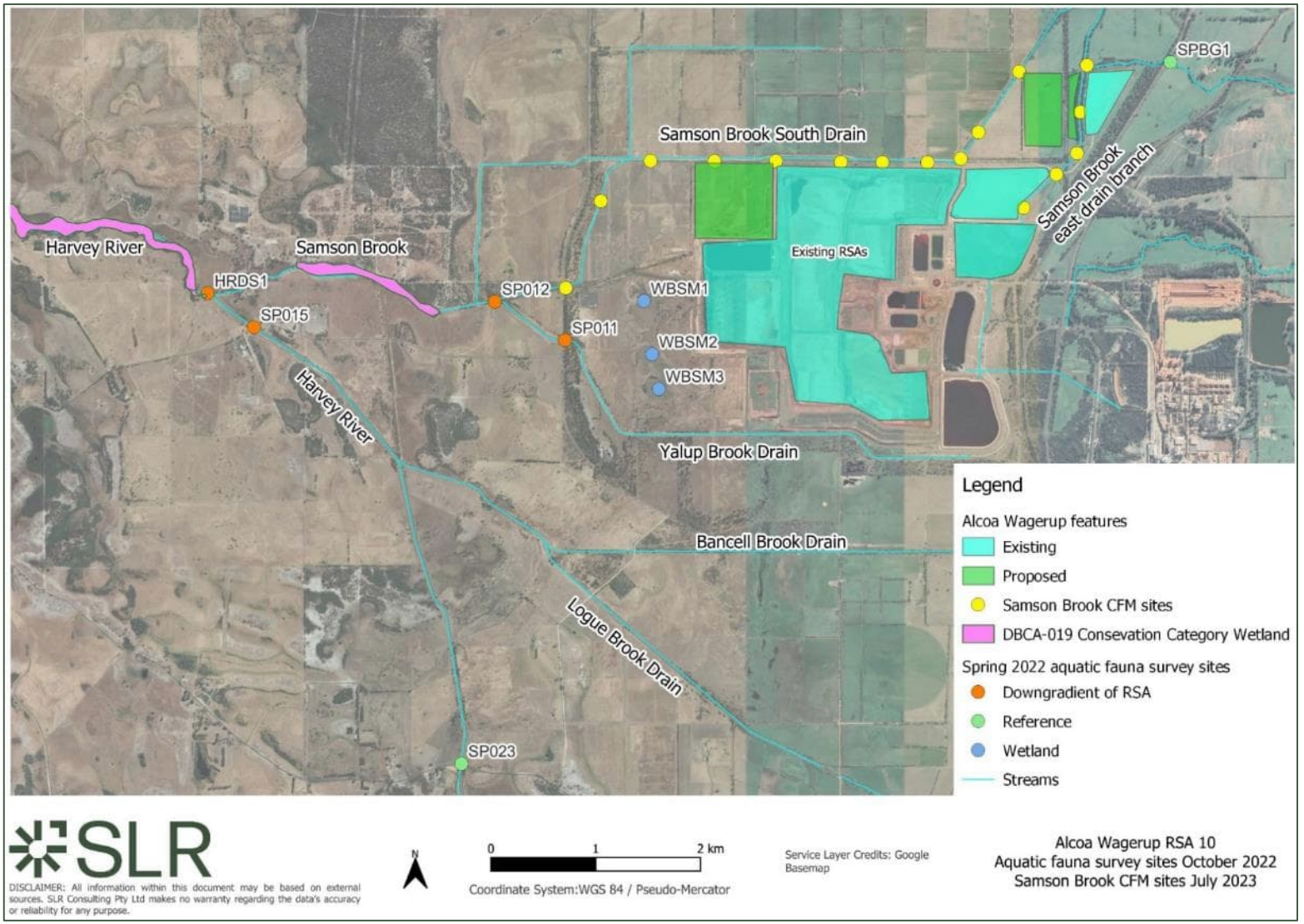

Figure 2. Aquatic fauna survey sites October 2022 and CFM targeted survey sites July 2023.

The creekline sites downstream of the RSAs support Carter's freshwater mussel, along with at least 122 macroinvertebrate taxa, five native fish species, at least two native crayfish species, two introduced fish species, one introduced crayfish species. Western minnow were the most common fish species, followed by nightfish and western pygmy perch. The native south-western snake-necked turtle was also recorded at downstream site HRDS1. The state-listed rakali (Australian water rat, *Hydromys chrysogaster* Priority 4) was not targeted during the survey but was sighted at upstream reference site SPBG1. Other than the Carter's freshwater mussel and the rakali, none of the fauna species captured or sighted during this survey are conservation-listed at a state or federal level. However, the native South-western snake-necked turtle (*Chelodina oblonga*, synonymous with *Chelodina colliei*) was captured at downstream site HRDS1. This species is widespread throughout the south-west region, however, it is listed as 'near threatened' at the international level, and its status has not been assessed for 20 years.

4.1 Significant aquatic fauna habitats

The desktop review (WRM 2022a) found no Conservation Category (CCW) or Resource Enhancement (REW) wetlands, as listed under Geomorphic Wetlands, Swan Coastal Plain (DBCA-019), within the Project area. The drains in and around the Project area are all classified as Multiple Use Wetlands (MUWs) and are predominantly farmland used for grazing livestock. Downstream and to the west of the proposed RSA 10 location, there are four CCWs and five REWs. The CCWs on Samson Brook (wetland UFI 4652) and on the Harvey River (wetlands UFI 4500 and UFI 14584) are the nearest significant aquatic fauna habitats downgradient of the Project area (Figure 2).

In general, CCWs are categorised on the basis of having "a reasonable level of functionality and are representative of wetland types that are rare or poorly protected", while REWs are categorised as "degraded, but still supporting substantial ecological attributes and functions" (DBCA 2020). However, current management categories for the CCWs and REWs in the vicinity of the Project appear to be based solely on the 1996 report, Wetlands of the Swan Coastal Plain Volume 2B Wetland Mapping, Classification and Evaluation: Wetland Atlas (Hill *et al.* 1996). The literature search did not find any recent field surveys confirming the current ecological condition of these wetlands.

4.2 Conservation-significant aquatic fauna

WRM (2022a) identified two aquatic fauna species listed under the EPBC Act that had been recorded within 50 km of the RSAs prior to the spring 2022 survey:

- *Westralunio carteri* Iredale, 1934 (Carter's freshwater mussel).
- *Galaxiella nigrostriata* Shipway, 1953 (black-stripe minnow, blackstriped dwarf minnow).

The October 2022 aquatic fauna survey of creeklines and wetlands upstream, adjacent to and downstream of the RSAs confirmed the presence of CFM in Samson Brook and Harvey River downstream of the proposed RSA 10 location, and upgradient of the RSAs in Black Tom Brook (WRM-SLR 2023).

Black-stripe minnow were not detected at any of the wetland or creekline sites sampled during the 2022 study. Sampling was conducted using proven capture methods during this species'

known emergence and breeding window in their preferred habitat (seasonal wetlands; where this habitat occurred within the study area). Therefore, it is reasonable to conclude that there are unlikely to be populations (either significant or otherwise) of this species adjacent to or downgradient of the Wagerup RSAs.

WRM (2022a) also identified the rakali (Australian water rat), *Hydromys chrysogaster*, a state-listed Priority 4[1] species (DBCA 2021), was likely to be present within 10 km of the RSAs. One rakali was briefly sighted during the spring 2022 survey at upstream reference site SPBG1 on Black Tom Brook, during early morning net/trap retrieval. Though rakali have been observed in irrigation channels and farm dams, and at the RSA upstream reference site in spring 2022, it is unlikely that the current study area of Samson Brook South Drain provides suitable habitat for these semi-aquatic mammals, as there is little riparian vegetation or root material for them to shelter and burrow in.

WRM (2022a) found records of an additional eight aquatic invertebrate and six aquatic vertebrate species of conservation interest within the greater Swan Coastal Plain region. Most of the nearest records of these species were greater than 50 km away from the Wagerup RSAs, and/or their known habitat did not occur within or downstream of the Project/study area.

4.2.1 Carter's freshwater mussel – EPBC Act protected matter

The finding of greatest significance to the RSA 10 project during the spring 2022 survey was the large population of CFM at surface water sampling site SP012 (Figure 2). SP012 is located on Samson Brook, approximately 2.8 km downstream of the proposed RSA 10 location adjacent to Samson Brook. Two hundred mussels were captured from along an undercut clay bank over an approximate distance of 20 m (estimate ~10 per m^2). Due to the large numbers of mussels at this location, counting was capped at 200, and the actual size of population is likely to be much higher. While this population likely represents a normal density of mussels for a south-west creekline (Ma *et al.* 2022), other populations detected at Harvey River and Black Tom Brook sites in the study area were comparatively low in density (estimate ≤ 2 m^2). Therefore, the CFM population at SP012 may meet the criteria as an "important population" under the EPBC Act 1999 Significant Impact Guidelines (Commonwealth of Australia 2013), as a key source population for breeding and dispersal in Samson Brook and Harvey River.

4.2.1.1 CFM conservation status, distribution, and biology

CFM is listed as a Vulnerable threatened species under the *Biodiversity Conservation Act 2016* (state, Western Australia), the Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth) and the ICUN Redlist of Threatened Species 2020 (International). The current distribution of CFM is limited to within 50-100 km of the coast from Gingin Brook in the north, to the Kent River and Waychinicup River along the southern coast (Klunzinger and Walker 2014, Klunzinger *et al.* 2015). However, a recently published study by Kunzinger *et al.* (2022) has undertaken morphological and genetic analysis of CFM across the south-west and determined there are additional species/subspecies present. CFM is restricted to western coastal drainages south of Perth, with those on the southwest and south coast described as

[1] Priority 4: Rare, Near Threatened and other species in need of monitoring (Conservation Codes for Western Australian Flora and Fauna).

a different species, split into two subspecies; those along the south coast and those in the very south-west corner around Margaret River. This paper therefore greatly reduces the known range of CFM to western flowing drainages off the Darling Scarp, and by inference increases its level of threat. CFM occurs in greatest abundance in slower flowing permanent/semi-permanent stream and riverine habitats with stable sediments and low salinity, living two thirds to almost fully buried in sand and finer sediment (Klunzinger *et al.* 2010, Klunzinger 2012). Klunzinger (2012) only found CFM in perennial (permanent/semi-permanent) stream and riverine habitats, and dehydration exposure experiments demonstrated CFM cannot survive prolonged drying (i.e., 76% mortality occurring under experimental conditions, within five days of exposure to dry conditions in sand filled bath tubs). CFM also occurs in lentic (still water) waters including large water supply dams and on-stream farm dams (Klunzinger *et al.* 2015, DWER 2022). The species is vulnerable to prolonged drying and cannot withstand exposure for longer than five days without moist sediments and shade (Lymbery *et al.* 2021). CFM require perennial streams or shallow pools or damp mud to retreat to during low water levels and drought, but may survive in seasonally-flowing creeks if the period of zero flow is sufficiently short, and/or there are residual pools or low lying area that remain damp/wet.

Freshwater mussels (Bivalvia: Unionoida) are a keystone species in freshwater ecosystems due to their filter-feeding ability, the important role they play in nutrient cycling and bio-deposition, as well as the structural habitat and the food source they provide for other organisms (Klunzinger *et al.* 2014, Vaughn and Hakenkamp 2001, Spooner and Vaughn 2008). Despite their immense importance, a number of freshwater mussel species remain endangered throughout the world, with a multitude of threats influencing their persistence and survival (Klunzinger and Walker 2014).

The CFM lifecycle involves an obligate parasitic 'larval' stage, known as glochidia, which attach to host fish for several weeks to complete their development (Bauer and Wächtler 2001, Strayer 2008, Klunzinger *et al.* 2012). The glochidia aids with the distribution of this species, with individuals being dispersed by migrating fish. CFM is a long-lived species, becoming sexually mature within 6 years at approximately 27 mm shell length, and living for at least 50 years (Klunzinger *et al.* 2014). Despite this known information, there is a distinct knowledge gap with respect to the ecology of CFM, thereby confounding conservation efforts and status of the species, whilst emphasizing the protection of any known/new populations of the species (Klunzinger *et al.* 2015).

CFM is currently under threat across south-western Australia due to secondary salinisation, loss of suitable host species, nutrient pollution, habitat loss, water extraction, as well as sedimentation resulting in increased turbidity. Reservoir dewatering and declining rainfall also appear to have had a negative effect on populations (Klunzinger *et al.* 2012). Secondary threats are trampling by cattle, changes in water quality and possible loss of suitable host fishes for larval stages (glochidia). Confirmed native host species for glochidia are freshwater cobbler, western minnows, western pygmy perch, nightfish, Swan River goby and southwestern goby, and exotic gambusia and one-spot livebearer (Klunzinger et al. 2012, 2015). Barriers to upstream movement of fish may therefore also restrict gene flow between mussel populations, limit upstream-downstream recruitment of CFM, restrict distributions and prevent recolonisation. As well as weirs and dams, barriers include low flow regimes that make natural barriers (waterfalls, riffle zones) impassable for fish. CFM are filter feeders and are vulnerable to water pollutants and sedimentation. Burial by deep loose sands and silts will also

kill CFM. CFM also appear intolerant of average salinity levels > 1,500 mg/L (~3,000 µS/cm; Klunzinger *et al.* 2012). Klunzinger *et al.* (2015) speculated that the species extent of occurrence (EOO) had declined by 49% in less than 50 years, due primarily to secondary salination, and emphasised the importance of habitat protection where the species persists. The former range for this species extended from Moore River in the north to King George Sound in the south and inland to the Avon River (Klunzinger & Walker 2014, Klunzinger *et al.* 2015), but now needs to be revised (Klunzinger *et al.* 2022).

4.3 Project-specific risks to aquatic fauna

Four potential RSA 10 project-specific risks to aquatic fauna present in downgradient environments have been identified:

1. Leaching or runoff transporting water containing potential contaminants from RSA 10 construction area.
2. Exposure of acid sulfate soils.
3. Unplanned dewatering discharge to Samson Brook.
4. Sediment transport via stormwater runoff.

Should any of these unplanned events occur, depending on the time of year and efficacy of management responses, aquatic fauna in downstream/adjacent environments may be at risk. The mechanisms of potential impact to aquatic fauna include sedimentation (increased turbidity of water, smothering of fauna and infilling of habitat) and exposure to potential toxic contaminants and elevated salinity transported in surface or ground water from the RSA 10 site and haul road construction areas. The aquatic fauna of greatest significance and most at-risk of impact, should these events occur, is the large population of EPBC-listed Vulnerable CFM at SP012 in Samson Brook, approximately 2.8 km downstream of the proposed RSA 10 location. CFM, as filter-feeding organisms, are vulnerable to bioaccumulation of metals (e.g., copper, iron and zinc) within their tissues, as well as smothering during sedimentation events. CFM are also sensitive to salinisation. The 80th percentile for electrical conductivity (a measure of salinity) in Guildford formation groundwater below RSA 10 was 4112 µS/cm, and the calculated 80th percentile for salinity was 1.39 g L, which approaches the acute salinity tolerance limit (LD50) of CFM of 1.6–3.0 g L (Klunzinger *et al.* 2012). The other non-listed aquatic fauna occupying the potential receiving environment are also likely to have varying levels (largely undocumented) of vulnerability to salinity, potential contaminant of concern (PCoCs) and sedimentation.

The entire area of the Wagerup Refinery including the RSA sits within an area mapped as having a moderate to low risk of acid sulfate soils (ASS). Dewatering and excavation below the water table can cause acidification in ASS, if present. Acidification of groundwater may have deleterious effects to aquatic fauna in downgradient ecosystems either through direct effects of acidity, or mobilisation of metals under reduced pH. At the time of this report, Alcoa were investigating the extent of ASS in the RSA 10 area.

The Wagerup refinery has been designed to operate an efficient closed water circuit, with losses from steam and evaporation, made up by the collection of all refinery surface water run-off, harvesting fresh surface water flows, and the purchase of make-up water from licenced bores, when required (Alcoa 2017). The Alcoa Wagerup Refinery Long Term Residue Management Strategy (LTRMS) 2017 also describes how the contamination of stormwater is

prevented, and that the RSA has a 100% surface water containment policy. Potential failures of RSA 10 dewatering infrastructure resulting in leakages are expected to be contained according to this policy through precautionary measures implemented by Alcoa, and prevented from entering downgradient aquatic environments.

A hazard analysis (HA) for potential unplanned inputs to aquatic environments from the RSA was conducted in early 2022, based on data available at the time (WRM 2022b). The aim of the HA was to identify potential contaminants of concern in RSA ground and surface water and document the current condition of water quality in streams both upstream, adjacent to, and downstream of the RSA. The HA proposed a set of site-specific guideline values that are intended to be used to monitor and assess the condition of aquatic environments downstream of the RSA in future, with the goal of preventing deterioration in water quality that may be attributable to RSA operations.

4.4 Desktop review summary

Overall, aquatic habitats in the vicinity of the RSAs were considered to be highly-modified in condition, although, water quality was generally good and the native aquatic faunal assemblages in Samson Brook downstream of the SBS drain were diverse and abundant. Of the conservation-significant fauna identified by the desktop review, only CFM were recorded in significant numbers in Samson Brook, downstream of SBS drain and the proposed RSA 10 location. This population may meet the criteria as an "important population" under the EPBC Act 1999 Significant Impact Guidelines (Commonwealth of Australia 2013), as a key source population for breeding and dispersal in Samson Brook and Harvey River.

The knowledge gaps identified in the desktop review (WRM 2022a) have been addressed by the subsequent aquatic fauna field survey, RSA hazard analysis and the current targeted CFM survey. The spring 2022 survey was conducted at the optimum time of year to allow species-level identification of fauna (i.e., peak breeding and emergence season), which allowed the conservation-significance of species within, and adjacent to, and downstream of the Project area to be determined. The spatial coverage captured upstream reference, adjacent and downstream aquatic habitat areas relevant to the Project. The potential risks to aquatic fauna in potential receiving aquatic environments from the proposed development have been analysed in regard to possible adverse changes in water quality. Baseline data have been collected to document current condition and facilitate monitoring for any potential Project-related changes.

The current targeted survey aims to determine the possible extent and density of CFM populations directly adjacent to, and downstream of, the proposed RSA 10 location and new borrow pit options. These areas were not intensively sampled for aquatic fauna during the spring 2022 survey.

5.0 Targeted survey methods

5.1 Site selection

Eleven sites along Samson Brook South Drain ("SBS"; representative sites along a 5.8 km linear channel length) and five sites along the eastern branch ("SBE"; representative sites along a 1.6 km linear channel length) were visited and surveyed for CFM in July 2023 (Table 1; Figure 1).

Table 1. CFM targeted survey site coordinates (datum WGS84).

Code	Area	Zone	Easting	Northing
SBS1	Samson Brook South	50	396806	6360768
SBS2	Samson Brook South	50	396415	6360175
SBS3	Samson Brook South	50	396249	6359921
SBS4	Samson Brook South	50	395931	6359883
SBS5	Samson Brook South	50	395500	6359879
SBS6	Samson Brook South	50	395104	6359876
SBS7	Samson Brook South	50	394483	6359880
SBS8	Samson Brook South	50	393898	6359873
SBS9	Samson Brook South	50	393286	6359870
SBS10	Samson Brook South	50	392815	6359482
SBS11	Samson Brook South	50	392490	6358653
SBE1	Samson Brook East	50	397421	6360818
SBE2	Samson Brook East	50	397373	6360378
SBE3	Samson Brook East	50	397355	6359981
SBE4	Samson Brook East	50	397156	6359775
SBE5	Samson Brook East	50	396850	6359456

5.2 Survey method

A team of two aquatic ecologists conducted targeted searching of the inundated channel area for mussels at each site location. In order to establish the presence of mussels, sediments were hand searched or raked (depending on depth) by the two personnel using mussel rakes (a long-handled bow rake (1.35 m handle with metal teeth) fitted with an 8 mm net pouch). For sites with water deeper than 1.35 m, a modified crab scoop net fitted with a finer 20mm wire mesh was used. Banks were also visually searched for evidence of mussels (either live of empty shells). Searches were be conducted 20 m of linear channel length at each site. When mussels were detected at a site, 8 randomly placed 1 m^2 quadrats were searched within the 20 m of channel length to estimate density (live mussels per m^2), and micro-habitat preference of populations were recorded. All mussels were gently returned alive to the site of capture. These targeted survey methods for CFM follow that of Klunzinger *et al.* (2012) and the *Technical Guidance – Terrestrial vertebrate fauna surveys for environmental impact assessment* (EPA, 2020).

In-situ water quality readings for dissolved oxygen saturation (DO%), pH, water temperature (°C) and electrical conductivity (µS/cm) were recorded using handheld meters at each survey site. Maximum water depth and channel width was estimated in meters, sediment characteristics were noted, and at least two photographs were taken to capture habitat

condition at each site. Site photographs are provided in Appendix D, and i*n-situ* water quality readings and habitat characteristics are provided in Appendix E.

5.3 Licensing and permits

Any activities which may result in the taking or disturbance of all fauna requires lawful authority under the *Biodiversity Conservation Act 2016* (BC Act). A Ministerial Authorisation to Take or Disturb Threatened Species (TFA) under section 40 of the BC Act is required to take or disturb threatened species (Critically Endangered, Endangered or Vulnerable).

The licenses obtained for the 2022 Wagerup Aquatic Fauna survey are current until 31st October 2023 (BA27000735 and TFA 2223-0096) and covered the activities required for the CFM targeted survey.

A condition of holding these licences is that taxa lists by site and time are provided to the relevant State Department for entry onto their database.

5.4 Limitations

Table 2 below summarises the potential limitations and constraints affecting the Alcoa Wagerup RSA 10 CFM targeted in July 2023.

Table 2. Survey limitations.

Aspect	Constraint?	Comment
Competency	No	The survey was conducted by two aquatic ecologists with prior experience in both general and targeted fauna surveys in South West Western Australia aquatic ecosystems. The combined number of years' experience in aquatic ecology held by the personnel is 10 years. Both personnel hold university-level degrees in biological sciences. The survey was conducted under a Fauna Taking (Biological Assessment) Licence and an Authorisation to Take or Disturb Threatened Species issued by DBCA on the 5th October 2022, expiry 31st October 2023.
Scope	No	The scope was prepared by Alcoa and WRM-SLR, informed by the consultants knowledge of previous, similar assessments and limited to areas upstream, adjacent to and downgradient of the proposed RSA and borrow pit locations. The scope was considered sufficient to characterise the extent of CFM populations in the study area.
Fauna detected if present in the survey area	Minor	It was not feasible to sample the entire area that may be affected by the proposed RSA, therefore 16 sites representative of habitat areas and locations were selected and targeted for sampling to maximise chances of detection. Populations with extremely low abundance may not have been detected.
Sources of information	No	The previous desktop assessment and aquatic fauna survey informed the scope of this survey.
The proportion of the task achieved and further work	No	The surveys were completed adequately, carried out to a sufficient level with respect to the scope.
Timing/weather/season/cycle	No	Surveys were carried out in favourable conditions. Timing of the survey was not a limitation for the survey. All areas were accessible (not yet flooded by winter rains).
Disturbances	No	There were no disturbances that affected the survey.
Intensity	No	The survey intensity is considered adequate to have met the scope.

Aspect	Constraint?	Comment
Completeness (e.g., was relevant area fully surveyed)	Minor	It was not feasible for the entire area of possible habitat within the survey area to be targeted. Areas of representative habitat were selected and targeted to maximise chances of detection within the spatial extent of channel area adjacent to the proposed developments.
Resources	No	The resources made available to the survey were sufficient.
Remoteness and/or access problems	No	There were no barriers to accessing the selected survey sites.

6.0 Targeted survey results

Carter's freshwater mussel was detected in July 2023 along the Samson Brook South Drain ("SBS") at targeted survey sites SBS1, SBS2, SBS3 (Photo 1) and SBS11 (Table 3, Figure 3). No CFM were found in the eastern branch of Samson Brook ("SBE"). Compared to the population found at SP012 in October 2022 (estimated 10 per m^2), population densities where CFM were detected in July 2023 along SBS drain were very low (estimated ≤ 0.3 per m^2). It is unlikely that these populations would be considered a key source population for breeding and dispersal in Samson Brook under the EPBC Act, compared with the population at SP012. Most mussels found would be considered to be in the adult life-stage, given the shell-lengths were mostly greater than 40 mm (Klunzinger *et al*. 2014). This indicates recruitment rate in the stretch of SBS surveyed is likely low.

At the sites where CFM were found, the in-stream habitat consisted of coarser sediment types and lower densities of in-stream vegetation. At the sites where CFM were not detected, sediments were finer "sludge" and densities of in-stream vegetation, such as emergent bullrush (*Typha* sp.), were higher. While CFM are reported to prefer finer sediment (Ma *et al.* 2022), the "sludgy" and potentially anoxic sediments observed at many of the Samson Brook sites without recorded CFM presence may unsuitable for their survival. This condition was observed along SBE. Where CFM were not found along the east-west stretch of SBS channel immediately north of the RSAs, it is possible that the high density of in-stream vegetation has presented a barrier to dispersal by fish as hosts to CFM glochidia, and/or has left no area of exposed, suitable sediment for CFM to burrow. The area of SBS drain flowing south-west adjacent to the Farmlands office contained a low-density population of CFM. This reach is likely to be hydrologically connected to upstream reaches of Samson Brook, below the water supply dams operated by Water Corporation, which are known to contain CFM and suitable host fish populations (WRM 2020).

Water quality was unlikely to be a limiting factor for CFM presence in Samson Brook. *In-situ* water quality at most sites was generally within the default guideline values (DGV) range or below the upper guideline value for lowland rivers in south-west Australia (ANZG 2018; see Appendix E). The electrical conductivity (indicative of salinity) level at all sites (range 255 – 565 µS/cm) was well below the documented tolerance level for CFM (~3,000 µS/cm). Turbidity levels were generally below the DGV (20 NTU), apart from SBS11 (25.8 NTU), where six CFM were recorded. The pH of all sites was within the DGV range (6.5 – 8.0 pH). Dissolved oxygen (DO levels were lower than the lower DGV (80%) at most SBS sites, however, this measure is highly dependent on the time of day it was recorded, as in-stream primary producers produce oxygen during the daylight, and aquatic organisms consume it overnight. None of the

DO values recorded from Samson Brook (range 55.2 – 108.4%) were considered to be of ecological concern for CFM.

Table 3. Samson Brook CFM abundance, density and shell length data, July 2023.

	SBS1	SBS2	SBS3	SBS11
Individual shell lengths (mm)	60 37	54 48 68	52 60 43 42 58 44	66 63 60 67 69
Total abundance (20 m linear channel length x 1 m channel width)	2	3	6	5
Density estimate (abundance / 20 m)	0.1	0.15	0.3	0.25

Photo 1. CFM captured at site SBS3, 6th July 2023.

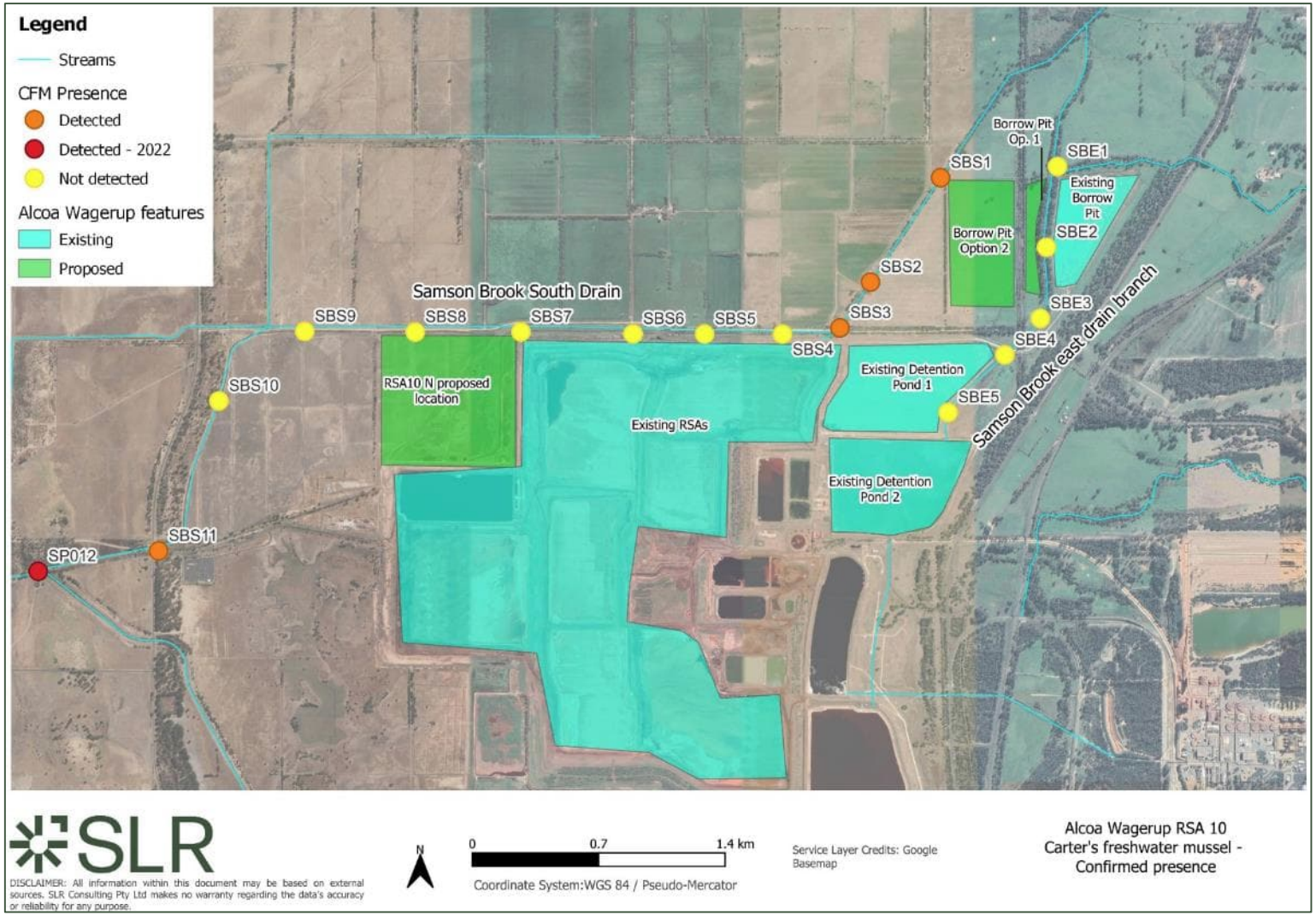

Figure 3. Samson Brook CFM confirmed presence and non-detection sites.

7.0 Summary and conclusion

The targeted survey, conducted in July 2023, aimed to determine the possible extent and density of CFM populations directly adjacent to, and downstream of, the proposed RSA 10 location and new borrow pit options. These areas were not intensively sampled for aquatic fauna during the spring 2022 survey. The survey did not detect any CFM along the SBS drain from SBS4 through to SBS10, which included the area directly adjacent to the northern boundary of the RSA 10 proposed location. A low-density population was detected at SBS11, located 700 m upstream of the higher-density population at SP012 (recorded in October 2022). Small populations were also present at SBS sites 1 to 3, adjacent to Borrow Pit option 2. No CFM were recorded along SBE.

The large CFM population at SP012 may meet the criteria as an "important population" under the EPBC Act 1999 Significant Impact Guidelines (Commonwealth of Australia 2013), as a key source population for breeding and dispersal in Samson Brook and Harvey River. As it is located 2.8 km downstream of the RSA 10 proposed location, it is theoretically considered to be potentially exposed to Project-related disturbances (i.e., changes in water quality and sedimentation). However, the high density of in-stream vegetation (mostly *Typha* sp. bullrush) present along approximately 2 km of that 2.8 km distance would most likely serve as a significant buffer for any potentially contaminated water originating from the RSA 10 site. It is likely that this vegetation also inhibits dispersal of CFM between the SP012 population and the SBS drain east-west stretch. The area of SBS drain running south-west adjacent to the Farmlands office contained a low-density population of CFM, which may have colonised the area via fish moving in from hydrologically-connected upstream reaches of Samson Brook. The very fine, sludgy substrate along SBE may represent unsuitable CFM habitat and might explain their non-detection along that drain. Habitat conditions in these drains where CFM were not detected are not related to Alcoa Wagerup activities, which occur downstream of these areas.

Appropriate management of stormwater runoff or other possible drainage from the RSA 10 site during and post-construction (as intended in the Wagerup Alumina Refinery Long Term Residue Management Strategy), and retention of the in-stream vegetation along the SBS drain, should provide adequate protection to the potentially "important population" of CFM at SP012, located downstream of the Project area. The low-density populations in SBS sites 1 to 3 are unlikely to represent an "important" population. However, if Alcoa progress with Borrow Pit option 2, appropriate management actions should be taken to protect them from potential impacts.

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Appendix A Aquatic fauna desktop review (WRM 2022a)

Wagerup RSA10
Aquatic Fauna Desk

Appendix B Aquatic fauna survey Spring 2022 (WRM-SLR 2023)

Wagerup
RSA10_Aquatic Faur

Appendix C Wagerup RSA Hazard Analysis (WRM 2022b)

Wagerup RSA
Water Quality Hazar

Appendix D Site photographs

SBS1

SBS2

SBS3

SBS4

SBS5

SBS6

SBS7

SBS8

SBS9

SBS10

SBS11

SBE1

SBE2

SBE3

SBE4

SBE5

Appendix E Site environmental data and default guideline values

Table E-1: *In-situ* water quality, July 2023.

Site	Date	Time	Temp ^{0}C	Turbidity (NTU)	Cond (us/cm)	pH	DO%
SBE1	7-07-2023	8:18	13.6	10.33	292.9	7.33	93.4
SBE2	7-07-2023	9:00	13.7	14.02	310.3	7.45	87.7
SBE3	7-07-2023	9:50	14.1	17.57	317	7.24	84.3
SBE4	6-07-2023	13:15	14	10.5	300.5	7.67	108.4
SBE5	6-07-2023	12:42	13	11.21	306.6	7.49	106.6
SBS1	6-07-2023	14:55	13	14.44	434.8	7.32	74
SBS2	6-07-2023	14:10	13.2	14.05	564.6	7.29	81.8
SBS3	6-07-2023	13:54	13.5	14.69	401.1	7.23	80.2
SBS4	6-07-2023	12:01	12.5	16.54	410.9	7.31	55.2
SBS5	6-07-2023	11:30	12.4	17.6	390.7	7.48	60.4
SBS6	6-07-2023	10:54	12.4	16.01	374.8	7.5	66.2
SBS7	6-07-2023	10:15	11.9	17.06	347.3	7.3	65.3
SBS8	6-07-2023	15:30	12.8	15.21	348.9	7.31	67.8
SBS9	6-07-2023	15:50	12.4	17.91	313.1	7.46	66.5
SBS10	7-07-2023	10:37	13.3	18.8	335	7.16	66.5
SBS11	7-07-2023	11:10	13.9	25.77	255	7.02	56.4

Table E-2: Samson Brook channel characteristics, July 2023.

Site	Max depth (m)	Length (m)	width (m)	Habitat notes
SBE1	0.6	20	4	Sludge sediment, open trapezoidal channel, flowing.
SBE2	0.3	20	3	Sludge sediment, open trapezoidal channel, emergent *Typha*, flowing.
SBE3	0.6	20	4	Sludge sediment, open trapezoidal channel, emergent *Typha*, flowing.
SBE4	1	20	5	Sludge sediment, open trapezoidal channel, emergent *Typha*.
SBE5	0.6	20	5	Sludge sediment, open trapezoidal channel, emergent *Typha*.
SBS1	0.05	20	0.5	Channel choked with tall pasture grass.
SBS2	0.2	20	1	In-stream bulk rubbish (chair, bucket, stakes), channel choked with tall pasture grass.
SBS3	0.2	20	2	Sediment gravelly sand/pebbles. Channel open, fringing sedges overhanging the bank.
SBS4	0.1	10	1	Channel choked with tall pasture grass and low herbaceous plant.
SBS5	0.1	15	2	Choked with *Typha*. Yabby observed.
SBS6	0.3	10	1	Sediment cobbles and fine. Channel open, fringing sedges overhanging the bank.
SBS7	0.1	6	1.5	Choked with *Typha* and fringing vegetation - could not rake bottom.
SBS8	0.3	20	2.5	Choked with *Typha*, could not rake bottom.
SBS9	0.3	20	2.5	Choked with *Typha*, could not rake bottom.
SBS10	0.2	20	2	Emergent rush filling most of the channel. Sludge sediment.
SBS11	0.3	20	3	Sediment gravelly sand/cobbles/boulders.

Table E-3: Default guideline values for physical and chemical stressors for south-west Australia for slightly disturbed ecosystems (Chl *a* = chlorophyll *a*, TP = total phosphorus; FRP = filterable reactive phosphorus; TN = total nitrogen; NOx = total nitrates/nitrites; NH3 = NH4+ = ammonium, DO = dissolved oxygen).

Ecosystem type	Chl *a*	TP	FRP	TN	NO_x	NH_4^+	DO (% saturation)[i]		pH	
	($\mu g\ L^{-1}$)	($\mu g\ P\ L^{-1}$)	($\mu g\ P\ L^{-1}$)	($\mu g\ N\ L^{-1}$)	($\mu g\ N\ L^{-1}$)	($\mu g\ N\ L^{-1}$)	Lower limit	Upper limit	Lower limit	Upper limit
Upland river[f]	na[a]	20	10	450	200	60	90	na	6.5	8.0
Lowland river[f]	3–5	65	40	1200	150	80	80	120	6.5	8.0
Freshwater lakes & reservoirs	3–5	10	5	350	10	10	90	no data	6.5	8.0
Wetlands[d]	30	60	30	1500	100	40	90	120	7.0[e]	8.5[e]
Estuaries	3	30	5	750	45	40	90	110	7.5	8.5
Marine[g,h] Inshore[c]	0.7	20[b]	5[b]	230	5	5	90	na	8.0	8.4
Offshore	0.3[b]	20[b]	5	230	5	5	90	na	8.2	8.2

na = not applicable

a = monitoring of periphyton and not phytoplankton biomass is recommended in upland rivers — values for periphyton biomass (mg Chl *a* m^{-2}) to be developed;

b = summer (low rainfall) values, values higher in winter for Chl *a* (1.0 $\mu g L^{-1}$), TP (40 $\mu g\ P\ L^{-1}$), FRP (10 $\mu g\ P\ L^{-1}$);

c = inshore waters defined as coastal lagoons (excluding estuaries) and embayments and waters less than 20 metres depth;

d = elevated nutrient concentrations in highly coloured wetlands (gilven >52 $g_{440}m^{-1}$) do not appear to stimulate algal growth;

e = in highly coloured wetlands (gilven >52 $g_{440}m^{-1}$) pH typically ranges 4.5–6.5;

f = all values derived during base river flow conditions not storm events;

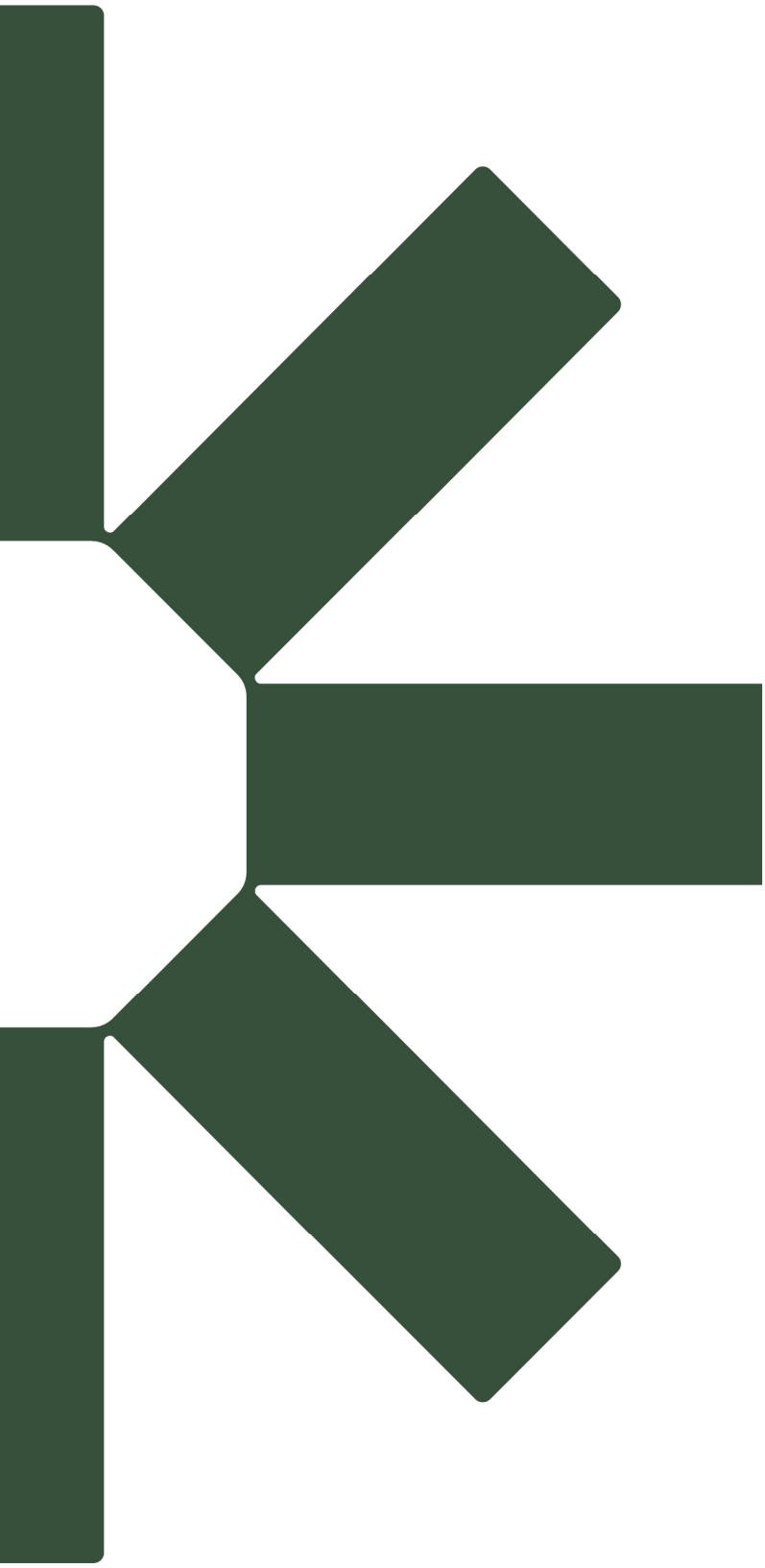
g = nutrient concentrations alone are poor indicators of marine trophic status;

h = these trigger values are generic and therefore do not necessarily apply in all circumstances e.g. for some unprotected coastlines, such as Albany and Geographe Bay, it may be more appropriate to use offshore values for inshore waters;

i = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability (see Section 3.3.3.2).

Table E-4: Range of default guideline values for salinity and turbidity for the protection of aquatic ecosystems, applicable to slightly disturbed ecosystems in south-west Australia.

Ecosystem type	Salinity (μScm^{-1})	Explanatory notes
Upland & lowland rivers	120–300	Conductivity in upland streams will vary depending upon catchment geology. Values at the lower end of the range are typically found in upland rivers, with higher values found in lowland rivers. Lower conductivity values are often observed following seasonal rainfall.
Lakes, reservoirs & wetlands	300–1500	Values at the lower end of the range are observed during seasonal rainfall events. Values even higher than 1500 μScm^{-1} are often found in saltwater lakes and marshes. Wetlands typically have conductivity values in the range 500—1500 μScm^{-1} over winter. Higher values (>3000 μScm^{-1}) are often measured in wetlands in summer due to evaporative water loss.
	Turbidity (NTU)	
Upland & lowland rivers	10–20	Turbidity and SPM are highly variable and dependent on seasonal rainfall runoff. These values representative of base river flow in lowland rivers.
Lakes, reservoirs & wetlands	10–100	Most deep lakes and reservoirs have low turbidity. However, shallow lakes and reservoirs may have higher turbidity naturally due to wind-induced resuspension of sediments. Lakes and reservoirs in catchments with highly dispersible soils will have high turbidity. Wetlands vary greatly in turbidity depending upon the general condition of the catchment or river system draining into the wetland and to the water level in the wetland.
Estuarine & marine	1–2	Turbidity is not a very useful indicator in estuarine and marine waters. A more appropriate measure for WA coastal waters is light attenuation coefficient. Light attenuation coefficients (log_{10}) of 0.05–0.08 m^{-1} are indicative of unmodified offshore waters and 0.09–0.13 m^{-1} for unmodified inshore waters, depending on exposure. Light attenuation coefficients (log_{10}) for unmodified estuaries typically range 0.3–1.0 m^{-1}, although more elevated values can be associated with increased particulate loading or humic rich waters following seasonal rainfall events.



Making Sustainability Happen